VISUALIZING THE WAVE: HOW PACIFIC NORTHWEST COMMUNITIES USE TSUNAMI HAZARD ASSESSMENT INFORMATION TO DESIGN EVACUATION MAPS FOR PUBLIC EDUCATION

by

Maciej (Matt) J. Kurowski
Bachelor of Engineering Science,
University of Western Ontario, 2003

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in the
Department Geography

SIMON FRASER UNIVERSITY
Spring 2011

Approval

Name: Maciej (Matt) Kurowski

Degree: Master of Science

Title of Thesis: Visualizing the Wave:
How Pacific Northwest Communities Use
Tsunami Hazard Assessment Information to
Design Evacuation Maps for Public Education

Examining Committee:

Chair: **Paul Kingsbury**
Assistant Professor, Department of Geography

Nick Hedley, Senior Supervisor
Associate Professor, Department of Geography

John Clague, Supervisory Committee Member
Professor, Department of Earth Sciences

Scott Miles, External Examiner
Assistant Professor, Department of Environmental Studies, Huxley College of Environment, Western Washington University

Date Defended/Approved: 11 April 2011

Declaration of Partial Copyright Licence

Abstract

Local officials in the Pacific Northwest of Canada and the United States influence how tsunami hazard assessments guide production of community evacuation map brochures. In both countries, cartographic decisions about brochures' tsunami hazard representation have been inconsistent and not based on user evaluations. This thesis uses cartographic abstraction principles to interrogate the similarities, differences, and limitations of tsunami hazard representations in 38 tsunami brochures for Washington and Oregon communities, and a State-developed interactive map in Oregon. Based on an assessment of tsunami hazard in Ucluelet, British Columbia, this research demonstrates how decisions limit hazard representations and identifies critical tsunami hazard education information that remains unrepresented. Although the literature reveals a need for improved public access to information, Pacific Northwest evacuation maps retain significant information limitations, primarily due the existing 'one map' tsunami brochure paradigm. This research provides a foundation for future evaluation and development of socially situated evacuation map characteristics.

Keywords: tsunami education; cartographic abstraction; tsunami hazard assessment; cartography

Dedication

For my parents, who inspired my interest in geography through our many shared travels, and taught me the value of adventure and perseverance.

Acknowledgements

I would like to express my gratitude for the Geomatics for Informed Decisions SII research funding that helped create a place for this thesis within a larger project – Canada's first community-scale tsunami hazard assessment in Ucluelet, British Columbia. Many people in the project contributed information and advice for this thesis. Specifically, I would like to thank Kelli Kryzanowski and Maiclaire Bolton from the British Columbia Provincial Emergency Program, Bill Johnstone and Barbara Lence from the University of British Columbia Civil Engineering Department, Jeff Clark and David Alexander from Spatial Vision Group, and Fletcher Chrisholm from the District of Ucluelet.

I would like to thank my senior supervisor Nick Hedley, who gave me insight into theories within cartography and supported my turn from empirical to theoretical research. Thanks to John Clague, my supervisory committee member, for his encouragement and writing expertise that helped me to better articulate my ideas. I am also grateful to my external examiner, Scott Miles, who provided valuable suggestions to improve this thesis.

From within the Simon Fraser University Geography Department, I am indebted to Dr. Nadine Schuurman, who offered me valuable mentorship about how to structure research papers. For technical GIS issues, I could always count on Justin Song to give me suggestions that always resulted in solutions. Also, many thanks to all my friends I met in the Geography Department. In particular, I wish to thank Dawn Hoogeveen and Annamarie Sasagawa who both took an interest in my research and helped me to refine my thoughts and writing.

Finally, I wish to thank all my wonderful friends and family who made my completion of this thesis possible through their encouragement and support.

Table of Contents

List of Figures

Chapter 1: Introduction

1.1 Overview

A tsunami is a series of ocean waves that result in any large, sudden disturbance of the sea surface (Bernard et al., 2006). Earthquakes that displace the sea floor are the most common cause of tsunami in the Pacific Ocean (Bernard et al., 2006). When undersea earthquakes occur near shore, they can produce a near-source tsunami that inundates proximal coastal areas on the order of minutes (Darienzo et al., 2005). Great undersea earthquakes can cause significantly larger near-source tsunami that also propagate to the coasts of other regions to produce distant (tele-) tsunami on the order of hours (Darienzo et al., 2005).

Many Pacific Northwest coastal communities in the Province of British Columbia (BC) and the Pacific states of Washington and Oregon in the United States (US) are vulnerable to tele-tsunami, and to near-source tsunami earthquakes at the Cascadia Subduction Zone (CSZ) (Clague et al., 2000). To reduce tsunami vulnerability of these communities, there is a strong emphasis on tsunami mitigation in BC (British Columbia Provincial Emergency Program, 2001) and in all United States (US) Pacific states (Dengler, 2005; Bernard, 2005). Mitigation, in its broadest sense, refers to the implementation of actions well in advance of hazard events that aim to reduce potential disaster losses (Newton, 1997; Haque and Burton, 2005).

Public education is an important mitigation strategy for reducing loss of life in tele-tsunami and near-source tsunami (Dengler, 2005). The West Coast/Alaska Tsunami Warning Centre issues warnings of detected tele-tsunami to BC, Washington, and Oregon (Darienzo et al., 2005). Once local governments receive and issue a tele-tsunami warning, the public must have the knowledge to react accordingly and, in the absence of local media communication, must be able to take action upon recognizing signs of an impeding tele-tsunami (Anderson and Gow, 2004). A CSZ earthquake that triggers a near-source tsunami poses a significantly higher risk because the earthquake may largely destroy the infrastructures of communities before the tsunami strikes (British Columbia Provincial Emergency Program, 2001). After the ground stops shaking, the public must immediately evacuate to safe areas with no guidance from authorities.

Tsunami evacuation maps are one of several types of community-specific tsunami education tools. Examples of other tools include evacuation signage on roads, education programs in schools, and community tsunami evacuation drills. In Washington and Oregon, educational evacuation maps are designed based on tsunami hazard assessments and are the result of state and local officials working together in a community to interpret state-developed community-scale tsunami inundation maps (Gonzalez et al., 2001, 2005). This process results in an evacuation map brochure that is made available to the public in print and online. Evacuation map production in BC is a much more recent development compared to Washington and Oregon. BC organized its first tsunami hazard assessment in Ucluelet, on the west coast of Vancouver Island, in response to increased tsunami awareness caused by the massive 2004 tsunami in the Indian Ocean.

The Ucluelet pilot project brought together local government officials and tsunami modelling experts from the private and academic sectors. Project goals included modelling the effects of a CSZ tsunami in Ucluelet in order to assess community vulnerability and mitigation measures, and to publish an educational evacuation map. BC's close collaboration with Pacific states in tsunami mitigation efforts (British Columbia Provincial Emergency Program, 2001) provided a template for Ucluelet's tsunami hazard assessment and educational evacuation map strategy. Ucluelet's resulting educational evacuation map strategy was influenced by practices in communities of its closest neighbouring States of Washington and Oregon. The practices of Washington and Oregon influencing those in Ucluelet reflected existing guidelines in the US that encourage communities to adopt neighbouring tsunami education tools (Dengler, 2005; Jonientz-Trisler et al., 2005).

This thesis resulted from joining the Ucluelet project to research cartographic communication of the tsunami hazard assessment results. The development of an educational evacuation map in Ucluelet was already in progress – a project goal that most directly involved tsunami scientists and local government emergency management officials. A literature review conducted as part of this thesis revealed that, although numerous scientific approaches to tsunami hazard assessments have been published, no research has explicitly considered how community stakeholders responsible for evacuation map design utilize available tsunami hazard information. This thesis addresses this existing gap in research through a focus on practices in BC, Washington, and Oregon.

1.2 The research problem

Communities in BC, Washington, and Oregon are similar in that they disseminate a single tsunami evacuation map brochure based on available scientific tsunami hazard assessment information. However, these brochures have been developed locally, resulting in mapmakers using and communicating hazard information differently. For example, some community evacuation maps include information about terrain, whereas others do not; some include two types of tsunami hazard zones, others include only one.

The efficacy of particular evacuation map designs remains unknown. Evacuation maps have, however, been evaluated as part of communities' tsunami education toolsets. Studies in Washington (Johnston et al., 2002) and Oregon (Karel, 1998) used survey methodologies to measure the effectiveness of communities' public educational tools. These researchers found that tools were able to influence tsunami awareness, but failed to create citizens with adequate perceptions of the tsunami hazard.

Efforts to improve tsunami mitigation in the US are overseen by the National Hazard Tsunami Mitigation Program (NTHMP) (Bernard, 2005; Gonzalez et al., 2005). The NTHMP's mitigation efforts are encouraging communities to view mitigation in terms of resilience through a set of broad guidelines that, in part, encourage communities to adopt existing educational tools in neighbouring communities (Dengler, 2005; Jonientz-Trisler et al., 2005). The NTHMP summarizes a tsunami-resilient community as one that:

> …may suffer some inevitable damage, but will have planned, exercised, and educated its citizens and its leaders in ways to save lives, protected as much property as possible, tried to ensure safe locations for critical functions the community needs, and will use lessons from a tsunami event suffered by their community or other communities to improve their level of resilience for future events. (Jonientz-Trisler et al., 2005)

Although focus on tsunami resilience provides a guiding vision, it does not offer any specific advice about how to improve educational evacuation maps. Currently, the leading evacuation map developments in the Pacific Northwest are in Oregon. Oregon has proposed a standard evacuation map design for its communities and has also recently introduced a State-wide Google Maps evacuation map tool. These efforts may be helpful in education, but a significant gap remains between scientifically known and publicly accessible tsunami hazard information. Some recent pilot studies in Indonesia (Goto et al., 2010) and Australia (Dall'Osso and Dominey-Howes, 2010) indicate that providing the public maps with detailed tsunami hazard information is beneficial to public education. The information that these two studies provided was considerably more detailed than information found in the evacuation maps of BC, Washington, and Oregon.

Enhancing tsunami hazard information in evacuation map tools may be an important factor in increasing resilience in communities. The lack of progress by governments on this issue reflects challenges common in all tsunami mitigation, and more broadly, all natural hazards mitigation. As many social scientists have stated, there exist competing social, political, and economic interests that undermine implementation of successful natural hazard mitigation (Wolensky and Wolensky, 1990; Newton, 1997; Quarantelli, 1997; Morrow, 1999; White et al., 2001; Pearce, 2003; Somers and Svara, 2009). For natural hazard mitigation to improve, greater acknowledgement of how natural hazard vulnerabilities result from social choices is required – especially at the community planning level (Morrow, 1999; Pearce, 2003; Haque and Burton, 2005).

Determining how evacuation maps can better contribute to tsunami mitigation requires a more organized effort by many stakeholders at a variety of scales included scientists, policy makers, regional governments, local governments, and the public. An essential first step is the assessment of how officials in communities currently use available information to design evacuation maps. A productive approach to this problem must relate the goals of community-scale tsunami education to evacuation mapping practices in a way that is useful for the stakeholders and that supports future development.

1.3 Conceptual framework

This thesis uses cartographic abstraction principles to describe how community evacuation mapping practices in BC, Washington, and Oregon contribute to the complex relationship between tsunami science and the public's ability to perceive tsunami science.

The principles of cartographic abstraction describe the process of how mapmakers select, generalize, and symbolize information in order to define representation (Robinson et al., 1995). Selection refers to information that is included in order to contribute to the purpose of the map. Generalization refers to the preparation of the selected information for symbolization through operations that eliminate unnecessary details while considering limitations of the quality of underlying data, map scale, and medium. Symbolization refers to the use of cartographic variables to visually represent generalized information (Robinson et al., 1995).

Abstraction is an intrinsic concept of maps and to the Geographic Information Systems (GIS) that produce them (Schuurman, 2006). Principles of cartographic abstraction have grown in sophistication since their first expressions in the early 20th century – more recently for the intent of structuring GIS functions (McMaster and Shea, 1992). For the purposes of describing evacuation map practices, it is appropriate to apply a simple version of a recent cartographic abstraction articulation in the 6th edition of Elements of Cartography (Robinson et al., 1995) (the first edition being published in 1953). The use of only basic cartographic abstraction principles can still capture the essence of how communities use GIS to produce public evacuation maps, while maintaining readability for those who are not cartography experts.

1.4 Research objectives

The goal of this research is to express how social decisions affect tsunami hazard information in evacuation maps. The research focuses on how BC could improve recent approaches to evacuation maps by first describing evacuation map design practices and developments in the neighbouring states of Washington and Oregon, then describing an evacuation map production process in Ucluelet, BC.

The goal of this research is achieved through two research components:

1) Application of cartographic abstraction principles to:

a) compare and contrast a sample of 38 Washington and Oregon tsunami evacuation map, including a new proposed design standard in Oregon, in order to reveal their similarities, differences, and limitations in tsunami hazard information.

b) assess the design of tsunami hazard information in the new state-developed Google Maps tsunami evacuation map in Oregon.

2) Using a case study of the tsunami hazard assessment in Ucluelet to:

a) describe how scientists and local government officials utilized tsunami hazard assessment information to develop a tsunami evacuation map through the application of cartographic abstraction principles.

b) illustrate how non-utilized assessment information may drive the design of additional, more advanced tsunami evacuation map tools for interested citizens.

1.5 Thesis organization

This thesis has two main chapters written as stand-alone papers for journal publication. Both papers introduce cartographic concepts into tsunami science literature in order to reach the tsunami scientists and policy makers who will oversee future evacuation map developments. The two papers, Chapters 2 and 3, address, respectively, the above first and second components of the research.

Chapter 2 assesses current evacuation map practices in Washington and Oregon. The purposes of this chapter are to increase awareness about how social decisions have created differences in information content of evacuation map brochures, and to respond to the lack of attention about how social decisions are affecting current educational evacuation map developments that are taking place in Oregon.

Chapter 3 describes an evacuation map development process in Ucluelet, BC. The purposes of this chapter are to point out the potential of currently unused scientific and citizen knowledge in BC, Washington, and Oregon, and to propose community-developed evacuation map strategies that respond to a need for increased public access to information that both empirical evidence and resilience goals support.

Chapter 4 is the conclusion and identifies the significance of the research in Chapters 2 and 3 and further identifies future needs of evacuation map developments in BC, Washington, and Oregon.

1.6 References

Anderson P., and Gow G.A. (2004). *Tsunamis and coastal communities in British Columbia: an assessment of the B.C. tsunami warning system and related risk reduction practices*. Retrieved from Government of Canada Publications website: http://publications.gc.ca/site/eng/267201/publication.html

Bernard E. (2005). The U.S. National Tsunami Hazard Mitigation Program – a successful State–Federal partnership. *Natural Hazards, 35*, 5–24.

Bernard, E.N., Mofjeld, H.O., Titov, V.V., Synolakis, C.E., and Gonzalez, F.I. (2006). Tsunami: scientific frontiers, mitigation, forecasting, and policy implications. *Phil. Trans. Roy. Soc. A*, *364*(1845), 1989–2007.

British Columbia Provincial Emergency Program (2001). *British Columbia tsunami warning and alerting plan*. Retrieved from Ministry of Public Safety and Solicitor General website: http://209.87.31.75/hazard_plans/tsunami2001/Tsunami_Warning_and_Alerting_Plan-2001.pdf

Clague, J. J., Bobrowsky, P. T., and Hutchinson, I. (2000). A review of geological records of large tsunamis at Vancouver Island, British Columbia, and implications for hazard. *Quaternary Science Reviews*, *19*, 849–863.

Darienzo, M., Aray A.L., Crawford G.L., Gibbs, D., Whistmore, P.M., Wilde T., and Yanagi B.S. (2005). Local tsunami warning in the Pacific coastal United States. *Natural Hazards, 35*,111–119.

Dall'Osso, F., and Dominey-Howes, D. (2010). Public assessment of the usefulness of "draft" tsunami evacuation maps from Sydney, Australia – implications for the establishment of formal evacuation plans. *Natural Hazards and Earth Systems Science,10*,1739–1750. doi:10.5194/nhess-10-1739-2010.

Dengler L. (2005). The role of education in the National Tsunami Hazard Mitigation Program. *Natural Hazards, 35*, 141–153.

Gonzalez F.I., Titov V.V., Mofjeld H.O., Venturato A.J., and Newman J.C. (2001).The NTHMP inundation mapping program. In *Proceedings of the International Tsunami Symposium 2001*. National Tsunami Hazard Mapping Program Review Session, R-2, Seattle, WA, 7–10 August 2001, 29–54.

Gonzalez F.I., Titov V.V., Mofjeld H.O., Venturato A.J., Simmons R.S., Hansen R., Combellick R., Eisner R.K., Hoirup D.F., Yanagi B.S., Yong S., Darienzo M., Priest G.R., Crawford G.L., and Walsh T.J. (2005). Progress in NTHMP hazard assessment. *Natural Hazards, 35*, 89–110.

Goto Y., Ogawa Y., and Komura T. (2010). Tsunami disaster reduction education using town watching and moving tsunami evacuation animation – trial in Banda Aceh. *Journal of Earthquake and Tsunami, 4*(2), 115-126.

Haque, C. E., and Burton, I. (2005). Adaptation options strategies for hazards and vulnerability mitigation. *An international perspective, Mitigation and Adaption Strategies for Global Change, 10*(3), 335–353.

Johnson D., Paton D., Houghton B., Becker J., and Crumbie G. (2002). *Results of the August-September 2001 Washington State tsunami survey*. New Zealand Institute of Geological and Nuclear Sciences, Science Report 2002/17, Lower Hutt, New Zealand.

Jonientz-Trisler C., Simmons R.S., Yanag B.S., Crawford G.L., Darienzo M., Eisner R.K., Petty E., and Priest G.R. (2005). Planning for tsunami-resilient communities. *Natural Hazards, 35*, 121–139.

Karel A. (1998). Oregonians need more information about tsunamis to save lives. *Oregon Geology, 60*(3), 56.

McMaster R.B., and Shea K.S. (1992). *Generalization in digital cartography*. Washington, DC: Association of American Geographers.

Morrow B.H. (1999). Identifying and mapping community vulnerability. *Disasters, 23*(1), 1–18.

Newton J. (1997). Federal legislation for disaster mitigation: A comparative assessment between Canada and the United States. *Natural Hazards, 16*, 219–241.

Pearce L. (2003). Disaster management and community planning, and public participation: How to achieve sustainable hazard mitigation. *Natural Hazards, 28*, 211–228.

Quarantelli, E.L. (1997). Problematic aspects of the information/communication revolution for disaster planning and research: Ten non-technical issues and questions. *Disaster Prevention and Management Journal, 6*(2), 94–116.

Robinson A.H., Morrison J.L., Muehrcke P.C., Kimerling A.J., and Guptill S.C. (1995). *Elements of cartography* (6th edition). New York: Wiley.

Schuurman N. (2006). Why formalization matters: critical GIS and ontology research. *Annals of the Association of American Geographers, 96*(4), 726–739.

Somers S., and Svara J.H. (2009). Assessing and managing environmental risk: Connecting local government management with emergency management. *Public Administration Review, 69*(2), 181–193.

White G.F., Kates R.W., and Burton I. (2001). Knowing better and losing even more: The use of knowledge in hazards management. *Environmental Hazards, 3*, 81–92.

Wolensky R.P., and Wolensky K.C. (1990). Local government's problem with disaster management: a literature review and structural analysis. *Policy Studies Review, 9*(4), 703–725.

