Variations in Community Exposure and Sensitivity to Tsunami Hazards on the Open-Ocean and Strait of Juan de Fuca Coasts of Washington

In cooperation with the

Washington Military Department Emergency Management Division

Scientific Investigations Report 2008-5004

U.S. Department of the Interior
U.S. Geological Survey

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By Nathan Wood and Christopher Soulard

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FRONT COVER—The incorporated cities of Ocean Shores (left) and Port Angeles (right) on the Washington coast, shown with the internationally adopted tsunami-evacuation sign (Intergovernmental Oceanographic Commission, 2003). (Photographs from the Washington Department of Ecology, 2007).

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Variations in Community Exposure and Sensitivity to Tsunami Hazards on the Open-Ocean and Strait of Juan de Fuca Coasts of Washington

By Nathan Wood and Christopher Soulard

Abstract

Evidence of past events and modeling of potential future events suggest that tsunamis are significant threats to communities on the open-ocean and Strait of Juan de Fuca coasts of Washington. Although potential tsunami-inundation zones from a Cascadia Subduction Zone (CSZ) earthquake have been delineated, the amount and type of human development in tsunami-prone areas have not been documented. A vulnerability assessment using geographic-information-system tools was conducted to document variations in developed land, human populations, economic assets, and critical facilities relative to CSZ-related tsunami-inundation zones among communities on the open-ocean and Strait of Juan de Fuca coasts of Washington (including Clallam, Jefferson, Grays Harbor, and Pacific Counties). The tsunami-inundation zone in these counties contains 42,972 residents (24 percent of the total study-area population), 24,934 employees (33 percent of the total labor force), and 17,029 daily visitors to coastal Washington State Parks. The tsunami-inundation zone also contains 2,908 businesses that generate $4.6 billion in annual sales volume (31 and 40 percent of study-area totals, respectively) and tax parcels with a combined total value of $4.5 billion (25 percent of the study-area total). Although occupancy values are not known for each site, the tsunami-inundation zone also contains numerous dependent-population facilities (for example, schools and child-day-care centers), public venues (for example, religious organizations), and critical facilities (for example, police stations and public-work facilities). Racial diversity of residents in tsunami-prone areas is low—89 percent of residents are White and 8 percent are American Indian or Alaska Native. Nineteen percent of the residents in the tsunami-inundation zone are over 65 years in age, 30 percent of the residents live on unincorporated county lands, and 35 percent of the households are renter occupied. Employees in the tsunami-inundation zone are largely in businesses related to health care and social assistance, accommodation and food services, and retail trade, reflecting businesses that cater to a growing retiree and tourist population. Community vulnerability, described here by exposure (the amount of assets in tsunami-prone areas) and sensitivity (the relative percentage of assets in tsunami-prone areas) varies among 13 incorporated cities, 7 Indian reservations, and 4 counties. The City of Aberdeen has the highest relative community exposure to tsunamis, whereas the City of Long Beach has the highest relative community sensitivity. Levels of community exposure and sensitivity to tsunamis are found to be related to the amount and percentage, respectively, of a community's land that is in a tsunami-inundation zone. This report will further the dialogue on societal risk to tsunami hazards in Washington and help risk managers to determine where additional risk-reduction strategies may be needed.

Introduction

The 2004 Sumatra-Andaman earthquake and tsunami devastated communities throughout the Indian Ocean and demonstrated to the world how tsunamis are significant threats to coastal communities. Historical and geologic evidence indicate that the Washington coast has experienced similar large-magnitude tsunamis and is likely to experience more (Heaton and Snavely, 1985; Heaton and Hartzell, 1987; Atwater, 1987; Lander and Lockridge, 1989; Atwater and Yamaguichi, 1991; Atwater, 1992; Atwater and others, 1995; Atwater, 1996; Satake and others, 1996; Atwater and Hemphill-Haley, 1997; Clague, 1997; Jacoby and others, 1997; Peters and others, 2001; McMillan and Hutchinson, 2002; Leonard and others, 2004; Atwater and others, 2005; Kilfeather and others, 2007).

The Washington coast is susceptible to tsunamis generated by multiple sources. One source is a distant earthquake on the seismically active Pacific Ocean margin. A recent example is the tsunami associated with the 1964 magnitude 9.2 earthquake in the eastern Aleutian-Alaska Subduction Zone that inundated the outer Washington coast approximately 4 hours after initial ground shaking in Alaska (Landers and Lockridge, 1989). Another tsunami source is the submarine rupturing of a fault in the crustal North America tectonic plate, such as the rupturing of the Utsalady Point Fault in the northern Puget lowlands approximately 300 to 500 years ago (Johnson and others, 2004) and of the Seattle Fault in Puget Sound approximately 1,000 years ago (Atwater and Moore, 1992; Nelson and others, 2003). A third source for tsunamis is a landslide within Puget Sound; a recent example is the local tsunami generated by a landslide in the Tacoma Narrows a few days after the 1949 magnitude 7.1 Olympia earthquake (Washington Emergency Management Division, 2004).

For communities on the open-ocean and Strait of Juan de Fuca coasts of Washington, the most significant tsunami threat is associated with local earthquakes emanating along the Cascadia Subduction Zone (CSZ), the interface of the North America and Juan de Fuca tectonic plates that extends more than 1,000 kilometers from northern California to southern British Columbia (Rogers and others, 1996; fig. 1). Based on geologic evidence along the Washington coast, the CSZ has ruptured and created tsunamis at least seven times in the past 3,500 years and has a considerable range in recurrence intervals, from as little as 140 years between events to more than 1,000 years (Atwater and Hemphill-Haley, 1997; Clague 1997; Goldfinger and others, 2003). The last CSZ-related earthquake is believed to have occurred on January 26, 1700 (Satake and others, 1996; Jacoby and others, 1997; Atwater and others, 2005; Williams and others, 2005; Kilfeather and others, 2007), and researchers predict a 10 to 14 percent chance that another could occur in the next 50 years (Petersen and others, 2002). Future CSZ-related earthquakes have been predicted to be magnitude 8 or greater and could subject communities on the Washington open-ocean and Strait of Juan de Fuca coasts to intense ground shaking, subsidence, landslides, and liquefaction of unconsolidated sediments. In addition, a series of tsunami waves possibly 8 meters or higher are predicted to inundate the outer Washington coast in 30 to 60 minutes after initial ground shaking in a magnitude 8 or larger earthquake (Myers and others, 1999; Walsh and others, 2000; Washington Emergency Management Division, 2004; CREW, 2005; Geist, 2005).

To reduce tsunami risk in the U.S. Pacific Northwest, the National Tsunami Hazard Mitigation Program, a State-Federal partnership, has supported several efforts to improve hazard assessments, warning guidance, and mitigation (Bernard, 2005). Tsunami hazard assessments in Washington include a series of tsunami-inundation maps (Walsh and others, 2000; Walsh and others, 2002a,b; Walsh and others, 2003a,b) and tsunami-evacuation maps (Washington Emergency Management Division, 2007; Washington Division of Geology and Earth Resources, 2007) created with modeling support provided by the Tsunami Inundation Mapping Effort (TIME) Center (Gonzales and others, 2005b). Efforts to improve tsunami-warning guidance include a network of deep-ocean tsunami detection stations (Gonzales and others, 2005a), enhancements to existing tsunami-warning centers (Darienzo and others, 2005; McCreery, 2005), real-time tsunami forecasting capabilities (Titov and others, 2005), and use of the National Oceanic and Atmospheric Administration (NOAA) Weather Radio "All-Hazards Alert Broadcast" warning system (Crawford, 2005). Mitigation efforts to reduce societal risk to tsunamis include the creation and dissemination of educational materials (for example, signage and school curricula) to raise awareness of the potential of CSZ-related tsunamis, to improve evacuation procedures (Dengler, 2005; Washington Emergency Management Division, 2007), and to promote regional mitigation and land-use strategies that reduce tsunami risk (Eisner, 2005; Jonientz-Trisler and others, 2005).

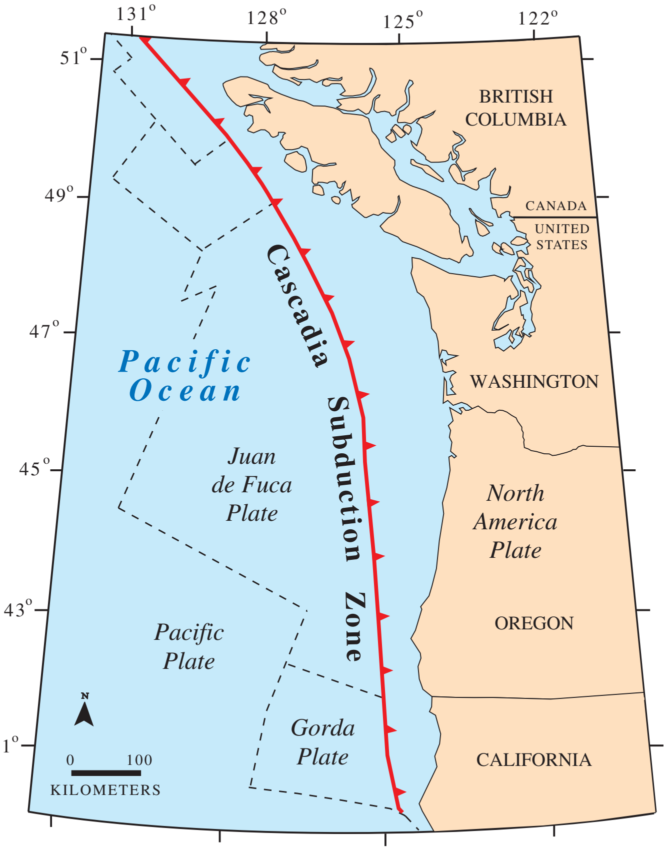

Figure 1. Map of the Cascadia Subduction Zone (adapted from U.S. Geological Survey, 2007).

Although much has been done to improve our understanding of tsunami hazards and to develop warning systems and awareness programs, less has been done to understand community vulnerability to these hazards, specifically the potential impacts on people and infrastructure (U.S. Government Accountability Office, 2006). Community vulnerability, defined as the attributes of a human-environmental system that increase the potential for hazard-related losses or reduced performance, is influenced by how communities occupy and use hazard-prone areas. Along the Washington coast, occupation and use of tsunami-prone areas varies considerably, including low-density residential development (fig. 2*A*), mixed commercial and residential (fig. 2*B*), marinas (fig. 2*C*), and industrial sites (fig. 2*D*). These land-use variations influence each community's vulnerability, typically characterized by the exposure, sensitivity, and resilience of a community and its assets in relation to potential tsunamis (Turner and others, 2003). A tsunami may cause damage to buildings or injure people, but the cumulative choices a community makes with regards to its use of hazard-prone areas and its willingness to develop risk-reduction strategies (for example, education programs and evacuation training) before an extreme event occurs will determine the extent of these losses (Mileti, 1999; Wisner and others, 2004).

Figure 2. Photographs of tsunami-prone areas in the cities of (*A*) Ocean Shores, (*B*) Aberdeen, (*C*) Westport, and (*D*) Raymond.

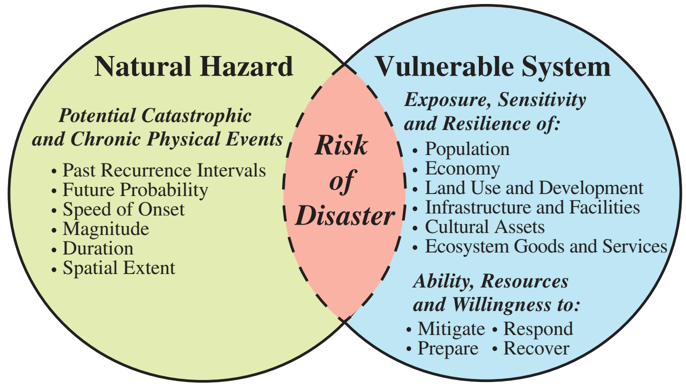

Figure 3. Conceptual diagram of societal risk to disasters (Wood, 2007).

The risk of future tsunami disasters is therefore a function of predicted hazards and the vulnerable human systems that occupy tsunami-prone areas (fig. 3; Wood, 2007).

Research to understand societal vulnerability to tsunamis in Washington has focused primarily on documenting tsunami-related perceptions of various at-risk populations on the Washington coast. Although expressed perceptions do not directly equate with action, they do provide some context on risk tolerance and the potential for the development of human adjustments to hazards (for example, evacuation plans or land-use setbacks), and are therefore considered critical elements of vulnerability assessments (Parker and Harding, 1979; Heijmans, 2004; Hilhorst and Bankoff, 2004). Results of a regional perception study of public officials and private-sector representatives in Washington and Oregon coastal communities conducted in 2001 indicate that most Washington participants considered tsunamis to be low probability events that pose somewhat of a threat to human life and property (Wood and Good, 2005). Survey results also indicate a regional emphasis on preparedness planning efforts, rather than mitigation or post-event recovery planning, and the majority of tsunami-related risk-reduction activities are regional efforts implemented by public officials. Less is being done to make offices safer or more resilient (Wood and Good, 2005). Results of a perception study of residents and tourists on the outer Washington coast indicate that hazard awareness was high among survey participants, but awareness levels did not translate into preparedness actions (Johnston and others, 2005). Results of focus groups conducted in Ocean Shores, Washington, as part of this same study indicate that participants desire hazard information that is tailored to the diverse needs and expectations in each community and that limited knowledge regarding tsunami risks has led to apathy and low preparedness (Johnston and others, 2005). Low preparedness was also a finding in a perception study conducted of staff at several hotels in Ocean Shores. Although hospitality staff will likely play a significant role in evacuating tourists who will likely have little knowledge of tsunamis or evacuation procedures, only 22 percent of the hotel staff interviewed in the study had been exposed to training on how to respond to tsunami warnings and only

22 percent of establishments had tsunami-specific information available for guests (Johnston and others, 2007).

To complement these research efforts and improve understanding of societal risk to tsunamis in Washington, the Washington Military Department Emergency Management Division (WEMD) contacted the U.S. Geological Survey (USGS) in 2006 seeking technical assistance in assessing community vulnerability to tsunami hazards on the open-ocean and Strait of Juan de Fuca coasts of Washington. Tsunami-inundation zones have been developed (for example, Walsh and others, 2000), but the WEMD was interested in knowing what assets were in these areas and the potential impact of their loss to communities. Understanding how communities vary in their vulnerability to tsunamis will allow WEMD and other risk-related agencies and organizations to understand potential societal impacts of CSZ-related tsunamis, as well as help them determine where to augment regional risk-reduction strategies with site-specific efforts that reflect local conditions and needs (for example, targeted education programs, evacuation procedures for certain special-needs populations, or land-use changes).

Purpose and Scope

The purpose of this report is to describe tsunami-prone landscapes and document geographic variations in community vulnerability to CSZ-related tsunamis on the open-ocean and Strait of Juan de Fuca coasts in Washington. Data presented in this report include city-level descriptions and comparisons of the amount and percentage of community assets in tsunami-prone areas, based on the distribution of developed land, human populations, economic assets, and critical facilities relative to a CSZ-related tsunami-inundation zone. Variations in community vulnerability to tsunamis are based on the presence of assets in tsunami-prone areas; results are not engineering-based loss estimates for any particular facility. Certain vulnerability aspects were considered outside the scope of this report, including potential ecosystem impacts, risk perceptions, and social capital (Alwang and others, 2001; Pelling, 2002). Community resilience, another component of vulnerability and defined as the ability to withstand, absorb, adapt to, and recover from losses (Turner and others, 2003), is also considered outside the scope of this regional assessment. Finally, the report focuses exclusively on tsunami-prone areas of the Washington coast and does not discuss the additional geologic hazards associated with a CSZ earthquake including ground shaking, liquefaction, subsidence, and landslides.

To understand the potential impacts of future tsunamis in Washington, policymakers, managers, and private citizens must understand the current vulnerability of communities that occupy tsunami-prone land. This analysis is intended to serve as a foundation for additional risk-related studies and to help community members and local, State, and Federal policymakers (for example, in the emergency-management or land-use arena) in their efforts to develop and prioritize risk-reduction strategies that are tailored to local needs.

Study Area

This study focuses on the open-ocean and Strait of Juan de Fuca coasts of Washington, including Clallam, Jefferson, Grays Harbor, and Pacific Counties, and the 13 incorporated cities and 7 Indian reservations (hereafter collectively referred to as communities) within them that intersect a tsunami-inundation zone (fig. 4). These counties also contain 24 unincorporated towns, as delineated by census-designated-place boundaries (U.S. Census Bureau, 2007a), that intersect the tsunami-inundation zone (fig. 4); however, because emergency services and land-use planning for these towns are performed by county offices, results related to unincorporated towns are reported at the county level.

