LIVING IN LAHAR ZONES: ASSESSING HAZARD EXPOSURE, RISK PERCEPTION, AND PREPAREDNESS BEHAVIORS IN COMMUNITIES WITHIN THE MOUNT BAKER AND GLACIER PEAK VOLCANIC HAZARD ZONES

by

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DEDICATION

I would like to dedicate this thesis to a woman whose hard work, dedication, perseverance, and independence I have always admired and aspired to imitate. Always telling me that I can do whatever my heart desires, encouraging my interests, and supporting my geology adventures from Cape Cod to New Zealand to Chile and Boise. For being my best role model and a source of unending encouragement, this thesis is dedicated to my mother Karen Anne Brown.

I would also like to dedicate this thesis to two incredible female scientists: Dr. Brittany Brand (my thesis advisor) and Dr. Britt Argow (my undergraduate advisor). You have both been great inspirations to me as scientists and women in science.

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ABSTRACT

As the number of people living at risk from volcanic hazards in the U.S. Pacific Northwest grows, more detailed studies of community hazard exposure, risk perception, and preparedness levels become critical to developing effective mitigation, response, and recovery plans. This thesis uses risk mapping and a knowledge, risk perception, and preparedness survey to examine the risk that lahars from Mount Baker and Glacier Peak volcanoes pose to nearby communities in the Skagit Valley (WA). The risk map component of this research identifies spatial variations in lahar risk and estimates potential losses associated with a maximum envisioned lahar. The survey component seeks to (1) explore the existence of a disconnect between accurate risk perception and adequate preparedness; (2) isolate the factors that facilitate or present barriers to the adoption of preparedness behaviors; and (3) determine how professional participation in hazard risk management influences knowledge, risk perception, and preparedness in the Skagit Valley. Elements of the Protective Motivation Theory (PMT) and Values-Beliefs-Norms (VBN) theory are used to frame the survey results.

The risk maps generated in this study show that towns with populations smaller than 1,000 people (e.g., Concrete, Lyman) will likely be disproportionately affected by lahars, supporting the findings of Diefenbach *et al*. (2015). Lahar zones intersect large portions of these smaller towns, including critical roads that link them to nearby towns and emergency services. Such a loss of infrastructure would greatly reduce response capacity. Burlington represents one of the most at-risk towns in the Skagit Valley since a

relatively large population (8,466) lives in this city that is almost entirely in the lahar zone. In a total loss scenario, the maximum envisioned lahar would place nearly 40,000 lives at risk along with extensive tracts of residential and agricultural land. Overall monetary damages could amount to over $5 billion (total assessed value) and nearly $62 million in tax revenue. Additional geologic modeling of lahar paths would greatly improve the ability to produce more complex loss scenarios.

Results from over 500 survey responses indicate that a disconnect exists between perception and preparedness among respondents. The 82 percent of respondents who accurately anticipate that future volcanic hazards will impact the Skagit Valley fail to prepare more than those unaware of the hazard. When asked what prevents them from preparing, respondents deny that perceived response-efficacy and perceived protective response pose substantial barriers. Perceived self-efficacy and ascription of responsibility beliefs appear to play a more dominant role in determining preparedness behaviors, albeit a less readily recognized role. Ascription of responsibility beliefs (VBN) seems to explain an element of preparedness motivation not fully incorporated within PMT. Finally, results show that professional participation in response-related activities minimally influences household preparedness, but successfully improves perceived self-efficacy, confidence in officials, and information seeking behavior. Thus, participation's affect on household preparedness may be tied to specific types of participation (e.g., public, professional, specific training programs), whereas self-efficacy and confidence in officials, being independent of participation type, may improve due to increased interaction with emergency officials.

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LIST OF ABBREVIATIONS

FEMA	Federal Emergency Management Agency
PADM	Protective Action Decision Model
PMT	Protection Motivation Theory
POLR	Proportional odds cumulative logit regression
SARF	Social Amplification of Risk Framework
USGS	United States Geological Survey
VBN	Values-Beliefs-Norms Theory

CHAPTER ONE: INTRODUCTION

The following master's thesis presents interdisciplinary research combining elements of geology, geography, sociology, public administration, and community and regional planning to better understand the spatial and human dimensions of volcanic hazards in the United States Pacific Northwest. In particular, this thesis focuses on understanding these two dimensions as associated with lahars—volcanic mudflows that move under the force of gravity, flow like wet concrete, entrain large debris, and pose a greater threat to life and property than all other volcanic hazards. As the number of people living at risk from lahars grows, so does the need for interdisciplinary hazard research. Studies seeking to more accurately define lahar risk must consider both the nature of the hazard itself and the nature of those living in at-risk communities. Understanding the physical extent of hazard exposure as well as how risky people consider the hazard to be, how they may respond during a hazardous event, and whether or not they adopt prior preparedness actions helps emergency managers develop more effective mitigation, response, and recovery plans.

This thesis focuses on the potential physical and social implications of future lahars from Mount Baker or Glacier Peak reaching communities in the Skagit Valley of northwestern Washington State (Figure 1.1). This location was selected because both Mount Baker and Glacier Peak have erupted during the Holocene and produced lahars capable of traveling over 100 km downstream to populated areas. Seven towns (Mount Vernon, pop. 32,356; Sedro-Woolley, pop. 10,645; Burlington, pop. 8,466; La Conner, pop. 783; Concrete, pop. 751; Hamilton, pop. 252; Lyman, pop. 549; U.S. Census, 2015) and extensive agricultural lands lie either partially or fully within the lahar zones. Additionally, major transportation routes, such as Interstate 5 (north-south) and the North Cascades Highway (east-west), intersect the lahar zones.

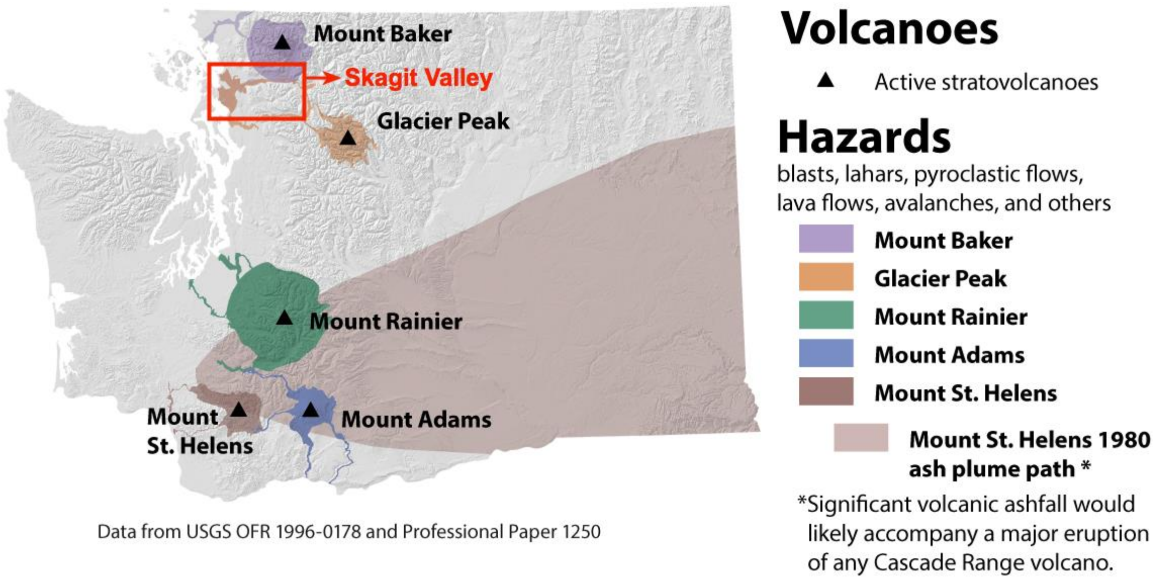

Figure 1.1: Map of Washington State showing the Skagit Valley (red box), active volcanoes, and volcanic hazard zones (Washington Department of Natural Resources, 2016; adapted from data from Schilling, 1996).

Lahars warrant study in this region because they are low probability-high impact events and unique in terms of emergency management. Unlike floods and earthquakes, which pose regular hazards to the Skagit Valley, lahars occur infrequently. Consequently, most people have never directly experienced a lahar, which influences their perception of the risk that lahars represent. Instead, people must rely on indirect experiences to learn about lahars and shape their perceptions. These experiences often include educational programs and media coverage of lahars elsewhere around the world (see Factors Controlling Risk Perception - Past Experience section Chapter 2).

Additionally, the uncertainty of warnings, rapid travel speeds, and devastating impacts associated with lahars distinguish lahars from more frequent hazards. Few lahar drainages in the world and none leading into the Skagit Valley contain sirens or warning devices that detect lahar movement. As such, lahars not associated with volcanic activity may occur with little or no warning. Precursory events marking the onset of volcanic activity offer some warning that a lahar is possible. However, even with warning, the speed and rapid arrival times associated with lahars necessitate fast reaction times and prior preparedness among at-risk populations. Both floods and lahars require evacuation, but the timescale over which that evacuation must take place is greatly shortened for a lahar. Finally, lahars are high-impact events that devastate the built environment. Unlike floods, lahars do not recede after inundating an area. Rather, they bury communities and cut off access to homes and supplies. Thus, while the supplies and plans required for different hazards may be similar, lahars require these provision be prepared prior to an event to prove effective.

The unique nature of lahar hazards and the presence of at-risk communities in the Skagit Valley motivates this research into the physical and human components of volcanic risk. The physical component of this thesis examines the spatial extent to which Mount Baker and Glacier Peak pose a threat to nearby communities. Areas at risk are those where lahar hazards intersect vulnerable systems such as towns, schools, hospitals, transportation networks, recreation sites, agricultural lands, and emergency service facilities (after Carlino *et al.*, 2008). This definition allows for the design of volcanic risk maps that assess which vulnerable systems may experience damage from lahars and how these systems are distributed. Knowledge of the spatial distribution of impacts and estimates of loss in terms of life, property, and monetary resources helps emergency managers better target and frame planning efforts.

The second component of this thesis focuses on the human dimension of risk. Effective planning for lahars, as with planning for all hazards, cannot take place without accounting for how the public perceives of the risk and how they may behave before and during an event. For example, an attempt to change zoning laws based on lahar hazard zone maps may fail if people are either not concerned about lahars or believe their effects insurmountable. Similarly, the best evacuation routes are only as effective as a resident's willingness to leave their home. This component of my thesis primarily seeks to (1) explore the existence of a disconnect between accurate risk perception and adequate preparedness; (2) isolate the factors that motivate or prevent the adoption of preparedness behaviors; and (3) determine how professional participation in hazard risk management influences knowledge, risk perception, and preparedness at home.

To address these two components' objectives, a combination of geographic information systems (GIS) and survey methods are used. Hazard and risk maps are generated in ArcGIS using volcanic hazard zone data from the United States Geological Survey (USGS; Schilling, 1996) and population, infrastructure, and vulnerable system data from local, state, and federal agencies. Quantitative survey methods are employed to investigate variations in the hazard knowledge, risk perception, and household preparedness levels. An online questionnaire garnered over 500 responses that are analyzed using multiple statistical methods. Methodologies are described in greater detail in the methods sections of Chapters Three and Four.

This thesis is organized into five chapters and four appendices. Chapter One provides an introduction to the work as a whole, outlining the motivation, research questions, and methods that guide this thesis. Chapter Two presents a review of the relevant literature for this thesis, incorporating necessary background information on lahars, hazard and risk mapping, risk perception, and preparedness behavior motivation. Chapter Three focuses on the lahar hazard and risk mapping components of the thesis, detailing the methods used and results generated. The final hazard and risk maps are presented here. Chapter Four is dedicated to the risk perception and preparedness behavior motivation component of the thesis. This chapter provides the methods, results, and discussion sections written in the format of a journal article with multiple authors. Portions of Chapter Four will be submitted for publication in a scientific, peer-reviewed journal. Chapter Five provides a short conclusion combining insights from this thesis's two components. Appendix A contains a full copy of the questions and figures presented in the online questionnaire, and Appendix B presents the corresponding response frequency data. Appendix C contains a copy of the postcard distributed throughout the Skagit Valley as an advertisement for the survey. Appendix D presents additional correlation analyses omitted from the results section of Chapter Four.

CHAPTER TWO: LITERATURE REVIEW

The following is a review of literature relevant to this thesis. As the research presented is interdisciplinary, comprising (1) a hazard and risk mapping component and (2) a risk perception and preparedness motivation component, the literature review builds a background in both elements and links them through the concept of risk.

Risk

Risk is defined herein as the intersection of a natural hazard with vulnerable systems such as towns, schools, hospitals, transportation networks, and emergency service facilities (after Carlino *et al.*, 2008). Within this definition, researchers can conceptualize risk in two ways: technical and perceived. Technical risk refers strictly to the extent of hazard exposure and probability of the hazard occurring (Slovic, 1987). Perceived risk refers to how individuals intuitively judge hazards and their potential impacts (Slovic *et al.*, 1982; Slovic, 1987). Risk perception accounts for more than the probability of a hazard occurring; it incorporates the psychological, social, and cultural lenses through which people view the world (Schmidt, 2004). This thesis treats risk as a combination of both the physical hazard and human perceptions and behaviors, which allows for a more holistic investigation of risk. Given this duel focus, the following literature review focuses first on describing the hazard—lahars—and then on laying the foundation for investigating risk perception and preparedness motivation as it relates to natural hazards.

The Physical Dimension: Lahar Hazards and Mapping

An Introduction to Lahars

The Indonesian word lahar refers to debris flows, transitional flows, and hyperconcentrated flows triggered on a volcano (Vallance, 2000; Volcano Hazards Program, 2016). Lahars are also commonly referred to as volcanic mudflows (Waitt *et al.*, 1995). These different terms all refer to mixtures of water and debris that flow downslope under the influence of gravity. Therefore, for a lahar to form, the following must be available: water, unconsolidated sediment, steep slopes, and a triggering event (Vallance, 2000).

Primary lahars are those triggered during volcanic eruptions while secondary lahars are those unassociated with an eruption or triggered post-eruption (Rodolfo, 2000; Vallance, 2000). Lahars typically result from either sudden water release or edifice collapse, both of which have a variety of triggers. Sudden water release occurs when water from ice, lakes, and precipitation suddenly become available to mix with debris. For example, hot erupted material can melt glaciers and mix with resulting water to form a lahar. Alternatively, after an eruption, loose pyroclastic deposits are easily remobilized by intense rainfall and lake breakouts to form lahars. Edifice collapses are triggered largely by magma intrusions at a shallow depth, magmatic and phreatic eruptions, and earthquakes of both volcanic and non-volcanic origins. These collapses take the form of debris flows rather than debris avalanches due to the high pore water content and easy disintegration of hydrothermally altered minerals that cause the flow to liquefy (Vallance, 2000).