Chapter 2: An Assessment of Educational Tsunami Evacuation Map Designs in Washington and Oregon[1]

2.1 Abstract

Educational tsunami evacuation map brochures in Washington and Oregon have been developed locally, resulting in significant differences between the types of tsunami hazard information they include. This paper identifies six tsunami hazard information types present in 38 brochures in Washington and Oregon: (1) tsunami hazard zone, (2) road network, (3) assembly areas, (4) evacuation guidance, (5) infrastructure, and (6) terrain. It compares and contrasts these information types in the maps and text of six of the brochures, including a proposed design standard in Oregon. Design differences of all 38 brochure maps are then organized using principles of cartographic abstraction, which describe mapmaker decisions about selection, generalization, and symbolization of information. We further use this framework to situate the information content of a new interactive Google Maps tool in Oregon. Our assessment identifies limitations of current tsunami hazard information that may be relevant to improving tsunami education. In theory, more advanced evacuation map tools can play an important role in reducing the limitations of tsunami hazard information relevant to the public. The new Google Maps tool addresses few of these limitations. Recognizing how map-making decisions define the underlying

[1] A version of this Chapter has been accepted in *Natural Hazards* under the co-authorship of Nick Hedley and John Clague.

information content of evacuation maps can facilitate much needed future evaluations and developments in evacuation map design.

2.2 Introduction

The National Tsunami Hazard Mitigation Program (NTHMP) is a United States initiative led by a steering committee with representatives from the National Science Foundation, three federal agencies, and five Pacific states (Bernard, 2005). Its principal aim is to mitigate the tsunami hazard to all vulnerable US communities (Bernard, 2005; Gonzalez et al., 2005). The NTHMP has three components: warning guidance, hazard assessment, and mitigation (Jonientz-Trisler et al., 2005). The last two components, hazard assessment and mitigation, play essential roles in the NTHMP's efforts to produce evacuation maps for tsunami education.

The NTHMP's hazard assessment component produces scientific community-scale inundation maps that are used to develop evacuation maps (Gonzalez et al., 2001, 2005). Evacuation maps then become important mitigation tools for both planning and public education (Gonzales et al., 2001). These applications of evacuation maps are facilitated by the NTHMP's mitigation component, which oversees the translation of tsunami science into planning and education products (Jonientz-Trisler et al., 2005).

All stages in the development of evacuation maps involve significant interpretation of tsunami science. The interpretation involved in using inundation maps to guide the development of evacuation maps has received some commentary (Eisner et al., 2001; Gonzalez et al., 2001, 2005, Priest et al., 2001; Chowdhury et al. 2005; Dengler 2005); however, to our knowledge, no research has considered cartographic design choices that are necessary to produce educational evacuation maps. This paper situates cartographic design issues by focusing on educational tsunami evacuation map designs in Washington and Oregon.

State agencies in both Washington and Oregon are the leads in NTHMP evacuation mapping efforts, which are based on inundation maps of a credible worst-case, local, Cascadia Subduction Zone tsunami (Gonzalez et al., 2005). These agencies and local officials use state-developed inundation maps to identify evacuation routes (Gonzalez et al. 2001, 2005). In many instances, states have hosted community meeting to present developed evacuation plans (Dengler, 2005). At these meetings, members of communities have had opportunities to ask tsunami experts about inundation modelling and to influence decisions about evacuation routes (Dengler, 2005). State, county, and local governments then work together to produce an educational tsunami evacuation map brochure (Gonzalez et al., 2001, 2005). A final brochure is published and made available in print and online. The brochure includes an evacuation map and accompanying explanatory text, as well as valuable tsunami information on the back of the brochure. Local community involvement is critical to the success of evacuation maps (Gonzalez et al., 2001), but the involvement and input of local officials in the production of evacuation map brochures has led to inconsistencies in evacuation map designs between communities. Cartographic design choices made in designing and producing evacuation maps include style, for example layout and colour choices, and, more fundamentally, information content.

This paper compares and contrasts the design of cartographic information in Washington and Oregon evacuation maps. We first identify six types of tsunami hazard information that appear in a sample of 38 evacuation map brochures (Fig. 1-1). We then assess the design of each information type by comparing and contrasting the maps and texts of a subsample of six representative brochures. One of these six brochures is a proposed design standard for Oregon coastal communities. Finally, we use basic cartographic principles to summarize (1) information differences between the maps in the six brochures, (2) information differences between the maps of all 38 brochures, and (3) information limitations in the map brochures compared with those of a new Oregon-wide interactive educational evacuation map tool.

2.3 Types of tsunami hazard information in evacuation maps of Washington and Oregon communities

Our assessment is based on 16 Washington and 22 Oregon map brochures available at http://www.dnr.wa.gov/ResearchScience/Topics/GeologyPublicationsLibrary/Pages/tsuevac.aspx and http://www.oregongeology.org/sub/earthquakes/Coastal/Tsubrochures.htm.

List of 38 Brochure Sample from Washington and Oregon

	Washington
1	Point Roberts
2	Lummi Reservation
3	Bellingham
4	Port Townsend and Vicinity
5	Clallam Bay and Vicinity
6	Neah Bay and Vicinity
7	La Push and Vicinity
8	Hoh
9	Ocean City, Copalis Beach, Pacific Beach, and Moclips
10	Ocean Shores and Vicinity
11	Aberdeen and Hoquiam
12	Westport, Grayland, and Ocosta
13	North Cove, Tokeland, and Shoalwater Bay Tribe
14	Ramond and South Bend
15	Bay Center and Vicinity
16	Long Beach and Ilwaco
	Oregon
17	Warrenton
18	Gearhart
19	Seaside
20	Cannon Beach and Arch Cape Areas
21	Manzanita - Nehalem Wheeler
22	Rockaway Beach
23	Netarts - Oceanside Cape Meares
24	Nestucca Fire District
25	Lincoln City
26	Salishan - Glenden Beach
27	Depoe Bay
28	Newport
29	Waldport
30	Yachts
31	City of Florence
32	Gardiner
33	Winchester Bay - Salmon Harbor
34	Charleston - Sunset Bay
35	Bandon
36	Port Orford
37	Gold Beach
38	Brookings - Harbor

Figure 1-1 – List of community evacuation map brochures in our sample.

By examining map elements of all 38 brochures (symbols, legend, and labels), we identified six relevant types of tsunami hazard information: (1) tsunami hazard zone, (2) road network, (3) assembly areas, (4) evacuation guidance, (5) infrastructure, and (6) terrain (Fig. 1-2).

Types of Tsunami Hazard Information
Identified in 38 Brochure Map Sample

Vulnerability Information

1) Tsunami hazard zone

Resilience Information

2) Road network
3) Assembly areas
4) Evacuation guidance
5) Infrastructure
6) Terrain

Figure 1-2 – Types of tsunami hazard information in all 38 Washington and Oregon brochures, classified according to their primary purpose to provide vulnerability or resilience information.

2.4 Comparing and contrasting tsunami hazard information in six evacuation map brochures

The 38 maps differ in both the types of information they include and their qualitative and quantitative information design. We selected a subsample of six brochures for detailed examination - two from Washington and four from Oregon - that capture the wide range of information and design elements in the entire sample (Figs. 1-3 – 1-8). Our assessment compares and contrasts each type of information in the six maps and associated text to reveal similarities, differences, and limitations of information design.

Our assessment has four main limitations. First, we only consider the text in the brochures that is directly relevant to information types. Second, we do not consider information limitations caused by scale, because this issue is inherent to any map brochure. Third, we do not focus on differences in cartographic style unless they significantly affect interpretation of information. Fourth, we do not reference other external sources, such as inundation maps that are not designed for tsunami education or tsunami science publications. This last limitation means that we are assessing the information in the same way as a capable map user who is able to read accompanying brochure text but is unfamiliar with the community.

Our six map subsample includes brochure maps for the following communities, from north to south: La Push, Washington (Washington Military Department Emergency Management Division, 2004); Westport, Washington (Washington State Department of Natural Resources, Division of Geology and Earth Resources, 2007); Warrenton, Oregon (The City of Warrington, 2005); Gearhart, Oregon (Oregon Department of Geology and Mineral Industries, 2005a); Cannon Beach, Oregon (Oregon Department of Geology and Mineral Industries, 2008); and Newport, Oregon (Oregon Department of Geology and Mineral Industries, 2005b). Hereafter, we reference the six maps in this geographical order. Map 5 (Cannon Beach) is especially noteworthy because it has been recently proposed as a design standard for Oregon (Western States Seismic Policy Council, 2008).

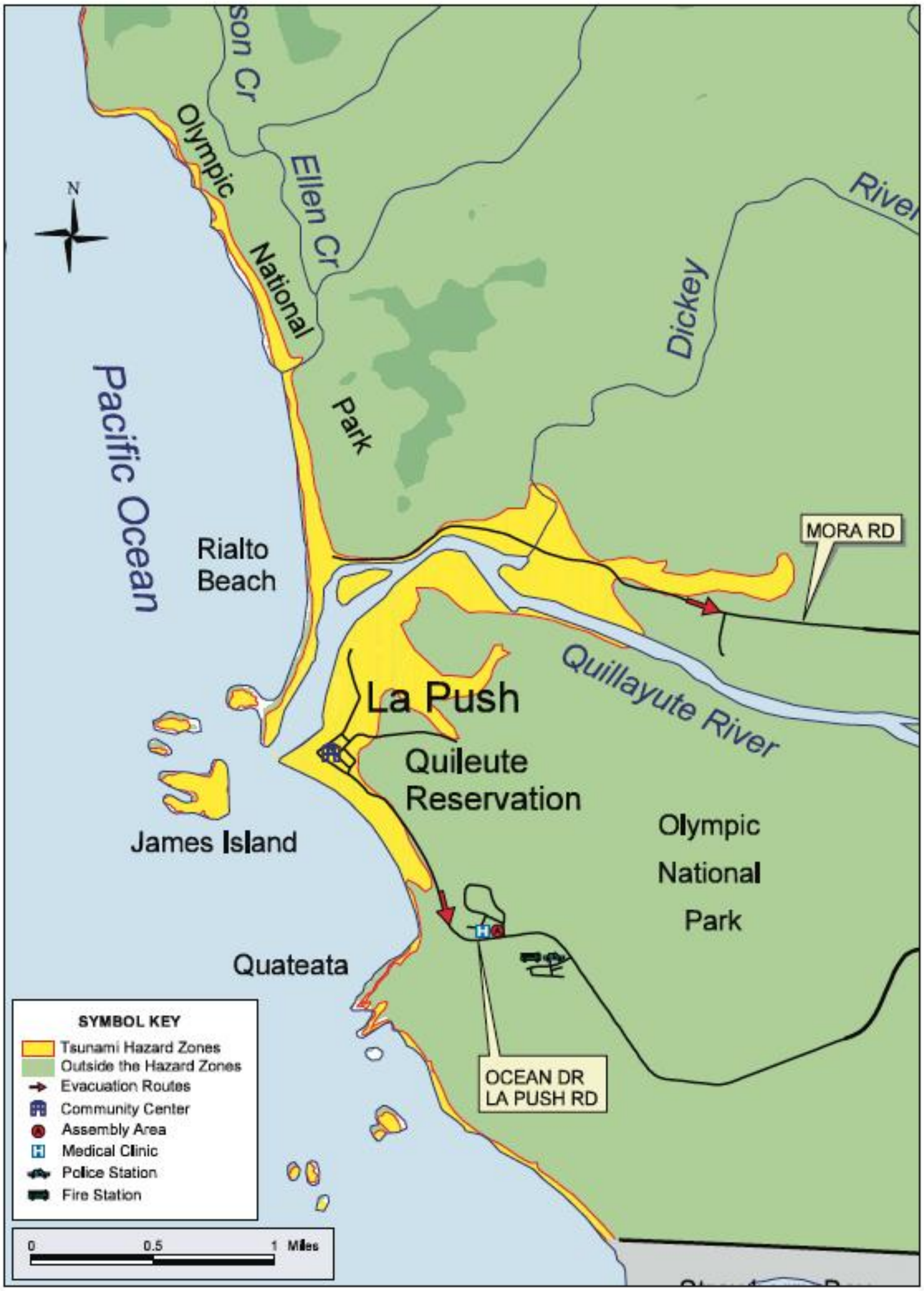

Figure 1-3 – Tsunami map for La Push, Washington (map 1 in the subsample of six maps). The Washington Military Department Emergency Management Division and the Quileute Tribal Council were involved in producing the brochure, but their roles are not explicit.

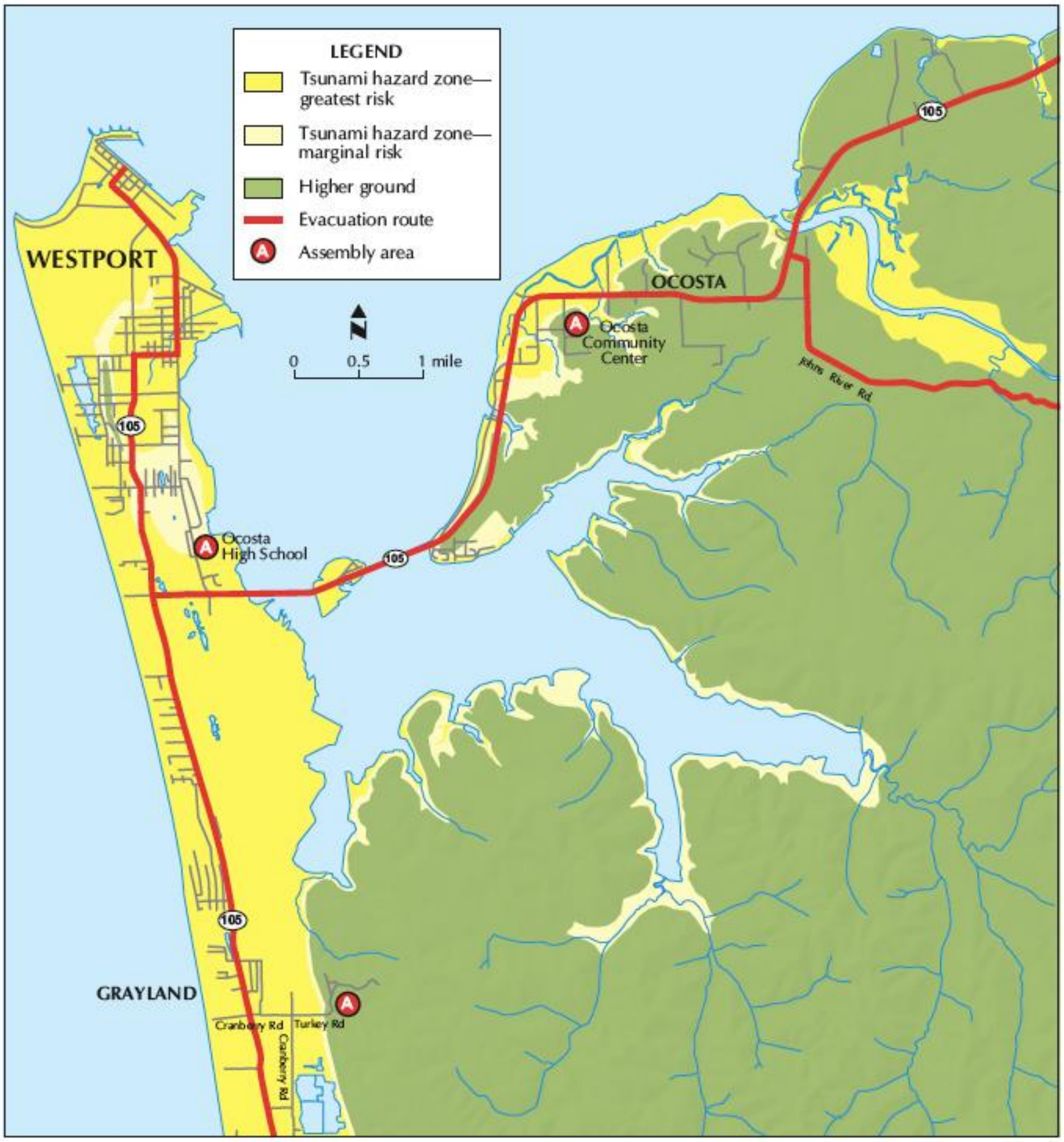

Figure 1-4 – Tsunami map for Westport, Washington (map 2 in the subsample of six maps). The brochure states "This map was produced by the Washington State Department of Natural Resources, Division of Geology and Earth Resources, in cooperation with local emergency management officials."

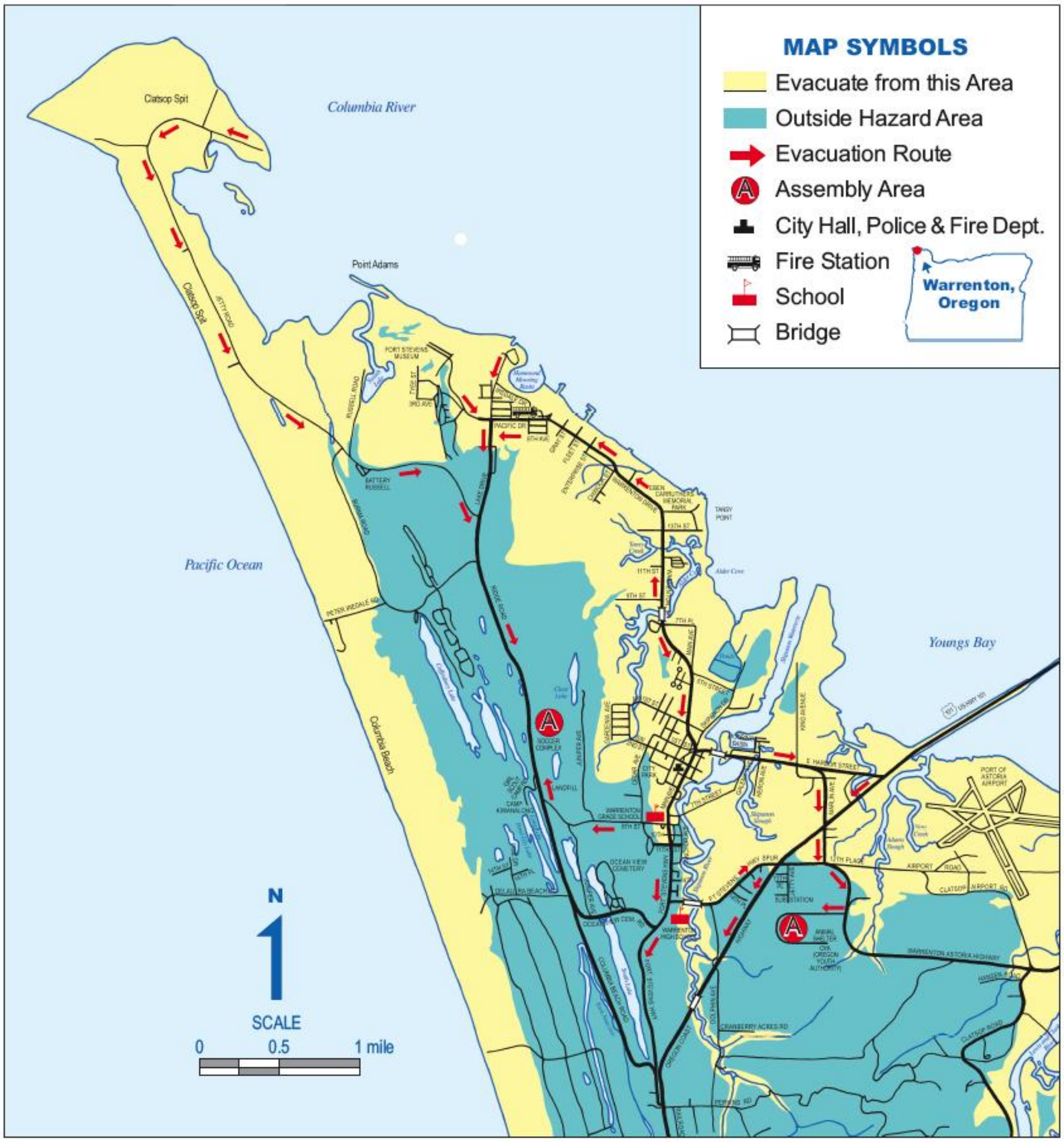

Figure 1-5 – Tsunami map for Warrenton, Oregon (map 3 in the subsample of six maps). The brochure states "The evacuation zone on this map was developed by the Oregon Department of Geology and Mineral Industries in consultation with local officials." It further states "The City of Warrenton is publishing this brochure because the information furthers the mission of the Department."