The tsunami-inundation zone used in this study is based on an earthquake and tsunami scenario identified as “Scenario 1A with an asperity” in a series of tsunami-inundation maps created by the Washington Department of Natural Resources for the southern Washington coast (Walsh and others, 2000) and for the areas near Port Angeles (Walsh and others, 2002a), Port Townsend (Walsh and others, 2002b), Quileute (Walsh and others, 2003a), and Neah Bay (Walsh and others, 2003b) (fig. 5). Developed using a finite-element model, this tsunami-inundation scenario is based on a Magnitude (Mw) 9.1 Cascadia subduction zone (CSZ) event and assumes a rupture length of 1,050 km, a rupture width of 70 km, a fault-plane asperity that generates a 6-meter uplift, and land subsidence of approximately 1.0 to 1.5 m during ground shaking. Mapped as the worst-case scenario, the lines attributed to Scenario 1A with asperity were also smoothed to compensate for resolution limitations and, in some instances, to place the inundation limit at nearby logical topographic boundaries. Horizontal resolution errors are believed to vary to as much as 50 meters; vertical resolution errors are on the order of 2 to 6 meters (Walsh and others, 2000). For the outer Washington coast, predicted wave crests would likely arrive between 30 and 60 minutes after the earthquake. For the areas of the Washington coast where tsunami-inundation modeling has not been completed (fig. 5), the 25-ft topographic contour is used to delineate areas of potential tsunami inundation (Walsh, Washington Department of Natural Resources, written communication, 2006). Figure 5 shows that most coastal communities have published tsunami-inundation zones and that the 25-ft contour line is used to approximate potential tsunami inundation only in the more rural portions of the four counties.

Methods and Data

To describe tsunami-prone landscapes on the Washington coast, we used geographic-information-system (GIS) tools to integrate publicly available hazard and socioeconomic data. Vulnerability calculations and comparisons consider community exposure and sensitivity based on the distribution of developed land, populations (residential, employee, and

Figure 4. Map of counties and communities on the open-ocean and Strait of Juan de Fuca coasts of Washington with land in the tsunami-inundation zone.

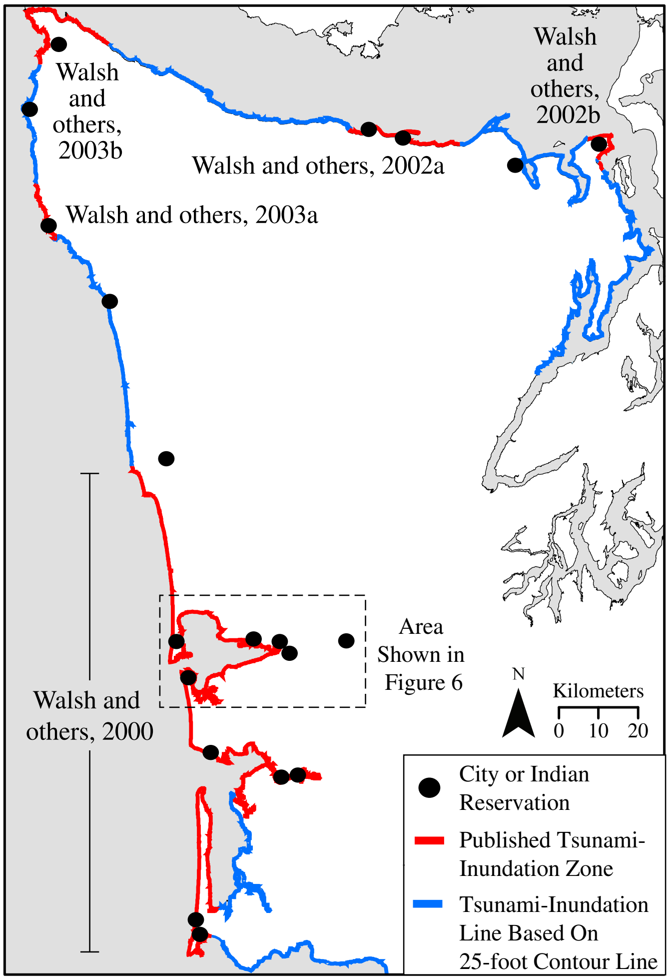

Figure 5. Map of data sources for tsunami-inundation zones for the Straits of Juan de Fuca and open-ocean coasts of Washington.

tourists), economic assets, and critical facilities. These assets are chosen based on the data U.S. jurisdictions are encouraged to collect as they develop State and local mitigation plans (Federal Emergency Management Agency, 2001), a requirement to qualify for funds under the U.S. Hazard Mitigation Grant Program in accordance with the Disaster Mitigation Act of 2000, Public Law 106-390. Exposure is based on the amount of an asset (for example, the number of residents) within a tsunami-inundation zone of a city. Sensitivity is defined as the relative impact of losses to an entire community (for example, the percentage of a community's workforce in a tsunami zone) and is calculated by dividing the amount of an asset in a tsunami-inundation zone by the total amount of that asset in a city. For example, if community A has 100 businesses in a tsunami-inundation zone (representing 10 percent of the local economy) and community B has 30 businesses in a tsunami- inundation zone (representing 90 percent of the local community), then community A has a higher economic exposure because it has more businesses in the tsunami zone, but community B is more economically sensitive because it has a higher proportion of its businesses in the tsunami zone.

Exposure and sensitivity values based on various socioeconomic assets are reported for each city and then combined to create overall indices of community exposure and sensitivity to tsunami hazards. Prior to analysis, we transformed all geospatial data to share the same datum (North American Datum of 1983, High Accuracy Reference Network) and projection (Washington State Plane, Lambert Conformal Conic). Spatial analysis of vector data (for example, business points and tax-parcel polygons) focused on determining if points or polygons are inside the tsunami-inundation-zone polygons. Slivers of polygons that overlap administrative boundaries and tsunami zones were taken into account during analysis and final values were adjusted proportionately.

Land-Cover Data

A first step in understanding community vulnerability to tsunamis is to determine the types of land use and land cover (LULC) in predicted hazard zones. Land-cover descriptions of the tsunami-inundation zone are based on data compiled in 2001 by the National Oceanic and Atmospheric Administration's (NOAA) Coastal-Change Analysis Program (C-CAP). C-CAP land-cover data is nationally standardized for the coastal regions of the United States (NOAA CSC, 2007; Dobson and others, 1995) and is part of the National Land Cover Database (NLCD) effort through the interagency Multi-Resolution Land Characteristics (MRLC) Consortium (Homer and others, 2004; Loveland and Shaw, 1996). NLCD products, including LULC, percent impervious cover, and percent canopy cover, are automatically derived from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM) digital satellite imagery, which is produced at a 30-meter horizontal resolution. C-CAP data generated before 2005 have 22 land-cover classes and a reported accuracy standard of 85 percent (Dobson and others, 1995).

One set of societal vulnerability indicators assessed in this study is the amount and percentage of developed land relative to the tsunami-inundation zone in each incorporated city, Indian reservation, and for the remaining unincorporated portions of each county. Community vulnerability is assumed to increase with greater amounts and percentages of developed land in tsunami-prone areas. Developed land is represented by low-intensity developed and high-intensity developed classes in C-CAP data generated before 2005. Low-intensity developed cells contain 50 to 79 percent of constructed surfaces, are a mix of substantial constructed and vegetated surfaces, and typically represent small buildings, streets, and cemeteries. High-intensity developed cells contain more than 80 percent of constructed surfaces, have little or no vegetation, and typically represent heavily built-up urban centers, large buildings, and large paved surfaces, such as runways and interstate highways (Dobson and others, 1995). Since 2005, a medium-intensity developed class was added to 2001 land-cover data; however, the pre-2005 classification scheme is used here to allow for comparisons to tsunami assessments already completed in other States (Wood and others, 2007; Wood, 2007). Based on the distribution of cells classified as high- and low-intensity

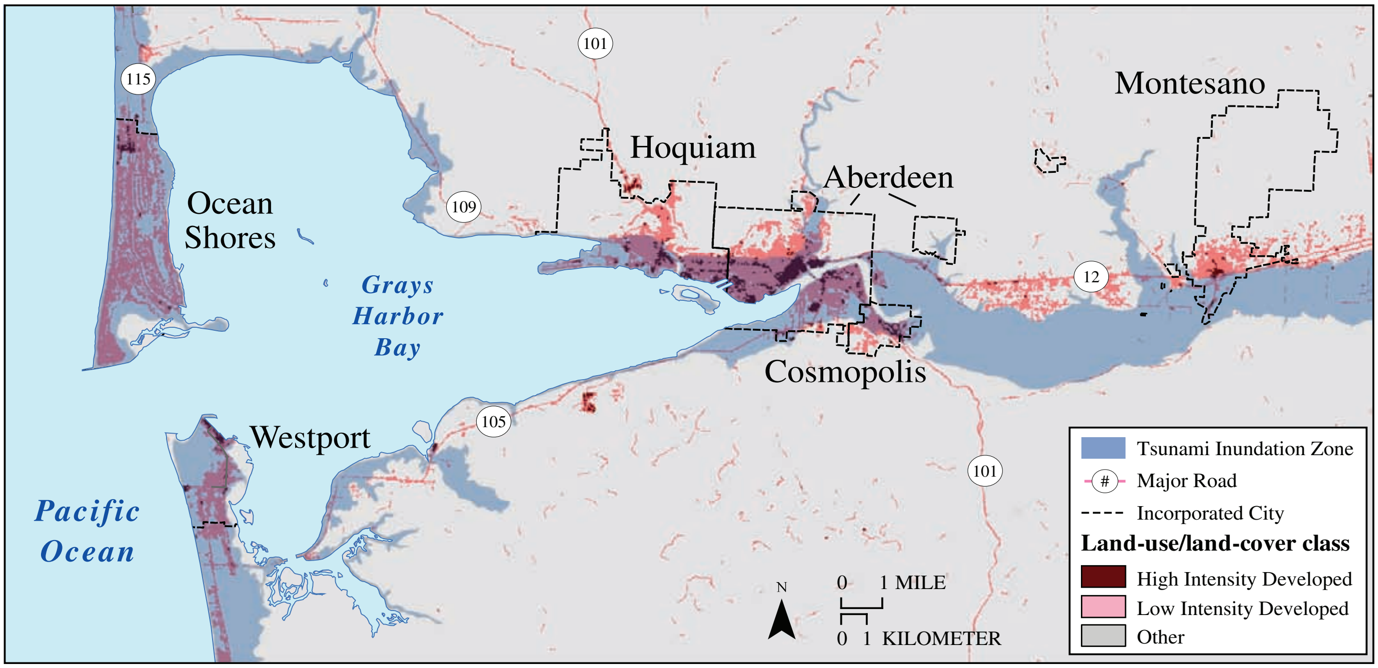

Figure 6. Map of Grays Harbor Bay with the tsunami-inundation zone and 2001 NOAA C-CAP land-cover data.

developed in relation to the tsunami-inundation zone, the majority of development in the cities of Ocean Shores, Westport, Hoquiam, Aberdeen, and Cosmopolis is inside the tsunami-inundation zone (fig. 6).

Population Data

The size and type of local populations (including residents, employees, and dependents) and tourist populations that are in hazard-prone areas are additional elements of community vulnerability. The number and type of residents in the tsunami-inundation zone were determined using demographic data from census blocks of the 2000 U.S. Census (U.S. Bureau of Census, 2000). In addition to total population and households, demographic information for each community is summarized relating to ethnicity (Hispanic or Latino), race (American Indian and Alaska Native, Asian, Black or African American, Native Hawaiian and other Pacific Islander, and White—all alone or in combination with one or more other races), age (individuals under 5 and over 65 years in age), gender (female population and female-headed households with children and no spouse present), and tenancy (renter-occupied households). Census block-group and tract data are summarized at the city and county level to provide additional insight on local conditions if a disaster were to occur and not at the hazard-level due to the size differences between inundation polygons and the larger census units.

Other local at-risk populations include employees and dependents. The number and types of employees in the study area were determined using the 2006 InfoUSA Employer Database. Because no fieldwork was conducted to verify locations of the 9,351 businesses in the study area, results based on the Employer Database throughout this report should be considered first approximations and developed to generate discussions for additional, more-detailed studies. Dependent populations are defined as individuals who temporarily reside in facilities and would require assistance to evacuate and recover. North American Industry Classification System (NAICS) codes for businesses in the InfoUSA Employer Database (appendix A) were used to identify the following dependent-population facilities:

- Medical facilities, including hospitals, psychiatrics and substance abuse hospitals, mental health services and psychiatric treatment facilities, pregnancy counseling, clinics, and physician offices;
- Adult residential care, including adult care facilities, hospices, nursing homes, rest homes, retirement communities, adult homes, senior citizens services, residential care homes, group homes, foster care, and adult day care centers;
- Child day care, including large babysitting facilities, childcare centers, pre-schools and nursery schools (both public and private);
- Schools (including religious schools, public and private schools, schools with special academics, and home-schooling centers); and
- Correctional facilities, including State and Federal facilities.

Tourists are another significant population in coastal communities and can often outnumber residents and employees in tsunami-prone areas (Wood and Good, 2004). No consistent census count for tourists exists; therefore, public venues and Washington State Park visitor data are used. Businesses that likely attract both residents and nonresidents are considered public venues and are identified using NAICS codes in the 2006 InfoUSA Employer Database (appendix A). Public venues include aquariums, botanical gardens, casinos, colleges and universities, historical places, libraries, museums, parks, religious organizations, shopping centers and malls, sporting facilities, theaters (including live and cinematic), and zoos. Data on the annual-average number of visitors from Washington State Parks (Washington State Parks, unpub. data, 2007) are used to assess geographic variations in the number of visitors along the Washington coast that may be in the tsunami-inundation zone. To gauge the potential impact to communities in the event of a tsunami, parks are coded by the community closest to them, based on road distance. The number of annual visitors to nearby parks is summed for each community and a relative percentage is calculated for each community based on the overall sum of annual visitors to parks on the Washington coast. These calculations are done to approximate the community services (for example, police, hospitals) that will be most impacted by high casualties in nearby parks. This approach also indicates the number of day tourists that may be in a community should a tsunami occur; for example, visitors to a State park may have lunch or shop in a nearby town.

Economic Data

Economic analyses for this study focus on two elements of the coastal economy—tax base and business community. Tax base, as represented by county parcel values, is an attribute of societal vulnerability because cities and counties rely on property taxes for local services. Communities can typically expect disaster-relief aid from external sources, but long-term funds for the restoration of county services typically come from revenue generated by property taxes. If an extreme event destroys property, land values will be reassessed at some point and likely lowered, the community tax base will shrink, and disaster recovery may be more difficult. Tax-parcel databases were provided by all four counties in 2006 and parcel-polygon attributes include property value and content value (both in 2006 U.S. dollars).

Potential impacts to the business community in each city and county are determined by calculating the amount and percentage of businesses, employees, and generated sales volumes in the tsunami-inundation zone using data from the InfoUSA Employer Database. Businesses in the tsunami-inundation zone with “P.O. box” mailing addresses (three percent of the database) were counted in the city- and county-totals and not the tsunami-inundation totals, because point locations were for the P.O. box and not the actual business. Economic conditions, such as the dominance of specific sectors, are based on employee distributions, an indicator routinely used by the private and public sector to evaluate economic health and market trends (Marshall, 1989; Bureau of Labor Statistics, 2007a).

Critical-Facilities Data

Certain facilities are considered critical for short-term response and others are considered essential for long-term recovery of a community following a disaster. As a starting point for discussing critical and essential facilities along the Washington coast, certain facilities were identified using NAICS codes in the InfoUSA Employer database (appendix A). Critical facilities include those used for public safety purposes (civil-defense facilities, fire stations, national-security facilities, police stations, and radio and television stations), medical services (ambulances, hospitals, outpatient-care centers, and physician offices) and infrastructure maintenance (electric, public-works, natural-gas, waste-water, and water and sewer facilities). Essential facilities include those that provide for basic necessities (banks and credit unions, gas stations, and grocery stores) or serve government functions (courts and legal offices, government offices, international-affairs offices, and U.S. Post Offices).

Composite Indices of Exposure and Sensitivity

To compare community vulnerability, composite exposure and sensitivity indices were developed for the 24 geographic units (13 incorporated cities, 7 Indian reservations, and unincorporated land in the four counties) and are based on the amounts and percentages, respectively, of five categories—developed lands, residents, employees, public venues and hotel facilities, and total tax-parcel values. Composite indices of exposure and sensitivity were developed by first normalizing values in the five categories to the maximum value found within that category. Normalizing data to maximum values creates a common data range of zero to one for all five categories and is a simple approach for enabling comparisons among disparate datasets. The five normalized values are then summed, resulting in one final score ranging from zero to five for each of the 24 geographic units. These are relative scores developed to compare the 24 geographic units and have no stand-alone meaning for a community. A final score integrating the composite exposure and sensitivity values is determined for each of the 24 geographic units by first normalizing each of the composite scores to maximum values, creating common data ranges of zero to one for each of the indices and minimizing any weighting bias between the indices. Normalized values are then added with no additional weighting, resulting in a final combined score ranging from zero to two.