Lahars wax and wane as they flow downstream, changing in terms of size, density, composition, and dynamics (Vallance, 2000; Volcano Hazards Program, 2016). After their initiation, lahars bulk up by eroding and incorporating surrounding material (Rodolfo, 2000; Vallance, 2000); hyperconcentrated flows can transition to debris flows during this early stage (Vallance, 2000). Dense, cohesive, concentrated lahars with a high carrying capacity entrain large boulders and debris. Behaving as a non-Newtonian fluid, these boulders often float at the top and are pushed to the front and sides of the flow rather than settling to the base (Pierson & Scott, 1985; Vallance, 2000). More dilute, non-cohesive lahars allow large debris to settle out while smaller, more buoyant particles remain entrained (Pierson & Scott, 1985; Vallance, 2000). Typically traveling down valleys with active rivers, lahars incorporate water at the flow front. Eventually, this water dilutes the lahar, causing a loss of energy and carrying capacity that leads to increased deposition (Vallance, 2000). Finally, the flow comes to rest after depositing much of the sediment load. Lahars are capable of traveling at speeds ranging from a few meters per second to several tens of meters per second. In extremely steep regions, speeds may reach over 200 km/hr and decrease later upon reaching flatter areas (Volcano Hazards Program, 2016).

Lahars pose a significant hazard to communities located in drainages downstream from volcanoes. With the exception of ash fall, lahars represent one of the most far-reaching volcanic hazards. Lahars are also typically the most frequent volcanic hazard in the glaciated Cascades (Gardner *et al.*, 1995; Waitt *et al.*, 1995; Diefenbach *et al*,. 2015). While more frequent small lahars may only travel a few kilometers, the runout distances of the more rare and largest lahars can exceed 100 km (Vallance, 2000). Additionally, both cohesive and non-cohesive lahars can cause extensive damage to the built environment. The former carry large debris that destroys buildings and other structures upon impact (Rodolfo, 2000). Figure 2.1 shows the destruction caused by cohesive debris flows in the town of Armero following the 1985 Nevado del Ruiz eruption. Non-cohesive flows, in contrast, can flood into and bury buildings as was evident for years following the 1991 Mount Pinatubo eruption (Figure 2.2). Both types injure and bury people in their path.

Figure 2.1: Cohesive lahars destroy buildings in Armero, Columbia following the 1985 Nevado del Ruiz eruption that resulted in the death of around 23,000 people (Volcano Hazards Program, 1998).

Figure 2.2: Non-cohesive lahars bury buildings in the Philippines following the 1991 Mount Pinatubo eruption (Mouginis-Mark, n.d.).

History of Volcanic Activity at Mount Baker and Glacier Peak

Mount Baker and Glacier Peak are andesitic and dacitic stratovolcanoes, respectively, of the Garibaldi Volcanic Belt in northwestern Washington State (Hildreth, 2007). Mount Baker is the second most glaciated volcano in the Cascades after Mount Rainier (Gardner *et al.*, 1995), and Glacier Peak is the second most explosive after Mount St. Helens (Waitt *et al.*, 1995). Extensive glaciation and available pyroclastic material leaves each prone to lahars. Geologic assessments indicate eruptive activity and lahar generation at both volcanoes during the past 14,000 years (Hyde & Crandell, 1978; Beget, 1982, 1983; Gardner *et al.*, 1995; Waitt *et al.*, 1995; Diefenbach *et al.*, 2015). Extensive erosion in the northern Cascade region during the Fraser Glaciation removed deposits from older eruptive episodes, thus restricting estimates of future behavior. Recurrence intervals are based on the assumption that the past 14,000 years are representative of activity levels at both volcanoes.

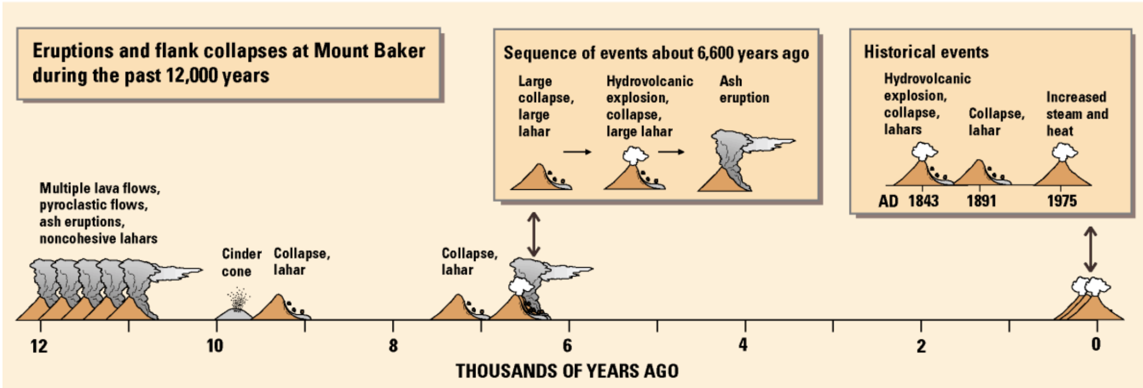

Figure 2.3: Timeline of eruptive episodes at Mount Baker over the past 12,000 years (Scott *et al*., 2000). Each episode represents a series of closely spaced individual eruptions. Seven lahar episodes are indicated including a large lahar around 6,600 years ago believed to have reached Puget Sound.

During the Holocene, Mount Baker experienced four eruptive ash-producing episodes and at least seven periods of lahar deposition (Figure 2.3; Kovanen *et al.*, 2001). Some of those seven lahar episodes represent single lahars while others represent sequences of over a dozen (Hyde & Crandell, 1978; Kovanen *et al.*, 2001). Most lahars from Mount Baker were small (volume < 0.01 km^3) and traveled no more than a few kilometers. Some moderate-sized lahars (volume 0.01-0.1 km^3) traveled 10 to 14 kilometers and at least one large lahar (volume > 0.1 km^3) traveled even further. This large lahar occurred around 6600 years ago, traveled at least 35 km down the Middle Fork of the Nooksack river, and likely reached Puget Sound (Hyde & Crandell, 1978; Gardner *et al.*, 1995; Kovanen *et al.*, 2001). The presence of an 8 m thick terrace elevated 100 m above the 15 m thick deposit near the valley floor indicates that at some point during the lahar's movement it reached a local thickness of 100 m (Kovanen *et al.*, 2001). Kovanen *et al.* (2001) also document an additional large lahar that traveled around 25 km down the Middle Fork of the Nooksack river. They date this lahar to 3120 ± 50 ^{14}C year BP and note the thickness and extent of the lahar remain unknown due to a lack of exposed deposits.

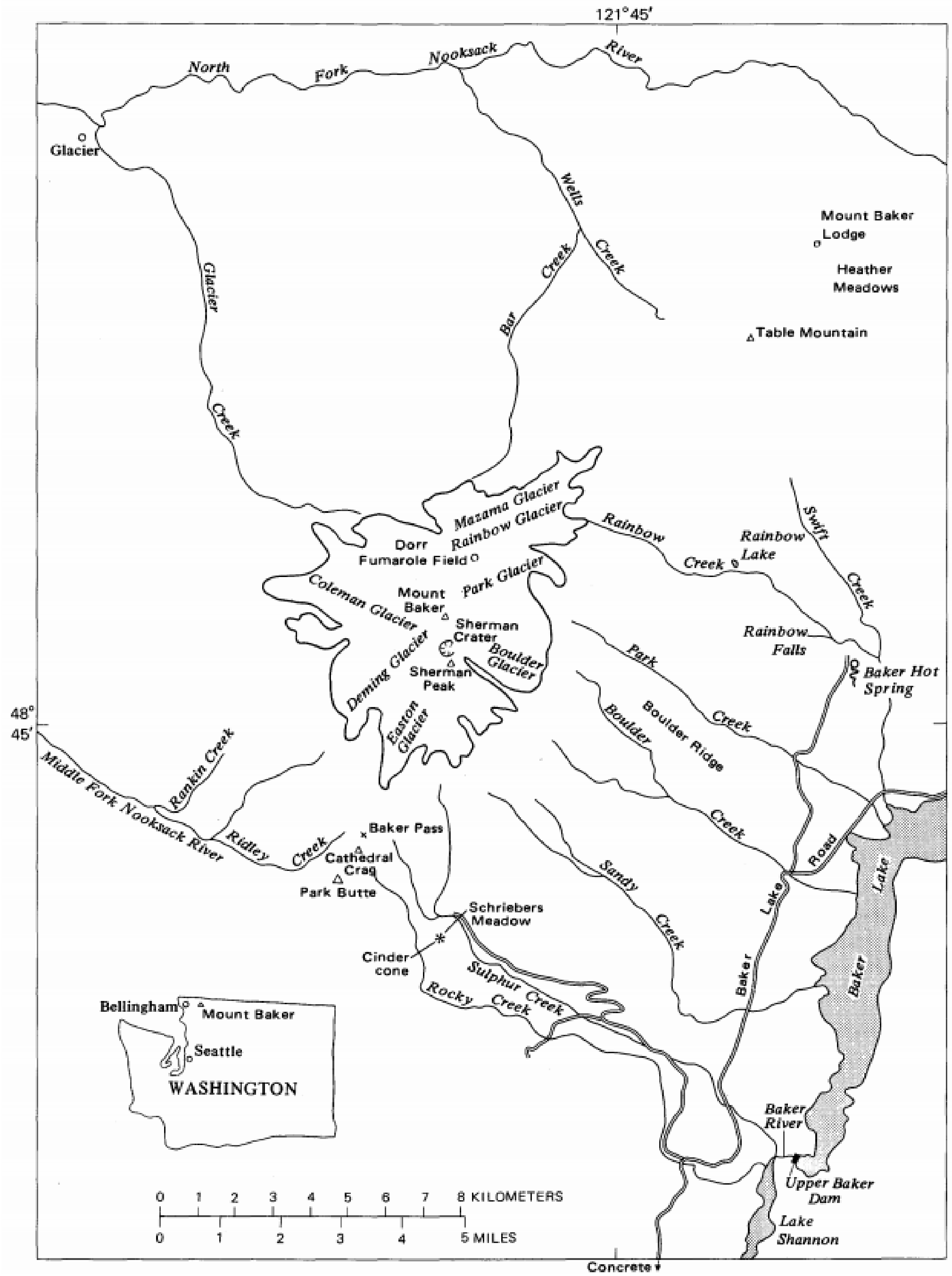

Figure 2.4: Map of drainages emanating from Mount Baker's summit (Hyde & Crandell, 1978). On the southeastern flank, multiple drainage systems flow into Baker Lake and Lake Shannon. Deposits reveal lahars previously descended Sulphur, Boulder, Park, and Rainbow creeks. Future lahars, debris avalanches, or pyroclastic flows that extend into these lakes pose a threat to the stability of Upper and Lower Baker Dam.

While no large lahar deposits from Mount Baker have been identified along the Skagit Valley, multiple drainages head on the volcano's southeastern flank, which feeds into the lower Baker River and, subsequently, the Skagit River (Figure 2.4). Lahar deposits are documented in each of these drainages with small and moderate-sized lahars occurring multiple times over the last few centuries. Additionally, deposits indicate that lahars from Boulder and Park Creeks previously inundated the Baker River valley. The exact extent of lahar impacts on the Baker River Valley remains difficult to constrain as deposits are now submerged beneath artificial reservoirs. Today, the lower Baker River valley is occupied by Baker Lake and Lake Shannon: reservoirs created by Upper Baker Dam (est. 1959) and Lower Baker Dam (est. 1925), respectively.

Depending on the volume of a lahar and how it was triggered, the reservoirs and dams could either increase or decrease the hazard. For lahars associated with volcanic activity, precursory events provide early warning, which gives officials the opportunity to lower reservoir water levels. If lowered sufficiently, the reservoir could act as a trap for incoming debris, preventing a lahar from flowing further downstream into the Skagit Valley. However, non-volcanic lahars can occur without warning, limiting the ability to lower reservoir levels sufficiently. The impact of a lahar on a reservoir whose water level remains high could cause a tsunami (Walder *et al.*, 2003) and raise the lake level high enough to overtop or cause failure of the dam (Gardner *et al.*, 1995), sending a torrent of water and debris down the Skagit Valley.

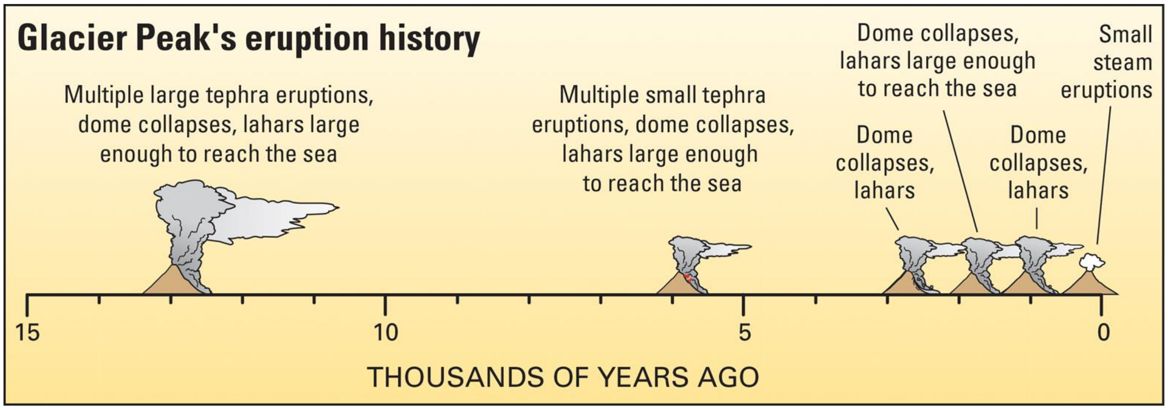

Figure 2.5: Timeline of eruptive episodes at Glacier Peak over the past 15,000 years (Mastin & Waitt, 2000). Some eruptive episodes represents a series of closely spaced individual eruptions. Large lahars believed to have reached Puget Sound occurred around 13,000 and 6,000 years ago.

At least six tephra-producing eruptions occurred at Glacier Peak between 13,000 years ago and the present, resulting in a recurrence interval of 2000 years; however, Glacier Peak's eruptive history is one of intermittent and irregularly spaced periods of activity (Figure 2.5; Mastin & Waitt, 2000; Waitt *et al.*, 1995). Large eruptions occurred approximately 13,000 and 6,000 years ago while four small eruptive episodes took place over the past 3,000 years. Lahars resulted during each of these episodes.