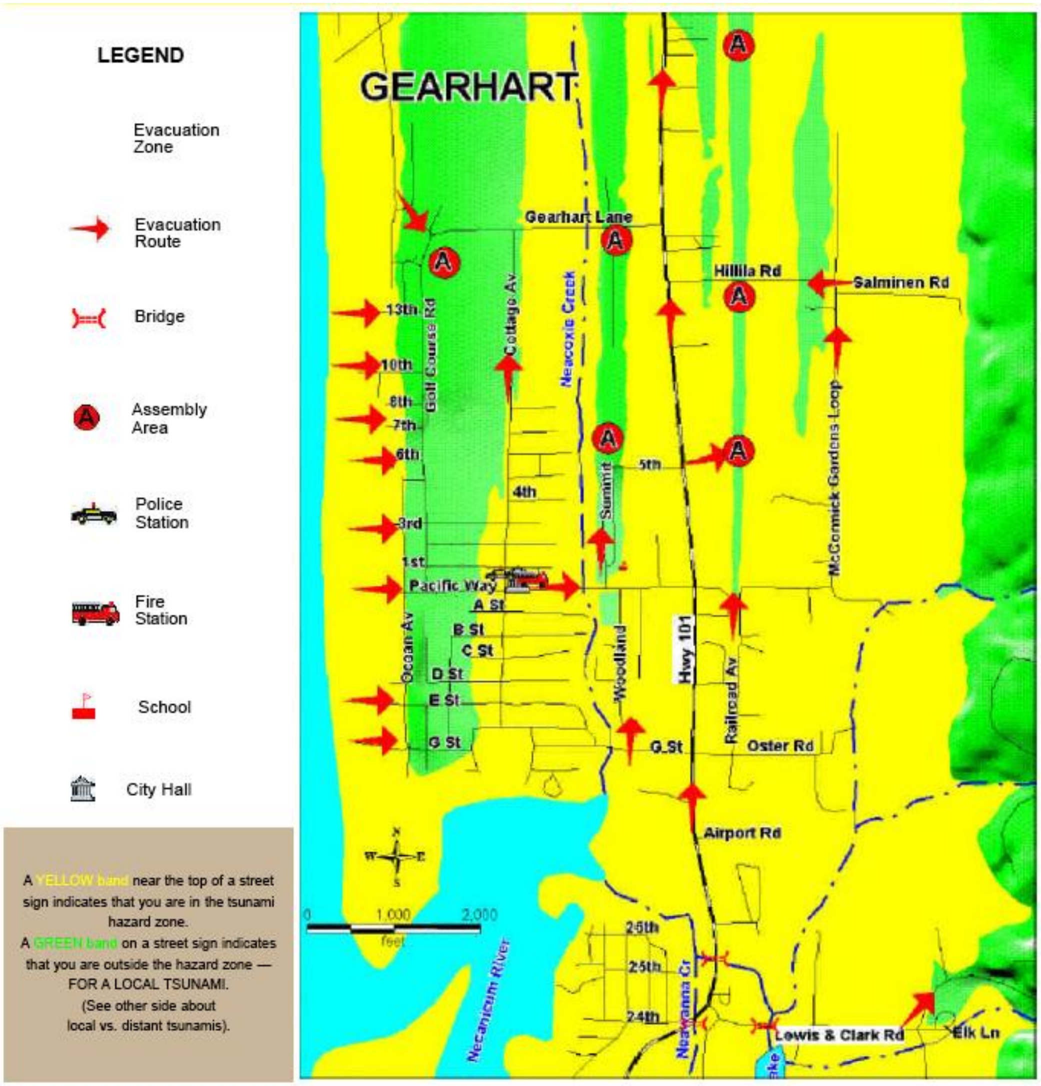

Figure 1-6 – Tsunami map for Gearhart, Oregon (map 4 in the subsample of six maps). The brochure states "The evacuation zone on this map was developed by the Oregon Department of Geology and Mineral Industries in consultation with local officials". It further states "The Oregon Department of Geology and Mineral Industries is publishing this brochure because the information furthers the mission of the Department."

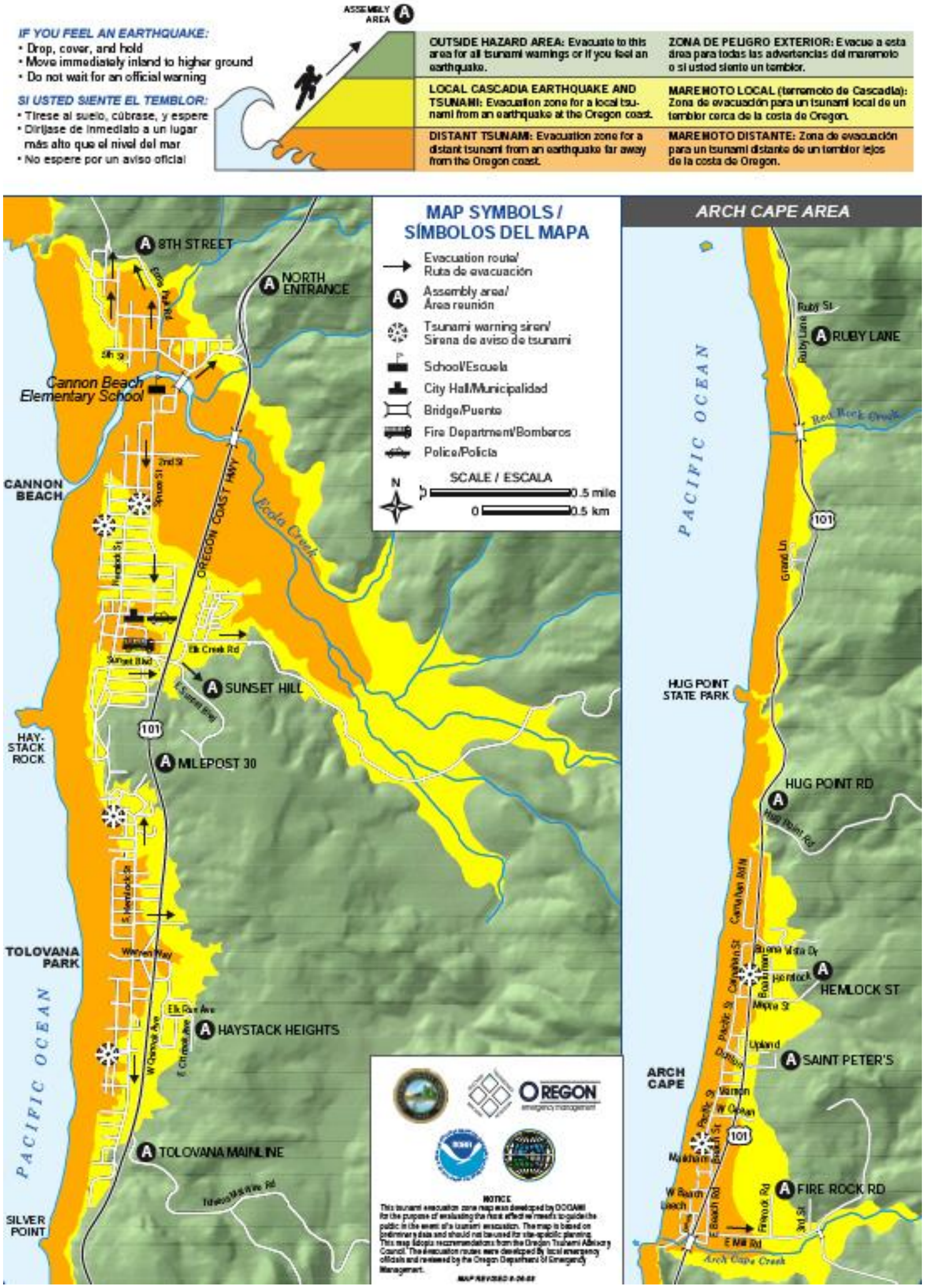

Figure 1-7 –Tsunami map for Cannon Beach and Arch Cape areas, Oregon (map 5 in the subsample of six maps). This map is the proposed design standard for Oregon. The brochures states that it was "published by the Oregon Department of Geology and Mineral Industries in consultation with Cannon Beach RFPD Fire and Rescue officials."

Figure 1-8 –Tsunami map for Newport, Oregon (map 6 in the subsample of six maps). The map of the north section of Newport is on the reverse side of the brochure. The brochure states that is was "published by the Oregon Department of Geology and Mineral Industries with assistance by Shoreland Solutions, Newport, Oregon, and in cooperation with Oregon Emergency Management and Lincoln County."

2.4.1 Tsunami hazard zone information

Tsunami hazard zone information is a fundamental component of evacuation maps. All six maps in our subsample include tsunami hazard zone information and use coloured areas to portray safe and hazardous zones.

All maps include safe zones, but they use different naming conventions: “outside the hazard zones” (map 1); “higher ground” (map 2); “outside hazard area” (map 3); “outside the hazard area” (map 4); “outside the hazard area” (map 5); and “high ground” (map 6). In five of the six cases, this information is presented in map legends; the text of the brochure for map 6 conveys this information.

The number of hazard zones is the most significant difference in our subsample of six maps. Maps 1, 3, 4, and 6 include only one tsunami hazard zone, but have different names for the zone: “tsunami hazard zones” (map 1); “evacuate from this area” (map 3); and “evacuation zone” (maps 4 and 6). With one exception, these maps require users to read the brochure text to learn that the hazard zone specifically represents a local tsunami scenario. The exception is map 4, which includes this information in the legend. Maps 2 and 5 include two tsunami hazard zones. The legend of map 5 states that the two zones refer to distant and local tsunami hazards. The legend of map 2 states that one zone has a marginal risk and the other has a higher risk. Although there is a discussion of both local and distant tsunamis in the brochure text accompanying map 2, the text does not explicitly discuss the meaning of greatest and marginal risk on the map. Users could therefore interpret the map as showing variability associated with risk of local tsunami or possibly the difference between the risk of local and distant tsunamis. None of the brochures states the method used to derive the tsunami hazard zone boundaries.

2.4.2 Road network information

Road network information is an important element of evacuation maps. Intersections of roads and hazard areas are sites of vulnerability. Road networks also provide critical resilience information for evacuation planning. All six maps show road network information using lines and also name some roads.

The number of labelled roads differs among the maps. Maps 1 and 2 have two and four named roads, respectively, whereas map 3 labels over 60 roads. The scale of the map limits the number of roads than can be labelled and how much road network information can be depicted, but the producers of map 2 clearly chose to label only a few roads. Maps 1 and 2 could also have provided more road detail if an enlarged inset map had been included in available space where there is no useful information.

It is not possible to draw conclusions about the limitations of road network information based on our evacuation map assessment. Choice of scale may necessitate selective labelling of roads and the exclusion of smaller roads or paths that may be important in evacuation. Map users familiar with the community’s geography may be able to identify omitted roads, but others will be unaware of those roads.

2.4.3 Assembly area information

Assembly area information depends on tsunami hazard zone information, road networks, availability of assembly areas, and decisions made during the tsunami assessment stage of developing evacuation maps. Circles with the letter "A" are used to visualize assembly areas where that information is included.

All maps, except 6, include assembly area locations, but labelling differs among the maps. Map 5 labels each assembly area by its road location or place name; maps 1 and 4 do not explicitly name the assembly areas, although they do label roads close to them; map 3 labels assembly areas as a structure and another as a soccer field complex; and map 2 labels a school, a community centre, and a road.

The amount of information about assembly areas in the brochure text differs significantly. The text of maps 3, 4, and 5 does not provide significant additional information, whereas the text of brochures 1 and 2 state that if residents do not live close to an assembly area, they should establish their own plan for assembling and make sure that the plan takes into account evacuation routes, the number of people expected to arrive at the assembly point, and private property access rights. The text of map 2 further states that its outdoor assembly areas will have emergency services.

All maps only implicitly state the significance of assembly areas. The text in all brochures advises that the public should evacuate inland and to high ground in case of an earthquake, with minor differences in terminology, but does not explicitly state that assembly areas are most useful for distant tsunamis.

Other than map 2, which states that one of the assembly areas will have emergency services, no maps communicate the advantages of evacuating to an official assembly area.

Locations of assembly areas differ as a function of community geographies. Maps 2, 3, 4, and 6 show temporary islands of safety that will exist during a tsunami; in the case of map 2, the islands apply to both “greatest risk” hazard areas and “marginal risk” areas. Maps 2, 3, and 6 do not include assembly areas on these islands, whereas map 4 includes assembly areas on some, but not all, of the islands.

Much other potentially useful assembly area information, which is unique to community geographies, is not provided. In the case of map 2, for example, the user has a choice of evacuating to the high school, which is the official assembly in the marginal risk zone, or to the unofficial small island of safety on the peninsula. Which is the better option? Is the island of safety not included as an official assembly area due to issues of land ownership, as the accompanying text of brochure broadly discusses, the number of people that the island can accommodate, or is the high school a safer assembly area with its additional building elevation? Similarly, are some islands of safety on map 3 not identified as official assembly areas because they provide little additional protection in terms of elevation, because of private land access issues, because of the capacity of the islands, or some combination of these issues? Why are some roads that lead to safety on map 5 not identified as assembly areas, whereas others are? What was the rationale for the choice of the number of assembly areas? Was this decision arbitrary or was there a good reason to preclude some locations for a distant or local evacuation event?

2.4.4 Evacuation guidance information

Evacuation guidance is intended to provide users with information that will aid their decisions about the best route to take to higher ground. It depends on the location and extent of the tsunami hazard zone, road network information, and decisions made about assembly areas during the tsunami assessment stage of evacuation map development. Unlike other types of information, evacuation guidance visualizes an action rather than a physical location.

With one exception, the text of all brochures advises that people should evacuate on foot if possible in the event of an earthquake. The exception is the text accompanying map 1, which recommends evacuation on foot if necessary. The text of brochures 3, 4, and 5 explicitly advise evacuation on foot for both local and distant tsunamis. The other brochure texts do not recommend a particular evacuation method for a distant tsunami event.

All maps, except no. 2, visualize evacuation guidance by using arrows, but there are five differences in the design of the arrows. First, the thickness of the arrows differs from map to map. Map 6, for example, has much thicker arrows than maps 3, 4, and 5. Thicker arrows provide more general information, but they obstruct road network information. Second, the spacing between arrows differs. Maps 3, 4, 5, and 6 have more arrows than map 1. Third, the locations of arrows in relation to road networks are different. Map 1, for example, does not include an arrow for an alternative evacuation route from the main populated area. In contrast, map 3 has arrows for many roads but not others for no apparent reason. Fourth, the locations of arrows in relation to hazard zones differ from map to map. For example, map 3 includes arrows in the hazard zone and in the safe zone, whereas map 1 only includes arrows in safe areas. Fifth, arrow orientation differs. Arrows on maps 1, 4, 5, and 6 point toward the closest safe area, but some do not direct the user to an assembly area. Conversely, arrows on map 3 point toward assembly areas and avoid islands of safety. No map that uses arrows has a legend or accompanying text explicitly stating that it is guidance for evacuation during a local or distant tsunami, or for both scenarios.

Tsunami evacuation guidance is related to evacuation signage. The text in all brochures, except nos. 4 and 6, discuss evacuation signage. The producers of maps 4 and 6 may have chosen not to mention signs or, alternatively, the signs may not exist. The text for maps 1 and 2 specifically mentions that signs provide additional information at locations where there is more than one evacuation route. The small amount of evacuation guidance provided in maps 1 and 2 implies that, at least in these two communities, signage offers much more guidance than the maps.

Arrows do not provide clear evacuation guidance for certain areas of the community. In the case of map 1, for example, where is the boundary that defines equal time for a resident in the populated area of the hazard zone to reach alternative safe areas? Signage may address this issue, but the maps do not.

2.4.5 Infrastructure information

Infrastructure information can provide landmarks to plan evacuation and may help identify safe areas. Icons display infrastructure information, but different icon styles are employed where that information is included.

Deducing differences in types of infrastructure featured on maps is not possible in our assessment because some communities may not have certain types of infrastructures and others may have chosen not to include them on the map. Nevertheless maps 4 and 5 include and identify several types of infrastructures, whereas map 2 shows none.

The reason for including particular infrastructure is not clear. If buildings are in safe zones, they presumably represent areas of refuge, as for example on map 6, which may explain why this map does not show explicit assembly areas. In addition, these buildings may serve as landmarks. Buildings in tsunami hazard areas may also serve as landmarks, or alternatively represent locations for vertical evacuation. Only maps 1 and 2, however, mention vertical evacuation, and they do not emphasize evacuation toward buildings. The texts of these brochures state that if you are in a multi-story building during the earthquake, you should move to the top of the building after the ground stops shaking.

2.4.6 Terrain information

Terrain information, like infrastructure location, can provide orientation for map users. It may also provide information about the relative safety of areas inside and outside of the tsunami hazard zone. Maps visualize terrain information using either hillshading or topographic contours.

Map 3 does not include terrain information. Map 2 arguably includes some terrain information but, if so, it is extremely faint and may be unnoticed by users. The other four maps include terrain information only for safe areas. A variety of cartographic methods are used to provide this information. Maps 1 and 6 use contours; map 1 includes only two contour lines; and map 6 includes four. Map 5 provides terrain information using hillshading. Map 4 appears to use a combination of hillshading and contours, but the quality and style of the contour lines make it difficult to determine how many contours are present. It is possible that what appear to be contours on map 4 are instead artifacts of the hillshading technique.

The educational value of terrain information on maps is questionable. Maps that use contours provide no text or legend to explain the meaning of the contours. Few contour lines may improve user orientation but provide only very general information. Hillshading in map 5 is of higher quality than that in map 4, but still adds little information other than providing orientation. Although the hillshading in map 4 is of marginal quality, it seems to include contours and therefore may offer the greatest overall educational value in terms of terrain.

For certain communities, it would be beneficial to provide more information about terrain. People in areas distant from a safe haven may have to choose between evacuating to different areas within the tsunami hazard zone. Because maps do not provide detailed terrain information, individuals would have to make decisions based only on their geographic perceptions of the elevation of their community in tsunami hazard areas and not on educational map tools.

2.5 A cartographic perspective on tsunami evacuation map design issues

The preceding assessment has highlighted many cartographic information design issues from the map-user's perspective. Map design issues can alternatively be viewed in the context of map-making decisions. In this section, we introduce the principles of cartographic abstraction - an implicit and critical part of governments' role as mapmakers. Cartographic abstraction provides a useful framework for summarizing information on (1) design differences in the six map brochures discussed in this paper, (2) design differences in the maps of the entire brochure sample, and (3) a new Google Maps evacuation map tool used in Oregon.