Statistical Methods

Descriptive statistics are used to summarize general trends and identify extremes in community exposure and sensitivity. Several datasets have non-normal distributions, based on D’Agostino normality tests at $\alpha = 0.05$ (Zar, 1984). Therefore, median and third-quartile (75th percentile) values are reported instead of mean values and their standard errors, which are commonly used to describe normal distributions. One hypothesis that arises in the process of documenting these variations is that the amount of city assets and amount of city land in the tsunami-inundation zone are related; that is, more community land in the tsunami zone means there are more community assets in the zone. To test this hypothesis, a series of linear-regression analyses were conducted between land-area data and several city assets, including developed lands (lands classified as either low- or high-intensity developed), residents, employees, total parcel values, and public venues and hotels. Linear regressions were conducted for exposure values (the amounts of city land and assets in the tsunami-inundation zone) and for sensitivity values (the percentages of city land and assets in the tsunami-inundation zone) to determine if the amount and percentage of city land in tsunami-prone areas are significant factors in the distribution of city and county assets. The independent variable was the amount or percentage of land, regardless of land-cover class, within city and county limits. The dependent variables were the amount or percentage of assets within city and county limits. The null hypothesis in each of the analysis-of-variances tests is that no statistically significant relationship exists. Significance is assumed if calculated Fisher (F) values comparing the mean squares of the linear regression and residuals are greater than 4.30, which represents the critical F-value for a one-tailed test at $\alpha = 0.5$ and 22 degrees of freedom (Zar, 1984). Tests are done with an assumption of normality in the distribution of residuals (or homoscedasticity), based on a graphical examination of residual plots (Zar, 1984). In addition to F-values, the Pearson product-moment-correlation coefficient (r), the square of the Pearson product-moment correlation (r^2), and p-values are calculated. A significant statistical relationship between land area and the specific asset is assumed if a p-value is less than 0.05. A p-value greater than 0.05 suggests that differences in the variances of the data being compared (for example, land-area and number of residents) are too large to propose that a relationship exists.

Results

Descriptions of tsunami-prone landscapes in Washington focus on land use and land cover, populations, economic assets, and critical and essential facilities. Third quartiles, also known as 75th-percentiles, are noted on bar-graphs in each section so that readers can easily identify which cities are in the top 25 percent of exposure and sensitivity calculations and, therefore, can be considered the most vulnerable in a category. Data on cities and counties are also provided in an accompanying database (appendix B).

Land Cover

Based on the spatial overlay of 2001 C-CAP data, administrative boundaries, and the predicted tsunami-inundation zone, the distribution of land-cover types (by area) in tsunami-prone land was determined for the entire study area and for land just within incorporated cities and Indian reservations (fig. 7). Percentages represent the amount of land area classified as a specific land-cover class (for example, grassland) relative to the total hazard-prone area. For the purposes of this report, all wetland-related C-CAP categories are aggregated into one class, as are all forest-related C-CAP categories. Results indicate that 92 percent of the land in the tsunami-inundation zone is undeveloped (classified as neither high- nor low-intensity developed) (fig. 7*A*). Wetland-related classes were the most common type of land cover found in the tsunami-inundation zone (46 percent), followed by forests (19 percent) and grasslands (14 percent). For land just in the 20 communities (fig. 7*B*), 71 percent of land is classified as undeveloped, with most land classified as wetland (31 percent) or grassland (15 percent). Although significant losses may still be possible in individual communities, tsunami-prone land in the study area is largely undeveloped with a series of small

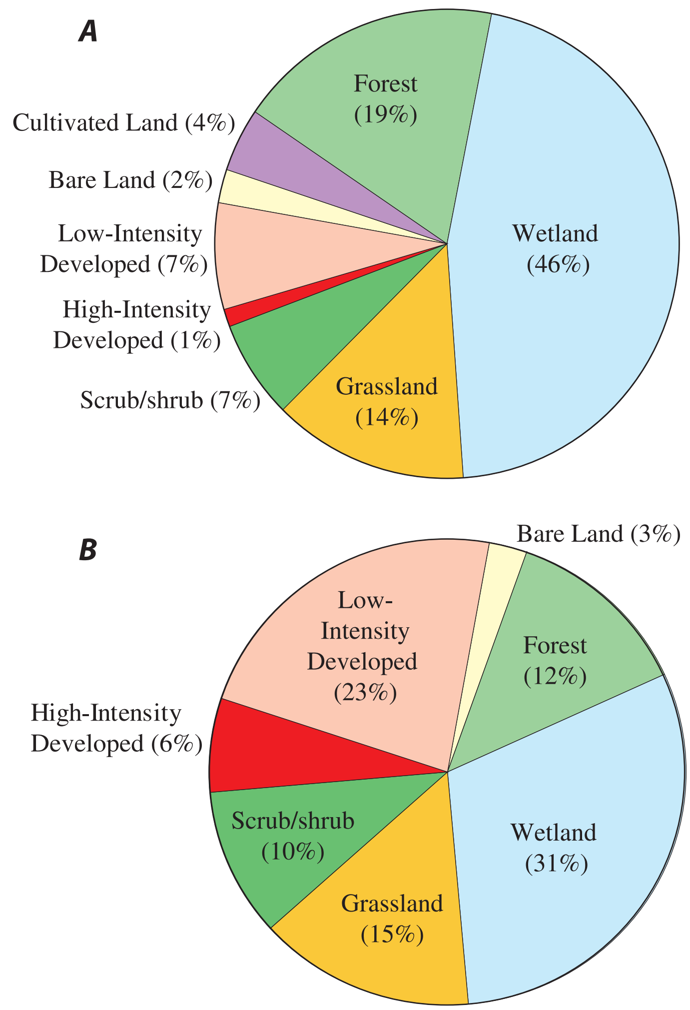

Figure 7. Distribution of land-cover classes (by area) in the tsunami-inundation zone for (*A*) the entire study area, and (*B*) land within the incorporated cities and Indian reservations.

communities and not a highly-developed megalopolis (for example, the nearby urban corridor from Olympia to Seattle).

Although the majority of tsunami-prone land is classified as undeveloped, these areas can still represent socioeconomic vulnerability issues for the region. First, undeveloped areas, such as beaches and wetlands, can attract recreationists (local residents as well as tourists) who could be impacted by a CSZ-generated tsunami. Second, undeveloped areas may represent significant habitats, natural resources, or ecosystem services (for example, water-quality improvement), either locally or regionally. For example, estuarine wetlands are important in the lifecycle of many aquatic species that are crucial to the Washington commercial-fishing industry (such as chinook salmon, shrimp, and oysters), an industry that contributed $294 million to the Washington State economy in 2001 (Washington Department of Fish and Wildlife, 2002). Wetlands are also important to the life cycles of fish considered crucial to the sport-fishing industry (for example, salmon and steelhead), an industry which generated more than $854 million in recreational expenditures in Washington State in 2001 (U.S. Fish and Wildlife and U.S. Census Bureau, 2003). These expenditures are cited as the cause for a three-fold increase in personal incomes in 2001 (relative to the average of the previous five years) for coastal communities on the open-ocean coast of Washington (Washington Department of Fish and Wildlife, 2002). Short- or long-term loss of or damage to coastal wetlands due to deposition of tsunami-related sediment and debris could impact fishery-based economies and therefore represent an economic vulnerability issue not only for local communities but also for the region and for Washington State.

Focusing on the distribution of human development in the region, results indicate that the amount (fig. 8*A*) and percentage (fig. 8*B*) of developed land (cells classified as either low- or high-intensity developed) varies within the 20 communities and four counties. Communities in the y-axes of figure 8, as well as in subsequent bar graphs in this report, are arranged from north to south, starting with cities in Clallam County in the north and ending with cities in Pacific County in the south. Third-quartile values (75th percentile) for the amount and percentage of developed land in communities are 1.5 km^2 and 74 percent, respectively. In general, community exposure and sensitivity is highest in the southern portion of the study area, specifically the counties of Grays Harbor and Pacific. The City of Aberdeen has the largest amount of developed land in the tsunami-inundation zone (7.3 km^2), and the City of Ocean Shores has the highest percentage of land area in the zone (100 percent). Some communities, including Aberdeen, Ocean Shores, Hoquiam, and Westport, are above the third-quartile values for both amount and percentage. Other communities, such as the Shoalwater Indian Reservation, Cosmopolis, and Long Beach, have relatively low amounts of developed land in tsunami-prone areas, but these lands represent the majority of their total urban footprint. Finally, the unincorporated and non-tribal areas of Grays Harbor and Pacific Counties also contain a high amount of tsunami-prone developed areas, reflecting the numerous unincorporated towns in each county (fig. 4).

Population

Residents

The tsunami-inundation zone contains 42,972 residents and 18,397 households (table 1), representing approximately 24 and 25 percent, respectively, of the total population in the four coastal counties. The total number (fig. 9*A*) and percentage (fig. 9*B*) of residents in the tsunami-inundation zone varies significantly across the four coastal counties. The City of Aberdeen has the highest number of residents (11,781) in the tsunami-inundation zone, whereas the City of Long Beach has the highest percentage (100 percent) of its residents in the tsunami-inundation zone. Results also indicate that 13,096 residents in tsunami-prone areas (30 percent of the total) are outside of the 13 incorporated cities and 7 Indian reservations. These residents are primarily in the unincorporated portions of Pacific County (6,823) and Grays Harbor County (3,957), reflecting the unincorporated towns of Ocean Park and Copalis Beach, among others (fig. 4). Many communities have low numbers but high percentages of residents in the tsunami-inundation zone, including the Makah Indian Reservation (802 residents, representing 59 percent of the community), the Hoh Indian Reservation (62 residents, 61 percent), South Bend (900 residents, 50 percent), and Long Beach (1,281 residents, 100 percent). As was the case with land-cover data, only the cities of Ocean Shores, Hoquiam, Aberdeen, and Westport, are above the regional third quartile values in both the amount and percentage of residents in the tsunami-inundation zone.

All individuals occupying tsunami-prone land are vulnerable to some extent, but demographic factors like age, race, gender, and socioeconomic status in specific situations can amplify this vulnerability, thereby increasing the potential for loss, present unique response needs, or slow recovery after an extreme event (Morrow, 1999; Ngo, 2003; Cutter and others, 2003; Laska and Morrow, 2007). Demographic attributes of race, age, gender, and tenancy are determined for residents in the tsunami-inundation zone and for the four counties (table 1). Results characterizing demographic attributes of residents in the study area (table 1) do not imply that all individuals of a certain demographic group will exhibit identical behavior during or after a tsunami. Variations in local cultures and situations, as well as individual and community resilience, will influence the extent of these demographic sensitivities.

One set of demographic characteristics that influences an individual's sensitivity are race and ethnicity, as studies have shown that households of racial and ethnic minorities tend to be more vulnerable to extreme events and have higher mortality rates (Morrow, 1999). This reflects not characteristics of the individual but rather historic patterns of racial and ethnic inequalities within a society that result in minority communities which are more likely to have inferior public services, infrastructure, and building stock (Laska and Morrow, 2007) and that may be excluded from disaster planning efforts (Morrow, 1999). Minorities that speak a language other than the primary language of an area can also have higher vulnerability,

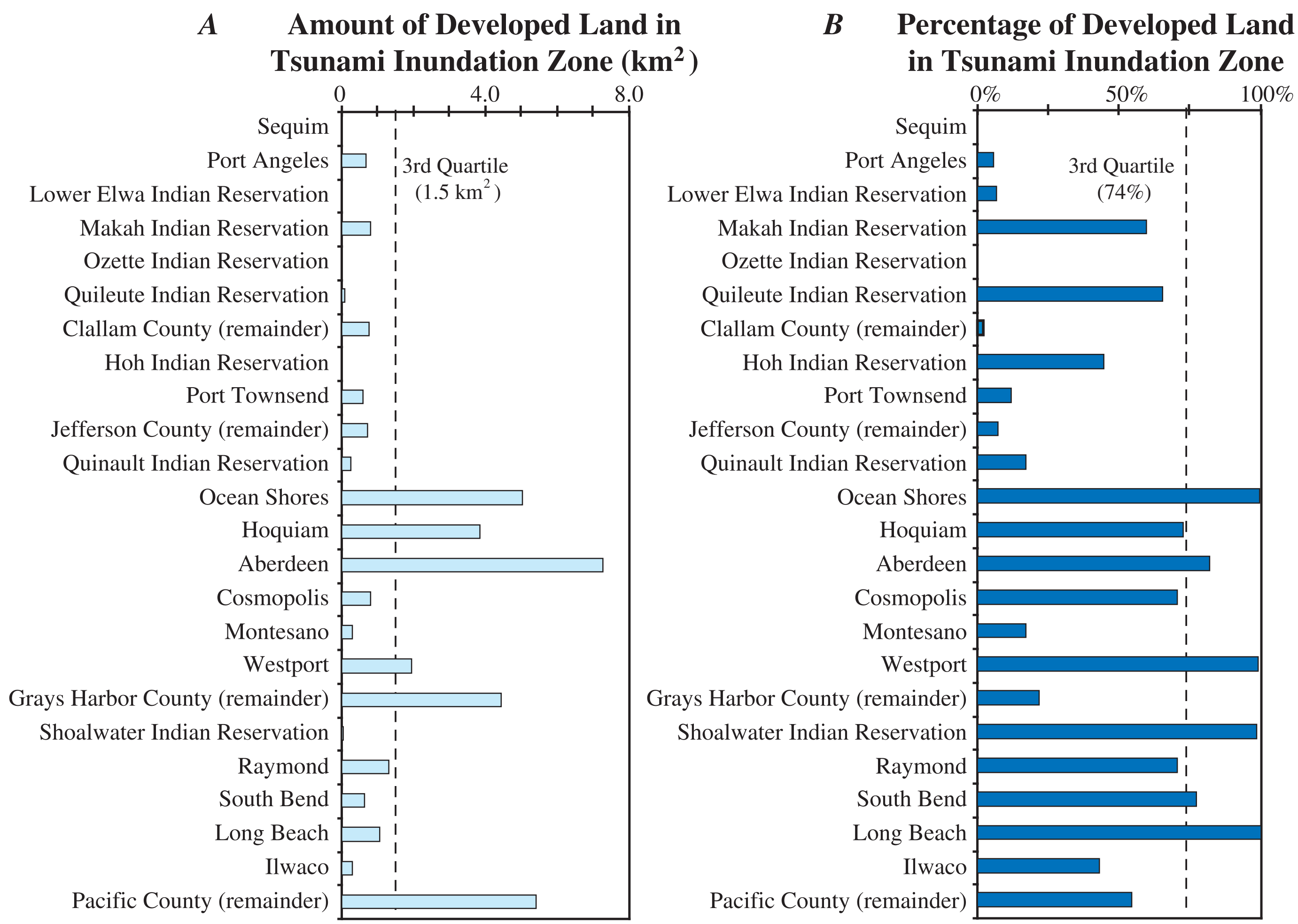

Figure 8. Amount (*A*) and percentage (*B*) of developed land in the tsunami-inundation zone for communities on the Straits of Juan de Fuca and open-ocean coasts of Washington.

as language barriers and cultural differences could hinder the effectiveness of awareness campaigns, evacuation procedures, and post-disaster recovery opportunities. Racial and ethnic diversity is generally low for the tsunami-prone areas of the four coastal counties, where 89 percent of all residents in the tsunami-inundation zone of the study area identified themselves in the 2000 Census as White, alone or in combination with one or more other races (table 1). Other reported races for residents in the tsunami-prone areas of the study area include Black or African American (less than 1 percent), American Indian and Alaska Native (8 percent) and Asian (2 percent). The percentage of Hispanic populations in the tsunami-inundation zone is also low (6 percent). Percentages in table 1 and the accompanying database in the race categories do not sum to 100 percent because individuals were able to report multiple races in Census 2000. Comparisons of race and ethnicity of residents in tsunami-prone areas (tsunami-zone percentage in table 1) to those of the entire study-area population (study-area percentage in table 1) indicate that no group is disproportionately represented in hazard-prone areas. Within the 20 areas, the maximum percentage of residents in the tsunami-inundation zone reporting a non-White race (alone or in combination with one or more other races) is low for most race categories, including Black or African American (2 percent), Asian (11 percent), and Native Hawaiian and Other Pacific Islander (1 percent). The exception is the percentage of residents that identify themselves as American Indian and Alaska Native, ranging from zero percent to as much as 94 percent among the 20 communities, where high percentages represent the numerous Indian reservations (fig. 10*A*).