The largest lahars, which are believed to have reached Puget Sound, are associated with the 13 and 6 ka Plinian eruptions and have recurrence intervals of 10,000 to 5,000 years (Waitt *et al.*, 1995; Gardner *et al.*, 1998; Hildreth, 2007). The 13 ka lahars of the White Chuck assemblage originated from mobilization of vast quantities of erupted pyroclastic material and traveled down the White Chuck River to the Sauk and Stillaguamish Rivers. Deposits from this lahar exist along the Stillaguamish River at least 100 km downstream from Glacier Peak that are 2 m thick and contain clasts 1 m in diameter (Figure 2.6; Beget, 1982). Deposit buildup during this eruptive episode eventually isolated the Stillaguamish River, diverting future flows along the Sauk River to the Skagit River. Outcrops, well logs, and borehole data show that the 6 ka lahars of the Kennedy Creek assemblage moved at least 135 km down the Skagit River (Figure 2.6; Dragovich & McKay, 2000). Deposits range in thickness from 3 to 18 m. Dragovich and McKay (2000) estimate that between 2 and 3 km^3 of lahar debris inundated the lower Skagit Valley west of Hamilton. Subsequent smaller eruptions in the past 3,000 years produced several lahars that traveled at most 30 km from Glacier Peak (Beget, 1982, 1983). Lahars flowing at least as far as the lower Suiattle River have a recurrence interval of 2,000 to 1,000 years.

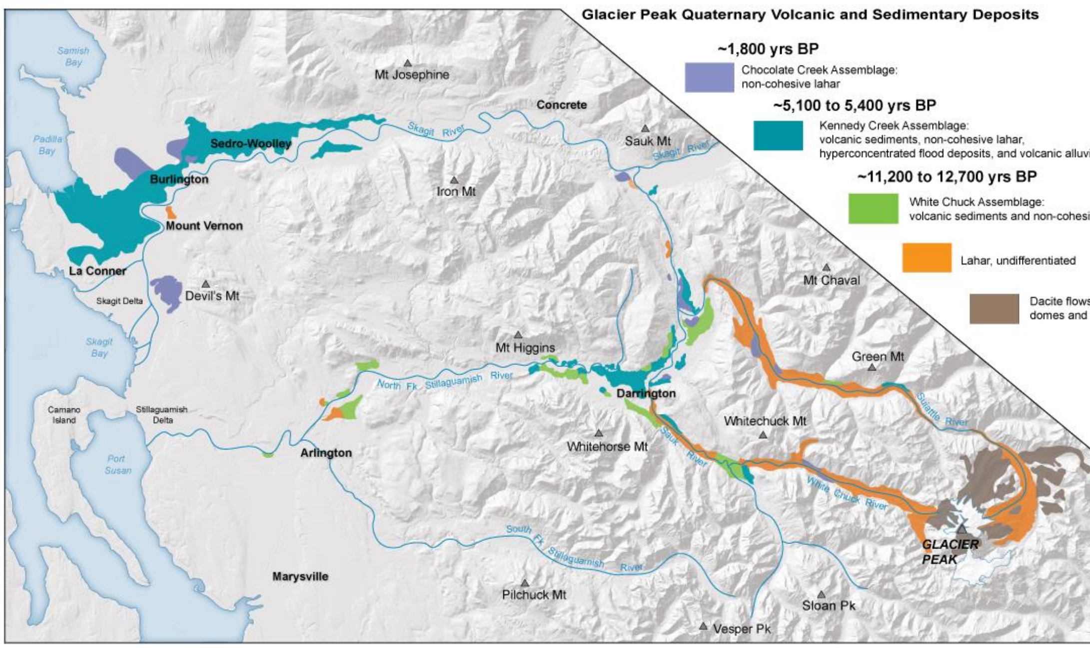

Figure 2.6: Map of Glacier Peak Quaternary volcanic and sedimentary deposits showing deposits remaining from large, far-reaching lahars (Washington Department of Natural Resources, 2016). Kennedy Creek Assemblage lahar deposits demonstrate that large flows can reach the Skagit River delta. White Chuck Assemblage lahar deposits along the lower Stillaguamish River also support the possibility of far-reaching lahars from Glacier Peak.

As with Mount Baker, the small to moderate-sized lahars that are incapable of reaching the Skagit Valley occur much more frequently than the large lahars that can impact the Skagit Valley. Yet, these large lahars have happened in the past and are anticipated to happen again in the future as shown by the official volcanic hazard maps for both volcanoes. Also, while less frequent, such large lahars pose a much greater threat to communities in the populated Puget Sound lowlands.

<u>Mapping the Mount Baker and Glacier Peak Lahar Hazard Zones</u>

Hazard maps provide essential information to emergency managers and the public regarding which areas of their communities are exposed to volcanic hazards. For this thesis, the Mount Baker and Glacier Peak volcanic hazard map (Figure 2.7) produced by the Cascade Volcano Observatory, forms the basis for understanding the Skagit Valley's exposure to volcanic hazards, particularly lahars. The Mount Baker hazard zones were outlined by Gardner *et al*. (1995, plate 1), drawing from the work of Hyde and Crandell (1978, plate 1), while the Glacier Peak hazard zones were outlined by Waitt *et al.* (1995) and drew from the work of Beget (1982, 1983).

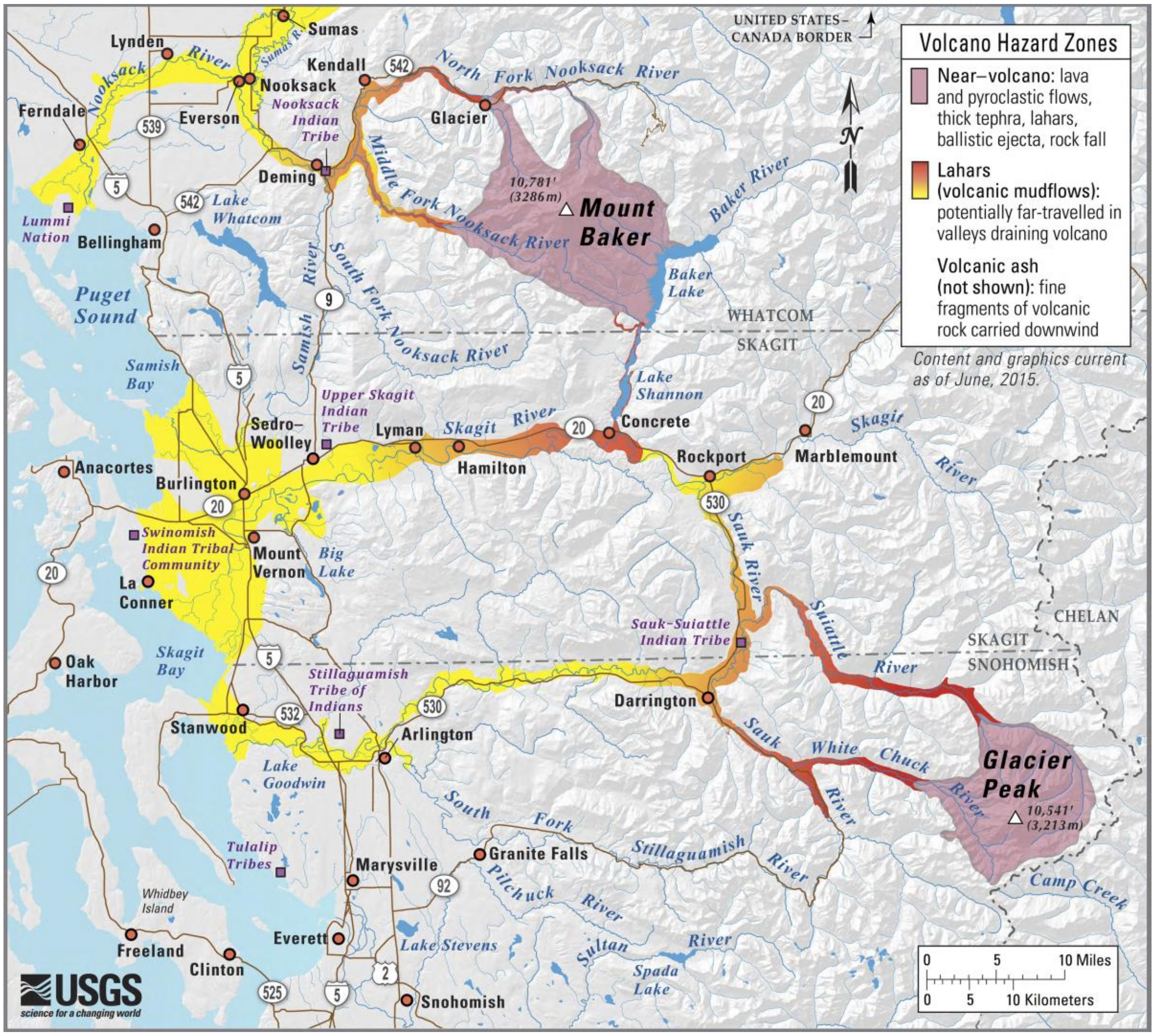

Figure 2.7: Official volcanic hazard map for Mount Baker and Glacier Peak produced by the Cascade Volcano Observatory, U.S. Geological Survey. (U.S. Geological Survey, 2014)

Near-volcano hazards including pyroclastic flows, lava flows, debris avalanches, ballistic ejecta, and thick tephra remain largely confined to the flanks of the volcano, only traveling a few kilometers from the vent through largely unpopulated wilderness. Other than ash fall, which is not depicted in these maps, lahars are by far the farthest reaching hazards and pose the greatest danger to populated areas. The lahar zones outlined for Mount Baker and Glacier Peak extend down valley drainages to Puget Sound. Gardner *et al.* (1995) and Waitt *et al.* (1995) delineated these lahar hazard zones based on deposits from the previous 14,000 years, current topography, the degree of hydrothermal alteration of the volcanic edifice, and comparisons with activity at similar volcanoes (e.g., Mount Rainier, Mount St. Helens).

At Mount Baker, three lahar scenarios are included in the hazard maps: cases 1, 2, and M. Case 1 and case 2 lahars represent small to moderate-sized lahars with recurrence intervals of more than 500 years and less than 100 years, respectively. While case 1 lahars are non-cohesive flows triggered by increased melting of snow and ice, case 2 lahars are cohesive flows triggered by debris avalanches. These lahars primarily impact drainages within a few kilometers of the summit. Case M refers to the maximum known or envisioned lahar path. Inundation projections for the Skagit Valley represent a case M lahar resulting from the overtopping or failure of Baker Dam. The impact on the dam depends on the reservoir water level and the flow volume, but the dam could be negatively impacted by case 1 lahars (RI > 500 years), case 2 lahars (RI ≤ 100 years), pyroclastic flows, or debris avalanches if they are of sufficient size and the reservoir level is not adequately lowered. Gardner *et al.* (1995) state that the scenarios associated with failure are too varied and complex to determine specific inundation levels. As such, they assume a 5 m inundation level covering the entire delta (Hyde & Crandell, 1978).

For Glacier Peak, Waitt *et al.* (1995) delineated the lahar zones using two methods. Upstream of the Sauk-Skagit confluence, inundation depths were estimated using the following empirical relationship in which V refers to the lahar volume and A is the cross sectional area of the valley:

$$\frac{V}{A^{3/2}} = \sim 100$$

This relationship is based on analyses of past lahars at Mount Rainier and Mount St. Helens and a flow volume of approximately 0.03 km^3. Downstream of the Sauk-Skagit confluence, in the Skagit Valley, the lahar zone is assumed to extend over the entire floodplain. As with Mount Baker, only the largest lahars from Glacier Peak are projected to influence the Skagit Valley and a more detailed delineation of these zones based on different scenarios is currently unavailable.

Incorporating the Build Environment: Risk Maps Motivation

Geologists provide essential information to emergency managers in the form of hazard maps. Hazard maps outline the potential extent of hazard impact based on local geology and topography. These maps form a necessary first step in the risk management process. Once hazard exposure for an area is known, it is possible to determine whether or not these hazards intersect with vulnerable systems to create a risky environment. Risk maps reveal the number and type of systems at risk as well as their distribution throughout the community. By understanding the spatial distribution of risk, emergency managers are better able to direct hazard mitigation, response, and recovery efforts to locations where these efforts will make the greatest impact.

Conducting risk mapping in the Skagit Valley presents an important and incomplete task that is undertaken as part of this thesis. The Cascade Volcano Observatory conducted a similar study concurrently that explores risk mapping and community lahar exposure around five volcanoes (Diefenbach *et al*., 2015). Diefenbach *et al*. examine the risk posed by lahars to developed land, residents, employees, public venues, and dependent-care facilities such as child services, elderly services, medical centers, and K-12 schools. Their results indicate that the abundance of vulnerable systems in the Mount Baker and Glacier Peak lahar zones make Skagit Valley communities some of the most at-risk communities in Washington State. Although similar, Diefenbach *et al*. only present the number and percentage of vulnerable systems at risk in the Skagit Valley. Individual maps showing the spatial distribution of these systems are absent, as is an analysis of the potential monetary losses associated with lahars. Diefenbach *et al*. also omit details regarding the exposure of transportation networks and agricultural lands to lahars. By providing a more detailed study of the lahar risk in the Skagit Valley, the maps generated in this thesis and the corresponding analysis compliment the work of Diefenbach *et al.* (2015).

The Human Dimension: Risk Perception and Preparedness Motivation

Risk Perception Models

The field of risk perception began, in earnest, in the late 1970s-early 1980s with the rising opposition to nuclear energy (Fischhoff *et al.*, 1978; Slovic *et al.*, 1982; Douglas & Wildavsky, 1982). The apparent disconnect between expert assessments and public perceptions of the risk posed by nuclear energy prompted research into the factors that shape risk perceptions and behaviors across a multitude of hazards. Four dominant risk perception models emerged from this work: the psychometric paradigm, cultural theory of risk, social amplification of risk framework, and values-beliefs-norms theory.

Psychometric Paradigm Model

The psychometric paradigm, first outlined by Fischhoff *et al.* (1978) and largely developed by the work of Paul Slovic, examines how risk perception varies across different hazards. The model relies on survey responses to provide a quantitative assessment of how participants perceive of the risk posed by different hazards and how they rate the acceptability of that risk. Participants rate each hazard based on 18 characteristics (Fischhoff *et al.*, 1978; Slovic *et al.*, 1982). Using a multivariant factor analysis, the authors condense these 18 items into three factors: dread risk, unknown risk, and number of people exposed. Dread risk incorporates measures of controllability, dread, catastrophic potential, fatality, equity, geographic scale of impact, risk to future generations, ease of reduction, and voluntariness (the degree to which the risk is adopted willingly, without coercion or expectation of reward). Unknown risk includes variables that define whether or not the risk is new, observable, and known to science or the exposed population. Unknown risk also accounts for the temporal scale of impact—are the risk's effects felt immediately or in the future?