2.5.1 Cartographic abstraction

Cartographic abstraction principles reveal how mapmakers chose to select, generalize, and symbolize information to make a cartographic representation (Robinson et al., 1995). Selection refers to the choice as to whether or not to include a type of information on the map. Generalization is the preparation of the selected information for symbolization. Generalization eliminates unnecessary details for the purpose of enhancing the clarity of information while considering limitations of the quality of the underlying data, scale, and map medium. Symbolization refers to the use of cartographic variables to visually represent generalized information (McMaster and Shea, 1992; Robinson et al., 1995). The symbolizations of all types of information together create a cartographic representation.

Although generalization decisions precede those involving symbolization, choices about symbolization also can produce generalization effects (McMaster and Shea, 1992; Robinson et al., 1995). For example, the thickness of line used to symbolize a road can exaggerate the road's width, or the use of a point to locate a feature creates a circular area. Generalization stemming from symbolization is most significant when symbols take up a relatively large space on a map and the map scale is small.

2.5.2 Using cartographic abstraction to summarize the previous assessment of six maps

Selection decisions describe what types of information are portrayed on the six maps. The tsunami hazard zone and road networks are the only information types included to all six maps.

Generalization decisions result in most of the cartographic design differences in information types. Several information types involve more than one generalization method. *Tsunami hazard zone information* was generalized into either one or two hazard zones, by categorizing local and distant tsunamis and greatest and marginal risk. The hazard zone boundary was also generalized on all six maps by an unknown method. *Road network information* was generalized largely due to considerations of map scale; roads may have eliminated for this reason*. Assembly area information* was generalized to points during the hazard assessment process. *Evacuation guidance information* was generalized by decisions about arrow locations in relation to roads and hazard zones, and arrow orientation and spacing. *Infrastructure information* was generalized by decisions to exclude certain types and locations of buildings. *Terrain information* was generalized by choosing a number of contour lines or by the resolution of the hillshading, and by only showing the information in safe areas.

Symbolization decisions describe how information types are visualized on maps. Significant differences in symbolization were found only for terrain and evacuation guidance information. Terrain information used two different symbolization methods: hillshading and contours. Evacuation guidance was consistently provided by arrows, but symbolization differed in the thickness of the arrows. The use of thicker arrows produced a significant generalization effect. Symbolizing any information type causes some degree of generalization, but we did not consider these effects in other types of information because they are primarily caused by differences in map scale.

All design choices about types of information that are included in tsunami evacuation maps are likely in part map-making work that happens in a Geographic Information System (GIS) environment. A GIS enables the choice of cartographic abstractions for the production of evacuation map brochures (Fig. 1-9). Road networks, terrain, and infrastructure are generally available because they have several other uses for different projects. Tsunami hazard zone and assembly area information can be imported from tsunami hazard assessment models or created in a GIS, and evacuation guidance information can be created in the GIS. Any selected information also has some pre-existing generalization defined by how the information was modelled or obtained.

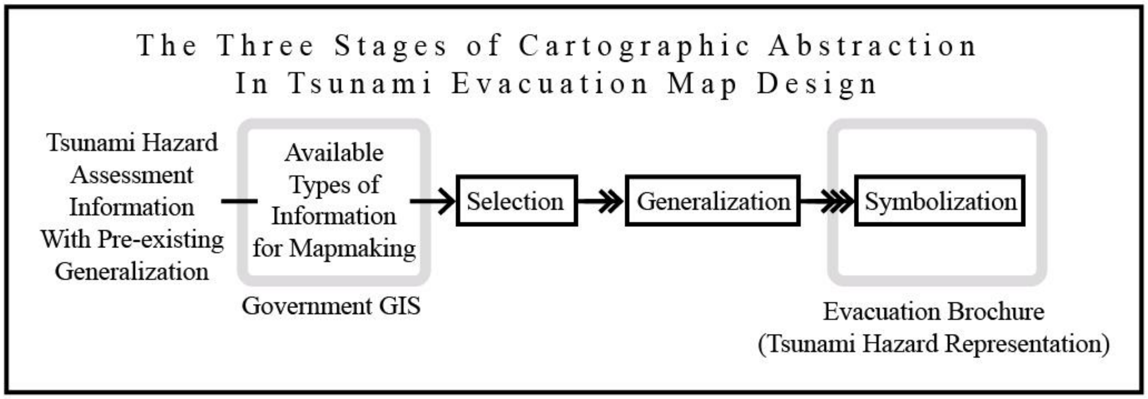

Figure 1-9 – Cartographic abstraction in tsunami evacuation map design involves selecting, generalizing, and symbolizing types of information. Cartographic abstraction is repeated for each selected type of information. Cumulatively, the symbolizations in a brochure result in a representation of tsunami hazard.

2.5.3 Using cartographic abstraction to summarize design differences in all 38 maps

Cartographic abstraction differences in the entire set of 38 tsunami evacuation maps are summarized in Figure 1-10. The figure shows differences in generalization that are certain and objective, and only distinguishes differences in symbolization techniques. It does not attempt to classify different generalizations of evacuation arrows because these differences depend on the size of the road network and its location relative to the hazard zone. A consideration of the level of generalization of evacuation guidance symbolization would also require subjective classifications of arrows and symbolization methods. The figure also does not include differences in terrain elevation generalization because the range of contour intervals is small. With one exception, all cartographic abstraction differences in this figure are exemplified by at least one of the six maps discussed in this paper. The single exception is the terrain generalization: some maps include information on both the safe and hazard areas.

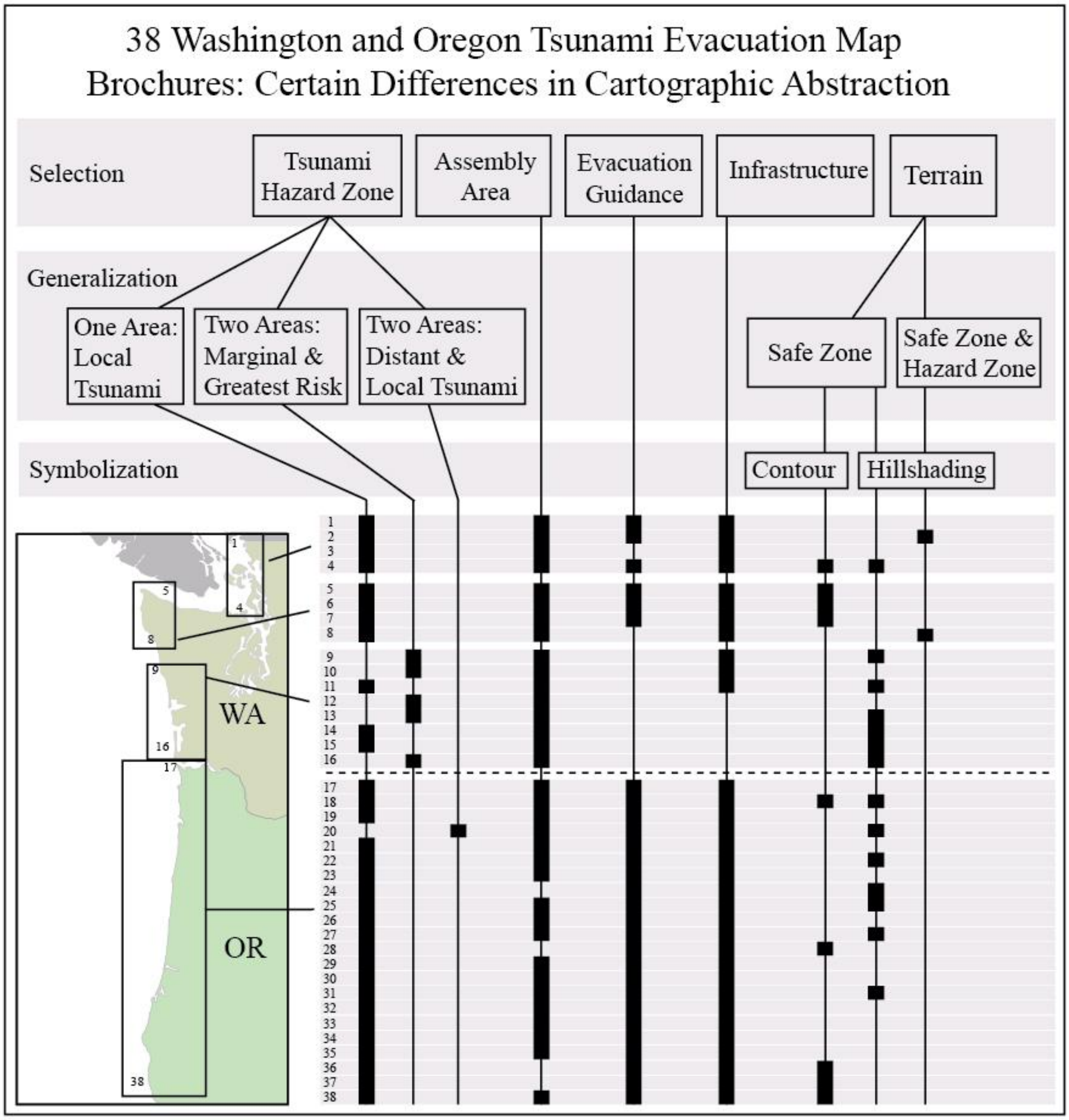

Figure 1-10 – Objective differences in cartographic abstraction of tsunami information types in 38 map brochures in Washington and Oregon. The numbers correspond to the communities listed in Figure 1-1. Black squares indicate the type of generalized and symbolized information contained within the community's evacuation map. Information on road networks is not included because generalization differences are unknown and all maps symbolize roads using lines.

2.5.4 Using cartographic abstraction to situate a new evacuation map design

A recently introduced interactive Google Maps tool in Oregon (Oregon Department of Geology and Mineral Industries, 2009) is currently the only other educational tsunami evacuation map tool available in Washington and Oregon. The State of Oregon developed the tool, which can be found athttp://www. nanoos.org/data/products/oregon_tsunami_evacuation_zones/index.php. The tool provides tsunami hazard information for most Oregon communities, but not all parts of the coastline are covered because inundation mapping is still being completed in Oregon. Figure 1-11 is a screenshot of the Google Maps interface for the community of Cannon Beach.

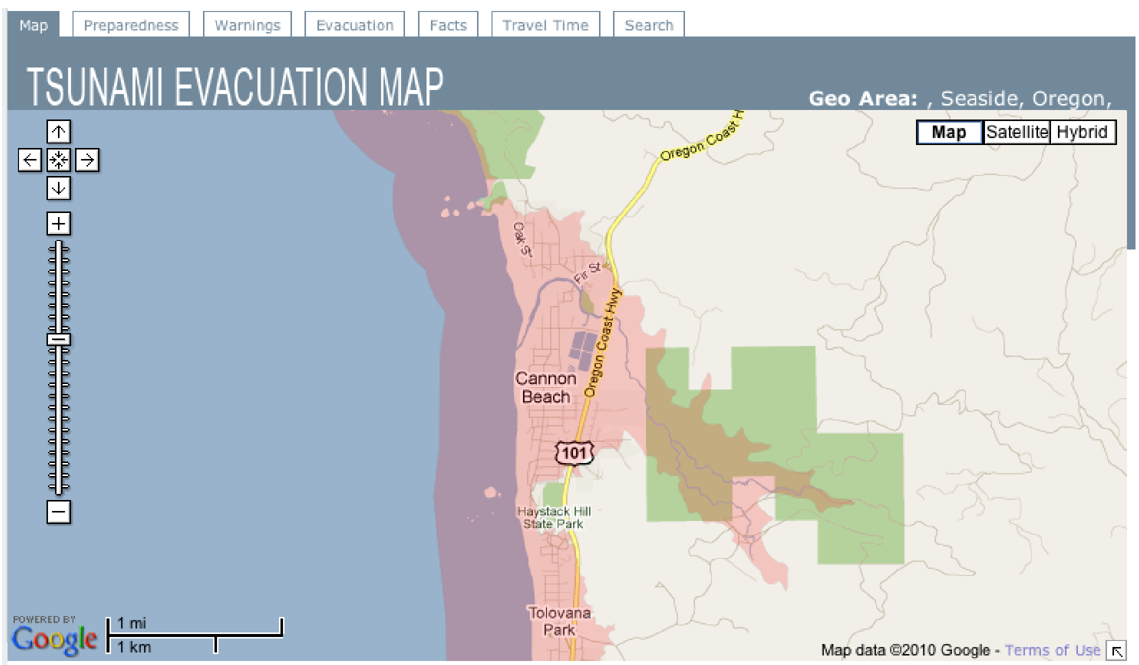

Figure 1-11 – Interface for the new Google Maps tsunami evacuation map in Oregon. This figure shows how the interface appears when a user looks for evacuation information for Cannon Beach. Residents can search for their address to see whether they live in the hazard area. The tsunami hazard zone information is symbolized by a transparent pink area overlay and is labelled "tsunami evacuation zones" in the legend (the legend is not shown).

Oregon citizens will probably find this tool useful. It introduces interactivity that is not possible with a brochure. Notably, users can zoom as well as search for the location of their residence or workplace within the local tsunami hazard zone. The tool also provides satellite image information and generalization of all included information types is not restricted by scale.

By zooming in, the user can acquire additional information on road and infrastructure and increased detail in the satellite image. Zooming in does not provide, however, additional detail on tsunami hazard zones because, as in brochures, accompanying text does not provide the generalization method used to delineate the area.

Although the Google Maps tool offers significant advantages over brochures, it has several limitations. The associated text is not significantly different from that in the map brochures. In fact, in many ways it is less detailed because it is not customized for communities. In addition, the cartographic abstraction of tsunami hazard information has many limitations compared with that of brochures. For example, the Google Maps interface, unlike the Cannon Beach brochure, generalizes tsunami hazard information to one area and does not show assembly areas or provide evacuation guidance or terrain information. It also does not emphasize important infrastructure relevant to evacuation; rather it depends on Google's GIS generalization algorithms. Given these limitations, the Google Maps tool does not eliminate the need for community tsunami evacuation brochures.

Figure 1-12 shows the cartographic abstraction of tsunami hazard information found in the Google Maps tool. The only information unique to the interface compared with the standard Google Maps interface is the tsunami hazard zone information. All other information types are directly dependent on Google's GIS.

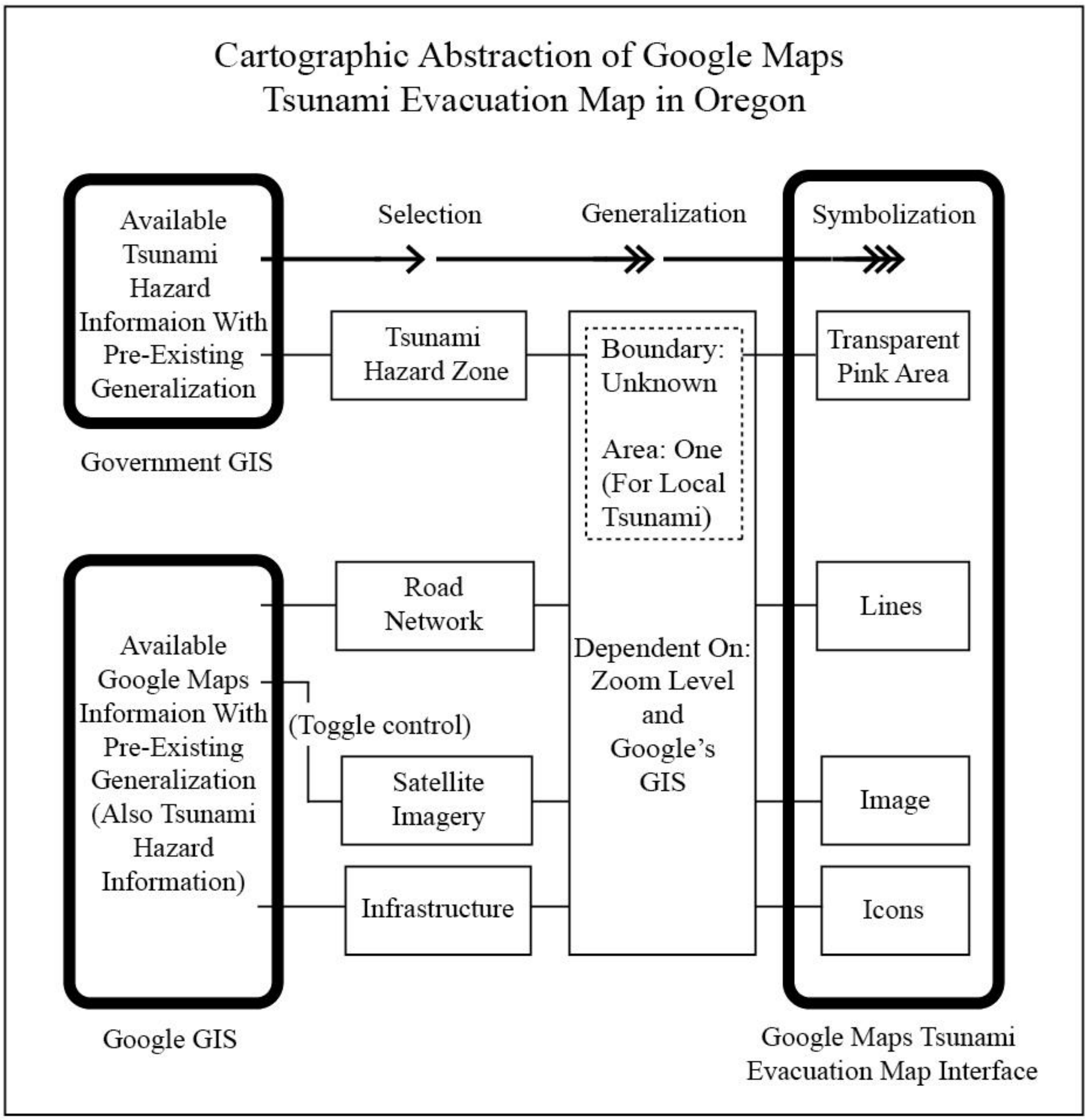

Figure 1-12 – The Google Maps tool provides satellite imagery not found in brochures, but it does not show assembly areas or provide evacuation guidance or terrain information. Its zoom capability eliminates generalization issues caused by fixed scales in brochures.

2.6 Discussion

We have compared and contrasted tsunami hazard map information included in 38 Washington and Oregon evacuation brochures. Recent efforts in Oregon to standardize brochures and introduce new technologies are important steps in improving evacuation maps, but they have not been evaluated for their educational efficacy. It is debatable whether these developments will improve tsunami education.

Previous work that used public surveys to evaluate the cumulative efficacy of all educational tools in communities of Oregon (Karel, 1998) and Washington (Johnson et al., 2002) suggests that the tools provide the public with only limited perceptions of tsunami hazards. As a follow-up to the Washington study, Johnston et al. (2005) conducted interviews to learn why existing tools did not have the desired effects. Some residents responded that the tools generally do not provide adequate detailed information.

Washington and Oregon evacuation maps do not provide the public detailed tsunami hazard information. As our study has revealed, there are many important questions that current evacuation maps do not answer. More advanced, supplementary evacuation maps could provide this information by including more types of information, decreasing information generalization, and offering more types of information symbology than are available with current cartographic products. The Google Maps tool supplements information content in brochures mainly through its satellite image information and reduced generalization of road network information. On the other hand, it reduces information by excluding assembly areas and evacuation guidance, and provides a more generalized tsunami hazard zone. Improving evacuation maps requires the development and evaluation of new tools to supplement existing tsunami hazard information.

Provision of supplementary tsunami information may improve tsunami mitigation by enhancing long-term experiential learning in communities. Creating supplementary evacuation map products, however, involves more than adopting new interactive technologies; new technologies do not directly address the issue of information content, which is socially, not technologically, defined. Considering evacuation maps as cartographic abstractions helps to situate the importance of these social decisions.