Another demographic characteristic that influences an individual's sensitivity is age (Morrow, 1999; Ngo, 2001; Balaban, 2006; Laska and Morrow, 2007; McGuire and others, 2007). For example, a survey of Indonesian households impacted by the 2004 Indian Ocean tsunami demonstrated that mortality was highest for the youngest and oldest age groups (Rofi and others, 2007). Younger individuals, defined here as less than 5 years in age, often require direction and assistance to evacuate due to their immaturity and size. They are also prone to developing post-traumatic stress disorders, depressions, anxieties, and behavioral disorders as a result of their inability to comprehend and process the effects of a disaster

Table 1. Block-level demographic characteristics for residents in the tsunami-inundation zone on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Demographic Category	Tsunami-Inundation Zone	Study Area Total	Tsunami-Zone Percentage[1]	Study Area Percentage[1]	Community Maximum Percentage
Total Population	42,972	178,656	24%	n/a	100%
Hispanic or Latino Population	2,684	7,048	6%	4%	16%
Race—White alone or in combination with one or more other races	38,049	164,443	89%	92%[2]	100%
Race—Black or African American alone or in combination with one or more other races	305	1,464	1%	1%[2]	2%
Race—American Indian and Alaska Native alone or in combination with one or more other races	3,440	10,398	8%	6%[2]	94%
Race—Asian alone or in combination with one or more other races	954	3,275	2%	2%[2]	11%
Race—Native Hawaiian and Other Pacific Islander alone or in combination with one or more other races	124	554	0%	0%[2]	1%
Population under 5 years old	2,567	9,520	6%	5%	16%
Population over 65 years	8,021	34,264	19%	19%	33%
Female population	21,621	90,114	50%	50%	55%
Total Households	18,397	74,713	25%	n/a	100%
Renter-Occupied Households	6,412	20,784	35%	28%	53%
Single-Mother Households	1,439	4,942	8%	7%	23%

[1]In-hazard percentages refer the percentage of individuals (or households for the last two rows) in the tsunami-inundation zone of a specific demographic category. Study area percentages refer to the percentage of individuals (or households for the last two rows) in the four coastal counties (Clallam, Jefferson, Grays Harbor, and Pacific) of a specific demographic category.

[2]The sum of percentages by race will not sum to 100%, as individuals are able to report multiple race categories in Census Bureau reports.

(Balaban, 2006). Results indicate that younger individuals represent 6 percent of residents in the study area tsunami-inundation zone, approximately equal to the study-area percentage (5 percent), and range from 0 to 16 percent in the 20 communities (table 1). The maximum value of 16 percent is in the Hoh Indian Reservation, a community with only 62 residents in the tsunami-inundation zone.

Older individuals, defined here as over 65 years in age, are also considered to be disproportionately more sensitive than other age groups due to potential mobility and health issues, reluctance to evacuate, the need for special medical equipment at shelters (McGuire and others, 2007), and the lack of social and economic resources to recover (Morrow, 1999; Ngo, 2001). Specific to tsunamis, older individuals are considered more sensitive than other demographic groups due to possible health issues and mobility issues related to the short evacuation time prior to tsunami inundation (less than 30 minutes after ground-shaking in some communities). In addition, if a tsunami were to occur in the winter months, emergency shelters may not adequately protect older individuals from low air temperatures and high precipitation (common during winter months on the Washington coast), thereby creating additional health complications. Results indicate that older individuals represent 19 percent of residents in the tsunami-inundation zone, equal to the 19 percent found in the entire study area. Within the 20 communities, percentages of older individuals range from zero percent in Sequim to 33 percent in Port Townsend (fig. 10*B*). Communities with high percentages of older populations in tsunami-prone land may require special evacuation and relief procedures for this special-needs population. Tsunami-risk issues related to older individuals will likely increase, as the region is becoming a retirement destination (Washington Emergency Management Division, 2004).

Gender differences also influence an individual's sensitivity to a stressor (Enarson and Morrow, 1998; Bateman and Edwards, 2002). Preliminary work by Oxfam (2005) in the wake of the 2004 Indian Ocean tsunami suggests that women had a disproportionately higher mortality rate. Research of gender differences in natural disasters indicates that women tend to have higher risk perceptions, demonstrate higher preparedness planning, and are more likely to respond to warnings than men but also are more likely to be single parents or primary care givers, have special medical needs, have lower incomes, and less autonomy than males. Research also indicates that there are more documented reports after natural disasters of women with post-traumatic stress (Ollenberger and Tobin, 1998) and of abuse against women (Enarson, 1999). Although some differences may be attributed to biological and physiological differences, the heightened vulnerability of women to extreme events is believed to be more a reflection of broader cultural, political, and economic inequalities within a society that translate into social norms and role behaviors, as well as discrimination in access to post-disaster resources (Morrow, 1999; Bateman and Edwards, 2002; Neumayer and

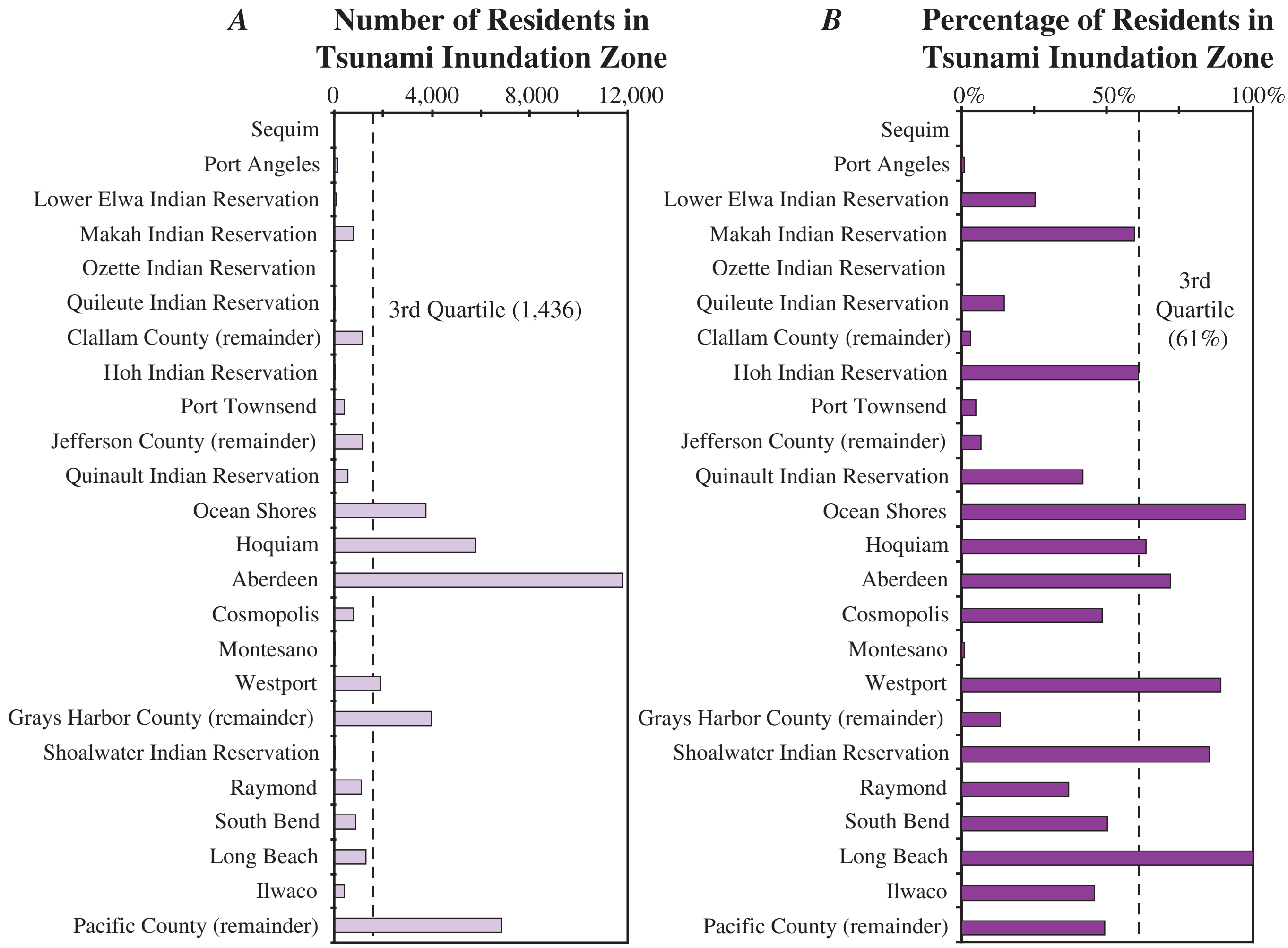

Figure 9. Number (*A*) and percentage (*B*) of residents in the tsunami-inundation zone for communities on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Plumper, 2007). Results indicate that 50 percent of individuals in the tsunami-inundation zone are women, equal to the study-area percentage (table 1). For the 20 communities, the percentage of residents in the tsunami-inundation zone that are female ranges from 38 percent (Port Angeles and Hoh Indian Reservation) to 55 percent (Lower Elwa Indian Reservation and Long Beach). Results also indicate that 8 percent of households in the tsunami-inundation zone are single-mother households, slightly higher than the 7 percent of households for the entire study area. Single-mother households may have unique evacuation and recovery issues, as they are more likely to have limited mobility during an evacuation and fewer financial resources to draw upon after a disaster (Laska and Morrow, 2007). The percentage of single-mother households in tsunami-prone land ranges from 0 percent in Sequim (due to the lack of any households in the tsunami-inundation zone here) to 23 percent in Quinault Indian Reservation (fig. 10C).

Tenancy is another demographic factor that influences individual sensitivity to stressors, as studies have shown that renters are less likely to prepare for catastrophic events than homeowners (Morrow, 1999; Burby and others, 2003). Theories on why this is the case include (1) higher turnover rates for renters that may limit their exposure to hazard-related outreach efforts, (2) preparedness campaigns may pay less attention to renters, (3) renters typically have lower incomes and fewer resources to recover, and (4) renters may lack the motivation to invest in mitigation measures for rented property (Burby and others, 2003). After a disaster, renters also have little control over the speed with which rental housing is repaired or replaced (Laska and Morrow, 2007). Results indicate that 35 percent of households in the tsunami-inundation zone are renter-occupied, higher than the 28 percent for the entire study area (table 1), and community values range from 0 percent in Sequim (due to the lack of any households in the tsunami-inundation zone here) to 53 percent in Raymond (fig. 10D).

Following the disaster pressure and release model (Wisner and others, 2004), vulnerability can be defined as the characteristics of a group that influence their ability to anticipate and cope with the impacts of a natural hazard. Demographic characteristics available at census block-group and tract levels

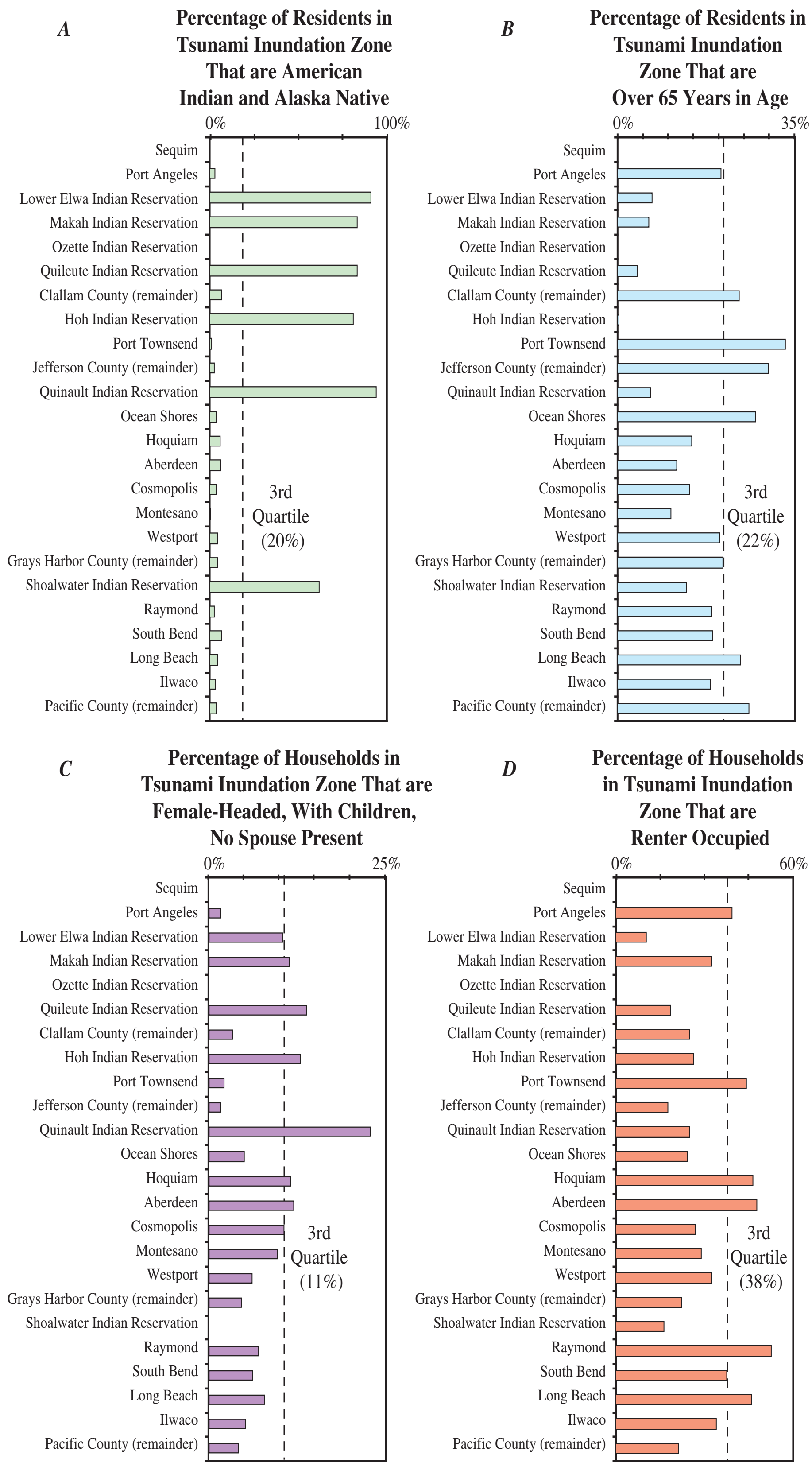

Figure 10. Percentages of residential population in the tsunami-inundation zone on the Straits of Juan de Fuca and open-ocean coasts of Washington that are (*A*) individuals who are American Indian and Alaska Native alone or in combination with one or more other races, (*B*) individuals who are over 65 years in age, (*C*) renter-occupied households, and (*D*) female-headed households, with children and no spouse present.

are summarized for each county and incorporated city in the study area (fig. 11) and can be considered pre-event characteristics that could attenuate or amplify the societal impact of a tsunami or any extreme event. Results indicate that the four coastal counties and the communities within them are generally below Washington and National averages in terms of the percentage of households earning more than $75,000 but fall between these averages with regards to the percentage of population that is 25 years or older with no high school diploma. The communities in the four coastal counties are above State and National averages in the percentage of housing units that are mobile homes, the percentage of individuals for whom poverty status is determined, the percentage of households receiving Social Security benefits, and the percentage of the civilian labor force that is unemployed. In 2003, the counties of Clallam, Grays Harbor, and Pacific were designated as economically distressed because of the high unemployment rates relative to the remainder of the State (Washington Emergency Management Division, 2004). Overall, these economic indicators suggest that post-tsunami recovery could be slow in the study area, considering the low earning levels of its residents and the high levels of unemployment, households in poverty status, and dependence on Federal benefits.

Employees

The tsunami-inundation zone contains 24,934 employees at 2,908 businesses, representing 31 percent of the businesses and 33 percent of the employees in the four coastal counties (table 2). Third-quartile values are 1,427 employees, representing 87 percent of a community's workforce. Similar to residential populations, the number (fig. 12*A*) and percentage (fig. 12*B*) of employees in tsunami-inundation zones vary considerably in the study area, with higher numbers of employees in tsunami-prone areas within Grays Harbor County and higher percentages in the Grays Harbor and Pacific Counties. Certain communities such as Hoquiam and Aberdeen have high numbers of employees in the tsunami-inundation zone (2,792 and 7,488, respectively) that represent high percentages of their community workforce (86 percent and 81 percent, respectively). Other communities have much lower numbers of employees in the tsunami-inundation zone, including Shoalwater Indian Reservation (138), but these employees also represent the majority of the local workforce (100 percent). Port Townsend has a high number of employees in tsunami-prone areas (2,228 employees), but these employees represent only 33 percent of the community's workforce. Unlike the residential data, there are not large numbers of employees in the tsunami-inundation zones of the unincorporated portions of the four counties.