The dread and unknown risk factors are used to plot hazards relative to one another on a cognitive map (Figure 2.8). Based on the risk's location on the cognitive map, Slovic (1987) argues that a person's perception and likely response to a risk event can be anticipated. Hazards that plot high on dread risk elicit the lowest levels of acceptance and the greatest feelings of risk (Slovic ,1987). They cause large ripple effects, meaning their social impact extends far beyond the immediate affects of the hazard itself (Slovic, 1987), and inspire calls for risk reduction. Hazards that rank high on dread and unknown risk are often overestimated while those that rank low on both scales are often underestimated (Schmidt, 2004). Fischhoff *et al.* (1978), Slovic *et al.* (1982), and Schmidt (2004) argue that similarities between risk characteristics allow for the prediction of public risk perception and response when presented with a new hazard.

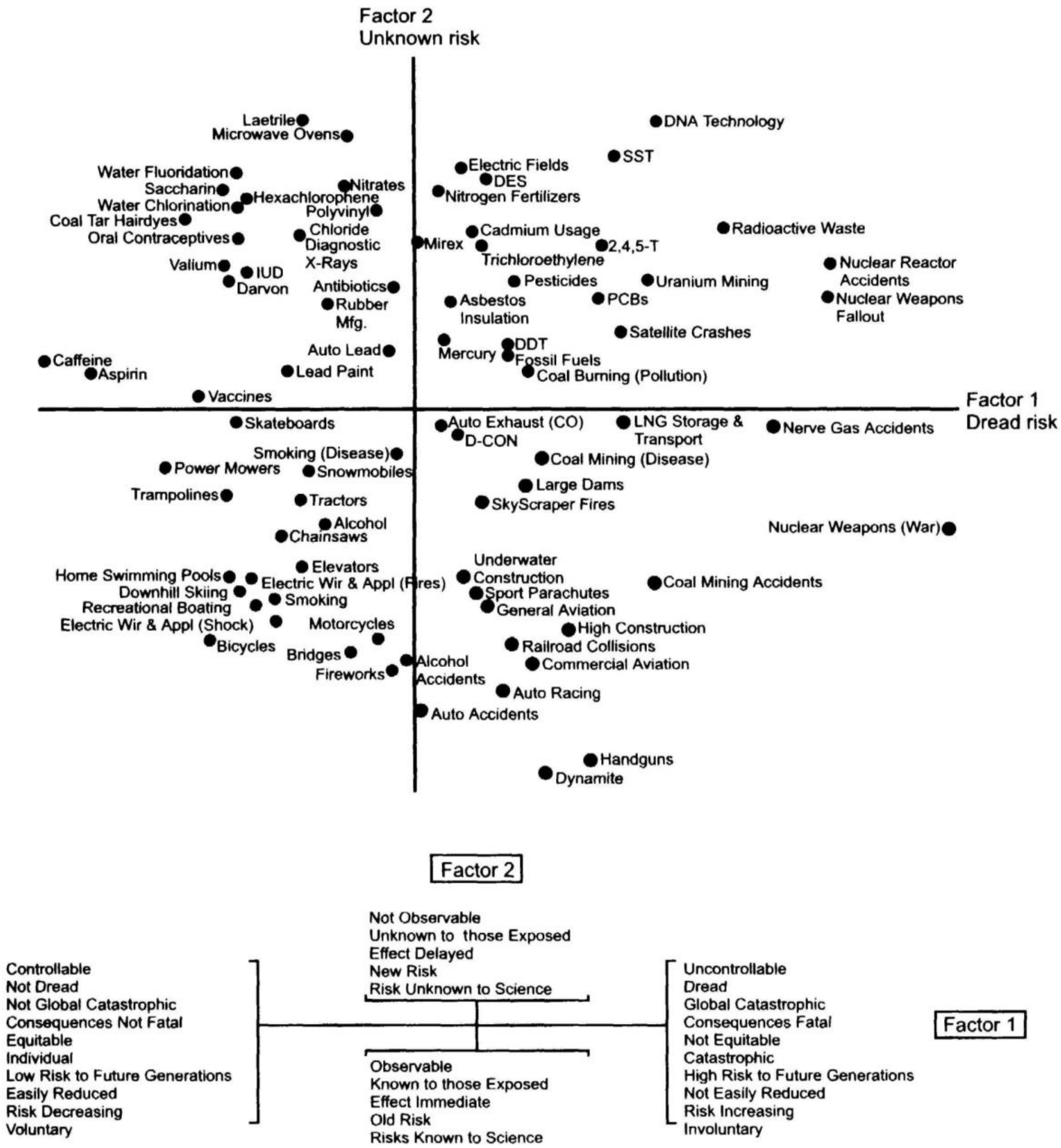

Figure 2.8: Psychometric paradigm cognitive map of hazards (adapted from Slovic *et al.*, 1982). The cognitive map (top) plots hazards based on two factors: dread and unknown risk. These two factors arise from a multivariant factor analysis of hazard ratings in 18 different categories (bottom). Hazards that plot high on dread risk elicit the lowest levels of acceptance and the greatest feelings of risk (Slovic, 1987).

The primary criticism of the psychometric paradigm centers on the unit of analysis, which is the risk itself. The psychometric paradigm focuses on explaining differences in risk perception across hazards rather than across individuals. By doing so, studies ignore the evidently extensive variation in risk perception at the individual level

(Sjöberg, 2000; Slimak & Dietz, 2006). Sjöberg (2000) further demonstrates that the usefulness of the psychometric paradigm is greatly reduced when applied to predicting individual rather than aggregate risk perception. When applied to individual data, the psychometric paradigm only explains 20-30 percent of the variance in risk perception (Sjöberg, 2000).

Cultural Theory of Risk Model

In 1982, Douglas and Wildavsky's essay *Risk and Culture* developed the foundation for the cultural theory of risk, which became the dominant sociological and anthropological risk perception model. This model seeks to understand why and how risk perception varies across individuals. Cultural theory argues that judgments regarding which hazards to fear and which to ignore stem from socially constructed values fostered by four worldviews or cultural biases—hierarchist, individualist, egalitarian, and fatalist. While four cultures are defined, risk analysis largely focuses on perceptions associated with hierarchists, individualists, and egalitarians.

These four cultures originate from a group-grid analysis (Figure 2.9). Group measures how strongly people are incorporated into a cultural unit as well as the nature of the boundary between this cultural unit and the rest of the outside world. Grid refers to a cultural unit's degree of internal social organization (Douglas & Wildavsky, 1982; Thompson *et al.*, 1990; Tansey & O'Riordan, 1999). For example, egalitarians form sects that erect strong boundaries but value equality of the individual, creating few internal distinctions or rankings. Thus, egalitarians rank high on group and low on grid. Hierarchists similarly have a high group value, but their strong internal organization indicates a high grid value as well.

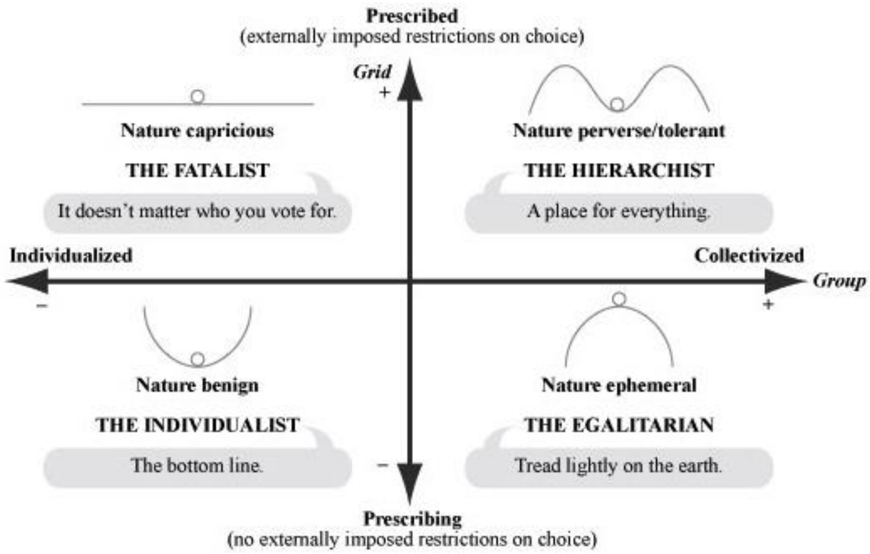

Figure 2.9: Diagram of cultural theory's four cultural biases plotted in terms of grid and group rankings (Schwarz & Thompson, 1990). The grid dimension ranks the level of internal social organization within a unit whereas the group dimension refers to the intensity of the boundary between that unit and the outside world. Egalitarians express the greatest concern for environmental risks. They view nature as ephemeral, meaning even small perturbations can lead to dramatic and irreversible harm to nature.

Each culture fosters specific values that inform how members perceive different risks (Figure 2.9; Douglas & Wildavsky, 1982; Wildavsky & Dake, 1990; Tansey & O'Riordan, 1999). Hierarchists value the collective over the individual. They primarily focus on the preservation of their organization and, thus, most fear threats to the whole system, such as foreign or civil war. Individualists value equality of the individual and self-reliance. Researchers associate the individualist view with the open market, where everyone is free to compete and possibly succeed. Individualists also fear threats to the system as a whole, particularly economic disruption. Egalitarians value equality above all else. They mainly fear technological and environmental threats, believing that even small perturbations can lead to dramatic and irreversible harm to nature.

Efforts to operationalize and test cultural theory's ability to explain risk perception have met with mixed results. Wildavsky and Dake (1990) investigate the ability of knowledge, personality, economics, political affiliations, and cultural biases to explain the variance in individual risk perception. They conclude that cultural theory best explains the observed patterns of risk perception: egalitarians mainly fear technological and environmental risks, individualists fear war and hazards that might disrupt the open market, and hierarchists fear social deviance and threats to their trusted institutions. However, Sjöberg (2000) finds that cultural theory accounts for only 5-10 percent of the variance in risk ratings.

Rayner (1992) notes two approaches to individual cultural bias: the bias is either stable, inherent, and consistent in all realms of life or it is mobile and changes in different contexts. Marris *et al.* (1998) find that two-thirds of individuals cannot be assigned to a single cultural identity. The inability to clearly categorize individuals into one of the four worldviews supports the idea that cultural biases are mobile. If people do not fall into a single category consistently, cultural theory cannot be operationalized using the quantitative survey methods commonly applied to the psychometric paradigm (Marris *et al.*, 1998).

Social Amplification of Risk Framework

Kasperson *et al.* (1988) argue that both the cultural theory and psychometric paradigm models provide valuable, albeit fragmented, insight into the controls on risk perception and response behaviors. The social amplification of risk framework (SARF) attempts to connect elements of pre-existing models into a more cohesive and comprehensive framework. SARF's basic premise argues that risk perceptions and behaviors change due to psychological, social, institutional, and cultural processes that either amplify (intensify) or attenuate (weaken or constrain) risk information. The following summarizes SARF and provides critiques of the model. The difficulties associated with quantitatively operationalizing SARF prevents this model from being applied to this thesis; however, as one of the major risk perception models, a brief description is warranted.

As risk event information is transmitted, it encounters social and individual amplification stations. At these stations, the information is received by different entities and the signals get filtered, amplified, or attenuated (Figure 2.10). At social amplification stations, various external entities such as the media, cultural groups, and government agencies influence risk signals. At individual amplification stations, internal heuristic, cognitive, and value driven signal interpretation by the individual occurs. Both result in either the intensification or weakening of risk signals. The nuclear accident at Three Mile Island provides an example of a risk event that underwent amplification via media coverage and strong, individual, anti-nuclear values.

In SARF, hazard events create ripple effects, the size of which depends on whether the risk signal is amplified or attenuated (Figure 2.10). The larger the ripples the further the effects of the event spread beyond those immediately affected and into the broader society. Amplification increases the ripple effects while attenuation reduces them. Impacts just beyond the immediate are termed secondary impacts. Signals from these secondary impacts then move through another set of amplification or attenuation stations. The resulting signal feeds back into perceptions and motivates new behaviors that can lead to third-order impacts (Kasperson *et al.*, 1988).

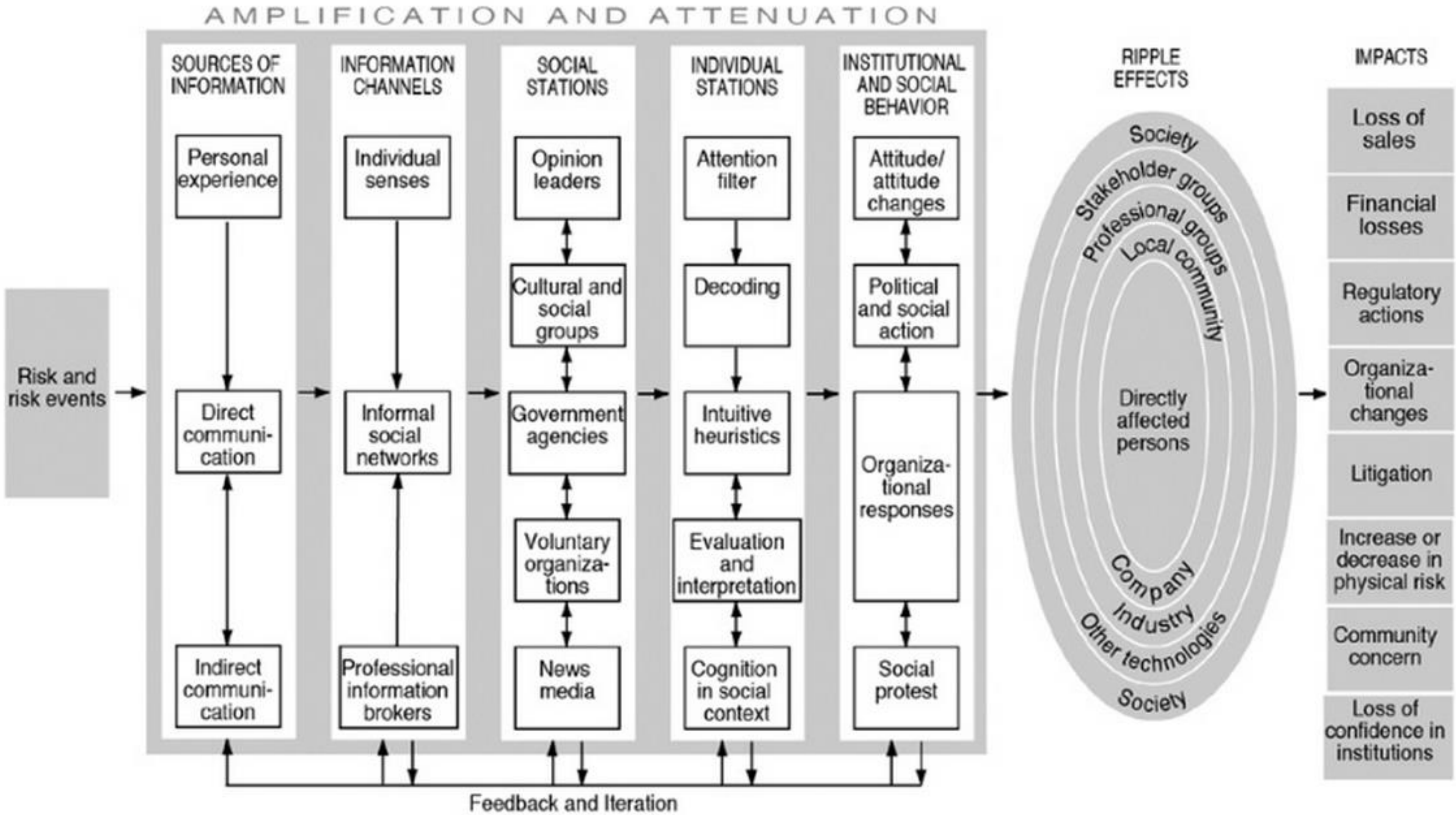

Figure 2.10: Flow diagram of Social Amplification of Risk Framework (Kasperson *et al.*, 2003). Risk information gets transmitted through various channels and undergoes amplification or attenuation at both the individual and social level. This results in behavioral changes that influence the extent of ripple effects and secondary impacts. These secondary impacts then feed back into the amplification and attenuation process, potentially leading to tertiary impacts.

