Appendix D. Variations in community vulnerability to tsunamis
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To develop realistic risk-reduction efforts, managers need to understand how coastal communities are vulnerable to future tsunamis. Vulnerability as a science involves examining the combination of physical and societal components that influence the degree to which an individual, community, or system is threatened by a particular event, as well as their ability to mitigate these threats and recover after an event. Population vulnerability to future tsunamis is a function of three components – *exposure, sensitivity,* and *adaptive capacity* (Cutter, 2003; Turner et al., 2003). Population exposure is related to hazard proximity and the physical characteristics of the tsunami (e.g., arrival times, spatial extent). Sensitivity refers to differential degrees of potential harm among at-risk populations, based on the internal characteristics of an individual, group, or socioeconomic system. Adaptive capacity describes possible adjustments and responses of a system to reduce a population's exposure or sensitivity.

Vulnerability assessments focus on characteristics of a system that make it more susceptible to losses, unlike risk assessments which typically incorporate the joint probabilities for the likelihood of tsunami occurrence and the likelihood of fatalities or asset failure. Vulnerability results therefore are most useful for mitigation efforts that do not require probabilistic judgments, such as educating at-risk populations on how to prepare for and evacuate from tsunamis. Vulnerability assessments are also useful when comparing communities with similar threats, such as a regional near-field tsunami hazard, but could be combined with data on the likelihood of events to inform tsunami-source comparisons. The following text summarizes examples of USGS work being done to assess community vulnerability to tsunamis but is not meant to be considered an exhaustive survey of all U.S. or international efforts on the topic.

Population ***exposure*** is largely a question of spatial coincidence – for example, are there people in tsunami-prone areas and if so, how many are there? This is often answered by integrating demographic data (e.g., U.S. Census blocks with population counts) and hazard zones to identify the number of people in tsunami-prone areas. Gonzales et al. (2001) provided the first estimate of the "at-risk population" in five states (Alaska, California, Hawaii, Oregon, and Washington), which was based on the number of people reported in 2000 Census blocks that are in officially recognized communities (incorporated cities and unincorporated designated places) and within 1 kilometer of the coastline. Estimates were based on distance from shoreline (1 km) and not actual tsunami-hazard zones, non-residential populations (e.g., tourists, employees) were excluded, and populations in unincorporated areas were also excluded.

Since the initial 2001 estimate, several reports have been published to improve understanding of population exposure to tsunami hazards in Hawaii (Wood et al., 2007), Washington (Wood and Soulard, 2008), Oregon (Wood, 2007), and California (Wood et al., 2012; Wood et al., 2013). In each report, population exposure is expressed in terms of residents (from U.S. Census block-level data), employees (from InfoGroup), state and national park data, and certain types of businesses (also infoGroup), such as dependent-care facilities (e.g., hospitals, schools, day-care centers), public venues (e.g., theaters, museums), and, in later reports, businesses that largely cater to local customers (e.g., retail, restaurants). Exposure estimates are derived by integrating population data with State-supplied tsunami hazard zones. Tsunami-hazard zones in Hawaii and California are maximum-inundation zones based on multiple sources, whereas they are based on Cascadia subduction zone earthquake scenarios in Oregon and Washington. A tsunami-hazard zone in California based on an Aleutian earthquake scenario served as the basis for the population-exposure analysis summarized in Wood et al. (2013).

In each population-exposure report, results are summarized by incorporated city, tribal reservation, and unincorporated County lands (which includes Census designated places). Communities are then compared using simple comparative metrics based on the number and percentage of various population-related attributes that are in these reports. This information helps emergency managers to target where outreach, preparedness plans, and mitigation strategies may be most warranted. Table 1 summarizes totals for the various at-risk population groups and tsunami-hazard zones in each State where work has been completed.

Table 1. Estimates of population exposure to tsunami-hazard zones in various States.