Dependents

Results indicate that several dependent-population facilities are in the tsunami-inundation zone (table 3), including 48 schools facilities, 36 outpatient-care facilities, 20 child-day-care centers, 14 adult residential care centers, and 1 correctional facility. Many of these facilities are in central-coast communities, specifically the cities of Aberdeen and Hoquiam (fig. 13). Additional evacuation planning may be required in communities with high dependent populations (for example, the City of Aberdeen) due to the limited mobility of certain groups, such as those in schools and nursing homes. Traditional relief efforts may also need to be augmented if a com-

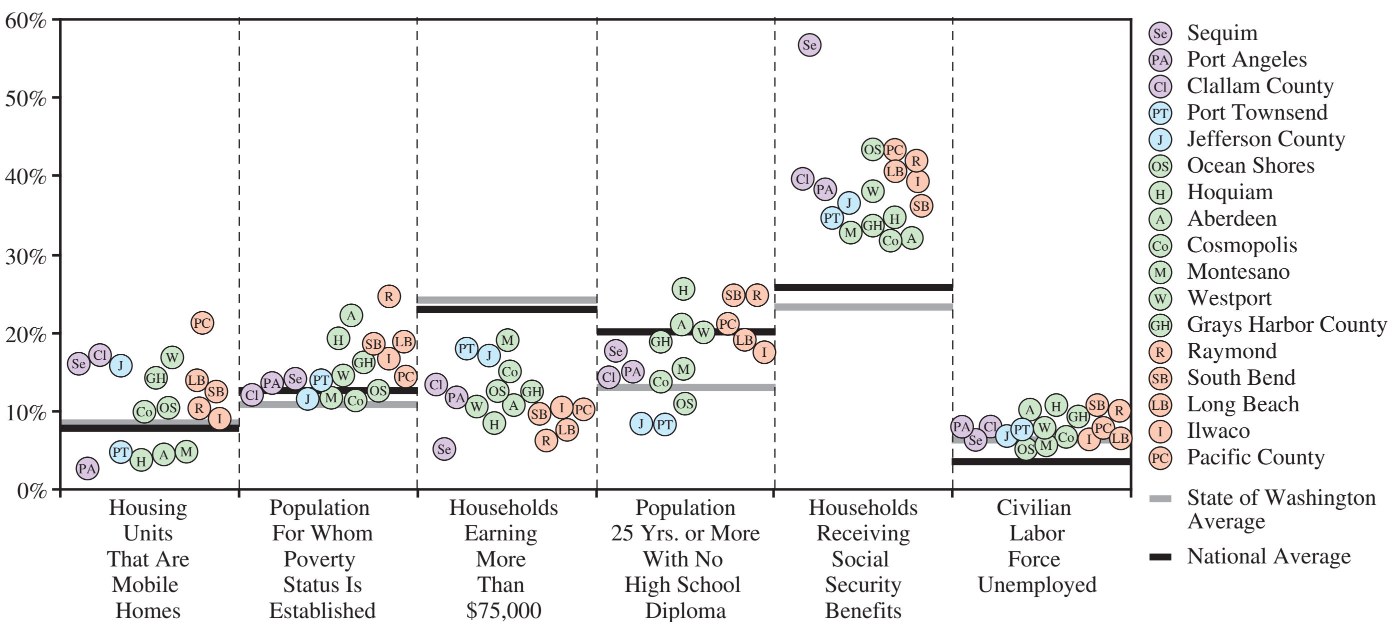

Figure 11. Blockgroup- and tract-level demographic characteristics for residents in communities on the Straits of Juan de Fuca and open-ocean coasts of Washington, based on the 2000 Census.

Table 2. Summary of the amount and percentage of economic assets in the tsunami-inundation zone on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Economic Asset	Inundation Zone	Study Area Total	Percentage
Businesses	2,908	9,351	31%
Employees	24,934	74,610	33%
Sales volume (in 2006 U.S. dollars)	$4,560,190,000	$11,538,110,000	40%
Total tax-parcel value (in 2006 U.S. dollars)	$4,507,058,438	$18,261,861,808	25%

munity has a significant adult residential care population due to potential health complications after a disaster. In addition to unique evacuation and relief issues, many dependent-population facilities represent critical social services that, if lost, could slow community recovery following an extreme event. For example, the loss of child-day-care facilities or schools could keep some parents from returning to their jobs until suitable arrangements can be made for their children and, in smaller communities, this delay could take weeks. Therefore, although a business may escape debilitating physical damage from the original earthquake and tsunami, it may suffer economic damages as a result of staffing challenges associated with the loss of community services.

Public Venues

Results indicate that there are several public venues in the tsunami-inundation zone that likely attract high numbers of local populations and tourists, including 54 religious facilities, 11 museums, and 10 libraries (table 4). The highest number of public venues in the tsunami-inundation zone are in the unincorporated areas of Pacific County (16 facilities) and the majority of them are religious facilities (for example, churches) (fig. 14). The next highest numbers of public venues in the tsunami-inundation zone are in the coastal communities of Grays Harbor County (for example, Aberdeen, Ocean Shores, Hoquiam, and Westport). The high numbers of public venues in the tsunami-inundation zone present both opportunities and challenges for the emergency-management community. An obvious challenge is the large number of individuals that would be in the tsunami-inundation zone if an event were to occur during a high-occupancy time (for

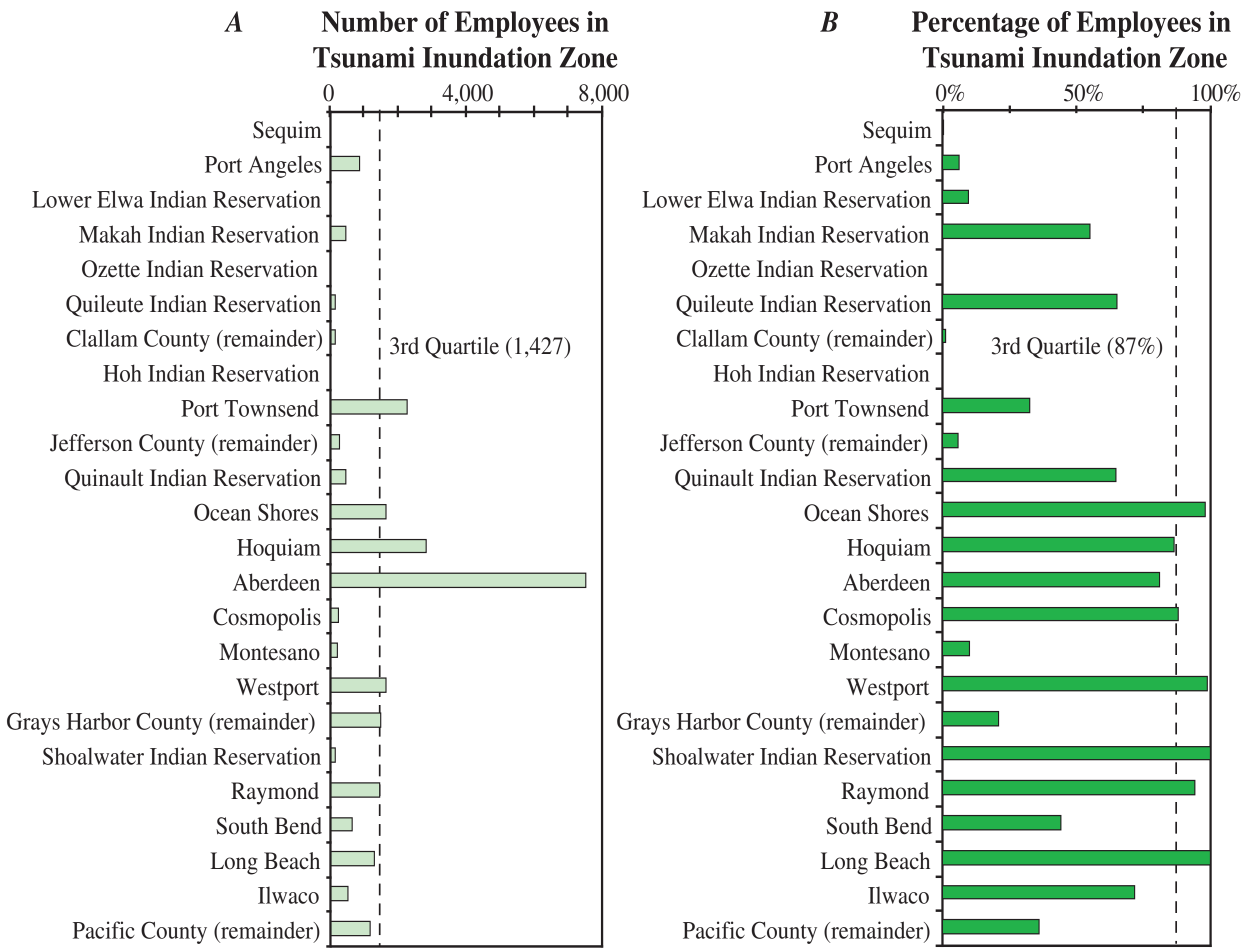

Figure 12. Number (*A*) and percentage (*B*) of employees in the tsunami-inundation zone for communities on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Table 3. Summary of the amount and percentage of dependent-population facilities in the tsunami-inundation zone on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Facility	Inundation Zone	Study Area Total	Percentage
Adult-residential-care facilities	14	50	28%
Child-day-care facilities	20	66	30%
Correctional facilities	1	10	10%
Hospitals	0	7	0%
Outpatient-care facilities	36	178	20%
Psychiatric and substance abuse hospitals	2	16	13%
Schools	48	167	29%

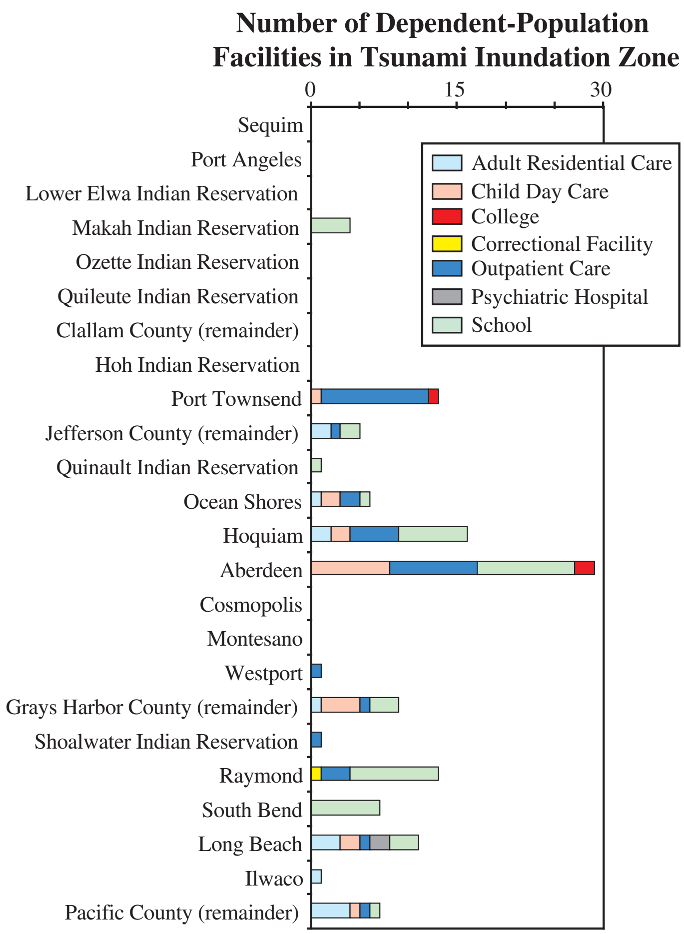

Figure 13. Number of dependent-population facilities in the tsunami-inundation zone of the Straits of Juan de Fuca and open-ocean coasts of Washington.

example, during a religious service). The presence of public venues in the tsunami-inundation zone, however, also presents an education/outreach opportunity for county and state emergency managers to work with owners and employees of these public venues to further educate local populations and to reach tourist populations.

Results indicate that there are 159 overnight-tourist facilities in the tsunami-inundation zone (representing 46 percent of all such facilities in the four coastal counties) and 32 of the hotels in tsunami-prone areas are in unincorporated areas of Pacific County (fig. 15). Overnight facilities include hotels, bed and breakfasts, inns, cabins, health resorts, resorts, tourist accommodations, campgrounds, camps, and hostels and were identified using NAICS codes in the InfoUSA Employer Database (appendix A). A third-quartile value of seven indicates that most communities do not have high numbers of tourist accommodations in the tsunami-inundation zone and that most of these businesses are clustered in only a few of the communities, such as in unincorporated areas of Pacific County (32), Ocean Shores (26), unincorporated areas of Grays Harbor County (21), and Westport (20) (fig. 15). Although tourist-related lodging in tsunami-prone areas provides some insight on tourist exposure, the number of tourists in the tsunami-inundation zone at any given time is likely much greater, due to the number of unaccountable individuals staying with friends and family, as well as those who go to the shoreline during the day but stay at hotels located further inland at higher elevations.

Analysis of visitor data from Washington State Parks suggests that 27 parks in the tsunami-inundation zone of the study area receive a significant amount of day tourists (fig. 16*A*). The highest annual average of day-use visitors for the 27 parks are for Fort Worden (1,164,125 visitors and near Port Townsend) and Cape Disappointment (1,162,447 visitors and near Ilwaco). The sum of annual average visitors to the 27 coastal parks of the Washington State parks selected for this study is 6,215,569 people. Assuming an equal distribution of visitors on every day of the year, this equates to 17,029 day-use visitors to coastal State parks on average every day. In reality, this number is low because attendance is not equally distributed throughout the year; there will be seasonal peaks in park attendance (for example, summer months and holidays). Clustering the number of visitors of coastal parks to nearby towns (fig. 16*B*), it is clear that the majority of visitors are going to parks near Port Townsend (36 percent) on the Strait of Juan de Fuca and Hood Canal coasts, followed by parks near Ilwaco (21 percent), Ocean Shores (16 percent), and Westport (14 percent). Therefore, in addition to dealing with residents and employees within the tsunami-inundation zones of their communities, cities like Port Townsend may have significant numbers of tourists that are visiting nearby State Parks when a tsunami occurs.

Economic Assets

The tsunami-inundation zone contains parcel values assessed at approximately $4.5 billion, representing 25 percent of the total parcel values in the four coastal counties. The

Table 4. Summary of the amount and percentage of public venues in the tsunami-inundation zone on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Public Venue	Inundation Zone	Study Area	Percentage
Aquariums	1	2	50%
Casinos	2	5	40%
Colleges and universities	3	11	27%
Libraries	10	26	38%
Museums	11	21	52%
Parks	7	20	35%
Religious organizations	54	235	23%
Shopping centers and malls	0	2	0%
Sporting facilities	0	1	0%
Theaters	5	14	36%
Zoos	0	1	0%

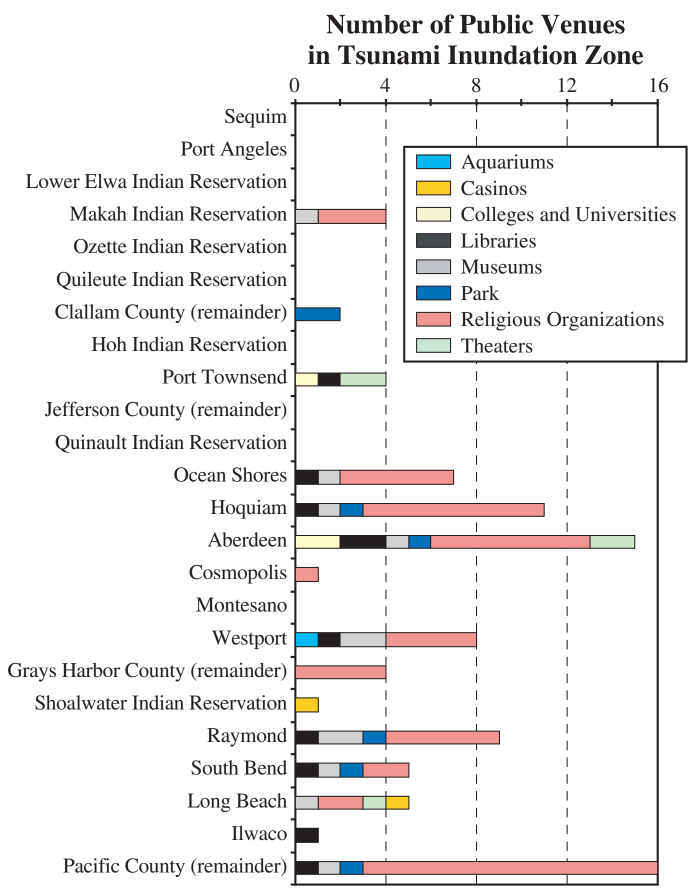

Figure 14. Number of public venues in the tsunami-inundation zone of the Straits of Juan de Fuca and open-ocean coasts of Washington.