Overall, the entire cycle of hazards and ripple effects forms a positive feedback loop with perceptions feeding into behaviors that alter the impacts and eventually result in the reshaping of perceptions. Therefore, amplification occurs during both the information transmission and the response processes. For example, the impacts of the 2010 eruption of Eyjafjallajökull in Iceland had ripple effects felt globally. The ash not only impacted the immediate surroundings via lahars and ashfall but also devastated the tourism industry in Iceland. This negatively impacted an already struggling economy (Donovan & Oppenheimer, 2011). Beyond the local impacts, ash caused the grounding of air traffic across Europe, negatively affecting economies worldwide.

One criticism of SARF described by Rayner (1988) rests on concerns that the use of the word amplification incorrectly suggests that there is a “true” risk that becomes altered. Kasperson *et al.* (2003) defend SARF stating that all risk information undergoes some degree of interpretation and construction during transmission. However, they recognize that the language in SARF implies a bias.

Another criticism of SARF, which Kasperson *et al.* (2003) acknowledge, is that the framework may be overly general, unable to provide new information, or be empirically tested and refuted. The authors note that the ability to empirically test SARF forms an important challenge that will dictate the fate of the framework. Yet, SARF continues to be of value in bringing together similar and disparate models, inspiring new hypotheses, and forming a general framework within which to organize multiple diverse risk perception models (Kasperson *et al.*, 2003). The controversial nature of quantitatively operationalizing SARF prevents the application of this framework to the research in this thesis.

Values-Beliefs-Norms Theory

The values-beliefs-norms (VBN) theory, developed to explain environmental movement support, unites elements of three theories of environmentalism: value theory, norm-activation theory, and the New Ecological Paradigm (NEP) (Stern *et al.*, 1999; Stern, 2000). Value theory proposes that the values important to an individual control their level of environmental concern and subsequent behaviors. VBN theory focuses primarily on the role of self-transcendent or altruistic values (i.e., caring about others) in shaping environmentalism; altruistic people are believed to be more sensitive to potential environmental threats and more likely to feel responsible for taking action (Stern, 2000). Norm-activation theory refers to the Schwartz moral norm-activation theory of altruism in which awareness of consequences and feelings of responsibility for preventing negative consequences activate the personal moral norms that drive altruistic behavior. In other words, people are motivated to behave altruistically because they feel a moral obligation to act. The NEP refers to an ecological worldview with a belief system centered on the relationship between humans and the natural world.

Combining these theories, Stern and colleagues (Stern *et al.*, 1999; Stern, 2000) propose that environmental support emanates from a five variables: personal values, NEP beliefs, awareness of consequences, ascription of responsibility to self, and personal norms (Stern *et al.*, 1999; Stern, 2000; Slimak & Dietz, 2006). In this causal chain, individuals hold certain values, beliefs, and worldviews and recognize when these are threatened. Believing themselves responsible for protecting their values, they feel obliged to take action.

Slimak and Dietz (2006) demonstrate that the values and beliefs portions of the VBN theory also apply to risk perception. They note that risk perception surveys require respondents to make rapid judgments as opposed to allowing them time for in-depth reflection. Tversky and Kahneman (1974) show that such quick decisions are influenced by heuristics and biases, which Slimak and Dietz (2006) argue are related to values and beliefs. Differences in values and beliefs across individuals result in variations in risk ratings. Therefore, unlike the psychometric paradigm, applying the VBN theory to risk perception studies allows researchers to examine variations in risk perception based on the characteristics of the individual rather than the characteristics of the hazard. Additionally, VBN theory does not attempt to categorize individuals into a limited number of extreme worldviews. The research presented herein applies the awareness of consequences and ascription of responsibility concepts from VBN theory to understand risk perception and preparedness behavior in the Skagit Valley.

Applying Risk Perception Concepts to Natural Hazards

The traditional, dominant risk perception models deal specifically with the perception of and response to environmental and technological hazards. Yet, these models and the literature on natural hazards identify similar controlling factors behind risk perception. Some of these factors include knowledge, past experience, gender, self-efficacy, and personal responsibility; these factors are described in the subsequent section, Factors Controlling Risk Perception.

Additionally, Wachinger *et al.* (2013) argue that the recent increase in human environmental intervention and technological innovation blur the line between man-made and natural hazards. Natural forces are no longer the sole trigger of natural hazards.

Hurricanes, droughts, and floods are influenced by anthropogenic climate change (Trenberth, 2012; IPCC, 2013) while earthquakes become the consequences of wastewater injection (Rubinstein & Mahani, 2015). As this distinction fades, the many insights derived from traditional risk models become increasingly applicable to natural hazard risk perception research.

Factors Controlling Risk Perception

The risk perception models and natural hazards literature identify a multitude of factors that drive risk perception to varying degrees, including: knowledge, trust, past experience, self-efficacy, socio-demographic variables, and identity as an expert. While outlining how every suggested factor influences risk perception falls beyond the scope of this thesis, the following provides a brief contextual survey of the most salient factors.

Knowledge

Individuals require hazard and preparedness knowledge to judge the riskiness of multiple hazards, adopt preparedness actions, make informed decisions, and evaluate official directives. If an individual does not know that a hazard exists, there is no reason for them to feel concerned or motivated to prepare. Likewise, if an individual does not know how or what to prepare, they cannot be expected to prepare adequately. Communication between the public, officials, and scientists also suffers when the public lacks important or sufficiently detailed hazard knowledge. Individuals may fail to understand the reasoning behind official decisions, choose to ignore directives, and generate conflicting information (Haynes *et al.*, 2008; Barclay *et al.*, 2015). Acquiring adequate and accurate knowledge represents a necessary step in ensuring that one is aware of hazards, can formulate an accurate risk perception, and knows how and why to prepare.

Given this necessity, early risk education efforts hoped that by simply providing information to people, officials and scientists could directly increase public hazard awareness and motivate preparedness actions. However, research repeatedly refutes the existence of a direct causal link between information provision, awareness, risk perception, and preparedness behavior (Handmer, 1980; Sims & Baumann, 1983 and references therein; Wildavsky & Dake, 1990; Paton *et al.*, 2008; Haynes *et al.*, 2008; Wachinger *et al.*, 2013; Barclay *et al.*, 2015). Handmer (1980) demonstrates that simply providing information can fail to improve awareness because doing so does not guarantee that the information is received or internalized (Sims & Baumann, 1983). Wildavsky and Dake (1990) show that even when awareness increases, risk perception may not change significantly. They find that neither education nor self-assessed knowledge level affect risk perception. Finally, awareness typically fails to motivate preparedness actions (Sims & Baumann, 1983 and references therein; Paton *et al.*, 2008; Haynes *et al.*, 2008; Wachinger *et al.*, 2013; Barclay *et al.*, 2015). Johnston *et al.* (1999), based on the reduction in perceived and actual preparedness levels following a volcanic eruption in New Zealand, find that those who are knowledgeable about local hazards may even reduce their preparedness actions. Therefore, although necessary, knowledge alone is insufficient for fully shaping risk perception or motivating preparedness actions (Sims & Baumann, 1983).

Trust

Effective risk management requires trust, especially when the nature of the hazard involves a high degree of uncertainty or the people at risk lack hazard knowledge (Siegrist & Cvetkovich, 2000). Uncertainty exists in determining the exact timing, duration, magnitude, and impact of volcanic hazards, such as lahars (Paton *et al.*, 2008; Barclay *et al.*, 2015). This uncertainty creates challenges for decision making during events and can leave the public unsure of what actions to take. Volcanic hazards also occur infrequently and, if no events have occurred in recent memory, people consider these hazards unfamiliar. As a result, people lack important hazard knowledge. Additionally, people are exposed to a plethora of hazards on a daily basis and cannot be expected to maintain a working knowledge of all hazards that could potentially affect them (Wachinger *et al.*, 2013). Instead, people rely on experts or institutions that they trust to help them process information about the risks that hazards pose and how to best respond to those risks.

Trust in scientists and emergency officials facilitates communication and forms the foundation for the acceptance or rejection of risk assessments, risk communications, and hazard mitigation, response, and recovery efforts (Slovic, 1999; Barclay *et al.*, 2015). Trust in scientists influences the public's opinion of hazard assessments (Slovic, 1999) while trust in officials influences how the public prepares for and responds during a natural hazard (Paton *et al.*, 2008). Trust in one's social networks, friends, and family members also affects the reception of risk information. Before acting, people mill information they receive with others in their social network who either offer confirmation or contradiction (Barclay *et al.*, 2015). Risk communication suffers when people distrust officials or mill information with those who distrust officials. Thus, it is necessary to foster trust in officials throughout the community. The lack of trust poses a challenge for ensuring that people heed the advice and instructions of emergency officials (Slovic, 1999).

Trust, however, is a double-edged sword with the potential to direct perception and preparedness in both beneficial and harmful ways. As noted, risk communication and management officials benefit from knowing that the public will accept their information and directives. But, excessive trust in authorities can be harmful and cause people to transfer responsibility for their own safety during hazardous events to emergency officials (Wachinger *et al.*, 2013). People relinquish their own agency in these situations (Wachinger *et al.*, 2013). In such cases, individuals mistakenly exaggerate the abilities of authorities and scientists to protect them. For example, they may overestimate a scientist's ability to predict with a high degree of certainty the onset and course of a volcanic eruption.

Past Experience

Literature indicates that past experience is one of the most important factors controlling risk perception and preparedness actions (e.g., Carlino *et al.*, 2008; Haynes *et al.*, 2008; Paton *et al.*, 2008; Wachinger *et al.*, 2013). Past experience influences the public's response to emergency directives, level of trust in officials and scientists, and hazard knowledge.

Wachinger *et al.* (2013) defines two different types of experience: direct and indirect. Direct experience refers to personal, first-hand experience such as watching a volcano erupt, feeling an earthquake, or surviving a flood in your community. However, direct experiences fades from memory over time, losing their saliency for shaping risk perception and motivating preparedness actions (Wachinger *et al.*, 2013). Indirect experience implies that the individual experiences the hazard by learning about it from another source, such as media stories or educational programs. Indirect experience provides individuals with images to recall and stories with which to empathize when considering hazards. These images and stories also help those with direct experience recall faded memories (Wachinger *et al.*, 2013). Since most volcanic hazards occur infrequently, indirect experience forms the primary method by which people gain experience with volcanic activity (Paton *et al.*, 2008; Wachinger *et al.*, 2013).

Simply experiencing a hazard does not, in itself, influence risk perception and preparedness actions. Rather, the characteristics of the experience and associated feelings drive perceptions and preparedness actions in both positive and negative directions based on the belief that future experiences will mimic past ones. (Wachinger *et al.*, 2013). Johnston *et al.* (1999) show that following effectively managed, mild volcanic events, people admit to feeling more prepared while actually decreasing their preparedness actions. People focus on the mild experience as an archetype and fail to recognize that a more severe event remains possible (Paton *et al.*, 2008). Such experiences give people a false sense of security (Haynes *et al.*, 2008; Wachinger *et al.*, 2013).

On the other hand, if people previously experienced devastation or poor management, they expect the same in the future (Haynes *et al.*, 2008, Paton *et al.*, 2008). When responses are ineffective or the scale of the hazard overwhelms emergency services, the public loses trust in officials and, occasionally, scientists. This leaves the public feeling more at risk. When managers issue warnings or evacuations and no event occurs, the public will view the hazard as less of a risk and future risk communications with incredulity. These false alarms are detrimental to trust and reduce the likelihood that the public will heed evacuation directives in the future (Wachinger *et al.*, 2013).

Self-efficacy and Personal Agency

Self-efficacy is defined as an individual's belief in their own ability to respond to hazardous events effectively (Bandura, 1997; Paton, 2003; Barclay *et al.*, 2015). Personal agency refers to an individual's actual ability to act intentionally on their own and protect themselves (Bandura, 1997). Everyone has agency during a natural hazard, but not everyone recognizes and acts upon this agency. People must first believe that they have the ability and responsibility to act before they will do so.

Self-efficacy and personal agency recognition influence risk perceptions and can motivate or hinder preparedness actions (Grothmann & Reusswig, 2006). People who believe they lack the ability to respond effectively or to survive a hazard will judge risks differently than those who believe they can protect themselves. Fatalistic attitudes, such as the former, fail to motivate the adoption of preparedness actions (Grothmann & Reusswig, 2006). Similarly, those who fail to recognize their personal agency often transfer responsibility for their safety to other entities, such as local emergency services. Alternatively, individuals with a strong sense of self-efficacy, who recognize their agency, are more likely to prepare (Bandura, 1997; Paton, 2003; Wachinger *et al.*, 2013).

Demographics

Social demographic variables such as gender, age, income, and education are frequently shown to influence risk perception. Women, as opposed to men, typically judge hazards as riskier (Savage, 1993; Slovic, 1999; Barberi *et al.*, 2008), but men view themselves as better prepared and able to protect themselves during a hazard (Barberi *et al.*, 2008). Slovic (1999) discusses two potential explanations for this phenomenon. First, women, traditionally, are responsible for raising and nurturing children, making them more concerned about the well-being of others and more sensitive to potential threats. Second, research shows that women are more vulnerable during disaster situations and to violence in general (Slovic, 1999; Barclay *et al.*, 2015).

