CHAPTER 11

USE OF MIDRESOLUTION LAND COVER DATA FOR RAPID COMPARISON OF COMMUNITY VULNERABILITY TO TSUNAMIS

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ABSTRACT

A Cascadia subduction-zone earthquake could generate tsunami waves which would impact more than 1,000 km of coastline on the west coast of the United States and Canada. The amount of development in tsunami-prone areas varies among coastal communities, creating variations in vulnerability. To illustrate the use of land cover data in comparing community vulnerability, the amount and percentage of developed land in the tsunami-prone areas of 26 Oregon coastal communities were calculated using land cover information derived from midresolution remotely-sensed imagery (e.g., 30-m-resolution Landsat Thematic Mapper imagery). Results demonstrate that in the absence of socioeconomic data or community-based knowledge of assets, information derived from the integration of hazards and midresolution landcover data provides insight on variations in community vulnerability and can identify areas for finer-scale assessments.

Key words: vulnerability, tsunami, Oregon, Cascadia, C-CAP, Landsat Thematic Mapper, remote sensing

INTRODUCTION

Societal vulnerability to extreme natural events is a function of how communities occupy hazard-prone land (Mileti 1999; Wisner et al. 2004). Vulnerability, defined as the characteristics of a system that increase the potential for hazard-related losses, is often described by the exposure, sensitivity, and resilience of a system and its assets relative to a hazard (Turner et al. 2002). Information on societal
vulnerability helps emergency and land-use managers develop appropriate mitigation, preparedness, response, and recovery strategies to minimize the impact of extreme natural events. To assess vulnerability, managers and researchers often use geographic-information-system (GIS) tools to overlay socioeconomic databases (ex. U.S. Census Bureau population data) and hazard information in order to identify general trends and potential hot spots for further site-specific studies (Cutter et al. 2003a; Wood and Good 2004).

Land cover information derived from midresolution remotely-sensed satellite imagery is another dataset that can be used for vulnerability assessments by providing practitioners a way to determine the distribution of developed land across a landscape. If higher-resolution socioeconomic information is unavailable or an immediate response is required, managers can use the distribution of developed land to approximate the location of people, buildings, and infrastructure and can combine land cover and hazard-zone data to determine where pre-event risks and post-event response issues may be greatest. Although great effort has gone into using land cover data to model population estimates at the pixel level (for example, Bhaduri et al. 2002), less attention has been paid to examine the use of aggregated land cover data for community-level comparisons of vulnerability.

This paper demonstrates the use of land cover information derived from midresolution remotely-sensed imagery for describing hazard-prone land and comparing community vulnerability. This case study focuses on 26 communities on the Oregon coast and their vulnerability to potential tsunami hazards related to a Cascadia subduction-zone (CSZ) earthquake. The ability to compare the distribution of developed land in relation to hazard zones using land cover data derived from midresolution remotely-sensed imagery could serve as one element in a national vulnerability monitoring program to identify at-risk areas, a priority identified in recent national research agendas (Cutter et al. 2003b; McMahon et al. 2005).

STUDY AREA

Historical and geological evidence suggest that the U.S. Pacific Northwest coast has experienced numerous tsunamis and is likely to experience more (Atwater et al. 1995). The most significant tsu-
The tsunami threat for coastal communities is waves generated by an earthquake within the Cascadia subduction zone (CSZ), the interface of the North American and Juan de Fuca tectonic plates that extends from northern California to southern British Columbia (Figure 1A). Geologic evidence and tsunami-inundation modeling suggest that tsunami waves as high as 10 meters could reach coastal communities minutes after a magnitude 8 or greater CSZ earthquake (Cascadia Region Earthquake Workgroup 2005). Recurrence intervals of past CSZ earthquakes vary considerably, ranging from 190 to more