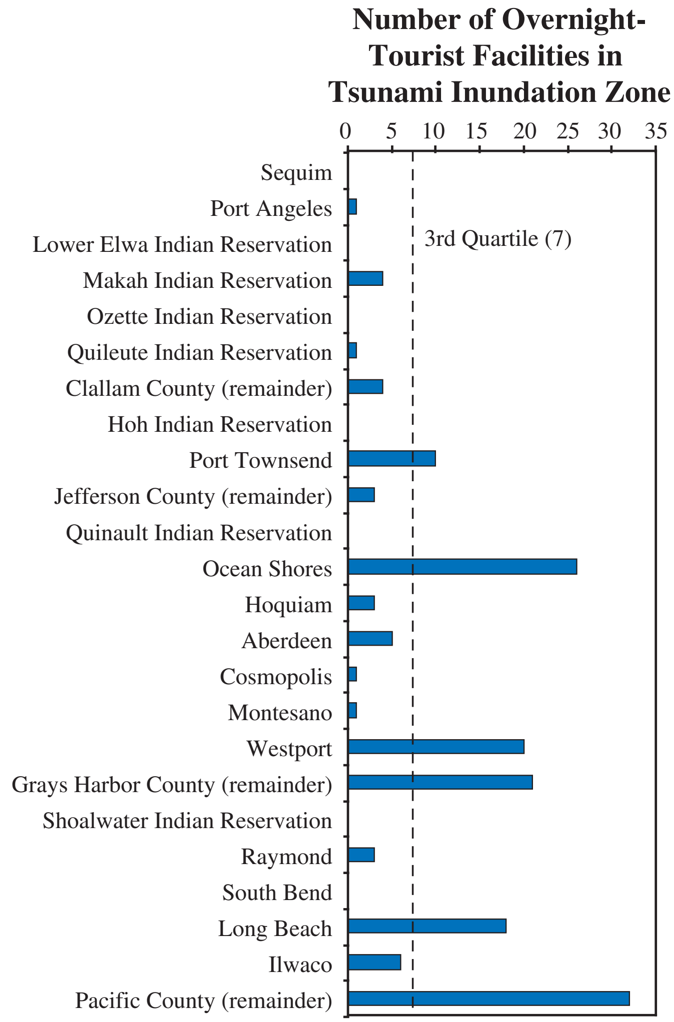

Figure 15. Number of overnight-tourist facilities in the tsunami-inundation zone for communities on the Straits of Juan de Fuca and open-ocean coasts of Washington.

amount (fig. 17*A*) and percentage (fig. 17*B*) of total parcel values varies significantly across the study area. Median value for total parcel values in the tsunami-inundation zone among the 20 communities is approximately $50 million and the third-quartile value is $271 million. The highest total exposed tax parcel values for the 20 communities are in Aberdeen ($887 million) and Ocean Shores ($759 million), representing 71 percent and 99 percent, respectively, of the total tax base in the communities. The third highest total parcel values is in the unincorporated portion of Pacific County, primarily reflecting the unincorporated town of Ocean Park (fig. 4). Although many communities have relatively low amounts of total parcel value in the tsunami-inundation zones, the exposed parcels represent a high percentage of a community's total assets, a finding also observed in the distribution of residential and employee populations. Communities such as Westport and Long Beach are well below the third quartile value of $271 million, but in each case, the parcels in these communities represent

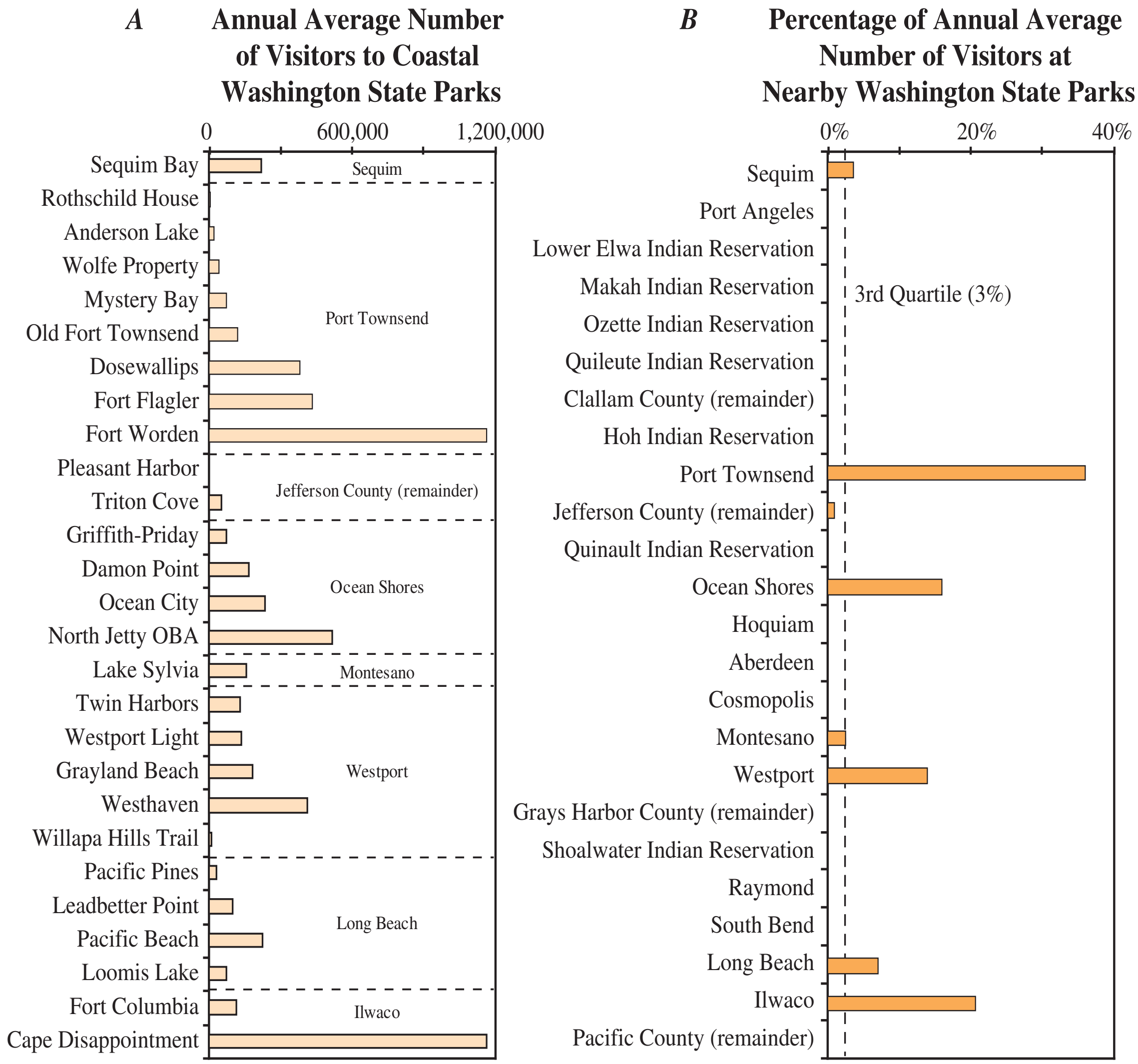

Figure16. Annual average number of visitors to coastal Washington State Parks illustrated (*A*) by the amount per park and (*B*) as a percentage related to nearby communities.

97 and 100 percent, respectively, percent of the local tax base. Building damages due to CSZ-related tsunamis, as well as from the preceding earthquake, could significantly lower the content value of individual properties, thereby lowering the tax base of a community after a tsunami disaster, and reducing the funds available for long-term recovery.

There are 2,908 businesses with 24,934 employees that generate more than $4.6 billion in sales volume in the Washington tsunami-inundation zone, representing 31 percent of all businesses, 33 percent of employees, and 40 percent of generated sales volume in the four Washington coastal counties (table 2). Communities on the central and southern Washington coasts have the highest percentages of their employees in the tsunami-inundation zone (fig. 12*B*), including Shoalwater Indian Reservation (100 percent), Long Beach (100 percent), Westport (99 percent), Ocean Shores (98 percent), and Raymond (94 percent). Some communities have significant numbers of employees in tsunami-inundation zones but these numbers represent a small proportion of the economies of these locales; for example, there are 2,228 employees in the tsunami-inundation zone in Port Townsend, but these employees represent 33 percent of the city's workforce. Smaller communities, such as Cosmopolis and Shoalwater Indian Reservation, have much smaller numbers of employees in their tsunami-inundation zones (229 and 138 employees, respectively), but face significant threats to their economies from a tsunami because of the high percentages (88 percent and 100 percent, respectively). High percentages of employees in tsunami-inundation zone represent economic fragility for a community, as unemployment could increase dramatically overnight if a tsunami injures or kills employees or if it damages or destroys businesses. Even if a business escapes damage or physical disruption from an extreme event, it may still experience significant customer and revenue loss if the neighborhood and other businesses around it are damaged, leading customers to shop elsewhere. Neighborhood effects

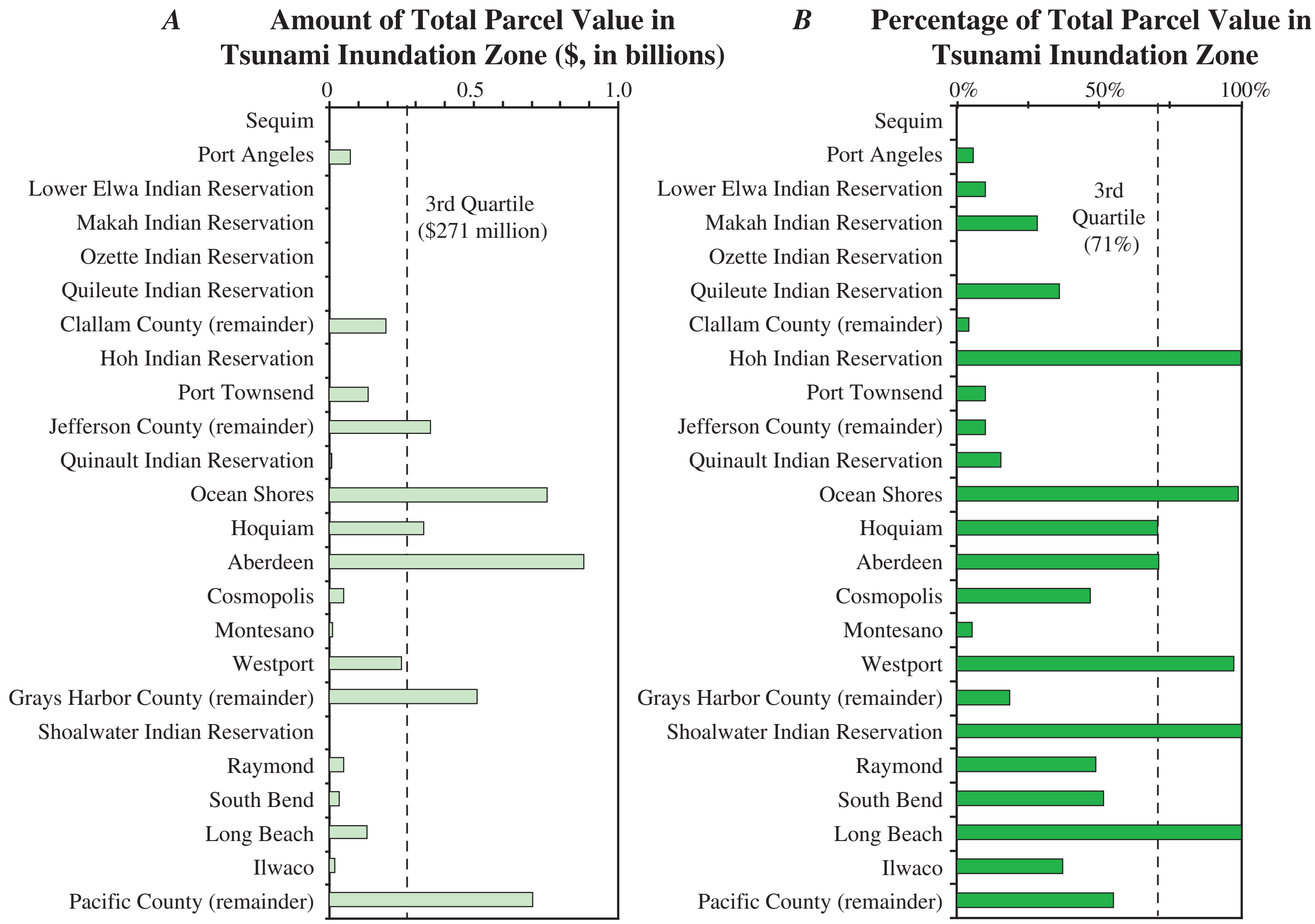

Figure 17. Amount (*A*) and percentage (*B*) of total tax-parcel value in the tsunami-inundation zone for communities on the Straits of Juan de Fuca and open-ocean coasts of Washington.

have been found to be especially important for retailers that rely on foot traffic (Chang and Falit-Baiamonte, 2002), a potentially significant issue for tourism-related retail and food services within Washington coastal communities.

Societal vulnerability is also influenced by the types of businesses in the tsunami-inundation zone. If the dominant business sectors in the tsunami-inundation zone are accommodations and food services, then a primary concern for local responders after a tsunami is the high number of tourists in the impacted area. If businesses are primarily manufacturing facilities, there are likely low numbers of tourists in the area and response issues may center on employees (where potential numbers and locations can be determined by working with business owners) and the potential for hazardous material spills. In addition, the success of manufacturing facilities after a tsunami will depend heavily on functioning infrastructure (for example, roads and energy) to transport and process materials, whereas tourist-related businesses will succeed only if they (and the larger community) can regain the aesthetic and cultural benefits of the area to attract tourists again.

The economies of the four counties have been historically dominated by timber and related industries but have diversified in the past decade and now also depend on trade and services sectors that cater to tourists and a growing retiree population (Washington Emergency Management Division, 2004). The distribution of employees by business type (fig. 18), based on the 2006 InfoUSA Employer Database, support these assertions and indicates that the highest percentage of employees in the four Washington coastal counties are currently in health care and social assistance (14 percent), likely reflecting services to support the growing retiree population, and followed by high employee percentages in retail trade (12 percent) and accommodations and food services (10 percent), likely reflecting the expansion of tourism in the region (Washington Emergency Management Division, 2004). Employees in the manufacturing sector only constitute 9 percent of the region, behind public administration (10 percent) and educational services (10 percent), indicating a considerable decline for a sector that historically dominated the region (Washington Emergency Management Division, 2004). Within the manufacturing sector, employment is highest at at ship and boat

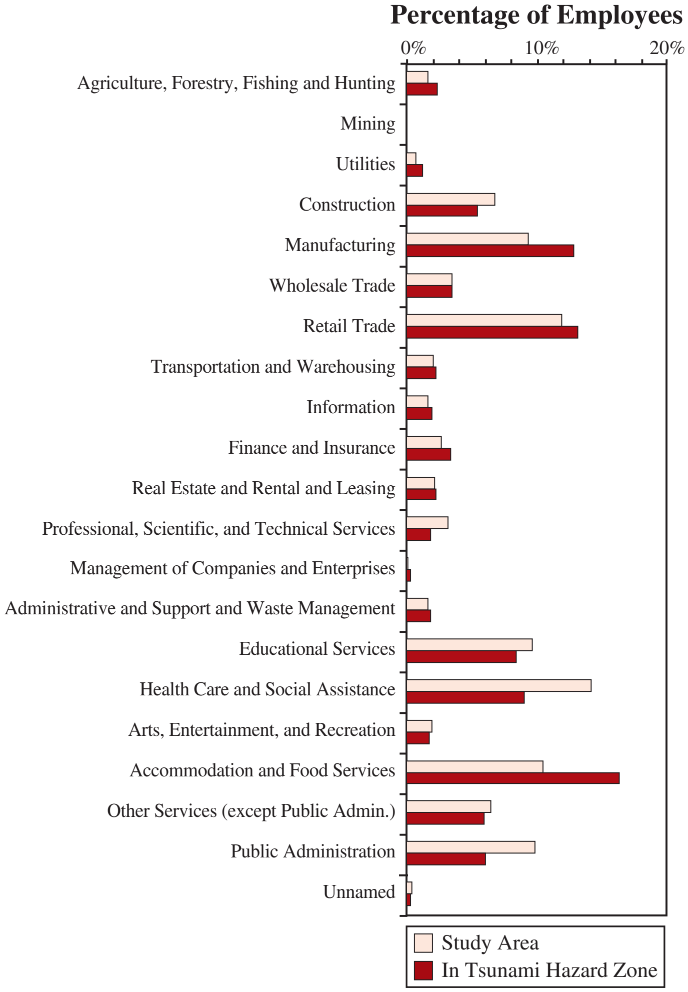

Figure 18. Percentage of employees, by business sector, in the tsunami-inundation zone for communities on the Straits of Juan de Fuca and open-ocean coasts of Washington.

building facilities (20 percent) and at timber-related businesses, including wood products (20 percent of employees), pulp, paper, and paperboard (19 percent), veneer and plywood production (7 percent), and saw mills (2 percent).