	California	**Hawaii**	**Oregon**	**Washington**
Report publication date	Wood et al., 2012	Wood et al., 2007	Wood, 2007	Wood and Soulard, 2008
Date of population/economic data	2010, 2011	2000, 2006	2000, 2006	2000, 2006
Geographic extent	Open-ocean coast and San Francisco Bay	Entire coastline	Entire coastline	Olympic Peninsula counties (4)
Tsunami-hazard zone	Maximum based on multiple scenarios	Maximum based on multiple scenarios	Cascadia subduction zone	Cascadia subduction zone
Number of residents in hazard zone	267,347	80,443	22,201	42,972
Number of employees in zone	168,565	67,113	14,857	24,934
Number of public venues in zone	1,152	603	231	252
Number of dependent-care facilities in hazard zone	1,388	313	43	121
Average estimated daily visitors to coastal State and/or National Parks	166,322	n/a[1]	53,714	17,029
Average estimated daily visitors to city or county beaches	384,801	n/a[1]	n/a[1]	n/a[1]

[1]Data unavailable at the time of analysis

Population ***sensitivity*** can be inferred using demographic data in a GIS analysis to identify the type of people in tsunami-prone areas. Certain demographic characteristics may influence one's ability to prepare for or respond to tsunamis. For example, 45% of residents in the tsunami-prone areas of the City of Bandon, Oregon, are over 65 years in age (Wood 2007), and these older residents may have difficulty in evacuating in the time between earthquake ground shaking and wave arrival, although this sensitivity effect may be tempered by research findings that greater knowledge of response actions often accompanies increasing age. The aforementioned reports for California, Oregon, Washington, and Hawaii include a summary for each community in a tsunami-hazard zone of demographic attributes of the at-risk population, including ethnicity (Hispanic or Latino), race (American Indian and Alaska Native, Asian, Black or African American, Native Hawaiian and other Pacific Islander, and White —either all alone for each race or in combination with one or more other races), age (individuals less than 5 and more than 65 years in age), gender with particular family structures (female-headed households with children under 18 years of age and no spouse present), and tenancy (renter-occupied households).

Wood et al. (2010) delves deeper into demographic sensitivity to tsunami hazards and summarizes a geospatial approach for identifying demographic hot-spots to tsunamis using statistical methods that address the multivariate nature of at-risk populations. A factor analysis of demographic data was conducted for all census blocks in the Oregon tsunami-hazard zone and blocks are then compared and mapped in terms of relative social vulnerability (figure 1). For example, high numbers of children, high numbers of renters, and low income levels are all indicators of heightened sensitivity but will amplify each other if they are all present in the same census block. Demographic-sensitivity information helps emergency managers determine not only where but also the types of risk-reduction actions are needed. For example, preparedness planning for an at-risk population comprised primarily of older individuals that are also renters may need to address potential, pre-existing health issues of the population, as well as the inherent difficulty in reaching renter populations with hazard information.

The ***adaptive capacity*** of at-risk populations to future tsunamis is a function of what at-risk individuals are able to and can do in light of potential threats. One example of geospatial research to study adaptive capacity is pedestrian-evacuation modeling, which can be done to estimate the amount of time required to escape tsunami-prone areas to high ground before tsunami-wave arrivals (Wood and

Schmidtlein, 2012, 2013; Wood et al. 2014). This information can then be merged with demographic data to compare population exposure of several communities as a function of travel time to safety. In the United States, tsunami-evacuation modeling has been completed for coastal communities in Pacific and Grays Harbor counties in southwest Washington (Wood and Schmidtlein, 2013) and for Seward, Alaska (Wood et al., 2014). In Seward, evacuation modeling was completed based on current population and landcover distributions, as well as a historic reconstruction of conditions prior to the 1964 Good Friday earthquake and tsunami disaster (figure 2). For southwest Washington, communities are compared in terms of population exposure to Cascadia-related tsunami hazards in terms of travel time to safety (figures 3 and 4). For example, Aberdeen has the highest number of residents in the tsunami-hazard zone (11,897), but 87% of them may have less than 25 minutes of travel time to safety (which is the predicated wave arrival time for a Cascadia-related tsunami in this area). Nearby Ocean Shores has only 5,500 residents in tsunami-hazard zone, but 90% of them may need more than 25 minutes to reach safety, meaning they may not have enough time to escape the waves.