Figure 1. Map of (A) the Cascadia subduction zone (adapted from U.S. Geological Survey 2007) and (B) Oregon coastal communities containing potential tsunami-inundation land.
than 1,000 years between events; the latest CSZ earthquake occurred in 1700 A.D. (Witter et al. 2003). Although much has been done to describe past tsunami events, assess current hazard zones, and develop ocean-monitoring systems, far less has been done to understand the potential socioeconomic impacts of future tsunamis to communities (U.S. Government Accountability Office 2006). Occupation of the tsunami-prone land in the Pacific Northwest varies considerably, from small fishing villages to large industrial cities and these variations in development influence a community’s vulnerability. A community with high-density residential and commercial development near the beachfront, for example, will fare worse after a tsunami and recover more slowly than a neighboring city with low-density residential development and open spaces in similar areas.

METHODS

This case study of tsunami hazards in the U.S. Pacific Northwest focuses on the 26 communities on the Oregon coast (Figure 1B) where 2003 city limit boundaries intersect a CSZ-related, tsunami-inundation zone developed for the entire coast (Oregon Geospatial Enterprise Office 2006). Land cover, city boundaries, and tsunami-hazard geospatial data were integrated with GIS tools to describe hazard-prone land and to assess variations in community vulnerability. Vulnerability is defined and used in numerous ways in the scientific literature and in practice by risk managers. Therefore, for the purposes of this paper, exposure and sensitivity – two components of vulnerability (Turner et al. 2002) -- are used to characterize community vulnerability and are determined by the distribution of developed land in a community (delineated by city-limit boundaries) in relation to predicted hazard zones. Exposure is determined by calculating the amount of developed land in tsunami-prone areas of a community; communities with high exposure values are assumed to have more assets in hazardous areas. Sensitivity is the percentage of developed land in tsunami-prone areas relative to the total amount of developed land within a community. Sensitivity values are calculated to approximate the overall impact to a community if developed land, and the assets it represents, in hazard-prone areas are damaged. Additional definitions of sensitivity (for example, the distribution of special-needs populations) and resilience (for example, adaptive capacity to extreme events) are not addressed here, nor are
The distribution of developed land is determined using 2001 land cover data of the National Oceanic and Atmospheric Administration’s (NOAA) Coastal Change Analysis Program (C-CAP). C-CAP is a nationally standardized land cover database for U.S. coastal regions (NOAA CSC 2007; Dobson et al. 1995) that is part of the National Land Cover Database (NLCD) effort through the interagency Multi-Resolution Land Characteristics (MRLC) consortium. C-CAP land cover products are automatically derived from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM) digital satellite imagery, have a 30-meter spatial resolution and have reported accuracy standards of 85 percent (Dobson et al. 1995). C-CAP data generated prior to 2005 has 22 land cover classes, with developed land represented by low-intensity developed (between 25 and 75 percent impervious cover) and high-intensity developed (greater than 75 percent impervious cover) (Dobson et al. 1995). Figure 2 demonstrates how maps of land cover, city boundaries and predicted hazard zones can quickly

![Figure 2. Examples of 2001 NOAA C-CAP land cover data for (A) City of Bandon, (B) City of Newport, and (C) City of Cannon Beach, Oregon.](image-url)
illustrate potential community exposure to tsunami hazards. Based on the distribution of high- and low-intensity developed cells, the majority of development is outside of the tsunami-hazard zone in the cities of Brookings (Figure 2A) and Florence (Figure 2B), but inside the tsunami-inundation zone in the City of Cannon Beach (Figure 2C). Maps of land cover data that highlight cells classified as developed may provide quicker situational awareness to response personnel than aerial photographs, where determining developed areas require additional visual interpretation.