2.7 Conclusion

Design of tsunami evacuation maps involves an interpretation of hazard assessment information. It also involves cartographic choices that may limit the public's access to scientific tsunami hazard information. In response to a lack of attention to the choices that mapmakers make when producing tsunami evacuation maps, we assessed the map and text of six tsunami brochures in Washington and Oregon. We introduce cartographic abstraction to situate the map information content of the brochures. Cartographic abstraction involves decisions in the selection, generalization, and symbolization of information. Using this framework, we summarize design differences in the information content of the six maps and more generally that of the maps in all 38 brochures. We also situate the information content of an interactive Google Maps tsunami evacuation map tool.

State and local officials collaborate to design tsunami evacuation maps in Washington and Oregon, but they must recognize the importance of cartographic abstraction of information that happens when designing evacuation map tools. Significant opportunities exist to improve tsunami evacuation maps, but social variables that define their design and production must be explicitly recognized.

Our assessment provides both a summary and examples of how mapmakers represent and limit community-scale tsunami hazard information, as well as insight into how we may describe and explore socially influenced aspects of tsunami evacuation map-making. In theory, mapmakers are free to develop many supplementary cartographic products that enhance existing hazard information provided by brochures. New interactive mapping technologies may have an important role in preparing citizens for tsunamis, but the social decisions about cartographic abstraction that define underlying tsunami hazard information content may be equally or more important.

2.8 References

Bernard E. (2005). The U.S. National Tsunami Hazard Mitigation Program – a successful State–Federal partnership. *Natural Hazards, 35*, 5–24.

Chowdhury S., Geist E., Gonzalez F., MacArthur R., and Synolakis C. (2005).*Tsunami hazards, FEMA coastal flood hazard analysis and mapping guidelines, focused study report.* Retrieved from the Federal Emergency Management Agency website: https://www.floodmaps.fema.gov/pdf/fhm/frm_p1zones.pdf.

Dengler L. (2005). The role of education in the National Tsunami Hazard Mitigation Program. *Natural Hazards, 35*, 141–153.

Eisner R.K., Borrero J.C., and Synolakis C.E. (2001). Inundation maps for the State of California. In *Proceedings of the International Tsunami Symposium 2001.* National Tsunami Hazard Mapping Program Review Session, R-4, Seattle WA 7–10 August 2001, 67–81.

Gonzalez F.I., Titov V.V., Mofjeld H.O., Venturato A.J., and Newman J.C. (2001).The NTHMP inundation mapping program. In *Proceedings of the International Tsunami Symposium 2001*. National Tsunami Hazard Mapping Program Review Session, R-2, Seattle, WA, 7–10 August 2001, 29–54.

Gonzalez F.I., Titov V.V., Mofjeld H.O., Venturato A.J., Simmons R.S., Hansen R., Combellick R., Eisner R.K., Hoirup D.F., Yanagi B.S., Yong S., Darienzo M., Priest G.R., Crawford G.L., and Walsh T.J. (2005). Progress in NTHMP hazard assessment. *Natural Hazards, 35*, 89–110.

Johnson D., Paton D., Houghton B., Becker J., and Crumbie G. (2002). *Results of the August-September 2001 Washington State tsunami survey*. New Zealand Institute of Geological and Nuclear Sciences, Science Report 2002/17, Lower Hutt, New Zealand.

Johnson D., Paton D., Crawford G., Ronan K., Houghton B., and Buergelt P. (2005). Measuring tsunami preparedness in coastal Washington, United States. *Natural Hazards, 35*,173–184.

Jonientz-Trisler C., Simmons R.S., Yanag B.S., Crawford G.L., Darienzo M., Eisner R.K., Petty E., and Priest G.R. (2005). Planning for tsunami-resilient communities. *Natural Hazards, 35*, 121–139.

Karel A. (1998). Oregonians need more information about tsunamis to save lives. *Oregon Geology, 60*(3), 56.

McMaster R.B., and Shea K.S. (1992). *Generalization in digital cartography*. Washington, DC: Association of American Geographers.

Oregon Department of Geology and Mineral Industries (2005a). Tsunami evacuation brochure for Gearhart, Oregon, 2 pp.

Oregon Department of Geology and Mineral Industries (2005b). Tsunami evacuation brochure for Newport, Oregon, 2 pp.

Oregon Department of Geology and Mineral Industries (2008). Tsunami evacuation brochure for Cannon Beach/Arch Cape, Oregon, 2 pp.

Oregon Department of Geology and Mineral Industries (2009). Oregon Coast tsunami hazards program tsunami map viewer. http://www.nanoos.org/data/products/oregon_tsunami_evacuation_zones/index.php Accessed March 2 2011.

Priest R., Baptista A.M., Myers E.P. III, and Kamphaus R.A. (2001). Tsunami hazard assessment in Oregon. In *Proceedings of the International Tsunami Symposium 2001.* NTHMP Review Session, R-3, Seattle, WA, 7–10 August 2001, pp. 55–65. http://nthmp-history.pmel.noaa.gov /its2001/Separate_Papers/R-03_Priest.pdf Accessed January 20 2011.

Robinson A.H., Morrison J.L., Muehrcke P.C., Kimerling A.J., and Guptill S.C. (1995). *Elements of cartography* (6th edition). New York: Wiley.

The City of Warrington (2005). Tsunami evacuation brochure for Warrington, Oregon, 2 pp.

Washington Military Department Emergency Management Division (2004). Evacuation map for La Push and Vicinity, Washington, 2 pp.

Washington State Department of Natural Resources, Division of Geology and Earth Resources (2007). Evacuation map for Westport, Grayland, and Ocosta, Washington, 2 pp.

Western States Seismic Policy Council (2008). *2008 Annual Report.* Retrieved from the Western States Seismic Policy Council website: http://www.wsspc.org/resources/Annual%20Reports/08_AR_FINAL.pdf

Chapter 3: The Transformation of Tsunami Hazard Information into an Educational Evacuation Map Strategy: A Case Study in Ucluelet, British Columbia[2]

3.1 Abstract

The development of educational tsunami evacuation maps in the Pacific Northwest of Canada and the United States is based on decisions about how to use available tsunami hazard information. This paper considers, on the one hand, how cartographic decisions influence tsunami hazard information of an educational evacuation map strategy and, on the other, the need for decisions to make more information publicly accessible. A case study of tsunami hazard assessment and evacuation map development is presented in Ucluelet, a small community on the west coast of Vancouver Island, Canada. We describe how scientific and government decisions influenced the transformation of tsunami hazard information into an educational evacuation map by applying cartographic abstraction principles, which consider the selection, generalization, and symbolization of information in maps. We argue that the development of Ucluelet's evacuation map involved many decisions and other factors that cumulatively marginalized potentially valuable educational information. The most significant decision was to produce only one educational tsunami evacuation map. This practice is common in Pacific Northwest communities in the United States. The goals of tsunami resilience and empirical tsunami education studies

[2] A version of this Chapter has been submitted to *Environmental Hazards: Human and Policy Dimensions* under the co-authorship of Nick Hedley.

challenge this longstanding one map paradigm. We illustrate examples of unused tsunami hazard information that could play a role in more advanced evacuation maps intended for public who seek the information.

3.2 Introduction

Coastal communities on Vancouver Island, British Columbia (BC) are vulnerable to both distant tele-tsunamis and near-source tsunamis generated by great earthquakes at the Cascadia Subduction Zone (CSZ) (Clague et al., 2003). BC's Provincial Emergency Program (PEP), now a division of Emergency Management BC, provides all vulnerable communities with tele-tsunami warnings, along with tsunami preparedness and mitigation guidance (British Columbia Provincial Emergency Program, 2001). In an assessment of BC's tsunami program, Anderson and Gow (2004) made a number of recommendations for improving tsunami monitoring and detection, emergency management, and public response. The recommendations included a need for increased inundation mapping efforts. At the time of Anderson and Gow's assessment, the Canadian Hydrological Service was conducting research on CSZ tsunami scenarios (2004), but had not yet developed any community-specific two-dimensional inundation maps.

The devastating 2004 Indian Ocean tsunami accelerated BC's tsunami preparedness efforts. In 2005, with funding from the Government of Canada, PEP initiated the Tsunami Integrated Preparedness (TIP) project (Kryzanowski, 2006). TIP funded many tsunami preparedness initiatives, mainly through community grants. As part of TIP, PEP coordinated a pilot study tsunami hazard assessment in Ucluelet. This initiative brought together Ucluelet's local government officials with tsunami modelling experts from the private and academic sectors. The goals of the project included developing a two-dimensional tsunami inundation model to assess Ucluelet's CSZ tsunami vulnerabilities, developing and assessing strategies for planning and evacuation, sharing results with the public, and applying the findings and methods to other communities. We joined this project with a broad aim of researching cartographic methods to communicate the assessment's results. As part of our research, we observed how the tsunami hazard assessment influenced the resulting educational evacuation map strategy – a process that involved tsunami scientists and local government emergency management officials.

The development of an educational evacuation map in Ucluelet was significantly influenced by developments in the United States (US). Ucluelet not only faces similar distant and CSZ tsunami vulnerabilities as US Pacific Northwest communities (Clague et al., 2000), but BC PEP also has a continuing relationship with all Pacific states in improving tsunami mitigation strategies (British Columbia Provincial Emergency Program, 2001). Pacific states, in turn, have a partnership with US federal government agencies that together constitute the National Tsunami Hazard Mitigation Program (NTHMP) (Bernard, 2005). The NTHMP oversees tsunami warning guidance, hazard assessment, and mitigation for all vulnerable US communities (Jonientz-Trisler et al., 2005). Anderson and Gow (2004) identified the potential benefit of BC drawing on experience from NTHMP developments, but the NTHMP offers no explicit guidance about educational evacuation map design and development. Instead, it broadly defines tsunami education as a form of mitigation able to create tsunami-resilient communities (Dengler, 2005).

The NTHMP defines tsunami-resilient communities as ones that: “(1) understand the nature of the tsunami hazard, (2) have the tools they need to mitigate the tsunami risk, (3) disseminate information about the tsunami hazard, (4) exchange information with other at-risk areas, and (5) institutionalize planning for a tsunami disaster” (Dengler, 2005; Jonientz-Trisler et al., 2005). The first and third points relate to educational tools, and the fourth point emphasizes adoption of tools used in neighbouring communities to encourage tool consistency and cost-effectiveness (Jonientz-Trisler et al., 2005). Ucluelet’s closest neighbouring states are Washington and Oregon, where State and local government officials develop educational evacuation maps by interpreting results of State-developed tsunami inundation maps (Gonzalez et al., 2001, 2005). Although communities in Washington and Oregon consistently disseminate one evacuation map brochure in print and online, these brochures have variable tsunami hazard information (Kurowski et al., in press), making adoption by Ucluelet not straightforward. Oregon has recently proposed a standard evacuation map brochure design and also has developed a state-wide Google Maps evacuation map application, but it has not rationalized why certain information is included or excluded (Kurowski et al., in press). Although all Washington and Oregon educational evacuation maps are based on scientific information, their designs have been socially defined. To our knowledge, this social process has not received explicit attention in the tsunami science literature.

This paper describes how social factors influenced the development of an educational evacuation map strategy in Ucluelet. We first provide an overview of Ucluelet's tsunami hazard assessment and how scientists communicated the results in a public forum. Using cartographic abstraction principles, we then describe a scientifically recommended evacuation map design, and a different, final evacuation map implemented by local officials. Most importantly, evacuation map decisions in Ucluelet generally followed those developed by communities in Washington and Oregon; in doing so, Ucluelet significantly simplified available and potentially relevant information for education. We argue that existing tsunami resilience principles and empirical evidence suggest a need for greater utilization of tsunami hazard assessment information in cartographic tsunami education efforts. We use Ucluelet as an example to illustrate evacuation map education strategies that may be able to communicate more information to the public.

3.3 The development of a tsunami evacuation map strategy in Ucluelet

Before the pilot project tsunami hazard assessment process began, Ucluelet had a simple draft plan. This plan used an elevation contour to define maximum tsunami run-up based on plans adopted by US Pacific coastal communities. Local officials had identified one central assembly area in the population centre, but had not yet implemented an evacuation map or any other tsunami education products such as tsunami evacuation signage on roads. The scientific tsunami hazard assessment aimed to more accurately define the community's vulnerabilities and to inform mitigation actions.

The methodology for Ucluelet's tsunami hazard assessment consisted of five stages: (1) characterizing the community; (2) characterizing and simulating the hazard; (3) assessing community vulnerabilities; (4) loss modelling and evacuation as a mitigation measure; and (5) review and public communication. Each of the first four stages included a review component of stage (5). Review by the local government was limited to qualitative components of community characterization (stage 1) and assessment of community vulnerabilities (stage 3), which were also the basis for the tsunami plan that was drafted before the scientific assessment began. The feedback from the local government enhanced information gathered by scientists, such as building characteristics and population information. This information was entered into the scientists' Geographic Information System (GIS) to later inform quantitative human and infrastructure estimates of loss. Review of simulation modelling (stage 2) and loss modelling (stage 4) were highly technical and required input from external scientists.

Public communication (stage 5) was the last stage of the methodology and consisted of a public forum presentation and provision of a recommended an educational evacuation map strategy to local officials. Considering all communicated information, local officials produced the final evacuation map strategy for the public.

3.3.1 Communication of tsunami hazard assessment results in a public forum

A public forum was arranged and attended by approximately 80 people, many of whom were emergency personnel, for example fire department and ambulance workers. Some local officials responsible for mitigation and preparedness had seen the results of the assessment before the public forum due to the iterative methodology of the scientific tsunami hazard assessment. The public meeting was filmed by the Canadian Broadcasting Corporation (CBC) as part of a documentary about tsunamis in the Pacific Northwest (http://www.cbc.ca/documentaries/doczone/2009/shockwave/). At the forum, scientists summarized new quantitative information gained from stages 2 and 4 of the assessment and answered questions. These two stages were most relevant to providing new scientifically derived information for the development of an educational evacuation map strategy.

3.3.1.1 Communicating results of tsunami inundation

The inundation modelling from stage 2 assumed a worst-case magnitude-9.1 Cascadia earthquake based upon geological assumptions made in a Washington study by Walsh et al. (2000) and simulated the tsunami using the TsunamiCLAW software developed by George and Leveque (2006). The modelling indicated that Ucluelet residents and visitors would have approximately 20 minutes before the first tsunami wave arrived and 40 minutes before the maximum run-up (Johnstone and Lence, 2009).

Tsunami inundation results were communicated using two-dimensional animations produced by TsunamiCLAW, which uses MATLAB visualization libraries (George, 2006). Three inundation visualizations of the same event were produced at three scales, including one at community scale. The three visualizations employed a colour gradient to depict the height of the wave. Figure 2-1 shows a frame of the community-scale animation 40 minutes after the tsunami was triggered.

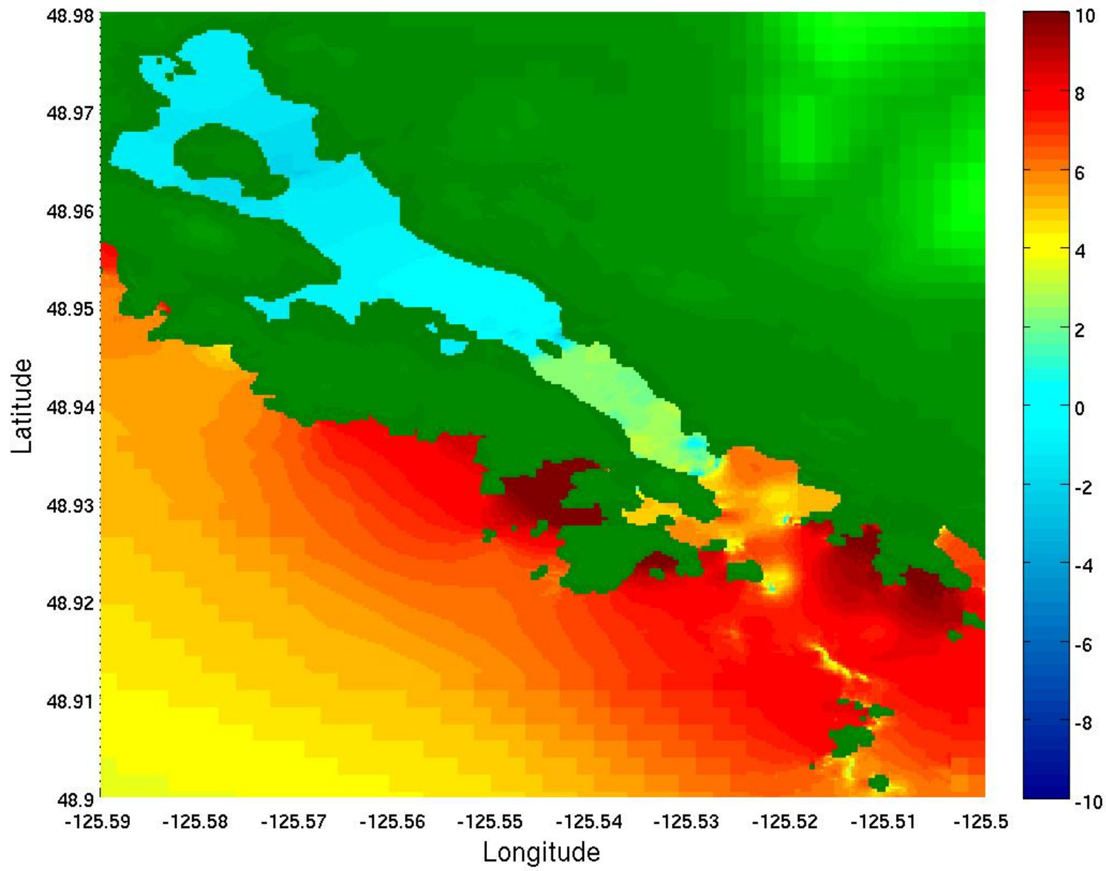

Figure 2-1 – A frame from TsunamiCLAW animation visualization showing the tsunami simulation 40 minutes after the tsunami is triggered. The tsunami wave height is shown in meters using hypsometric tint. Terrain is shown in green. The majority of Ucluelet's residents live along the inside of the peninsula, the centre of the frame. Wave height is shown in meters.

3.3.1.2 Communicating loss estimation and evacuation mitigation strategies

Loss estimation modelling used the inundation scenario from stage 2 to simulate different evacuation scenarios for stage 4. Different simulations in stage 4 were made by changing the time of day, season, mode of travel, the choice to evacuate or shelter in place, and the number of assembly areas. The simulations represented people evacuating and included many characteristics of behaviour such as time for mobilization. The quantitative comparison of alternative evacuation strategies was a principal contribution of the technical tsunami hazard assessment's methodology to the tsunami science literature (Johnstone and Lence, 2009). The simulations were made using the BC Hydro Life Safety Model (LSM) software package (Johnstone and Lence, 2009). In the best-case scenario, with multiple evacuation areas, 93% of people in the hazard area were able to survive the simulation by evacuating on foot.

Results of loss modelling and evacuation were communicated using several animated visualizations produced by LSM that represented people as moving points on roads, along with charts and graphs. Unlike inundation visualizations, the evacuation visualizations did not show exact spatial and temporal information; instead they visualized how quantitative results shown in charts and graphs were obtained. Figure 2-2 illustrates an example of a graph similar to some of those used in the public forum to communicate how many people reach safety under different choices about evacuation modes and assembly areas.