Emergency managers can use evacuation-modeling results to identify appropriate risk-reduction strategies. In areas where modeling indicates successful evacuations are possible, managers can use results in outreach efforts to raise positive outcome expectancy in at-risk individuals (i.e., people are more likely to participate in evacuation training if they believe their efforts will have a positive outcome). In areas where modeling results suggest evacuations are not likely to be successful, mitigation efforts, such as vertical evacuation berms or buildings, may be warranted to save lives.

Figure 1. Map of census blocks, classified by social vulnerability scores, in the City of Seaside, Oregon. Social vulnerability scores are classified in standard deviations from the mean; high scores mean higher relative demographic sensitivity to tsunami hazards (figure from Wood et al., 2010).

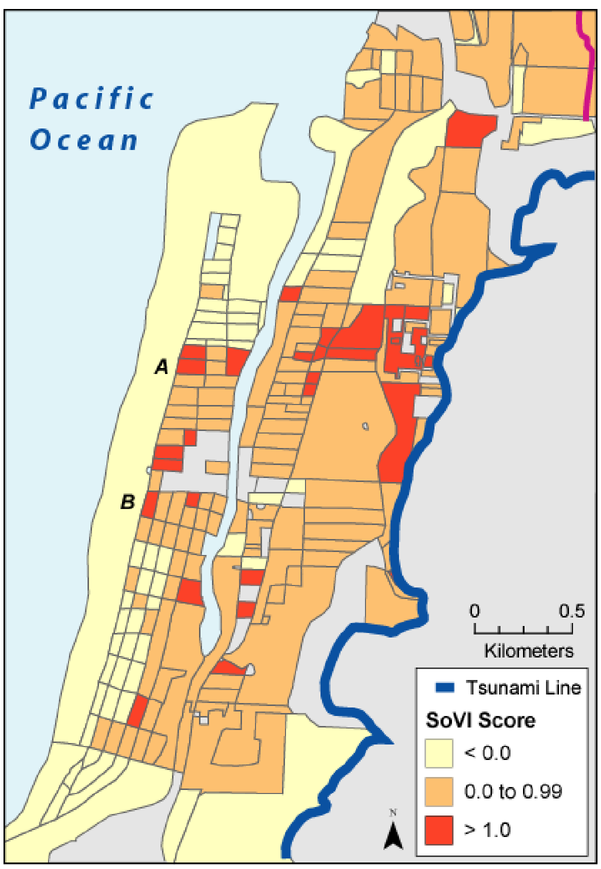


Figure 2. Maps of modeled evacuation travel times in downtown Seward assuming a slow running speed of 1.79 m/s based on a 1963 land cover and 1960 population distributions over a 1963 image of Seward and b modern day conditions over a 2005 image for Seward. Figure 2a also includes estimates of fatality locations as described in Lemke (1967) and Lander (1996)(figures from Wood et al., 2014).