Employee distributions for businesses in the tsunami-inundation zone vary slightly from that of the entire study area (fig. 18), with an increase in the accommodation and food services sector (from 10 percent for all businesses in the four counties to 16 percent for just those in the tsunami zone), an increase in the manufacturing sector (from 9 percent to 13 percent), similar percentages for retail trade (12 and 13 percent) and decrease in educational services, health care, and public administration. The percentage of employees in the accommodation and food services sector for businesses in the tsunami-inundation zone (16 percent) is twice the national average of 8.3 percent (2005 value) for the same industry sector (Bureau of Labor Statistics, 2007b). The high percentages of accommodations and food services, retail trade and manufacturing for businesses in the tsunami-inundation zone indicate that tsunami-impact zones will likely contain a significant number of non-residents at hotels and restaurants but also potentially contain hazardous materials, raw products (for example, timber), and heavy machinery that could be scattered across a community during a tsunami.

Although growth in the trade and services sectors is considered advantageous for the regional economy considering the decline in manufacturing sectors, one trade-off of this shift is the increase in lower-wage jobs (Washington Emergency Management Division, 2004). In the event of a tsunami, communities may have a hard time recovering if a significant portion of its pre-event economy is comprised of tourism-related, lower-wage jobs. Low-wage earners in the trade and services sectors may not have a great deal of capital to rebuild damaged property, may have been renting their homes prior to the tsunami (see renter-related issues in the population discussion), and their livelihoods after a catastrophic tsunami largely depend on the return of tourists.

Critical and Essential Facilities

Several critical and essential facilities are in the Washington tsunami-inundation zone (table 5). The low number of exposed hospitals (0) and outpatient-care centers (8), but high number of exposed physician and dentist offices (53) suggests that community hospitals may be able to handle casualties and injuries during the immediate response phase of a disaster but some communities may experience difficulties in maintaining medical services during the longer-term recovery phase if they lose a significant number of physician and dentist offices. Other critical facilities in the tsunami-inundation zone of the four coastal counties include public-work facilities (14), police stations (10), radio and television facilities (10), fire stations (8), and waste-water facilities (8). Loss or reduced function of these facilities could slow response and relief efforts should a series of CSZ-related tsunamis strike the coast. Long-term community recovery may also be hampered by the potential loss of the numerous essential facilities in the tsunami-inundation zone, including government offices (101), banks and credit unions (47), grocery stores (32), and U.S. Post Offices (16). Information on types of facilities within each community and whether they are in the tsunami-inundation zone is available in the accompanying project database (appendix B).

In most cases, the relative percentages are low for most categories when comparing facilities in the tsunami-inundation zone to the entire study area (table 5). For example, the exposed fire and police stations represent 22 and 34 percent, respectively, of similar facilities in the four counties. Percentages of study area totals are higher for infrastructure-related facilities–for example, electrical facilities (40 percent), gas facilities (50 percent), and waste-water facilities (53 percent). The highest percentage of exposed critical facilities was for ambulance services, where 100 percent of all facilities are in the tsunami-inundation zone. A next step for analysis is to determine the redundancy of facilities in an area. For example, results presented here indicate that a high number of

Table 5. Summary of the amount and percentage of critical and essential facilities in the tsunami-inundation zone on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Facility	Tsunami-Inundation Zone	Study Area Total	Percentage
Critical facilities			
Civil-defense facilities	0	7	0%
Fire stations	8	37	22%
National-security facilities	1	15	7%
Police stations	10	29	34%
Ambulance services	5	5	100%
Hospitals	0	7	0%
Outpatient-care centers	8	31	26%
Electrical facilities	4	10	40%
Public-works facilities	14	32	44%
Gas facilities	1	2	50%
Radio and television facilities	10	16	63%
Waste-water facilities	8	15	53%
Water and sewer facilities	4	19	21%
Essential facilities			
Banks and credit unions	47	106	44%
Courts and legal offices	9	30	30%
Gas stations	2	15	13%
Doctor and dentist offices	53	225	24%
Government offices	101	369	27%
Groceries	32	82	39%
International-affairs offices	0	2	0%
U.S. Post Offices	16	42	38%

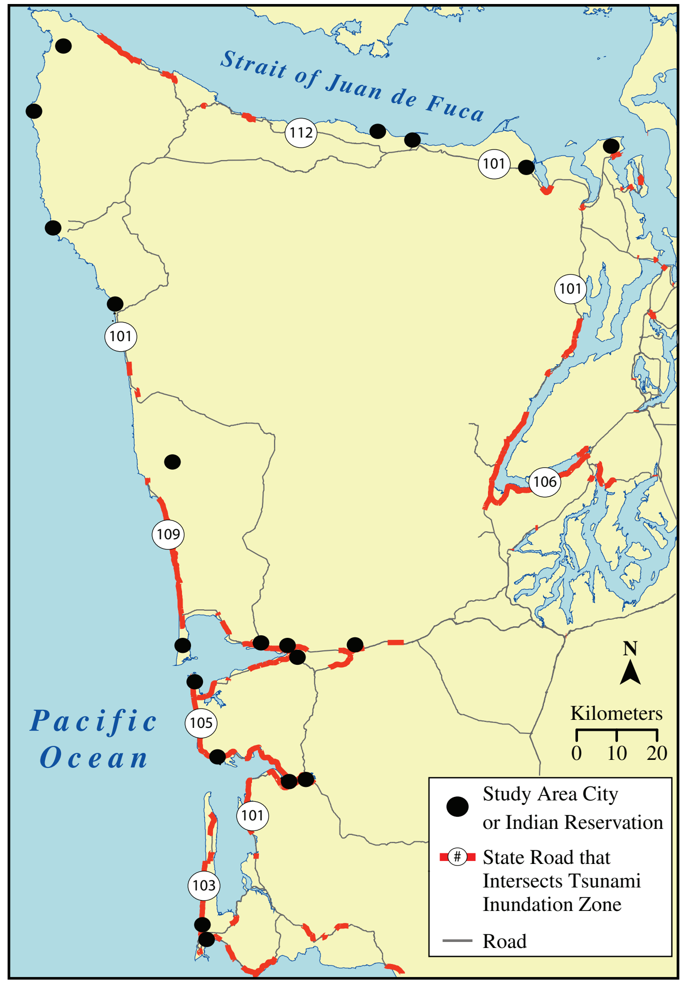

Figure 19. Map of State roads that intersect the tsunami-inundation zone along the Straits of Juan de Fuca and open-ocean coasts of Washington.

police stations (10) are in the tsunami-inundation zone. If one community lost its police station from tsunami impact and a neighboring community did not, it may be possible to share resources between communities. However, if both communities lose their police stations, then the ability to maintain public order for the region is significantly compromised. Another potential issue is facility access. For example, assuming each of the 8 hospitals escape damage from the CSZ-related earthquake and associated tsunamis, neighboring communities that rely on these hospitals for medical services may have difficulty accessing them due to blocked or impaired roads, impacted by earthquake-related sand boils or tsunami-related debris and deposition. An overlay of the tsunami-inundation zone and a State highways layer (Washington Department of Transportation, 2007) indicates that several major roads, including U.S. Highway 101 and State Roads (SR) 101, 103, 105, 106, 109, and 112, have segments in tsunami-prone areas (fig. 19). Impaired roads could hinder response efforts and isolate several communities in the study area. The level of dependency on critical facilities and other social services between communities, as well as the ability to access these facilities on impaired roads is an area that requires further analysis. The importance of functioning roads is also critical for the study area because a significant percentage of the region's workforce commutes to jobs outside of their counties of residence (Washington Emergency Management Division, 2004); therefore, functioning roads are critical in the short term for community services and in the long term for economic productivity.

Composite Indices of Community Exposure and Sensitivity

Composite indices of exposure (based on amounts) and sensitivity (based on percentages) for each of the 13 incorporated cities, 7 Indian reservations, and unincorporated portions of the four counties are the sums of normalized data in 5 categories—developed land, residents, employees, public venues, and total parcel value. Table 6 summarizes the composite exposure and sensitivity values (each with a range from 0 to 5) for the 24 jurisdictions where higher values indicate higher relative exposure or sensitivity; figure 20 provides the same

Table 6. Composite exposure and sensitivity values for communities in the tsunami-inundation zone on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Range	Composite Exposure Values	Composite Sensitivity Values
4.0 to 5.0	Aberdeen (4.4)	Long Beach (5.0) Ocean Shores Westport Shoalwater Indian Reservation
3.0 to 3.9	Pacific County (unincorporated portion)	Aberdeen Hoquiam Cosmopolis Raymond
2.0 to 2.9	Ocean Shores Grays Harbor County (unincorporated portion) Hoquiam	South Bend Makah Indian Reservation Quileute Indian Reservation Ilwaco Pacific County (unincorporated portion)
1.0 to 1.9	Westport Long Beach	Quinault Indian Reservation Hoh Indian Reservation Grays Harbor County (unincorporated portion)
0 to 0.9	Raymond Port Townsend Clallam County (unincorporated portion) Makah Indian Reservation South Bend Jefferson County (unincorporated portion) Port Angeles Ilwaco Cosmopolis Quinault Indian Reservation Montesano Quileute Indian Reservation Shoalwater Indian Reservation Lower Elwa Indian Reservation Hoh Indian Reservation Sequim Ozette Indian Reservation	Port Townsend Lower Elwa Indian Reservation Montesano Jefferson County (unincorporated portion) Port Angeles Clallam County (unincorporated portion) Sequim Ozette Indian Reservation

information in graphical form to better visualize geographic variations in composite scores along the Washington coast. Although the composite exposure and sensitivity indices share a common data range of 0 to 5, the exposure scale is graphically reversed in figure 20 to facilitate easier comparisons of composite exposure and sensitivity index values for individual communities. In general, the highest composite exposure and sensitivity scores are found in Grays Harbor and Pacific Counties (fig. 20). The City of Aberdeen has the highest composite exposure value (4.4), indicating that this community consistently has one of the highest amount of assets in the tsunami-inundation zone. The City of Long Beach has the highest composite sensitivity value (5.0), indicating it has the highest percentage of assets in the tsunami-inundation zone for each of the five categories. Results indicate that some communities (for example, the unincorporated areas of Grays Harbor and Pacific Counties) have higher relative exposure than sensitivity values, whereas others (for example, Makah Indian Reservation, Quileute Indian Reservation, Ocean Shores, Westport, Shoalwater Indian Reservation, Raymond, South Bend, Long Beach, and Ilwaco) have higher relative sensitivity than exposure (fig. 20).

A frequency histogram depicting the distribution of composite exposure and sensitivity values illustrates the relative vulnerability of the 24 jurisdictions (fig. 21). The x-axis shows the composite scores in 0.5 increments and the y-axis notes the number of communities for each category. Most communities have scores of 0 to 1 for relative composite exposure, indicating that they have considerably fewer people and societal assets in tsunami-prone areas than the City of Aberdeen, the unincorporated portion of Pacific County, and Ocean Shores. Unlike the composite exposure values, sensitivity values are equally distributed across the multiple ranges. This indicates that many communities face similar issues on the relative impact that CSZ-generated tsunamis could have on their community's populations and economic assets, regardless of the absolute amount of assets in the tsunami-inundation zone,

Composite exposure and sensitivity values are normalized to maximum values found in each category (thereby creating

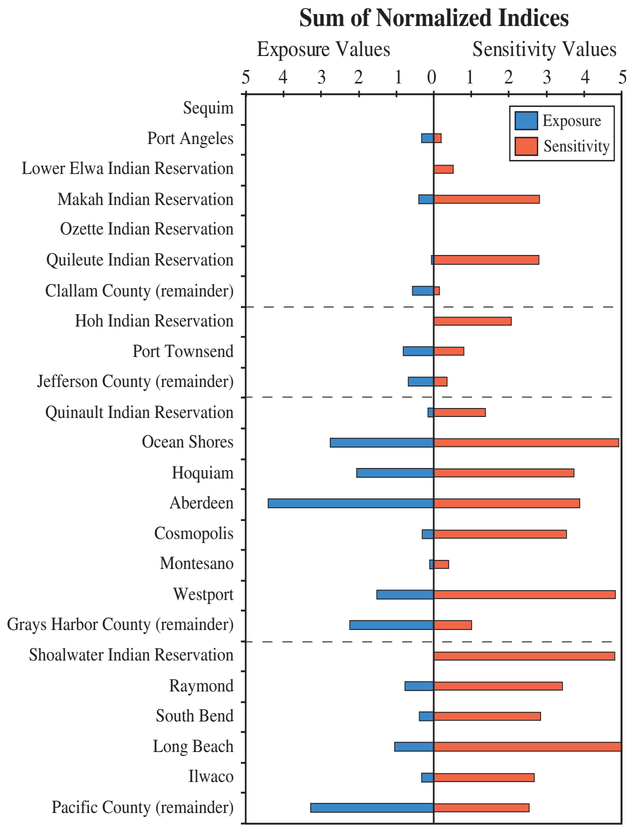

Figure 20. Comparison of normalized exposure and sensitivity indices for incorporated cities and Indian reservations on the Straits of Juan de Fuca and open-ocean coasts of Washington.

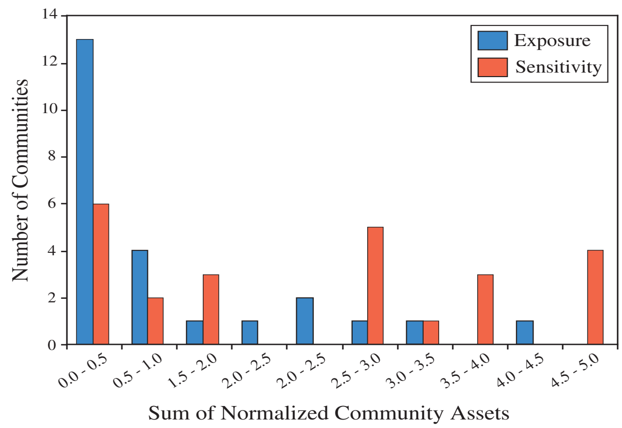

Figure 21. Frequency histogram of the sum of normalized exposure and sensitivity indices for incorporated cities and Indian reservations on the Straits of Juan de Fuca and open-ocean coasts of Washington.

a common data range of 0 to 1 for each category and minimizing any bias between the exposure and sensitivity categories) and then added to determine which communities have the highest combined exposure and sensitivity to tsunamis (fig. 22). The City of Aberdeen has the highest combined exposure and sensitivity score of 1.8, where its high relative vulnerability is primarily due to the exposure of its assets. It, however, is not an outlier of community vulnerability and other communities have high combined scores, including Ocean Shores (1.6) and Westport (1.3). Unlike Aberdeen, Ocean Shore's relative vulnerability is primarily due to its high sensitivity to tsunami hazards—low amounts of assets in the hazard-prone area that represent high percentages of the community's total assets. Some communities are primarily vulnerable to tsunamis due to the high number of assets in tsunami-prone areas (for example, the unincorporated areas of Pacific and Grays Harbor Counties), whereas others are vulnerable due to higher community sensitivity to the potential losses (for example, Ocean Shores, Westport, Hoquiam, and the Shoalwater Indian Reservation).

Exposure and sensitivity comparisons provide a first-order approximation of societal vulnerability because they do not include variations in resilience, the third component that influences vulnerability (Turner and others, 2003). The ability of a community to withstand, absorb, adapt to, and recover from losses defines its resilience, and—with other conditions remaining the same—greater resilience lowers a community's vulnerability to extreme events. For example, if two communities have identical community assets in tsunami-prone land, but one has a tsunami education program, a well-rehearsed evacuation plan, redundant critical infrastructure, and a holistic post-disaster recovery plan and has met the criteria for certification as a TsunamiReady community (National Weather Service, 2007), then that community is assumed to have greater resilience that should result in more-efficient response operations and shorter recovery times after the extreme event. Despite similar asset distributions, the same extreme natural event would mean a short-term crisis in the more resilient community and a longer-term disaster in less resilient community. Follow-up studies to document variations in community resilience would complement this report, providing the State of Washington with a more complete picture of societal vulnerability to tsunamis in these four counties.