Age and income are shown to vary inversely with risk ratings (Savage, 1993; Slovic, 1999; Slimak & Dietz, 2006). Older and wealthier populations tend to view risks as less concerning than younger and poorer populations. The relationship between education and risk perception is inconsistent from one study to the next (Wachinger *et al.*, 2013). Savage (1993) finds an inverse relationship between education and risk perception, but Sjöberg (2000) indicates that education has a negligible effect on risk perception. Additionally, it is important to note that these variables, particularly education and income, tend to be interrelated (Slimak & Dietz, 2006), making it challenging to identify the causal variable. Flynn *et al.* (1994) demonstrate the necessity of examining how risk perception changes when multiple demographic variables are combined. For instance, they show that the gender difference exists because of multiple factors. Women are not simply more concerned than men; rather, women are more concerned than highly educated, wealthy, politically conservative, white men.

Experts vs. the General Public

Risk perception research treats risk assessors, emergency managers, and technical specialists or scientists as experts. In this study, we refer to experts as response professionals, which we define as individuals who work as first responders or in leadership positions in local city government, hospitals, schools districts, Red Cross, or utilities, transportation, or water companies. We compare risk perception and preparedness behaviors among these experts and the general public. As such, we provide a brief review of the literature on differences between expert and general public perception.

Early risk perception research argues that experts equate risk with damage estimates or mortality rates while the public's concept of risk is far more complex, accounting for various psychological, social, and cultural factors (Slovic *et al.*, 1982; Slovic, 1987). Siegrist and Cvetkovich (2000) indicate that these differences stem from an expert's added training, experience, and knowledge about the hazard. Among other factors, Sjöberg (1999, 2002) attributes the difference to socialization, professional role, and trust. Socialization refers to the idea that professional training and experience eventually push experts to conform to the values and perceptions perpetuated by their organization. Professional role refers to an expert's occupational position and how it influences their goals. For example, first responders and emergency managers aim to protect the public from hazards and, as such, may have a higher risk perception. Other experts may want to promote a technology or activity and, thus, consider the risk small. Finally, trust in science and emergency agencies likely differs between experts and the public, with experts placing more trust in their own agency or scientific field.

However, experts are not a homogeneous group (Sjöberg, 2002). Differences in risk perception exist across individual experts that parallel patterns found in the public. The average risk rating may be offset between experts and the public, but within each group similar variations based on gender, worldview, and affect (i.e., knee-jerk feelings) are evident (Slovic, 1999; Savadori *et al.*, 2004). The presence of biases in expert risk perception is particularly evident when they are working at the edge of their knowledge and relying on intuitive judgments (Tversky & Kahneman, 1974). Overall, socio-demographic factors complicate the ability to separate risk perception simply in terms of expert verses general public (Rowe & Wright, 2001). Boiling down the drivers of risk perception solely to an individual's identity as an expert is an oversimplification.

The Risk Perception Paradox and Factors Controlling Preparedness Actions

Another aspect of risk perception research focuses on behavior motivation with the aim of determining how to better motivate individuals to adopt preparedness actions. Researchers have conducted scores of risk perception studies with the assumption that perception drives, or at least influences, actions. By identifying which factors influence perceptions, one assumes that researchers could recommend ways to shape or alter risk perception to improve accuracy and, subsequently, preparedness.

Ideally, those who are appropriately concerned should feel motivated to become better prepared; however, studies repeatedly indicate that a disconnect exists between perception and preparedness actions. Even individuals with accurate or heighted risk perceptions frequently fail to take adequate steps to prepare (Paton *et al.*, 2008; Wachinger *et al.*, 2013 and references therein). This disconnect suggests that, while necessary, knowledge and concern regarding hazard exposure are not sufficient to motivate preparedness actions (Paton *et al.*, 2008). Wachinger *et al.* (2013) term this phenomenon the risk perception paradox.

Behavioral motivation research seeks to determine which elements inspire or prevent the adoption of preparedness actions. The protection motivation theory (PMT;

Rogers, 1983; Rogers & Prentice-Dunn, 1997), as modified by Grothmann and Reusswig (2006), outlines why some individuals adopt protective actions in the face of natural hazards while others do not. PMT treats actions as the result of two processes: threat appraisal and coping appraisal. The threat appraisal process incorporates perceived probability of exposure, perceived severity of damage, and fear of the hazard. Grothmann and Reusswig (2006) equate threat appraisal with risk perception. Coping appraisal depends on perceived protective response-efficacy, perceived self-efficacy, and perceived protective response costs. In other words, coping appraisal depends on an individual's perception of (1) the effectiveness of preparedness actions for addressing the threat, (2) their own ability to act, and (3) the costs associated with taking action.

In PMT, risk perception motivates a response, but the results of the coping appraisal determine the direction of that response. A high threat appraisal and high coping appraisal lead an individual to form preparedness intentions (known as protection motivations) and, in some cases, take preparedness actions. In contrast, a high threat appraisal and low coping appraisal push people toward non-protective actions such as fatalism, wishful thinking, and denial.

Even if individuals intend or desire to prepare, they are not always able to do so. Actual barriers exist that hinder preparedness actions (Grothmann & Reusswig, 2006; Wachinger *et al.*, 2013). Suggested barriers include the lack of knowledge, time, money, or social support necessary to prepare (Grothmann & Reusswig, 2006; Siegrist & Gutscher, 2006; Bird *et al.*, 2010). Some of these barriers are considered in the perceived protective response costs component of the coping appraisal process. Other factors that may prevent preparedness actions even when individuals are aware of the hazard include risk selection, cost-benefit analyses, trust in officials, and personal agency, each of which can be tied to either the threat or coping appraisal components of PMT (Paton *et al.*, 2008; Wachinger *et al.*, 2013).

Risk selection refers to the idea that people select certain hazards to fear and others to ignore because a single person cannot, realistically, worry about every hazard they face (Douglas & Wildavsky, 1982). Risk selection reduces the perceived risk (i.e., threat appraisal) associated with certain hazards, and these ignored hazards fail to motivate preparedness actions. For example, often people deem the threat from natural hazards less pressing than other daily challenges they encounter, such as crime, traffic, unemployment, pollution, and issues with public services (Wachinger *et al.*, 2013). A study by Barberi *et al.* (2008) demonstrates that, for people living in modern day Pompeii (Italy), daily challenges are far more salient than concerns over volcanic hazards from Vesuvius, despite the fact that they live on the ruins of a town destroyed by the 79 AD eruption.

Individuals weigh the costs and benefits of being exposed to risks as well as the costs and benefits of adopting preparedness actions. If the perceived benefits associated with a certain risk outweigh the perceived costs, individuals are more inclined to accept the risk and avoid preparedness actions (Wachinger *et al.*, 2013). For instance, people may choose to live in towns at risk from lahars because the certainty of beautiful vistas or proximity to work outweighs the low probability of a lahar occurring. Similarly, individuals who believe preparedness actions require more money, time, or effort than the potential protective benefits warrant are less likely to prepare (Paton *et al.*, 2008). Such cost-benefit analyses in PMT fall within the realm of perceived protective response costs in the coping appraisal.

Trust, a common factor driving risk perception, also mediates decisions regarding preparedness intentions and actions. Trust can influence both the threat appraisal and coping appraisal. As discussed previously, trust in officials can positively influence acceptance of hazard information, preparedness instructions, and emergency directives (Paton *et al.*, 2008), improving perceived protective response-efficacy. But, excessive trust can cause the public to misunderstand and overestimate the abilities of emergency services, leading them to transfer their responsibility for their own safety to emergency services. This shift signifies that a person no longer recognizes their own agency during risk events (Wachinger *et al.*, 2013) and feels less need to prepare personally. This influences perceived self-efficacy, and increased feelings of safety reduce perceived risk (Ballantyne *et al.*, 2000; Paton *et al.*, 2008). Assessments of personal responsibility are more fully accounted for in VBN theory's ascription of responsibility variable.

Participation: The Solution to the Risk Perception Paradox?

Studies frequently propose that emergency managers increase public participation in the risk management process to help motivate preparedness actions, thereby closing the gap between risk perception and preparedness (e.g., Barberi *et al.*, 2008; Paton *et al.*, 2008; Wachinger *et al.*, 2013). Participation takes many forms, from public involvement in hazard response planning to public engagement in discussions with emergency officials regarding local risks (Barberi *et al.*, 2008; Paton *et al.*, 2008; Wachinger *et al.*, 2013). Participation provides an avenue for increased interaction between the public and officials as well as the sharing of information.

Participation positively impacts public knowledge, recognition of personal agency, trust in officials, and risk communication. By working with emergency officials, the public improves their knowledge of local hazards and how to prepare. They gain an appreciation for the role of emergency agencies during hazard responses, learning what external support to reasonably expect and when to rely on their own agency. People reclaim responsibility for their personal safety rather than placing this responsibility in the hands of emergency services, and this recognition of personal agency and responsibility helps motivate preparedness actions (Paton, 2003; Wachinger *et al.*, 2013).

Participation also increases interactions between stakeholders and emergency managers, which provides the latter with greater insight into how to best address the community's needs (Wachinger *et al.*, 2013). Officials discover ways to articulate information so as to meet the expectation and needs of their specific community (Paton *et al.*, 2008 and references therein). These interactions strengthen individual and community trust in officials. Trust in officials, combined with an understanding of the role of emergency agencies, fosters a setting in which individuals heed emergency information and warnings (Wachinger *et al.*, 2013). Overall, as the public feels increasingly knowledgeable, empowered, and trusting, they become more motivated to adopt preparedness actions.

<u>Knowledge Gap and Motivation for Human Dimension of Thesis</u>

The existence of a disconnect between awareness, perception, and preparedness behaviors is well-documented; however, questions remain regarding which barriers prevent action and how to counteract them. As discussed, risk perception and behavior motivation literature outline multiple potential barriers to preparedness actions, all of which are related to low threat appraisals, low coping appraisals, or low ascription of responsibility to self. These barriers include low levels of concern, trust, self-efficacy, response-efficacy, and perceived risk as well as the actual lack of necessary resources. Yet, little work examines the influence of these barriers based on individual traits. By suggesting that everyone faces the same barriers, studies fail to account for changes in the significance of these barriers based on individual socio-psychological and socio-demographic factors.

Studies also provide little information in terms of the self-expressed relative importance of different barriers, which can provide important information to emergency managers about the opinions of those they protect. In their study of floodplain residents in the Netherlands, Terpstra and Lindell (2012) provided respondents with an opportunity to indicate which factors were important to their preparedness decisions. This created a dichotomous variable that limited the ability of researchers to assess the relative importance of different factors in the respondent's decision-making. For example, a respondent could indicate that cost, effort, and the effectiveness of a preparedness measure to protect life and property are important, but they were unable to indicate which of these four attributes was most important to them. The use of scales to measure importance, as Terpstra and Lindell advocate, could address this limitation and are used herein.

As noted, a broad body of literature supports the idea that public participation in hazard management improves hazard plans and enhances household preparedness, self-efficacy, and trust. Given the numerous benefits associated with public participation, one might expect those professionally involved in response planning and implementation to experience similar benefits. However, few studies examine the preparedness behaviors of those already actively involved in these activities: response professionals. Traditionally, research comparing experts and the public focuses on examining differences in knowledge and risk perception rather than preparedness behaviors (See Experts vs. General Public). More recent research deals largely with organizational preparedness and professional competencies (i.e., whether or not an individual has the knowledge, skills, and abilities required to perform their professional response duties) with a focus on health care professionals (Parker *et al.*, 2005; Slepski, 2007). Those few studies that examine household preparedness levels among public health employees (Blessmann *et al.*, 2007; Rebmann *et al.*, 2013) and first responders (Federal Emergency Management Agency, n.d.) consistently indicate that household preparedness among respondents remains low. Yet, these studies fail to examine public household preparedness levels for comparison. As such, the influence of hazard management participation at a professional level on household preparedness, self-efficacy, personal responsibility beliefs, and trust remains unclear.

To address these gaps, the thesis presented herein explores (1) the existence of a disconnect between awareness, perception, and preparedness in a community at risk from volcanic lahars; (2) the barriers that prevent individuals from preparing; and (3) the influence of professional participation in hazard response planning and implementation on the household preparedness and personal beliefs of response professionals. Elements of PMT and VBN theory are applied to the results of a knowledge, risk perception, and preparedness survey in the Skagit Valley of Washington.

CHAPTER THREE: LAHAR HAZARD & RISK MAPPING

The objective of the mapping component of this thesis is to spatially and quantitatively examine the extent to which Mount Baker and Glacier Peak volcanoes pose a risk to nearby communities in the Skagit Valley. In particular, this analysis asks where and how many people and elements of the built environment fall within the maximum envisioned lahar zones for these volcanoes. To accomplish this objective, a series of hazard and risk maps were created (Figures 3.1 - 3.5). The maps focus on displaying how future volcanic hazards could impact incorporated towns, local recreation sites, emergency services, hospitals, transportation networks, and schools. Based on these maps, census data, and parcel records, estimates for total loss within the lahar zone in terms of population, land area, land type, and monetary value were calculated (Figure 3.6, Table 3.1, Table 3.2). Chapter Three presents the final hazard and risk maps as well as a description of the mapping methods and a discussion of insights gleaned from the maps.

Methods

Risk maps were generated by overlaying the USGS delineated volcanic hazard zones (Gardner *et al.*, 1995; Waitt *et al.*, 1995; Schilling, 1996) with vulnerable systems using geographic information system (GIS) software. A joint hazard map showing the location of both the Mount Baker and Glacier Peak hazard zones was created by combining the individual hazard zones for both volcanoes (Figure 3.1; Schilling, 1996). Geospatial data showing various elements of the build environment were added to the joint hazard map to determine where these features intersect the lahar zone. Color coding and the position of roads visually indicate vulnerable systems at risk from lahars

The Skagit County Digital Data Warehouse (SCDDW; 2014) provides access to parcel data and location records for the incorporated towns and cities, emergency service facilities, hospitals, and schools. Data on transportation networks were sourced from the Washington State Department of Transportation (2010) and additional land use data came from the United States Department of Agriculture (n.d.).

To quantify potential loss of life, property, and monetary resources associated with lahar activity, a total loss scenario is assumed. Such a scenario estimates the affects of the maximum envisioned lahar, meaning total loss within the entire delineated lahar zone. The 2014 American Community Survey's 5-year estimate of block group population (U.S. Census Bureau, 2015) was used to approximate potential loss of life. After isolating which block groups intersect the lahar zone, the population density of these block groups and the relative area within the lahar zone were used to calculate the number of people exposed. Data from the Skagit County assessor's office were used to identify which parcels overlap with the lahar zone and the area, land use, and monetary value corresponding to those parcels (SCDDW, 2014). The maximum land area affected was calculated as well as the area affected in various land use subclasses, such as residential and agricultural land. The building value, assessed value, and yearly tax revenue generated by the exposed parcel were also calculated. In terms of monetary loss, the results assume total loss of any parcel at least partially overlapping with the lahar zone.