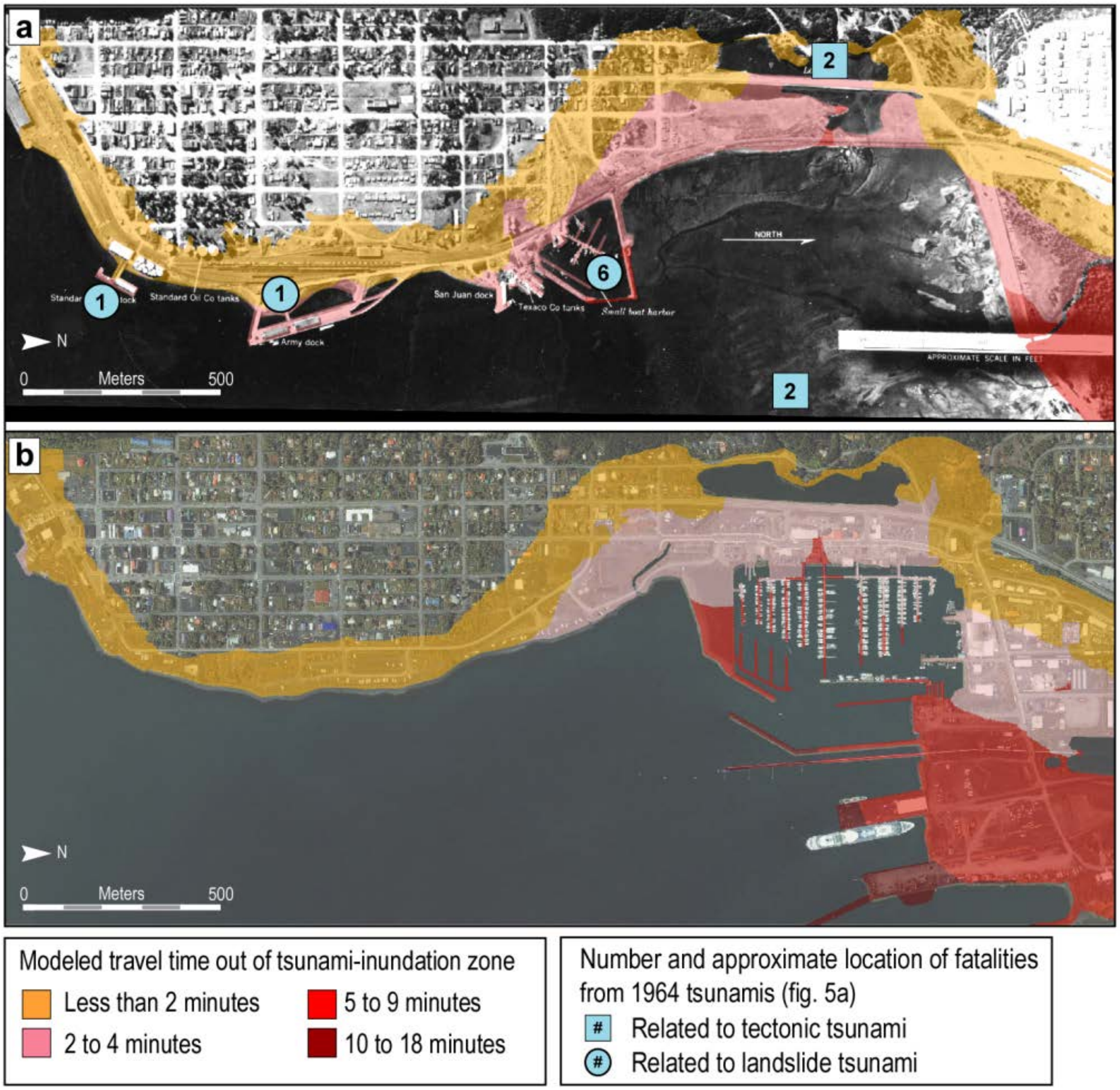


Figure 3. Examples of pedestrian-evacuation modeling in (a) southwest Washington, (b) Ocean Shores and surrounding communities and (c) Aberdeen showing modeled pedestrian travel times to safety, assuming a travel speed of 1.1 m/s. (figure from Wood and Schmidtlein, 2013)