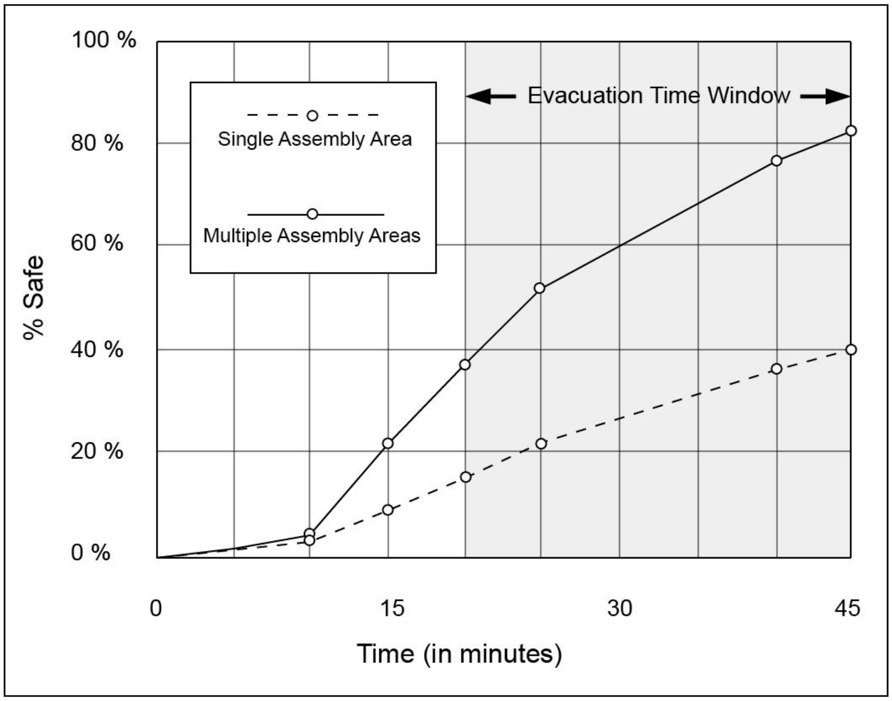

Figure 2-2 – Graph of a daytime evacuation simulation results for a summer population scenario, based on research by Johnstone and Lence (2009). The evacuation time window refers to the time period when the tsunami is inundating Ucluelet.

3.3.2 Use of results to develop an educational evacuation map strategy

Both evacuation map strategies recommended by scientists and local government involved cartographic design choices. These choices included symbolization, layout, legend, and text, all of which contribute to tsunami hazard representation. Cartographic abstraction principles reveal mapmakers' choices in selection, generalization, and symbolization of using available types of information that result in a representation (Robinson et al., 1995). Selection refers to the inclusion of information for the purpose of the map. Generalization refers the simplification of information to enhance communication. Symbolization refers to the use of cartographic design principles and graphic variables to visually communicate information. Characteristics of the map medium also affect representation (Slocum et al., 2003). In the case of tsunami brochure maps, all selected information is inherently generalized as a function of scale and the space considerations of paper map and brochure dimensions. Both the scientist-recommended and local government implemented brochure in Ucluelet used tsunami hazard information in a GIS to make decisions about cartographic abstraction.

3.3.2.1 Scientifically recommended educational evacuation map strategy

The first four stages of the scientific tsunami hazard assessment was in a GIS and provided information for potential selection. Following practices used in Washington and Oregon communities, the scientist-recommended evacuation map strategy for public education displayed all relevant information in a single map brochure. This one map solution also was part of the goals set out by the Ucluelet project.

Scientists working on the Ucluelet tsunami hazard assessment project used available information to design several possible versions of a tsunami evacuation map brochure. We participated in reviewing these maps. The map shown in Figure 2-3 was recommended by the team of scientists from both private and academic sectors who conducted the tsunami hazard assessment. This map was provided to local officials before the public forum and was not shown publicly. It did not include a design for educational text, which is on the back of brochures in Washington and Oregon, and therefore was not a complete product. The brochure also had a similar colour scheme to brochures of Washington and Oregon communities.

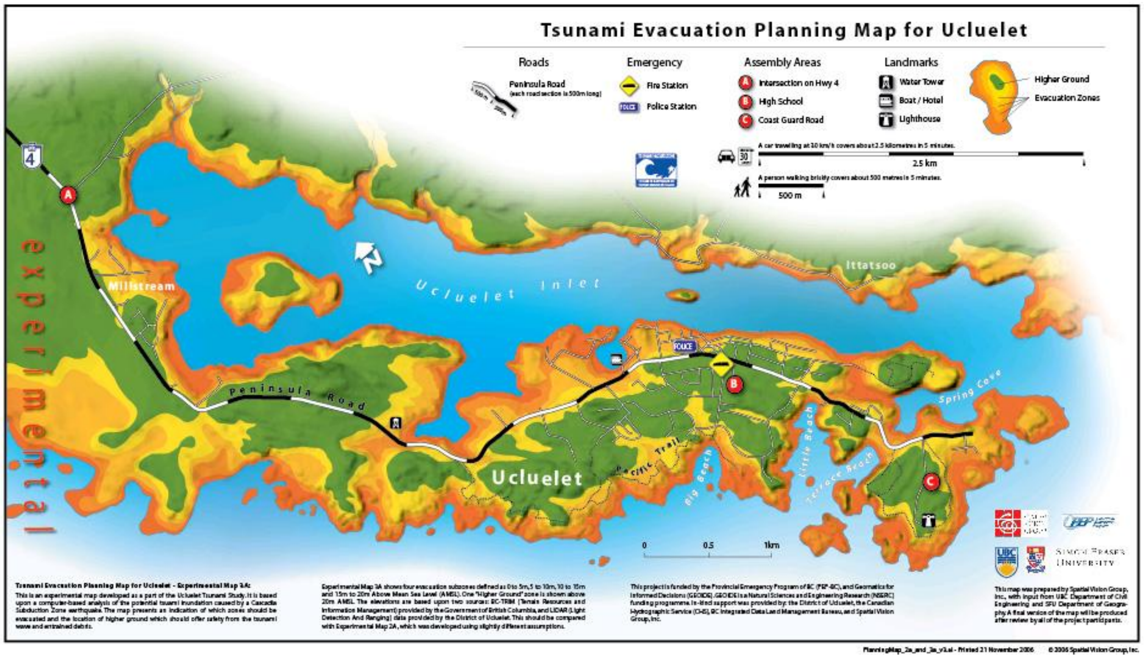

Figure 2-3 – Scientist-recommended tsunami map with three assembly areas. This map was produced by Jeff Clark at Spatial Vision Group, using information from the tsunami hazard assessment. The colour scheme is similar to evacuation map brochures in Washington and Oregon.

The scientist-recommended brochure selects several types of tsunami hazard information assembled in stage 1, 2, and 4 of the assessment. Roads, paths, infrastructure, and terrain were selected from stage 1. Several roads and paths use symbolizations to emphasize their relative importance. Only the most important emergency buildings and landmarks and are symbolized by icons. Terrain is generalized into three elevation ranges in the hazard area and is symbolized with an orange-yellow hypsometric colour ramp. Terrain is also symbolized using hillshading technique for the entire community. From stage 2, the modelled tsunami inundation area is selected and generalized by a boundary that uses a 15-meter contour. From stage 4, assembly area information is selected and generalized to two areas in the centre of Ucluelet (symbolized as "B “and “C”), and a third assembly area outside Ucluelet’s populated area on the peninsula (symbolized as “A”, on the left side of the map). The recommended two assembly areas in the Ucluelet peninsula were reduced from six used to obtain the best-case evacuation simulations from stage 4. This simplification was appropriate from a scientific view and less complex form a practical point of view.

Although this map brochure communicates the worst case near-source tsunami, it also visualizes information aimed for communicating a tele-tsunami event, because it has a legend that visualizes driving time – an action that would likely be impossible in the case of a near-source tsunami; in a CSZ event, the earthquake preceding a tsunami would largely destroy all infrastructure (British Columbia Provincial Emergency Program, 2001).

3.3.2.2 Implemented evacuation map

Following the completion of the scientist-recommended brochure and communication of results in the public forum, all components of the scientific tsunami hazard assessment were complete. The implementation of a final evacuation map strategy was the responsibility of the local government. Ucluelet waited to publish an evacuation map until its neighbouring community of Tofino completed its tsunami hazard assessment, so the two communities could jointly publish a brochure. The Tofino tsunami hazard assessment followed a similar scientific methodology as Ucluelet, except that no academic institutions were involved, and the methodology did not provide a recommended brochure design. The final implemented map is shown in Figure 2-4.

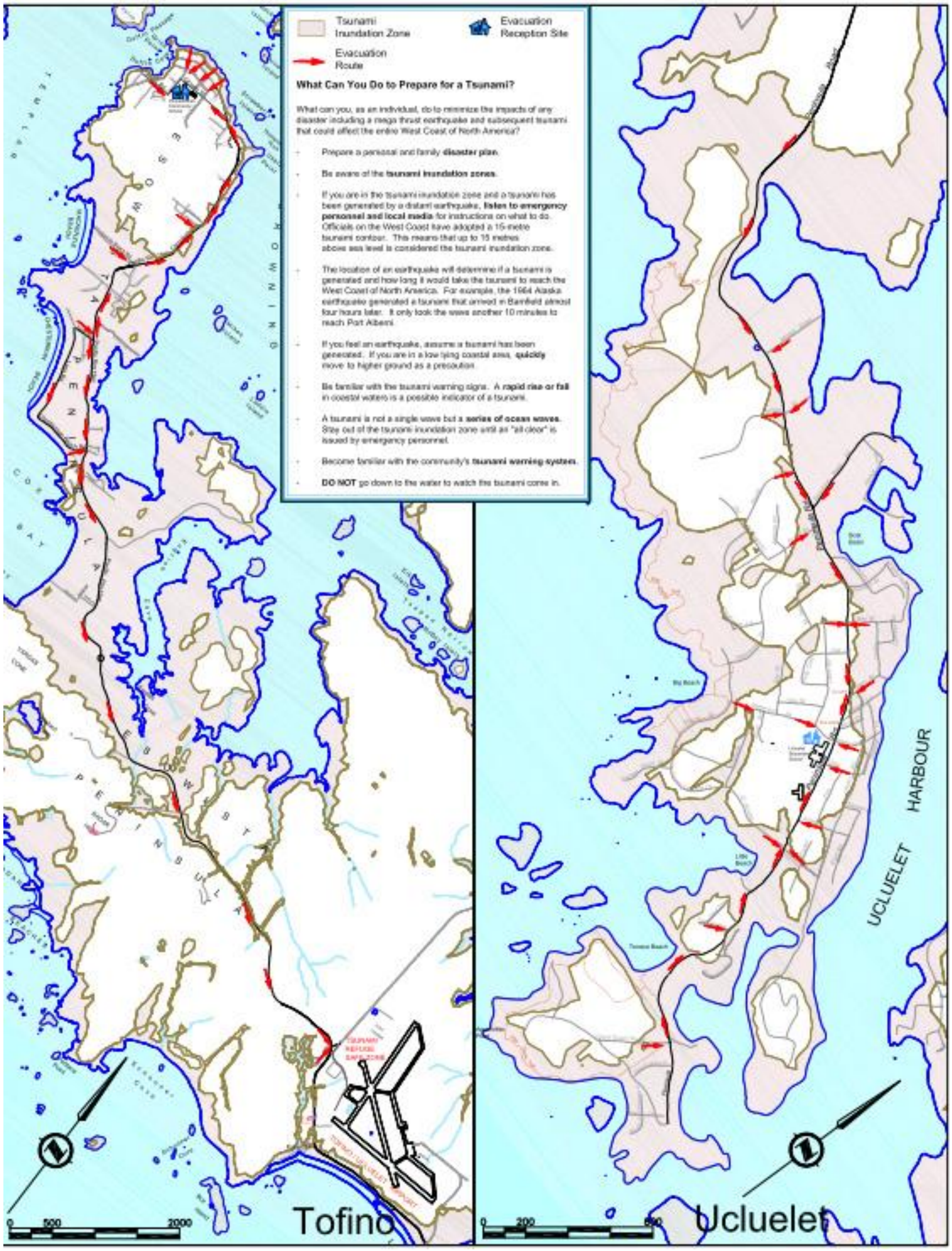

Figure 2-4 – Final published educational tsunami evacuation map for Ucluelet and Tofino. Ucluelet did not adopt all assembly areas recommended by scientists (see Figure 2-3).

The final brochure did not show the same geographical area as the scientist-recommended brochure (Figure 2-3). Three separate maps were produced: one of Ucluelet and Tofino, shown in Figure 2-4; one that focuses on the most populated part of Tofino; and one that covers the shoreline between the two communities, which is largely unpopulated. Figure 2-5 shows a part of the third map that includes most of the Ucluelet area that the scientist-recommend map covered. All three maps can be downloaded at http://www.gotofino.com /tofinoemergencyinfo.html.

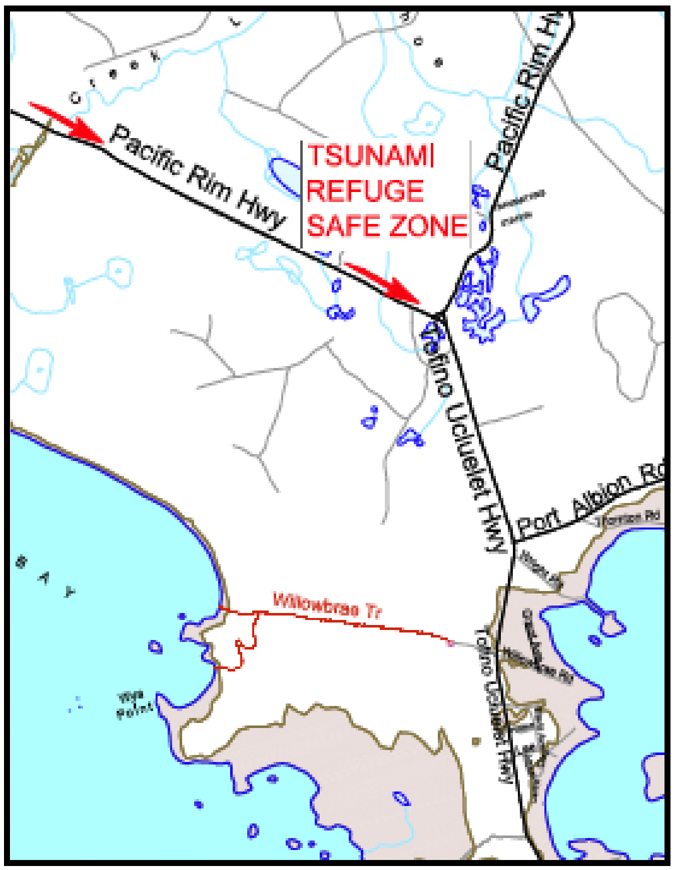

Figure 2-5 – Close-up of part of the published map that covers the area between Ucluelet and Tofino. The "tsunami refuge zone" corresponds to a nearby recommended location assembly area "A" in Figure 2-3.

The tsunami hazard representation of the Ucluelet portion of the final evacuation map brochure differs significantly from the scientist-recommended design in Figure 2-3, perhaps in part because local officials used their own GIS and cartographic software to produce the map. Terrain was not selected; roads were selected and are less generalization compared to those on the recommended map (all roads are labelled); infrastructure is generalized to two buildings at the central assembly area. As recommended, the tsunami hazard zone was selected and generalized by a 15-meter contour. The most interesting and relevant difference in the Ucluelet example is the change in the assembly areas from two locations in the centre of Ucluelet (locations B and C in Figure 2-3) to one location, which corresponds to B in Figure 2-3. Evacuation guidance was also symbolized with arrows all of which point toward the one assembly area, a decision that may have been influenced by the inclusion of arrows in some Washington and Oregon brochures.

The choice of one central assembly area and of evacuation guidance pointing to it emphasizes actions appropriate for a tele-tsunami scenario. Ucluelet's brochure communicates change the evacuation strategy of the lower probability Cascadia tsunami by stating, "If you feel an earthquake, assume a tsunami has been generated. If you are in a low lying coastal area, quickly move to higher ground as a precaution".

3.4 Discussion

Our description of the development of an educational evacuation map in Ucluelet provides an entry point to discuss issues common to all educational evacuation map strategies in the Pacific Northwest. All brochures in Washington and Oregon along with Ucluelet's involve the transformation of scientific information through conscious and/or inadvertent use of available information by mapmakers. This process implicitly involves cartographic abstraction.

The Ucluelet case study included a scientist-recommended brochure design that used the results of models to select an inundation area generalized by an elevation contour and qualitatively generalized assembly areas by the reduction of the number of assembly areas. Many decisions, such as inclusion of terrain information, were not based on scientific evidence that shows the information to be most effective for education. Much potentially relevant information presented at the public forum was not included. The map implemented by local officials also involved similar, but unique types of cartographic abstractions.

In the Ucluelet case study, a novel scientific methodology that quantitatively compared evacuation scenarios to arrive at recommended assembly area locations, played no role in the final educational evacuation map design; instead, local officials used the assembly area that was defined in their original draft evacuation plan. The scientific methodology only played a role in defining the inundation area (stage 2), which the local government draft plan assumed on the basis of previous studies in US communities.

The case study suggests that Ucluelet's local officials favoured their qualitative knowledge of the social and physical geography of Ucluelet over scientific evidence, prioritized simplicity as an overall hazard communication strategy, and visually emphasized actions appropriate for a tele-tsunami. This last choice may have been influenced by the fact that since the Indian Ocean tsunami of 2004, Ucluelet has experienced two tsunami alerts without a subsequent tsunami. Furthermore, unlike some other Pacific Northwest communities, Ucluelet has no tsunami sirens. Therefore, a brochure that visually emphasizes actions for a tele-tsunami is perhaps more appropriate. Choosing to include the second assembly area in the centre of the town, as the recommended brochure proposed, would create an undesirable logistical challenge in future tele-tsunami scenarios. The chosen assembly area is the community's high school, where the other recommended assembly area is a remote road, with the nearest public building a small lighthouse that is close to the hazard zone. It is interesting to consider that the local officials' decision not to use the scientist-recommended assembly areas may have in fact been the better solution.

3.4.1 Educational evacuation map practices and tsunami resilience

According to the NTHMP's five points that define the characteristics of a resilient community (see Introduction), Ucluelet's scientifically informed tsunami assessment information helped local officials to "have the tools they need to mitigate the tsunami risk". Ucluelet's adoption of the brochure evacuation map tool reflected the "exchange [of ways to communicate] information [to the public] with other [tsunami vulnerable communities in Washington and Oregon]". However it is difficult to make the case that the brochure "[disseminates] information about the tsunami hazard", while maximizing the public's ability to “understand the nature of the hazard”. The brochure provides some essential information, but does it provide enough?

The public may have many questions that are not answered by Ucluelet’s evacuation map brochure, the scientifically recommended brochure, or any other community brochures in Washington and Oregon. Some examples of these questions are: how quickly must a person move to avoid the tsunami? Are there certain areas that require running versus walking? Is there time to help others along the way to reaching safe haven? If a person is in a low-lying area is too far from a safe area, are certain areas within the hazard zone safer than others? Will the tsunami arrive at significantly different times in different parts of the hazard zone? Some of the answers are possible to deduce, but with what accuracy? Providing clear answers may increase the resilience of a community, but require moving beyond the current ‘one map’ solution and providing supplementary maps.

Government strategies and regional contexts have defined the current one map paradigm in Pacific Northwest communities. The adoption of a one map brochure solution across the Pacific Northwest represents a degree of tsunami resilience, but is often a result of neighbouring communities adopting similar methods. This strategy seems to reinforce single visual depictions of the hazard. It does not maximize the public’s ability to learn about the “nature of the hazard”.

3.4.2 The need to research supplementary maps

Widely disseminating a single tsunami evacuation map may be an appropriate approach for tsunami education, but having not other community-developed maps is not supported by research, which suggests that at least some public would like additional tsunami hazard information.