Results & Discussion

In total, five risk maps were generated to show the spatial extent of volcanic hazards (Figure 3.1) and where national forest recreation sites (Figure 3.2), incorporated towns and cities (Figure 3.3), emergency services and hospital facilities (Figure 3.4), and schools (Figure 3.5) are located relative to hazard zones. The potential impact on transportation networks is also readily visible (Figure 3.4 & 3.5). Estimated loss of life and property are discussed in terms of what would result given a scenario assuming total loss within the lahar zone.

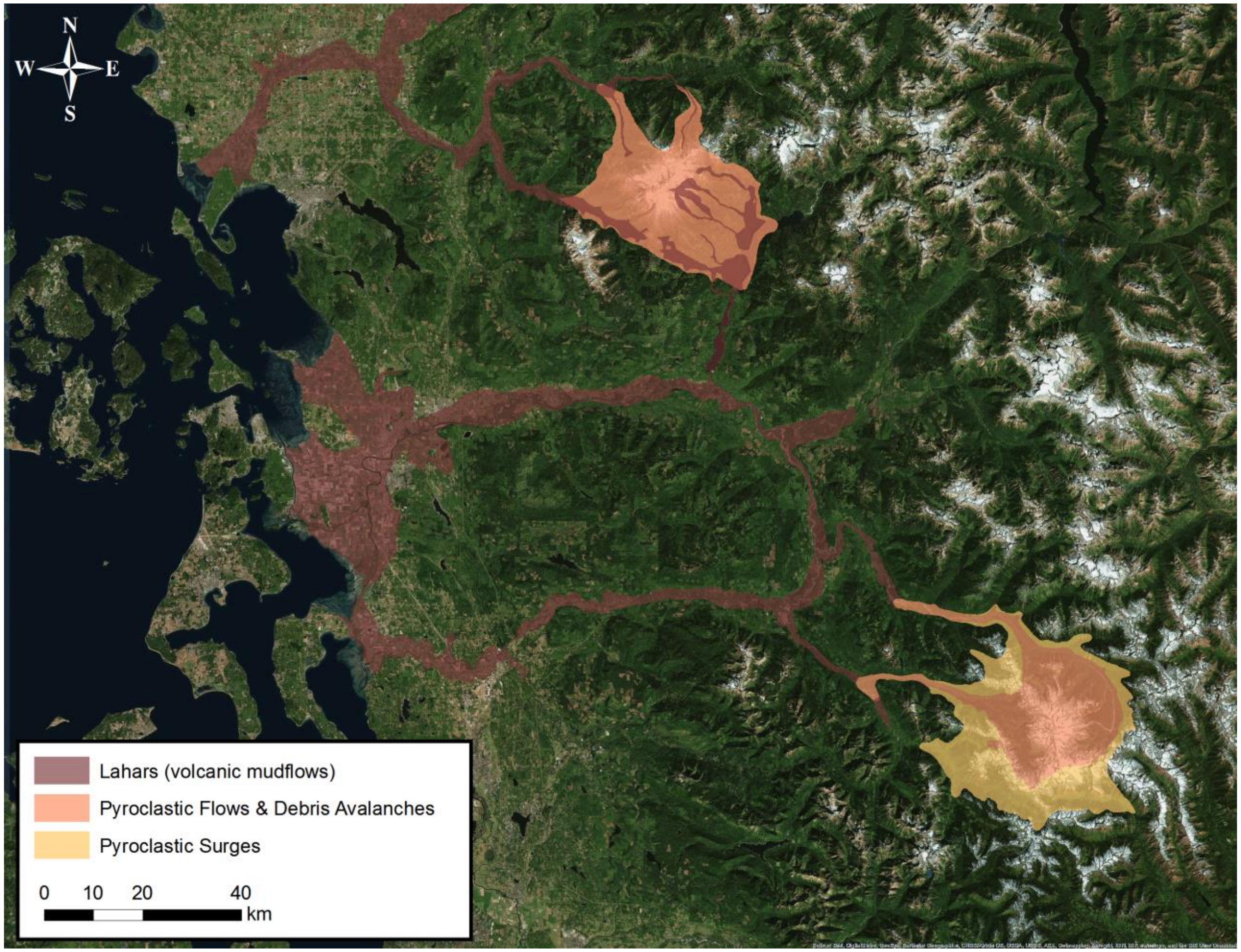

Figure 3.1: Mount Baker and Glacier Peak joint volcanic hazard map showing lahar, pyroclastic density current, and debris avalanche hazard zones

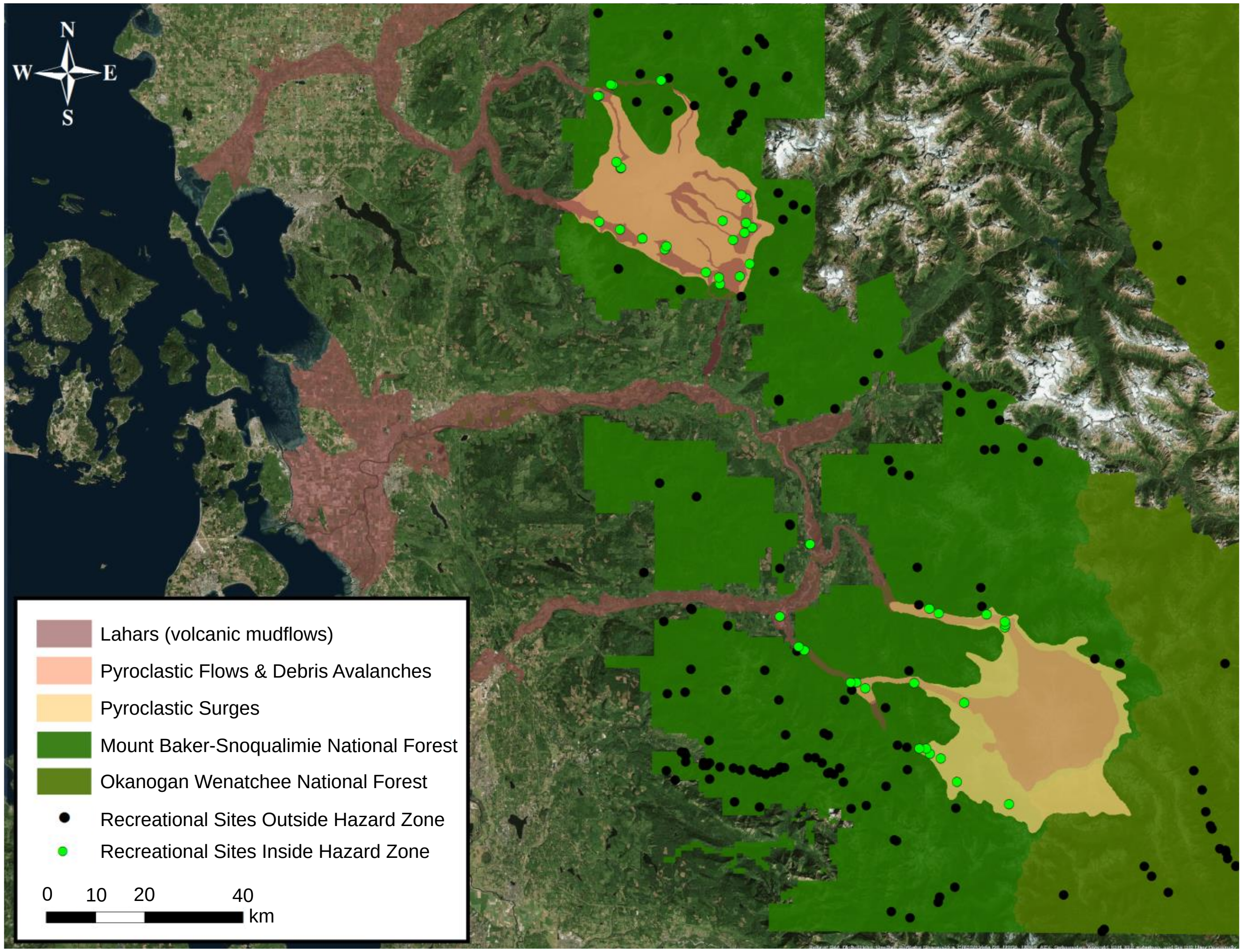

Figure 3.2: **Volcanic Risk Map – Intersection of volcanic hazard zones with national forest recreational sites**

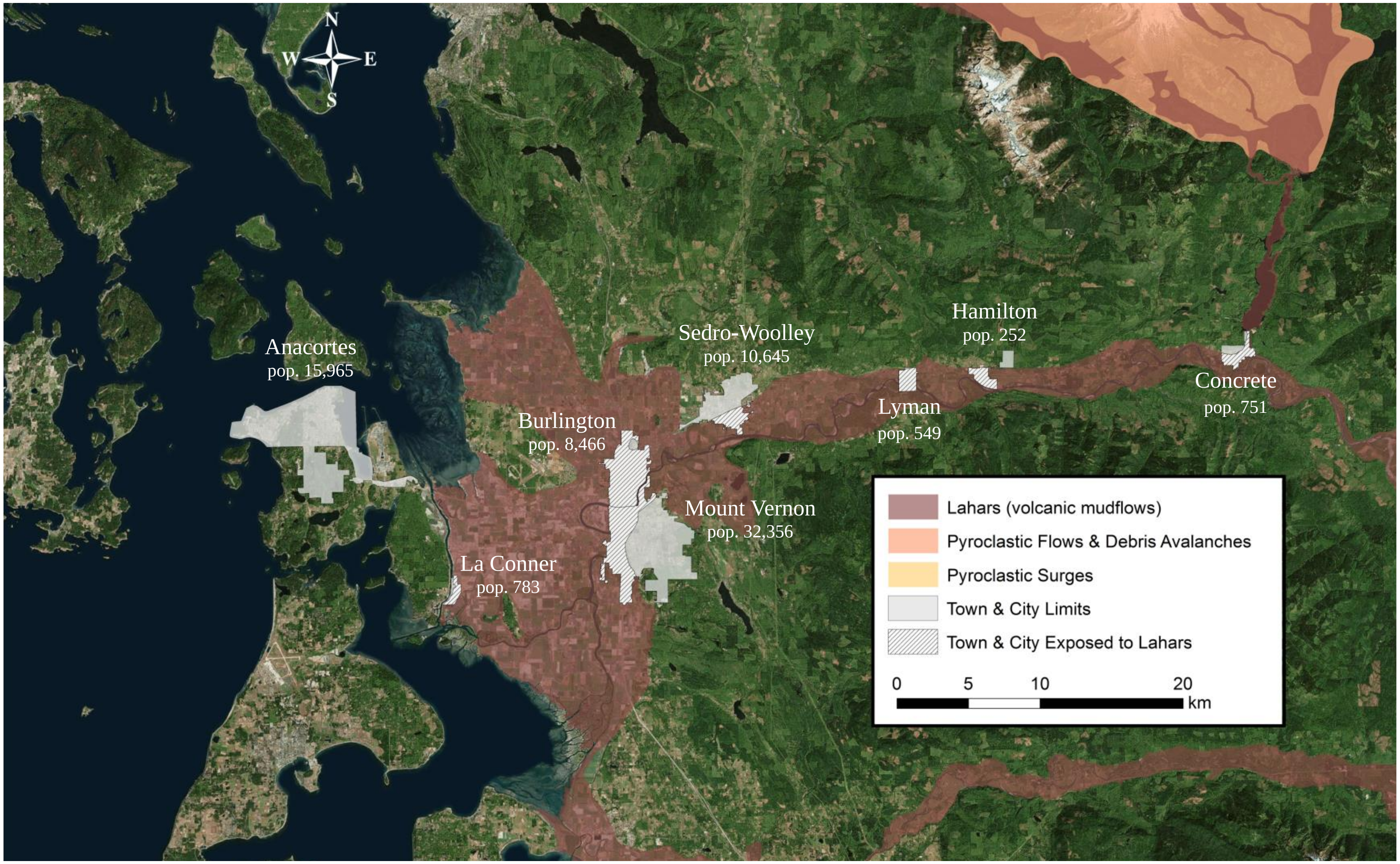

Figure 3.3: Lahar Risk Map – Intersection of lahar hazard zones with the incorporated towns of Skagit Valley

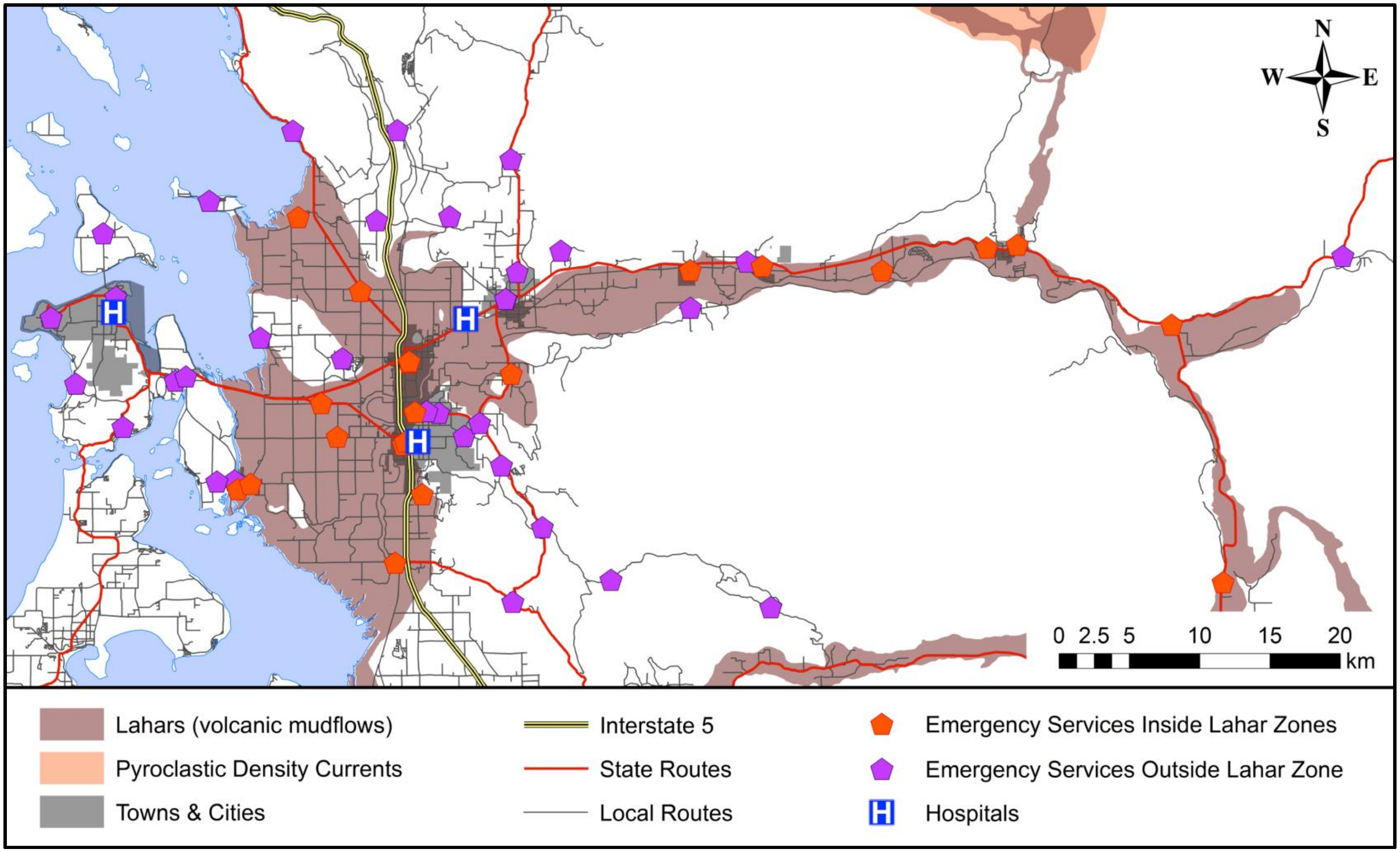

Figure 3.4: Lahar Risk Map – Intersection of lahar hazard zones with local emergency services and hospital facilities relative to local transportation networks