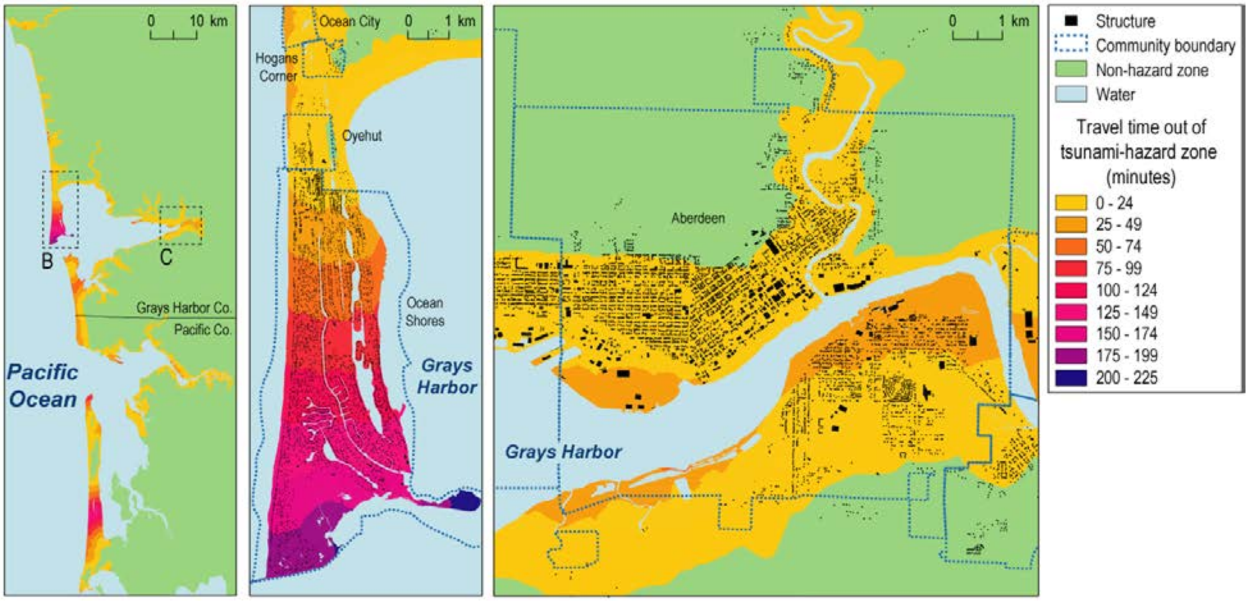
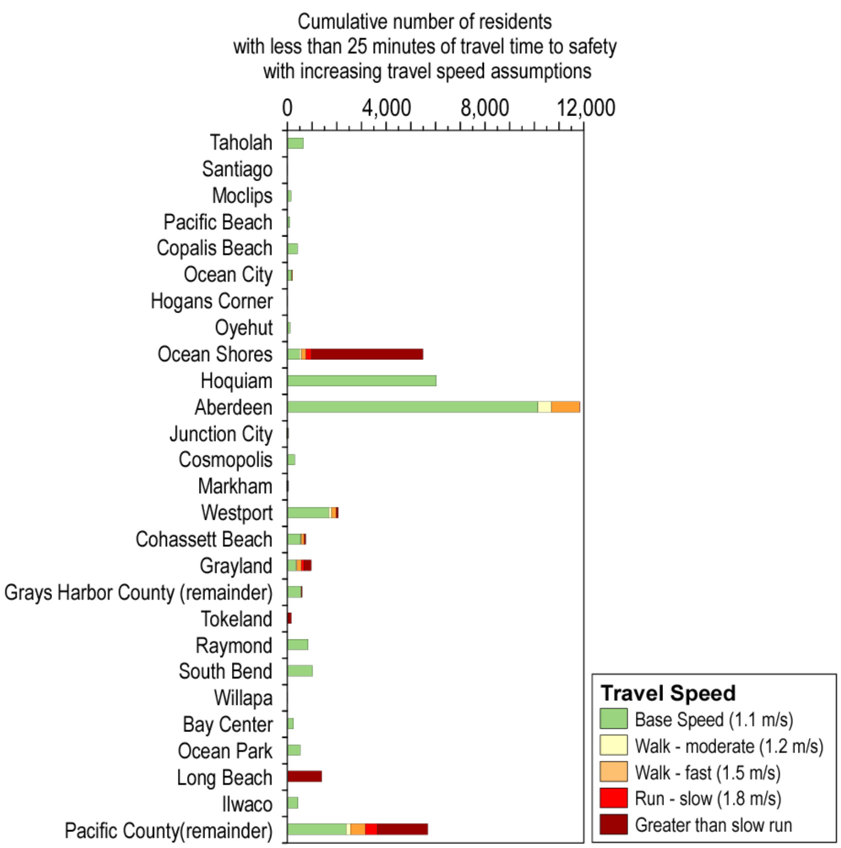


Figure 4. Graph showing the cumulative number of residents in southwest Washington coastal communities with 25 min or less of travel time out of tsunami-hazard zones based on increasing travel speed assumptions (figure from Wood and Schmidtlein, 2013)



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