Educational tsunami evacuation maps have not been investigated in detail, but studies suggest that evacuation maps, along with other tools, may not be fully effective. Studies in Washington (Johnson et al., 2002) and Oregon (Karel, 1998) used survey methodologies to gain insight into how tsunami education tools affected public tsunami education. Both found that existing tools led to limited perceptions about tsunami hazards. The Washington study was followed by citizen interviews to learn more about why tools did not have desired effects (Johnston et al., 2005). Some respondents stated that information disseminated about tsunami hazards was too general and in a too difficult format to understand. One of the conclusions of the research was that information should be better tailored to different individual needs.

Recent research in Indonesia measured the benefits of showing evacuation scenarios similar to those presented in the public forum in Ucluelet, to volunteers, teachers and the public. Goto et al. (2010) surveyed 40 participants and found that they all considered the additional information to be extremely useful. Dall'Osso and Dominey-Howes (2010) developed a draft tsunami evacuation map for a community in Australia where no map yet existed. They showed 500 residents a tsunami evacuation map that included information about specific buildings that could provide necessary safe havens in the hazard zone, as well as the depth of inundation. Interviews showed that while participants had some criticisms and questions about the map, they all thought the map was useful and thought the local government should produce such a map.

Supplementary tools should be made available to citizens who seek the information and should target certain members of the community. Webb concludes that Drabek's research on tsunami risk communication to tourists shows that tourists expect their guides to have risk information (as cited in Webb, 2005). The implication is that there is a need to aim additional educational material, not at tourists but rather personnel who could act as leaders in the event of a tsunami. This principle can be extended to supplementary maps that educate teachers, storeowners, and citizens who would be natural leaders of groups in the event of a tsunami.

3.4.3 Current focus in community-developed tsunami evacuation maps

Local government officials in the Pacific Northwest oversee community-specific tsunami education, but are not currently producing any types of supplementary tsunami evacuation maps. Efforts instead are focused on standardizing existing brochures. This standardization effort is being led by the State of Oregon, which has worked with the local officials in Cannon Beach to develop a new design as part of an inundation mapping modernization initiative (Western Seismic Policy Council, 2008). Brochure standardization will no doubt improve consistency of information between communities, but the proposed standard still imposes an arbitrary limit to tsunami hazard representation and is not based on empirical testing. Figure 2-6 shows a proposed brochure design standard design for Oregon.

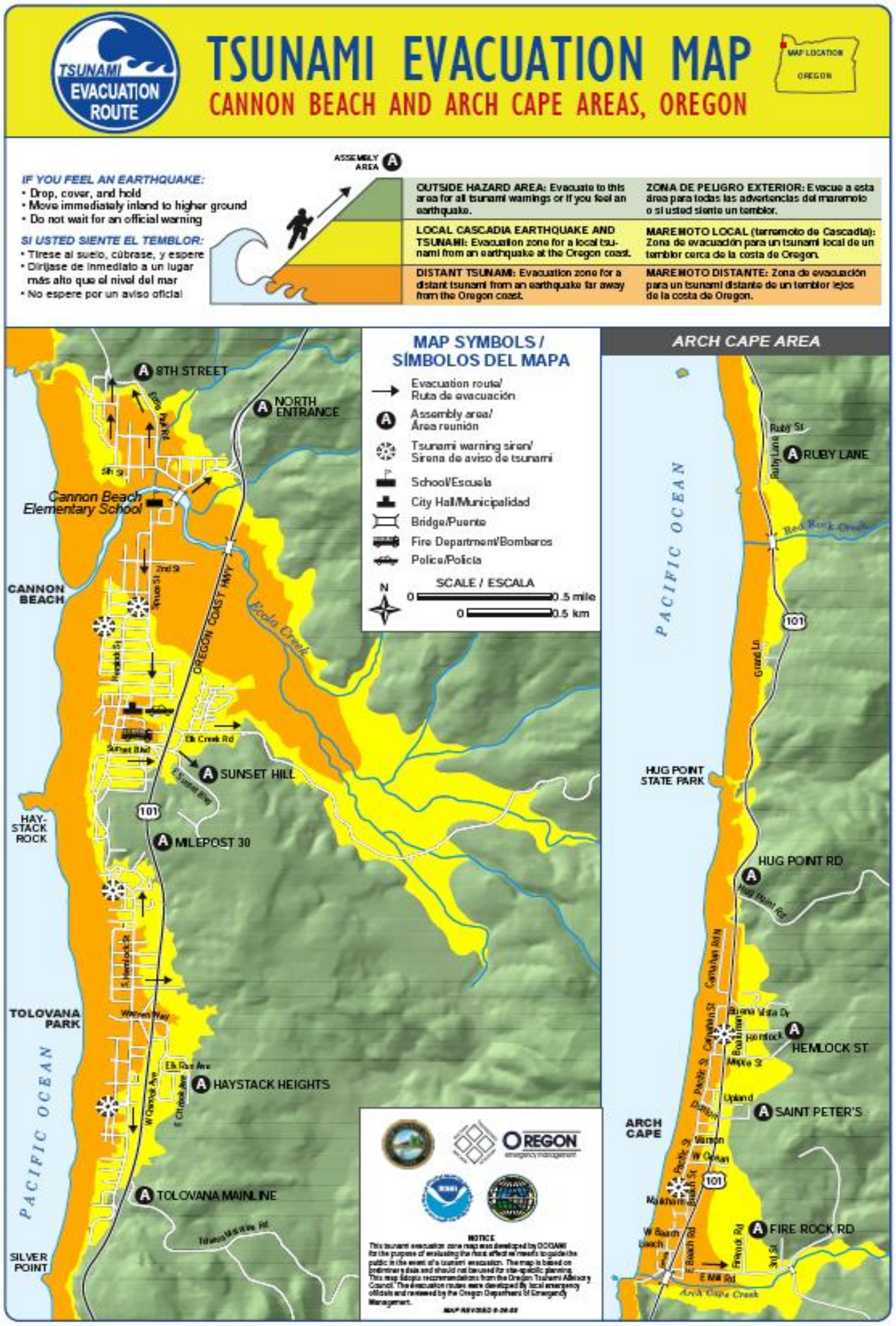

Figure 2-6 – The front of the proposed brochure standard in Oregon. This development that took place in Cannon Beach occurred after Ucluelet's implementation of an educational evacuation map brochure.

The Cannon Beach brochure includes a worst-case tele-tsunami hazard area, making use of the more detailed tsunami modelling that is part of Oregon's inundation mapping effort. But from an educational point of view, is the inclusion of the tele-tsunami inundation area the most important type of new information to include in a standardized map design? Does this design complicate the message by including too much information in a widely disseminated tool? Is this standard the most important element on which to invest the most time and resources? What about all the other tsunami hazard information that remains unrepresented because only one map is produced?

3.4.4 Opportunities in the use of tsunami hazard information with evacuation maps

In BC, Washington, and Oregon, insufficient attention is devoted to enhancing tsunami hazard representation of educational evacuation maps. The problem is exacerbated by the lack of research on the design of even existing evacuation maps. It is therefore necessary to clarify how supplementary cartographic tsunami education tools might utilize available, but unrepresented information.

We refer to Ucluelet's available tsunami hazard information, provided during each stage of the tsunami hazard assessment, to identify what information may be particularly useful and what types of cartographic abstractions may make the information more user-friendly. Our goal is to illustrate what kinds of information a supplementary map product may communicate for a Cascadia tsunami scenario. The ideas are also applicable to communicating a tele-tsunami scenario, as well as alternative local and tele-tsunami scenarios that were not modelled in the case study. We limit suggested cartographic representation to static methods, which do not rely on animations, in an effort to identify design elements that could be part of supplementary tools independent of any particular medium.

3.4.4.1 Using inundation results from stage 2

Inundation results from stage 2 of the tsunami hazard assessment were only utilized in the final evacuation map brochure in confirming a generalized worst-case inundation boundary. The animations of the inundation shown in the public forum hold valuable temporal information, as well as information about the height of the wave. Although the wave height information may be useful, its temporal movement is more fundamental and arguably more important for understanding the nature of the hazard. If citizens have no access to temporal information, they must infer it from non-local visualizations, tsunami video footage, or simply use their imagination, all of which could lead to misconceptions.

Figure 2-7 is a draft of a static visualization that communicates when the tsunami will reach the hazard area in Ucluelet. There is at least a 25-minute difference between when tsunami first reaches the outer coast and Ucluelet Harbour. The visualization was created by post-processing 173 frames of the animation shown at the public forum (one of these frames is shown in Figure 2-1). The visualization also shows the predicted affected area rather than the generalized 15-meter contour in the brochure.

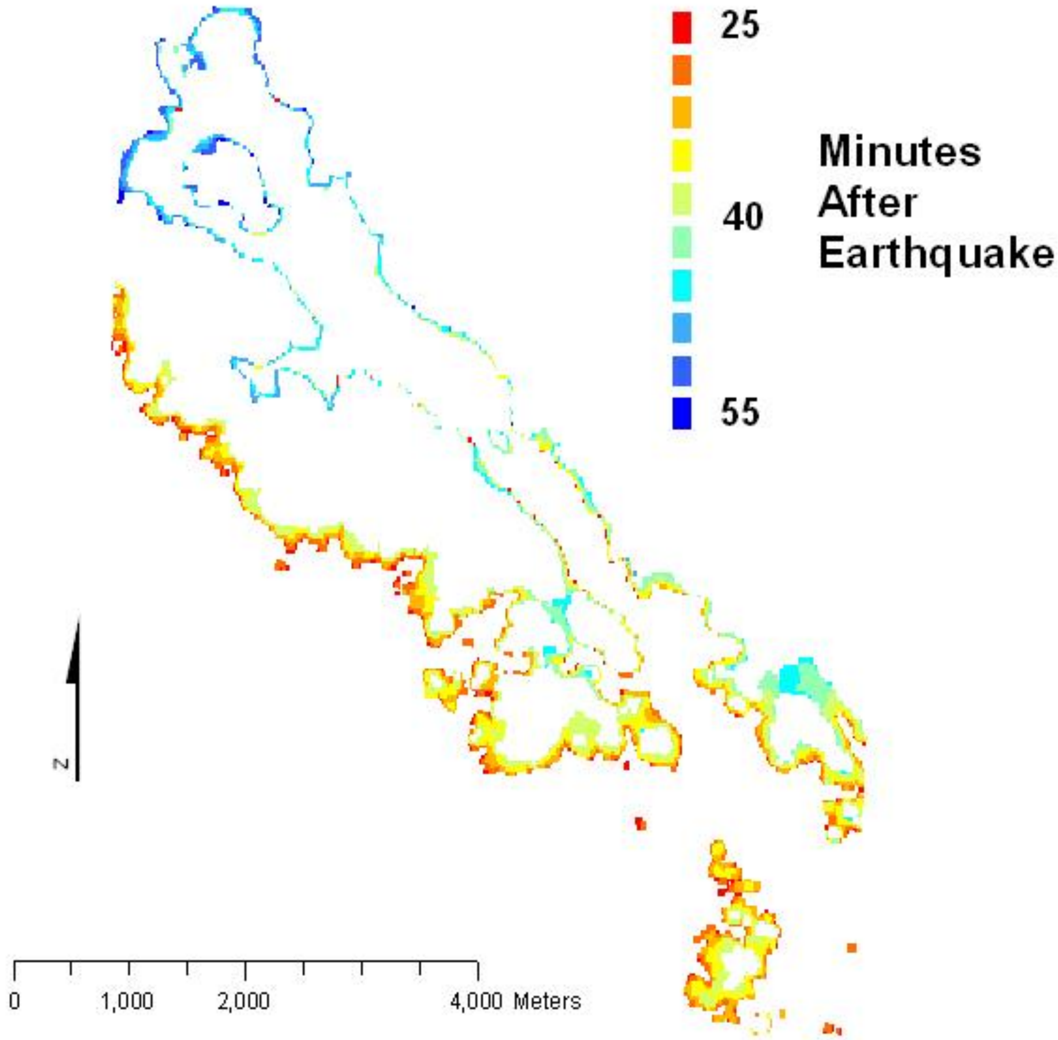

Figure 2-7 – Visualization showing different arrival times of arrival of a near-field tsunami communicated in an animation in the public forum in Ucluelet. The visualization was made by post-processing results derived from the TsunamiCLAW animation using ArcGIS, Excel, and Python.

A potential issue with temporal tsunami information is that while it looks certain, it is based on modelling that has an associated level of uncertainty. Local governments could choose to address this issue by classifying the information into groups with specified ranges. The use of fewer groups leads to more generalized statements about arrival time, whereas increasing the number of groups provides more detailed temporal information. Figure 2-7 is an example showing ten groups symbolized by a colour gradient.

More detail does not necessarily improve the representation. A balance must be struck between the value of the additional information for public education and the considerable uncertainties inherent in tsunami modelling. Alternate scenarios could also be visualized to emphasize the uncertain nature of the modelling.

3.4.4.2 Including safe-haven results from stage 4 and decreased terrain generalization from stage 1

Evacuation modelling in stage 4 of the tsunami hazard assessment identified optimal assembly areas in Ucluelet in a Cascadia tsunami. The safe havens in the final brochure are not as simple as the text implies. One particular safe haven was not used in simulations because, although is it an island of safety, it in fact has relatively low elevation, and does not have adequate sheltering space for evacuees. Without explicit explanations, citizens are left to themselves to assess the situation either before or during the event and are unlikely to come to the same conclusions as the scientists.

Figure 2-8 shows these distinctions between assembly areas used in simulations and further visualizes detailed terrain elevation using a colour gradient in the safe areas. By visualizing more detail about terrain, this figure clarifies the issue of why one of the islands of safety was not scientifically recommended: the island of safety above the most southern assembly area has no assembly area because of its relatively low factor of safety in elevation. The complex nature of the assembly areas in Ucluelet is a function of its geography. In many communities evacuation directions and assembly areas are the same irrespective of the type or severity of tsunami, making additional assembly area information unimportant.

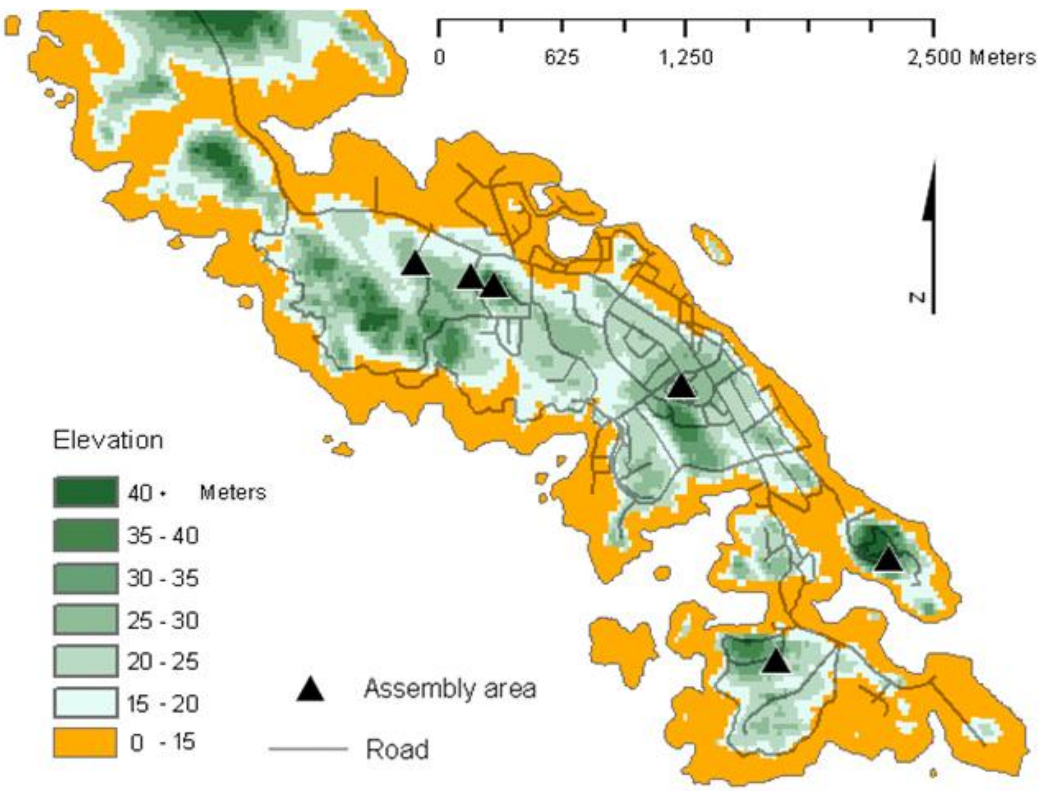

Figure 2-8 – Locations of safe havens used in evacuation simulations. The detailed elevation in safe areas can help explain why one of the islands of refuge is not recommended as an official assembly area. Including information about terrain in the hazard area may be useful in other communities where high ground is distant and the public must make choices between evacuating to high points of marginally safe areas.

Figure 2-8 does not include elevation for the hazard areas (as the scientist-recommended map did in Figure 2-3). Such information may not be of much use in Ucluelet, which is fortunate to have higher-ground near most hazard areas. In many other communities, however, the public may have to choose between safe haven options, none of which is optimal, but some may be safer than others based on elevation. For such communities, a supplementary map may also include buildings suitable for vertical evacuation. In Ucluelet, however, there are no high buildings that are closer or safer than high evacuation points.

3.4.4.3 Visualizing evacuation results from stage 4

Evacuation information from stage 4 of the tsunami hazard assessment was only shown during the public forum using animated outputs from the LSM software package (moving points along roads). The final brochure symbolizes evacuation guidance with arrows, but the arrows are not completely clear for all locations and only apply for a tele-tsunami scenario. If more than one assembly area were chosen in Ucluelet's peninsula, the directions would become questionable. Additionally, appropriate evacuation actions not only require knowledge of direction but also temporal information. Although users can derive both guidance and temporal information by dividing a distance by an assumed travel speed, or on experience, a more direct visualization reduces chances of error and in addition, emphasizes the importance of the information.

Figure 2-9 provides an example, assuming an average walking speed of 5 km/hour to the nearest high ground via a road. Unlike the previous temporal inundation visualization in Figure 2-7, this visualization adds no new information; rather it makes information visible that would otherwise have to be derived. While it is temporal information, it can also provide precise guidance information about direction. As with temporal inundation, this visualization can also use classifications to make more general statements about time. Other cartographic options exist to express this temporal variable, such as line width.