**DESCRIBING HAZARD-PRONE LAND**

A first step in understanding societal vulnerability to CSZ-related tsunamis is to determine what type of land is in tsunami-prone areas. Based on the spatial overlay of 2001 C-CAP land cover data with city-limit boundaries and the tsunami-inundation zone, the distribution of non-marine land cover classes (by area) in the tsunami hazard zone was determined for the entire Oregon coast (Figure 3). Results indicate that 95 percent of the tsunami-prone land in Oregon is undeveloped (classified as something other than high- or low-intensity developed). Wetland-related classes are the most common type of land cover found in the tsunami hazard zone (56 percent), followed by grasslands (15 percent).
Figure 4. The amount (A) and percentage (B) of land cover cells classified as either low- or high-intensity developed in the tsunami hazard zone for each community. City names are ordered geographically from north to south, with the most northern town at the top.
percent) and bare land (14 percent). Although the majority of hazard-prone land is not classified as developed, undeveloped areas can attract recreationists, local residents as well as tourists, who could be impacted by a Cascadia-related tsunami (Wood, Good, and Goodwin 2002; Wood and Good 2004).

**VARIATIONS IN COMMUNITY EXPOSURE AND SENSITIVITY**

Based on the spatial overlay of 2001 C-CAP data, city limits, and the predicted tsunami-inundation zone, the amount (Figure 4A) and percentage (Figure 4B) of land cover cells classified as developed (either low- or high-intensity) in tsunami-prone areas varies greatly among Oregon coastal communities (Figure 1B). Median and third-quartile values are noted for quick identification of communities that are above regional trends and are used due to the non-normal distributions and extreme ranges of the data.

Median values for the amount and percentage of developed land in hazard-prone lands are 0.21 km² and 17 percent, respectively; however, some communities are much higher, including the City of Seaside with 2.57 km² of developed land in hazard-prone areas that represents 88 percent of its developed land. In general, results indicate that communities on the northern coast have higher exposure and sensitivity to tsunami hazards than other Oregon coastal communities. Some communities have high amounts of developed land but these amounts represent small percentages of total land; for example, the cities of Newport and North Bend exceed the third-quartile (0.53 km²) in the amount of tsunami-prone developed land, yet these amounts represent only 15 and 16 percent, respectively, of each town’s overall developed area and well below the third-quartile value (42 percent). Conversely, the cities of Gearhart, Cannon Beach, Waldport, and Yachats have less than 0.53 km² of developed land in tsunami-prone land but these low amounts represent the majority of each town’s total development. Therefore, some communities have high exposure to tsunamis (ex. Newport) and other communities have high sensitivity (ex. Cannon Beach). It is up to managers to decide where to allocate limited risk-reduction resources—to the communities with high exposure and likely high loss potentials or to communities with high sensitivity that may be incapable of adapting to the loss of significant percentages of their assets.
The threat of Cascadia-related tsunamis in the U.S. Pacific Northwest has been recognized only in the past few decades and future studies of land cover patterns and land cover change will shed light on whether development increases or decreases in tsunami-prone areas of these 26 communities. A subset of the National Land Cover Database that characterizes land cover change at the 30-meter resolution and temporal periods of ten years or less, with specific attention to class transitions from natural classes (for example, forests, grasslands) to developed classes (either high- or low-intensity), would facilitate studies that focus on determining how and why societal vulnerability to tsunamis, or any natural hazard for that matter, changes over time. This information and subsequent studies would help communicate to policymakers and the general public that vulnerability is a dynamic characteristic of a society that changes over time due to social, political, and economic forces.

**SUMMARY**

This case study of tsunami hazards on the Oregon coast demonstrates how land cover information derived from midresolution remotely-sensed imagery can be used to compare variations in developed land relative to predicted hazard zones. Although the potential for tsunami hazard inundation is similar for low-lying portions of the Oregon coast, communities have made different decisions about where development occurs and these decisions shape each community’s vulnerability to future tsunamis. Estimation of vulnerability based on land cover patterns may be a starting point for many communities -- to be refined later with higher-resolution geospatial data and/or community-based socioeconomic information. For other communities or for agencies with national perspectives, the use of land cover data and other national databases may be the only approach available if the geographic scale of a hazard is so large that the collection of higher-resolution data is not feasible or if resources are not available for further studies. Whether it is a first step or the only step, the approach outlined here could provide practitioners and policymakers with methods for visualizing how development decisions influence the magnitude of future disasters.
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REFERENCES