Statistical Relationship to Land-Cover Data

Linear regression analyses were performed to test the hypothesis that the distribution of assets in a community depends on how much land is in the tsunami-inundation zone. Statistical tests were conducted for values of exposure (the amounts of land compared to the amounts of various assets in tsunami-inundation zones) and of sensitivity (the percentages of land compared to the percentage of various community assets in tsunami-prone areas). Based on criteria of $p < 0.05$, results indicate that most, but not all, relationships are significant (table 7). For exposure values, the only nonsignificant relationship is between the amount of tsunami-prone land in a community and the amount of employees on that land ($p = 0.68$). The relationships are significant between the amount of land and the amount of developed land ($p < 0.01$), residents ($p = 0.02$), public venues ($p < 0.01$), and total parcel value ($p < 0.01$); however, low explained variance (r^2) values for these assets (0.33, 0.22, 0.48, and 0.34, respectively) suggest that

Table 7. Statistical results of linear regression analyses comparing land data and community assets in the tsunami-inundation zone for communities on the Straits of Juan de Fuca and open-ocean coasts of Washington.

Regression significance between land cover and:	Exposure Values				Sensitivity Values			
	R	R^2	F*	P	R	R^2	F*	P
Developed land	0.58	0.33	10.93	< 0.01	0.79	0.62	35.90	< 0.01
Residents	0.47	0.22	6.10	0.02	0.78	0.60	33.46	< 0.01
Employees	0.09	0.01	0.17	0.68	0.69	0.47	19.73	< 0.01
Public venues and hotels	0.69	0.48	20.02	< 0.01	0.67	0.45	17.82	< 0.01
Total parcels value	0.59	0.34	11.50	< 0.01	0.76	0.57	29.64	< 0.01

*A regression relationship is considered significant at $p < 0.05$ if $F > 4.30$, as $F_{0.05(1),1,22} = 4.30$.

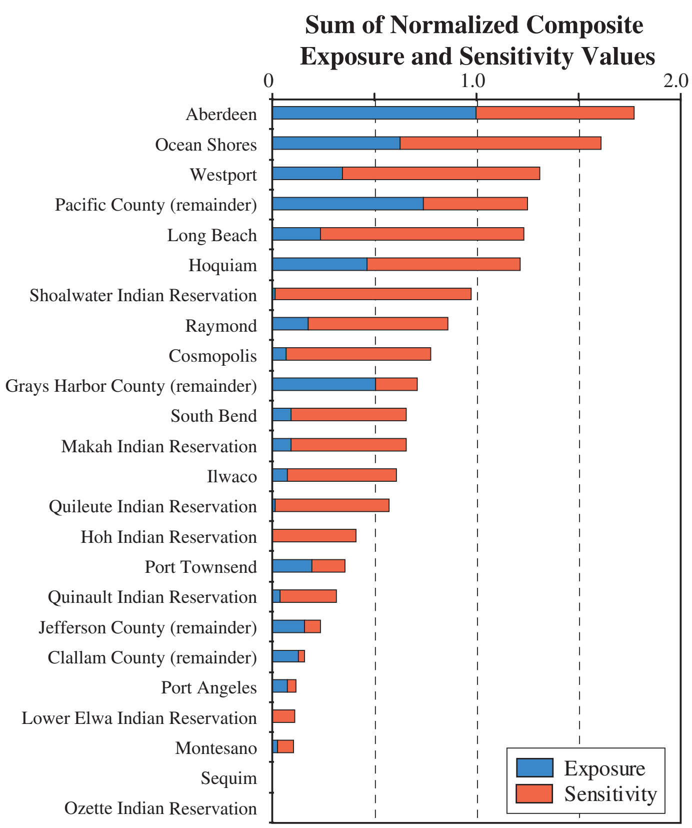

Figure 22. Sum of normalized exposure and sensitivity indices for incorporated cities and Indian reservations on the Straits of Juan de Fuca and open-ocean coasts of Washington.

the relationships, although statistically significant, are not strong. For sensitivity values, all relationships are statistically significant between the percentage of tsunami-prone land of a community and the percentage of all community assets (all $p < 0.01$). The r^2 values for sensitivity values are higher than those for the exposure values, ranging from 0.45 for public venues to as much as 0.62 for developed land.

These results demonstrate that the amount of community land in the tsunami-inundation zone has a significant but weak relationship to the amount of community assets found in the tsunami-inundation zone of the Washington coast. In other words, two communities with the same amount of tsunami-prone land have made different land-use decisions on how much and what kind of development is in these threatened areas. The percentage of a community's land that is in tsunami-prone areas is moderately related to the percentage of its assets—such as the percentage of a community's workforce—located in the hazard zone. Consequently, knowing the amount of tsunami-prone land in a community is not a strong indicator of the level of community exposure but knowing how much of a community's total land is located in a tsunami-prone area provides some insight on how sensitive a community may be to a tsunami.

Summary

This report focuses on the tsunami-prone landscape of the open-ocean and Strait of Juan de Fuca coasts of Washington and was developed to support collaboration between the Washington Military Department Emergency Management Division and the USGS that focuses on improving our understanding of community vulnerability to tsunamis. Based on a geospatial analysis of the distribution of landcover types, populations, economic assets, and critical facilities relative to Washington tsunami-inundation zones, the following conclusions can be made:

1. Ninety-two percent of the land in the tsunami-inundation zone is classified as undeveloped, indicating that the zone from a regional perspective contains relatively few people, structures, and other development;
2. A significant portion of the 42,972 residents in the tsunami-inundation zone are over 65 years in age (a population that may have difficulty evacuating given potential limitations in mobility and health concerns), and renters (a population that typically has lower hazard awareness and is less prepared for catastrophic events);
3. Thirty percent of the residents in the tsunami-inundation zone are in the unincorporated portions of the four counties (Clallam, Jefferson, Grays Harbor, and Pacific), indicating the importance of awareness programs and evacuation planning for rural communities;
4. Although the racial diversity of the residents in tsunami-prone areas for the region is low (where 89 percent

identify themselves as White), eight percent of residents identify themselves as American Indian or Alaska Native and targeted risk-reduction strategies for these populations (largely on Indian Reservations) that reflect potential cultural differences may be needed;

5. A tsunami could significantly impact the regional economy, as 33 percent of the study-area workforce is in tsunami-prone areas, and 3 of the 4 four counties (Clallam, Grays Harbor, and Pacific) are already considered economically distressed due to high unemployment and high numbers of households living in poverty;
6. The high number of average visitors per day to coastal Washington State Parks (17,029 people), tourist-related businesses (for example, accommodations and food services), public venues, hotels, and dependent-population facilities in the tsunami-inundation zone indicate that there are significant numbers of nonresidents that could be impacted by a tsunami;
7. The highest number of Washington State Park visitors are going to parks near Port Townsend; however, visitors could have more than 60 minutes between ground shaking caused by a CSZ earthquake and tsunami inundation to evacuate tsunami-prone areas;
8. The ability to maintain public order and restore infrastructure may be compromised after a tsunami, considering the high number of police stations, fire stations, public-works facilities, and roadways in tsunami-prone areas;
9. The City of Aberdeen has the highest amounts of developed land, residents, employees, dependent-population facilities, public venues, overnight facilities, and total parcel values of the 20 communities with land in the tsunami-inundation zone of the Olympic Peninsula; and
10. Aside from the City of Aberdeen, most cities in the tsunami-inundation zone have few societal assets (for example, residents, employees, and parcel values) in the tsunami-inundation zone, but these low amounts represent high percentages of total assets in these communities.

Information presented in this report will support emergency, land-use, and resource managers in their efforts to identify where additional preparedness, mitigation, recovery planning, and outreach activities may be needed within coastal communities and economic sectors. This information could also be used to help public officials determine where site-specific risk assessments and more-detailed tsunami-inundation modeling efforts may be warranted to further detail the threats posed by tsunamis to coastal communities in Washington. It is up to managers, policymakers, and private citizens to determine where to allocate limited risk-reduction resources and attention—to the communities with high loss potentials, to communities that may be incapable of adapting to the loss of significant percentages of their assets, or to a specific demographic or economic sector.

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Glossary

Dependents Individuals who temporarily reside in facilities where they would be dependent on external assistance to evacuate and recover, including adult residential-care facilities, child day-care facilities, correctional facilities, hospitals, outpatient-care centers, psychiatric and substance-abuse hospitals, and schools.

Exposure The first component of vulnerability, focusing on the amount of an asset (for example, the number of residents of a town) within a tsunami-inundation zone.

Resilience The third component of vulnerability, focusing on a community's ability to withstand, absorb, adapt to, and recover from losses.

Sensitivity The second component of vulnerability, focusing on the relative impact of losses to an entire community (for example, the percentage of a community's workforce in a tsunami zone); for population data, it refers to differential impacts between demographic groups (for example, differ ences based on age of individuals).

Vulnerability The attributes of a system that increase the potential for hazard-related losses or reduced performance; characterized by the exposure, sensitivity and resilience of a community and its assets in relation to stressors, either chronic or sudden (Turner and others 2003).

Appendix A. North American Industry Classification System

The North American Classification System (NAICS) is used to classify economic activity in Canada, Mexico, and the United States. The eight-digit code is read from left to right with the first two digits noting the business sector, the third and fourth digits noting the subsector and industry group, the fifth and sixth digits noting particular industries, and the seventh and eighth digits (if needed) noting the jurisdictional level (for example, county, State, or Federal). The following are the sector descriptions for the two-digit 2007 NAICS codes.

Sector number	Description
11	Agriculture, Forestry, Fishing and Hunting
21	Mining
22	Utilities
23	Construction
31–33	Manufacturing
42	Wholesale Trade
44–45	Retail Trade
48–49	Transportation and Warehousing
51	Information
52	Finance and Insurance
53	Real Estate and Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Administrative and Support and Waste Management and Remediation Services
61	Education Services
62	Health Care and Social Assistance
71	Arts, Entertainment, and Recreation
72	Accommodation and Food Services
81	Other Services (except Public Administration)
92	Public Administration

Appendix A—Continued.

In addition to classifying economic activity, the NAICS codes can be used to extract information on critical and essential facilities, public venues, and dependent-population facilities. The following is a list of community assets that can be extracted from the InfoUSA Employer Database. Numbers refer to the eight-digit code of the North American Industry Classification System (NAICS) code (U.S. Census Bureau, 2007).

Critical Facilities	Essential Facilities
• Public Order o Police stations Federal: 92212002 Police departments: 92212003 Sheriff: 92212004 State Police: 92212005 o Fire stations County Fire: 92216001 Local Fire: 92216003 State Fire: 92216004 o Civil Defense Civil Defense: 92219001 County: 92219003 o National Security Federal: 92811003 State: 92811007 • Medical Services o Hospitals: 62211002 o Outpatient care centers: Childbirth education: 62141003 Pregnancy counseling: 62141005 Clinics: 62149301 o Physician offices: 62111107, 62121003 o Ambulance services: 62191002 • Utilities o Wastewater treatment: City: 92613001 County: 92613002 o Water and sewage companies: 22131003 o Gas companies: 22121002, 22121007 o Electric companies: 22112202 o Public works: 23731004, 23731007 o Radio and TV Broadcasting: 51511203, 51512001	• Gas stations: 42472002, 42472005, 44511003, 44512001, 44719005 • Banks and Credit Unions: o Banks: 52211002 o Credit Unions: 52213003 • Retail Grocers: 44511003 • Courts and legal counsel o Municipal courts: 92211001 o County courts: 92211002 o Federal Courts: 92211004 o State Courts: 92211006 o City Legal Counsel: 92213001 o County Legal Counsel: 92213002 o State Legal Counsel: 92213004 • U.S. Post Offices: 4911101 • Government offices: o City government offices: 92111001, 92112006, 92113001, 92119001 o County government offices: 92112007, 92111002, 92113002, 92119002 o State government offices: 92112008, 92113005, 92119006 o Federal government offices: 92112009, 92119003 o Government weather offices: 92119000 o Tribal government: 92119004

Appendix A—Continued.

<table>
<tr><th>Public venues</th><th>Dependent Populations</th></tr>
<tr><td>

- Libraries
    - o City: 51912001, 51912002
    - o Federal: 51912003
    - o Institutional: 51912005
    - o Public: 51912006
    - o State: 51912011, 51912010
- Shopping centers and malls: 53112008
- Colleges: 61131009
- Museums: 71211001
- Casino: 71329002
- Historical Places: 71212001
- Botanical Gardens: 71213003
- Aquariums: 71219001
- Zoos: 71213006
- Parks: 71219004
- Theaters: 51213101, 71111007
- Spectator Sports: 71121203, 71121204
- Religious Organizations
    - o Christian Science: 81311005
    - o Church Organizations: 81311006
    - o Churches: 81311008
    - o Clergy: 81311009
    - o Convents and Monasteries: 81311010
    - o Mediation Organizations: 81311011
    - o Mosques: 81311015
    - o Religious Organizations: 81311021
    - o Retreat Houses: 81311023
    - o Spiritualists: 81311025
    - o Synagogues: 81311026
    - o Places of Worship (non-theistic): 81311031

Overnight Tourists

- Hotels: 72111002
- Bed and Breakfasts: 72119101
- Inns: 72119102
- Cabin Rentals: 72119903
- Health resorts: 72119907
- Resorts: 72119909
- Tourist accommodations: 72119911
- Campgrounds: 72121101
- Camps: 72121403
- Hostels: 72131006
- Student housing: 72131009

</td><td>

- Hospitals:
    - o Hospitals: 62211002
    - o Mental Health Services: 62221001
    - o Psychiatric treatment facilities: 62221003
- Outpatient Care Centers
    - o Childbirth education: 62141003
    - o Pregnancy counseling: 62141005
    - o Clinics: 62149301
    - o Offices of physicians: 62111107
- Adult residential care
    - o Adult care facilities: 62311001, 62311002, 62311008
    - o Hospices: 62311011
    - o Nursing homes: 62311016
    - o Nursing home services: 62311018
    - o Rest homes: 62311020
    - o Retirement communities: 62331101
    - o Homes – adult: 62331203
    - o Senior citizens services: 62331205
    - o Residential care homes: 62331206
    - o Sheltered care homes: 62399000
    - o Group homes: 62399007
    - o Foster care: 62399013
    - o Day care centers – adult: 62412002
- Child day care
    - o Babysitters: 62441001
    - o Childcare centers: 62441002, 62441003
    - o Pre-schools: 62441005
    - o Nursery schools: 62441006
- Schools
    - o Religious schools: 61111004
    - o Schools: 61111007
    - o Schools with special academics: 61111010
    - o Home schooling: 61111016
- Correctional Facilities
    - o City: 92214001
    - o State: 92214002
    - o Federal: 92214003
    - o County: 92214004

</td></tr>
</table>

Appendix B. Overview of Project Database

Additional data on the distribution of assets within specific communities is provided in the Excel database that accompanies this report (available at http://pubs.usgs.gov/sir/2008/5004).

Database Worksheets–Land Cover, Population, Economy, and Facilities

Information on the amount and percentage of various community assets are summarized in four worksheets–land cover, population, economy, and facilities. In these four worksheets, rows 3 through 35 refer to the 20 communities that have land in the tsunami-inundation zone, as well as the unincorporated portions of the four coastal counties. Rows 36 through 42 are county-level summaries and rows 43 through 48 provide descriptive statistics for the region, including study area totals, third quartiles, and maximum values.

In these worksheets, the first four columns identify the city name, a geographic identifier, and the county name. The geographic identifier is a number assigned to each community, starting at 1 with the City of Sequim in Clallam County (the northern-most county) and ending with 24 for the unincorporated portions in Pacific County (the southern-most county). Sorting and graphing information by the geographic identifier allows one to graph and visualize information in a consistent fashion based on geographic location. The remaining columns in the four note the following for each community:

- The amount of an attribute located in the tsunami-inundation zone of a community ("Inundation Zone");
- The total amount within a community, regardless of the hazard zone ("Community Total"); and
- The percentage of an attribute in the tsunami-inundation zone of a community ("% of Community"), which is derived by dividing the "Inundation Zone" amount by the "Community Total."

Again, land-cover data refer to the number of 30-m cells, residential and employee data refer to the number of individuals, parcel data refer to 2006 U.S. dollars, and facility data refer to the number of facilities. Demographic data includes an additional attribute noted as "% of Total Population in Inundation Zone." Whereas "% of Community" notes the percentage of a demographic category of a community in the hazard-prone area, "% of Total Population in Inundation Zone" notes the percentage of residents in the inundation zone of a city that are a certain demographic group. For example, a "% of Community" value of 34 in the Hispanic or Latino population category indicates that 34 percent of the Hispanic population of a city is in the tsunami-inundation zone. A "% of Total Population in Inundation Zone" value of 34 in the Hispanic or Latino population category indicates that 34 percent of the residents in the inundation zone are Hispanic.

Database Worksheet–Business Types

The distribution of business types are summarized in the database worksheet "Business Types." Rows in this worksheet are the 21 industry types, based on the first two digits of the North American Industry Classification System code attached to each business in the InfoUSA Employer Database. Information on businesses, employees and sales volume are each sorted by business type.

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