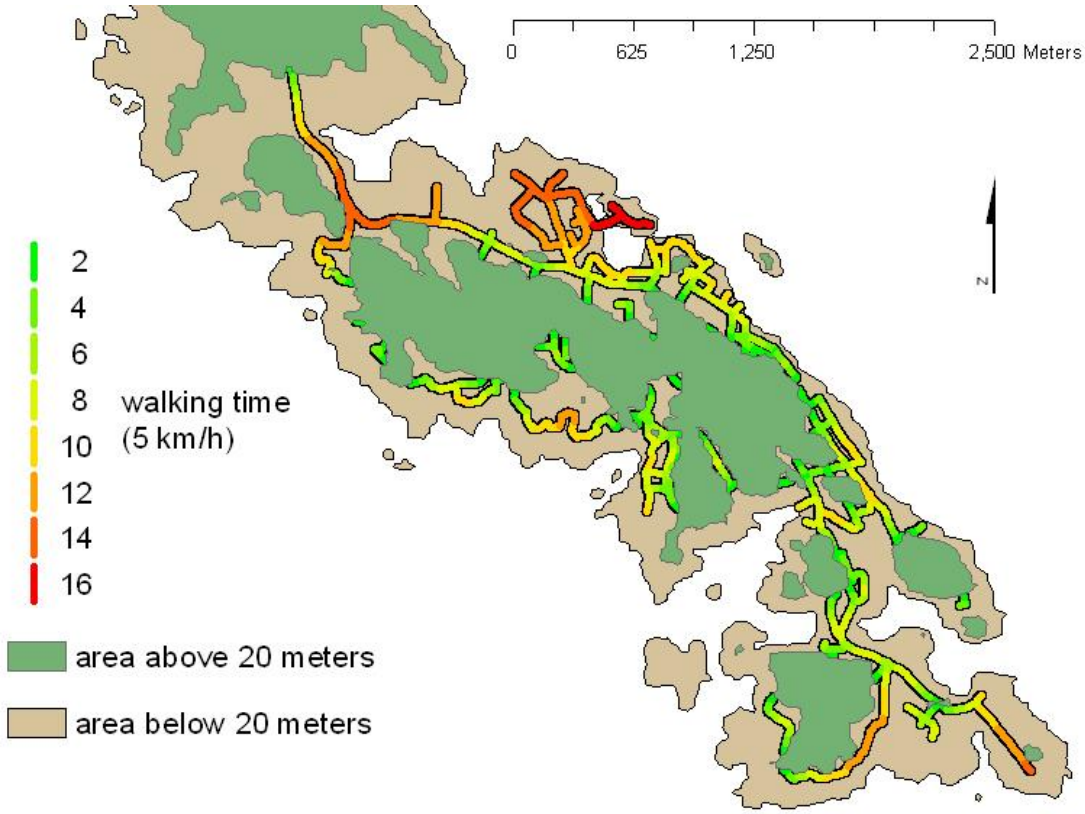

Figure 2-9 – Visualization showing walking times in minutes along roads to the nearest high ground, defined by the 20-m contour. Areas above 20 m elevation are green. ArcGIS network analyst extension was used to create the visualization.

Similar temporal evacuation visualizations can be used to compare travel speeds and destinations. In Ucluelet, it is possible to escape by walking to the nearest high ground, but other communities are not as fortunate. In other communities, temporal evacuation visualization may play a larger role in emphasizing that in some areas, citizens must run to make it to safety, or perhaps show temporal evacuation to non-optimal areas of safety.

3.4.5 Designing and disseminating supplementary map tools

Communicating all potentially relevant types of information requires more than a single extra map. Supplementary maps could potentially be combined with increasing levels of sophistication. Although interactive solutions might be most suitable to communicate many types of information, static maps are also an option. As we have shown, much relevant information can be communicated using static maps; perhaps supplementary brochures could be produced. Although more expensive than online maps, static brochure maps may be more appropriate for remote communities such as Ucluelet where many citizens may not have access to computers compared to more urban areas. Furthermore, because community geographies are unique, standardized tsunami hazard representation may be inappropriate for supplementary evacuation map tools.

The visualizations that we have shown are not difficult to implement. The temporal visualization in Figure 2-7 required use of ArcGIS, Excel, and Python scripting for temporal inundation visualization, and that in Figure 2-9 was made with ArcGIS Network Analyst, but the same results could be produced by hand in both cases. The scientific methodologies that create the base information could produce these visualizations, but unless local governments embrace the value of such information for educational purposes, it would be a waste of effort to produce them.

Much of the tsunami hazard information we have discussed is independent of scientific tsunami hazard information. If local officials use an elevation contour to define a hazard area, many other types of relevant information can be presented, such as information about terrain, roads, and assembly areas, all of which can be derived from local governments' GIS. There is also a wealth of qualitative geographical information known by the public that could contribute to more advanced evacuation map tools.

3.5 Conclusion

This paper has presented a case study tsunami hazard assessment in the context of its effect on an educational evacuation map. It has shown that both scientific and community knowledge played only partial roles in the educational evacuation map strategy. The totality of scientific tsunami hazard assessment information was only shown in the public forum and not in particularly user-friendly way. It was then simplified into a scientist-recommended brochure, and finally, further simplified by local officials.

We argue that the resulting lack of publicly available information on tsunami hazards can mostly be attributed to the long-standing practice of communities in the Pacific Northwest producing just one map. The NTHMP guidelines that define a resilient community do not support or defend the lack of supplementary maps; rather they require local communities to innovate. Empirical evidence suggests that supplementary evacuation maps can improve tsunami education. Supplementary educational evacuation maps therefore should receive more attention, not just from governments, but also from researchers. Scientists have not yet attempted to compare the efficacy of existing map brochures, let alone compare the educational effects of providing more advanced evacuation maps. Generally, there seems to be no emphasis on methods that evaluate tsunami education efficacy in terms of geographical preparedness.

This paper attempts to provide an entry point for much-needed progress and discussion of issues in educational evacuation map design. In this regard, the local government in Ucluelet, BC Provincial Emergency Program, and the tsunami scientists who conducted the hazard assessment, should be commended for supporting a place for our critical cartography perspective. The result of this cooperation is that we were able to identify relevant issues and opportunities of evacuation map design for tsunami education in a specific context. As we have previously emphasized, the issues raised in this case study apply to the entire Pacific Northwest, and even more generally to the United States and countries where communities constrain how tsunami hazard information is presented in educational evacuation maps.

Many communities in the Pacific Northwest have scientific, and community-based information about tsunami hazards that is un-utilized for education. As tsunami science becomes more sophisticated, further experimenting must be undertaken in how it is represented to the public. Innovations in tsunami education require simultaneous support from tsunami scientists, governments, and local communities. If one community successfully implements one of more supplementary tsunami evacuation map tools, other communities might adopt this strategy. Such a course of action would represent the true essence and power of tsunami-resilient communities.

3.6 References

Anderson P., and Gow G.A. (2004). *Tsunamis and coastal communities in British Columbia: an assessment of the B.C. tsunami warning system and related risk reduction practices*. Retrieved from Government of Canada Publications website: http://publications.gc.ca/site/eng/267201/ publication.html

Bernard E. (2005). The U.S. National Tsunami Hazard Mitigation Program – a successful State–Federal partnership. *Natural Hazards, 35*, 5–24.

British Columbia Provincial Emergency Program (2001). *British Columbia tsunami warning and alerting plan*. Retrieved from Ministry of Public Safety and Solicitor General website: http://209.87.31.75/hazard_plans/ tsunami2001/Tsunami_Warning_and_Alerting_Plan-2001.pdf

CBC. *Shock wave: surviving North America's biggest disaster* (2008). Vancouver, BC: Canadian Broadcasting Corporation and Omni Film Productions Ltd.

Clague J. J., Bobrowsky P. T., and Hutchinson I. (2000). A review of geological records of large tsunamis at Vancouver Island, British Columbia, and implications for hazard. *Quaternary Science Reviews, 19*, 849–863.

Clague J.J., Munro A., and Murty T. (2003). Tsunami hazard and risk in Canada. *Natural Hazards, 28*, 435–463.

Dall'Osso, F.,and Dominey-Howes, D. (2010). Public assessment of the usefulness of "draft" tsunami evacuation maps from Sydney, Australia – implications for the establishment of formal evacuation plans. *Natural Hazards and Earth System Sciences, 10*, 1739–1750 doi:10.5194/nhess-10-1739-2010.

Dengler L. (2005). The role of education in the National Tsunami Hazard Mitigation Program. *Natural Hazards, 35*, 141–153.

George D.L., and LeVeque R.J. (2006). Finite volume methods and adaptive refinement for global tsunami propagation and inundation. *Science of Tsunami Hazards, 24*(5), 319–328.

George D.L. (2006). *Introduction TsunamiClaw user's guide*. Available at http://www.amath.washington.edu/~rjl/pubs/icm06/TsunamiClawDoc.pdf

Gonzalez F.I., Titov V.V., Mofjeld H.O., Venturato A.J., and Newman J.C. (2001).The NTHMP inundation mapping program. In *Proceedings of the International Tsunami Symposium 2001*. National Tsunami Hazard Mapping Program Review Session, R-2, Seattle, WA, 7–10 August 2001, 29–54.

Gonzalez F.I., Titov V.V., Mofjeld H.O., Venturato A.J., Simmons R.S., Hansen R., Combellick R., Eisner R.K., Hoirup D.F., Yanagi B.S., Yong S., Darienzo M., Priest G.R., Crawford G.L., and Walsh T.J. (2005). Progress in NTHMP hazard assessment. *Natural Hazards, 35*, 89–110.

Goto Y., Ogawa Y., and Komura T. (2010). Tsunami disaster reduction education using town watching and moving tsunami evacuation animation – trial in Banda Aceh. *Journal of Earthquake and Tsunami, 4*(2), 115-126.

Jonientz-Trisler C., Simmons R.S., Yanag B.S., Crawford G.L., Darienzo M., Eisner R.K., Petty E., and Priest G.R. (2005). Planning for tsunami-resilient communities. *Natural Hazards, 35*, 121–139.

Johnson D., Paton D., Houghton B., Becker J., and Crumbie G. (2002).*Results of the August-September 2001 Washington State tsunami survey*. New Zealand Institute of Geological and Nuclear Sciences, Science Report 2002/17, Lower Hutt, New Zealand.

Johnson D., Paton D., Crawford G., Ronan K., Houghton B., and Buergelt P. (2005). Measuring tsunami preparedness in coastal Washington, United States. *Natural Hazards, 35*, 173–184.

Johnstone W.M., and Lence B.J. (2009). Assessing the value of mitigation strategies in reducing the impacts of rapid-onset, catastrophic floods. *Journal of Flood Risk Management, 2*, 209–221.

Karel A. (1998). Oregonians need more information about tsunamis to save lives. *Oregon Geology, 60*(3), 56.

Kryzanowski K. (2006).Tsunami Integrated Preparedness (TIP) Project. *19th Annual Emergency Preparedness Conference*, Pacific Northwest Preparedness Society, Vancouver, BC.

Kurowski M.J., Hedley N., and Clague J.J. (in press). An Assessment of Educational Evacuation Map Designs in Washington and Oregon. *Natural Hazards.*

Oregon Department of Geology and Mineral Industries (2008). Tsunami evacuation brochure for Cannon Beach/Arch Cape, Oregon, 2 pp.

Robinson A.H., Morrison J.L., Muehrcke P.C., Kimerling A.J., and Guptill S.C. (1995). *Elements of cartography* (6th edition). New York: Wiley.

Slocum T.A., McMaster R.B., Kessler F.C., and Howard, H.H. (2003). *Thematic Cartography and Visualization*. Upper Saddle River, New Jersey: Prentice Hall.

Walsh T.J., Caruthers C.G., Heinitz A.C. III., Myers E.P., Baptista A.M., Erdakos G.B., Kamphaus R.A. (2000).*Tsunami hazard map of the Southern Washington coast: modeled tsunami inundation from a Cascadia subduction zone earthquake*. Washington Department of Natural Resources, Seattle, WA.

Webb T. (2005). Review of New Zealand's preparedness for tsunami hazard, comparison to risk and recommendations for treatment. Client Report 2005/162, Institute of Geological and Nuclear Sciences Limited, 119 pp.

Western States Seismic Policy Council (2008). *2008 Annual Report.* Retrieved from the Western States Seismic Policy Council website: http://www.wsspc.org/resources/Annual%20Reports/08_AR_FINAL.pdf

Chapter 4: Conclusions

4.1 Summary

The goal of this thesis was to examine the social influences in current educational tsunami evacuation maps in BC, Washington, and Oregon. The thesis has successfully accomplished this goal through its two research components.

Chapter 2 addressed the lack of a prevailing structure in current evacuation map practices. Cartographic abstraction principles were applied to compare and contrast the information content of 38 evacuation map brochures in Washington and Oregon. Six types of tsunami hazard information were identified and compared: (1) tsunami hazard zone, (2) road network, (3) assembly areas, (4) evacuation guidance, (5) infrastructure and, (6) terrain. Cartographic abstraction principles were further used to situate the design of a new Google Maps evacuation map developed by Oregon. Satellite information was identified as an additional information type within the Google Maps tool. The cartographic abstraction of the Google Maps tool was compared to the brochures.

The research component assessed the limitations of current and developing evacuation map strategies in Washington and Oregon. The assessment provided a framework to discuss how socially based cartographic decisions affect evacuation map designs. It argued that, while evacuation map developments focusing on standardization and new interactive solutions may be helpful, they avoid focus on socially guided information content design. Current efforts are therefore not explicitly investigating the increase of public access to community-scale tsunami hazard information. Previous studies in Washington and Oregon suggest the need to provide the public more detailed information. Through the process of the evacuation map assessment, many opportunities for increasing information in future evacuation map developments were identified.

Chapter 3 focused on the evacuation map development process. It used the case study of Ucluelet to describe how tsunami assessment information was incorporated into an educational evacuation map strategy. This process involved scientists presenting tsunami hazard assessment results in a public forum, recommending an evacuation map design to the local officials, and, finally, local officials using this information to implement an alternative evacuation map design. Cartographic abstraction principles were applied to describe the tsunami hazard information of scientist-recommend and local government implemented evacuation map designs in relation to available tsunami hazard assessment information.

The research provided insight into the how social factors affect evacuation map design during development. It argued that the concept of resilience, which encourages communities to borrow existing types of tools from neighbours, depends on innovation at the community level. In the case of evacuation maps, communities must think beyond the current ‘one map’ brochure solution. Growing evidence in tsunami education studies and, more recently, tsunami evacuation map studies supports the approach of developing more than one evacuation map. To illustrate potential uses of more advanced evacuation maps, this research identified the potential educational benefits of information that remain unused in Ucluelet and communities of Washington and Oregon.

4.2 Research contributions

This thesis is a first assessment of how social decisions influence the design of educational tsunami evacuation maps. Further, the thesis provides a first study of how social decisions of community mapmakers influence the use of available tsunami hazard information in an evacuation map production process. These research contributions were accomplished by using cartographic abstraction principles (long-established concepts within cartographic literature) and demonstrating how they are embedded within tsunami evacuation maps in current use.

Both the assessment and case study components of the thesis introduce cartographic abstraction principles as both a conceptual framework and basis for tsunami hazard communication design. Cartographic abstraction principles are implicit within mapping practices. A better understanding of their role, and how they might be leveraged opens up new territory for discussion of how social decisions of communities' mapmakers mediate the use of tsunami science to produce evacuation maps. The resulting framework is specific to tsunami evacuation map design and may be useful to both governments and researchers because these two groups must work together to advance research about tsunami evacuation maps.

This thesis argues that recognizing the social nature of evacuation maps is an important part of addressing socially determined issues in tsunami mitigation. Progress in tsunami evacuation mapping that aims at tsunami resilience must bring together the combined resources of science, governments, communities and citizens. In practice, the most influential stakeholders are the local government officials who oversee tsunami evacuation map development. Local governments need to better understand information design issues that are specific to evacuation maps if they are also to develop other novel ways of delivering tsunami hazard information in educational tsunami evacuation maps.

Improving any type of hazard maps requires challenging the status quo and choices of organizations that produce them (such as governments and mapping agencies); hazard maps are rhetorical and can serve the producers' ulterior agendas (Monmonier, 1997). By critiquing current practices in educational tsunami evacuation map design, this thesis has emphasized that issues do not stem from a lack of scientific information. There needs to be a desire to better understand the use of this information by a range of stakeholders (citizens, planners, and others), matched by sustained effort to pursue these challenges.

This thesis began with a BC government response to the Indian Ocean tsunami of December 26, 2004. It now ends with another devastating tsunami in Japan on March 11, 2011. The findings and recommendations of this research aim to enable a deeper understanding of the nature of tsunami maps, and inspire innovation in their future design in Canada, the US, and other tsunami-vulnerable regions.

4.3 Future directions

This thesis provides theoretical foundations for applied research on the socially situated and cartographically transformed information design of tsunami evacuation maps. Many important questions exist about how current and alternative choices in educational tsunami evacuation maps designs specifically contribute to tsunami education.

Interviewing citizens about evacuation maps would be useful in establishing citizens' perceptions of existing evacuation map designs, current developments, and the future role of maps in tsunami education. It is likely that many citizens do not understand current evacuation maps, (and possibly any type of maps). It is also likely that a significant number of citizens would find more advanced, supplementary evacuation maps useful. Acquiring detailed information about citizen perceptions and 'usability' data for tsunami maps would help inform refinement of existing maps, and the development of supplementary maps.

Adding interaction to natural hazards mapping may afford users the ability to interactively explore the effects of specific circumstances (Monmonier, 1997), but to date, interactive tsunami evacuation maps in the Pacific Northwest have only been applied through a Google Maps application. This use of Google technology relies on modifying a tool normally designed for different purposes –

an approach that does not specifically tailor cartographic representation or interaction to the unique needs of tsunami education. Extending on the cartographic concepts operationalized in this thesis, future research will be required to evaluate the influence of the many possible combinations of tsunami representation, visual communication and interaction with tsunami hazard information.

Moving beyond the existing single-map paradigm with supplementary maps will likely reveal new challenges and questions. Once a supplementary map is ready for deployment, are there any issues with making it too accessible to anyone? Is it more effective to advertise it as available to those citizens who are interested, or should certain target citizens that have specified roles in communities be recruited? If there are multiple maps produced, will citizens need to see all of them? If so, how can we ensure this happens in communities?

Supplementary evacuation maps not only benefit from unused scientific tsunami hazard information, but also from existing geographical knowledge of citizens in tsunami-prone communities. Research on creating evacuation maps based on public knowledge could borrow methodologies from participatory methods of socio-behavioural decision-making with maps and Geographic Information Systems (for example Miles, 2011; Nyerges et al., 2002). It is possible that the act of making an evacuation map that involves citizens will be of greater value than the resulting map product. This might be the case if, for example, the resulting map product does not provide much new useful information, but the process of creating the map establishes greater trust between citizens and their local government.

Utilizing scientific and public geographical knowledge about tsunami hazards also requires researching tools that can communicate the breadth of available knowledge through information structures that do not depend so much on citizens’ abilities to understand the cartographic abstractions. New efforts are currently underway at the Spatial Interface Research Lab at Simon Fraser University to create mobile augmented reality interfaces. These interfaces may improve tsunami evacuation education with the ability to directly overlay tsunami hazard information, evacuation information and risk maps onto views of the real world using everyday mobile devices (such as smartphones and tablets). By enabling citizens to draw upon these types of maps *in situ*, it may be possible to facilitate an unprecedented new level of connection between spatial analysis and real geographic environments, and in doing so, reduce the cognitive demands on citizens to transpose tsunami information from 2D paper maps into everyday first-person situational awareness. Less technologically dependent approaches might involve directly marking information onto the community (such as ‘hazard contours’ or colour-coded evacuation routes). Any strategies that rely on less abstraction could be especially relevant for citizens who would like more information, but are not capable map-readers.

All future developments in tsunami evacuation mapping require the support of local governments and the implementation of collaborative research initiatives. The role of tsunami education researchers will be to propose and structure these developments, and evaluate new tools and strategies. This must be done in a context that is defined by the characteristics of tsunami hazards, the needs and venues of citizens using tsunami hazard information, and through partnerships between stakeholders.

4.4 References

Miles, S.B. (2011) Participatory model assessment of earthquake-induced landslide hazard models. *Natural Hazards, 56*, 749–766.

Monmonier, M. (1997) *Cartographies of Danger: Mapping Hazard in America*. Chicago: University of Chicago Press.

Nyerges, T., Jankowski, P., and Drew, C. (2002). Data-gathering strategies for social-behavioural research about participatory geographic information system use. *International Journal of Geographical Information Science*, *16*, 1–22.