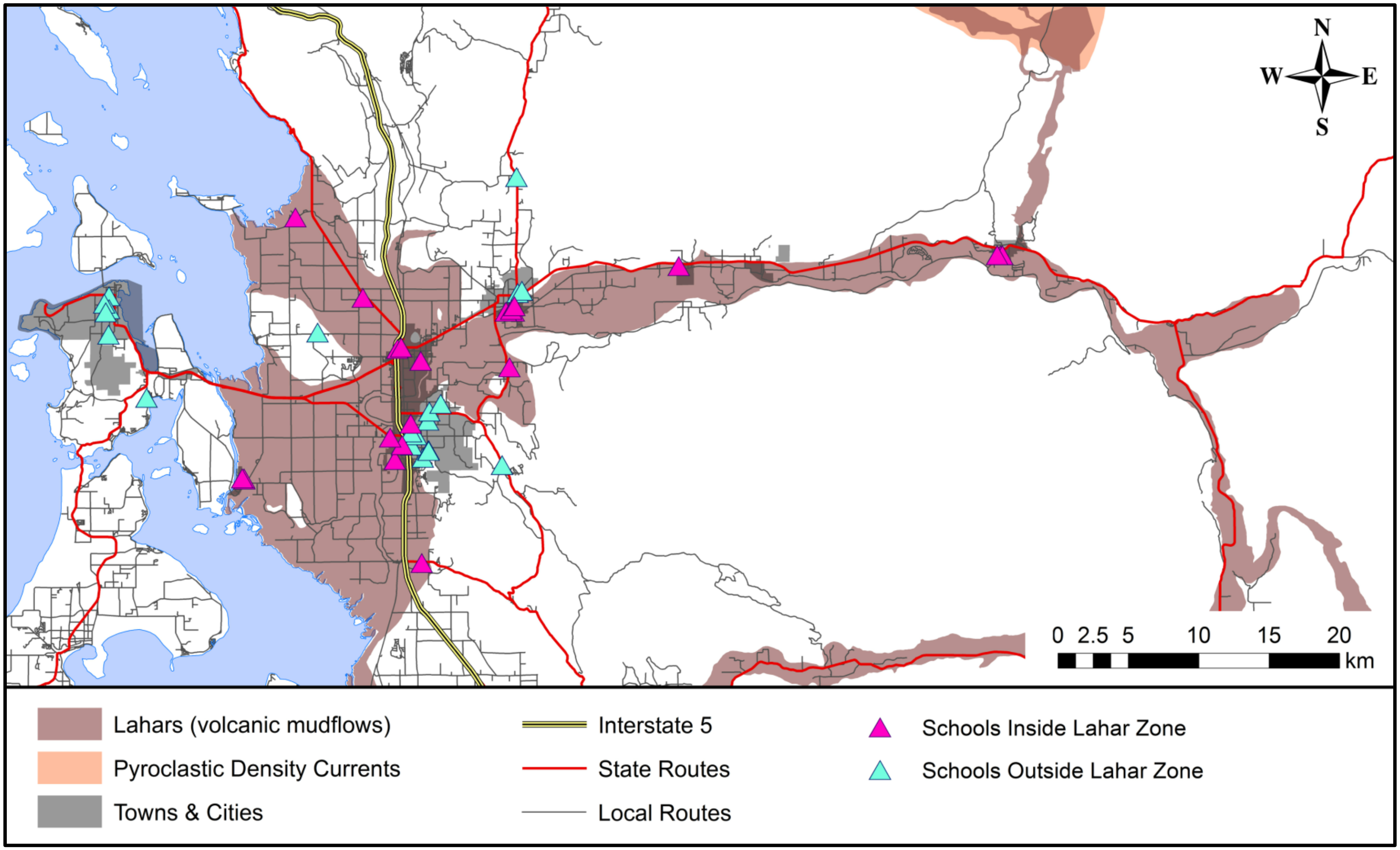

Figure 3.5: Lahar Risk Map – Intersection of lahar hazard zones with schools relative to transportation networks.

The joint hazard map (Figure 3.1) shows the lahar, pyroclastic density current (PDC), and debris avalanche hazard zones for both Mount Baker and Glacier Peak. Lahars are projected to affect multiple drainages that feed into the Skagit River. The area exposed to potential lahar hazards follows the path of the river, spreads out across the delta, and extends to Puget Sound. PDC and debris avalanche hazards remain confined to the immediate area around each volcano. Combined, these hazards are projected to influence up to 23 percent of the 212 recreational sites in the Mount Baker-Snoqualmie and Okanogan Wanatchee National Forests (Figure 3.2 & 3.6). PDCs and debris avalanches, however, are not projected to impact incorporated towns (Figure 3.3).

Figure 3.6: Potentially vulnerable systems in the Skagit Valley and the percent exposed (black) to lahar hazards

Seven incorporated towns lie partially or fully within the lahar zone (Figure 3.3). The towns of Concrete, Hamilton, Lyman, and La Conner have populations less than 1,000, but are almost entirely within the lahar zone (Table 3.1). Burlington hosts a large population (8,466 people) and is almost entirely (97%) within the lahar zone (Table 3.1).

Mount Vernon and Sedro-Woolley are the at-risk towns with the largest populations, but both only partially intersect the lahar zone (Table 3.1). Diefenbach *et al*. (2015) note similar findings in multiple lahar zones throughout the state: the towns with fewer people at risk also tend to be those for which a greater percentage of the town is within the lahar zone. Burlington represents the only exception to this finding. This distribution of exposure presents challenges for emergency managers in terms of how to best allocate planning efforts and resources.

Table 3.1 Incorporated Towns Exposure to Maximum Envisioned Lahar

Town	Town Population*	Total Area (km^2)	Area Within Lahar Zone (%)
Anacortes	15,965	40.71	0%
Burlington	8,466	11.43	97%
Concrete	751	3.1	68%
Hamilton	252	2.87	62%
La Conner	783	1.29	78%
Lyman	549	1.98	97%
Mount Vernon	32,356	32.26	35%
Sedro-Woolley	10,645	10.06	26%
Total	69,767	103.7	30%

*Population data from 2014 American Community Survey 5-year estimates.

The combined exposure of emergency service facilities and transportation networks (Figure 3.4) could greatly reduce response capabilities following a large lahar. Emergency services such as police and fire departments are essential for effective hazard responses, yet 39 percent of the facilities in western Skagit County will be damaged or inaccessible given a total loss scenario. Importantly, the two main routes through the county—Interstate 5 and Route 20, the main north-south and east-west transportation arteries, respectfully—and numerous local routes lie within the lahar zone and may be rendered unusable. Negative impacts on local transportation networks would isolate areas from remaining emergency service facilities, slow evacuation efforts, and impede access to victims. Also, although none are located within the lahar zone, hospital access would be reduced due to the impact on transportation networks.

Other important facilities such as city halls and schools will be affected by the maximum envisioned lahar. Nearly two-thirds of local city halls are within the lahar zone (Figure 3.6). The loss of government facilities may place additional stress on cities and their leadership during a hazard event. In terms of school exposure, 52 percent of the area's 42 schools are built within the lahar zone, which includes all schools between Concrete and Lyman and many on the delta (Figure 3.5). Most of the schools outside the lahar zone are either in Anacortes or on higher ground in Mount Vernon.

The location of schools relative to lahar hazard zones is of particular interest because children are a highly vulnerable population in natural disasters (Morrow, 1999; Cutter *et al*., 2003). A lahar occurring during school hours could pose a challenge in terms of evacuation. Following a lahar, the closure of damaged schools can create additional hardships for parents who work. Unable to send their children to school, parents stay home, and missing work negatively impacts their household income (Cutter *et al.*, 2003). For these reasons, Morrow (1999) emphasizes the importance of incorporating schools into hazard mitigation, evacuation, and rapid recovery planning efforts. Figure 3.5 highlights the need to account for schools in lahar planning in the Skagit Valley and specifically narrows down which schools warrant the most focus.

Table 3.2 Potential Losses Associated with the Maximum Envisioned Lahar

Exposed:	Count	Area (km^2)	Value: Building (billions)	Value: Assessed (billions)	Value: Taxes (millions)
Population+	39,706				
Parcels	24,283	418.6	$3.16	$5.16	$61.9
Residential	14,924	56.1	1.53	2.54	32.3
Single Family	11,840	45.2	1.22	2.00	26.0
Manufacturing	174	2.1	0.07	0.10	1.32
Transportation, Communications, Utilities	583	4.6	0.09	0.16	0.75
Trade	713	3.2	0.33	0.58	8.21
Services	1,319	8.8	0.80	1.14	11.0
Cultural, Entertainment, Recreational	453	9.9	0.06	0.10	0.35
Resource Production & Extraction	541	15.1	0.01	0.04	0.46
Undeveloped Land & Water Areas	5,576	318.7	0.25	0.52	7.53
Agricultural Land*	4,658	290.1	0.26	0.47	7.03

+ Estimates of the number of people at risk assume an equal distribution of the population within the census block groups. Population data from the 2014 American Community Survey 5-year estimates. *Combines all agricultural land classified within the Resource Production & Extraction and Undeveloped Land & Water Areas land use classes.

Table 3.2 provides estimates of the people and property at risk from lahars based on the census and county assessor’s data. Skagit County hosts a total population of 118,364 with 39,706 living in the joint lahar hazard zone for Mount Baker and Glacier Peak. This means that approximately one third of the county’s population lives at risk of injury or loss of life due to lahars. This value does not account for tourists or individuals who commute from outside the lahar zone to a workplace inside the lahar zone. As such, this value represents a lower bound estimate of exposure.

Assuming total loss within the lahar zone, the damage to property would be extensive, amounting to a total of 24,283 parcels lost. This represents $3.16 billion in losses due to building destruction alone and an overall loss of $5.16 billion in terms of total assessed value. The loss of these parcels would not only affect the rebuilding costs, but would also cost the county $61.9 million in tax revenue just in the first year following the disaster. In terms of the number and monetary value of exposed parcels, the most at-risk land use category under this scenario is the residential sector, which accounts for 61 percent of the parcels destroyed and around half of the projected monetary losses in terms of building value ($1.53 billion), assessed value ($2.54 billion), and tax revenue ($32.3 million). Single family residences would suffer the brunt of the impact with nearly 80 percent of affected residences falling into the single family home category. Substantial monetary losses would also result from the destruction of retail trade and service industry parcels. In terms of land area exposed, agricultural parcels would experience the most extensive loss under this scenario (approx. 290 km^2).

Overall, three key insights can be drawn from the production of these risk maps and the associated analysis. First, this work demonstrates the distribution of the maximum envisioned lahar's projected impact throughout the Skagit Valley. Smaller towns and unincorporated areas will likely be disproportionately affected by lahars as the majority of these areas lie within the lahar zone. The small towns and unincorporated areas face the loss of emergency service facilities as well as roads that would connect them to emergency services outside the lahar zone, likely reducing response capabilities. This is particularly true for the town of Concrete and the smaller, more impoverished towns upstream and closer to the volcanoes.

Based on vulnerable system and population exposure, Burlington represents one of the most at-risk locations in the Skagit Valley. Nearly the entire town of Burlington and all associated emergency services, schools, city halls, and transportation systems would be affected by the maximum envisioned lahar. Also, as the fourth largest town in the county, the Burlington's population is much larger than that of Concrete. This means that Burlington's exposure is high in terms of both raw numbers and percentages. A small region of Burlington is located above the lahar path and offers refuge, but this area would be isolated following a lahar, presenting a challenge for response efforts. Warning systems and evacuation routes would be especially helpful for Burlington since the town's distance downstream would allow greater time to mobilize evacuations.

Exposure also varies by land use. Residential housing represents the most at-risk land use category in terms of the number of parcels and monetary value exposed. Agricultural parcels are the most at-risk land use category in terms of amount of land area exposed. The bulk of these agricultural lands are clearly identifiable in the delta region (Figure 3.1) whereas the residential parcels largely cluster near incorporated towns.

By understanding the spatial distribution of risk throughout the community, emergency managers can better direct hazard response and recovery efforts to locations where they will be most effective. Contingency plans can be developed in advance to identify ways to adapt a response if emergency service facilities within the lahar zone become inaccessible. Emergency managers can identify improved means of supporting and protecting smaller communities upstream that lahars will likely cut off from surrounding areas and emergency services. Emergency managers can also use this information to tailor mitigation projects to address specific types of vulnerability. Based on the goal of the mitigation plan, efforts could reduce the number of people or parcels exposed, the percentage of different communities exposed, or the potential monetary losses associated with lahar activity. Alternately, planners could focus on mitigation projects that reduce the impact to certain types of parcels such as residential or agricultural land.

Second, limitations arise from using the maximum envisioned lahar zone to estimate impact. In reality, lahar hazards decrease with increasing distance downstream and elevation above the valley floor. Runout distances and the cross-sectional area of the lahar also vary based on the volume of material mobilized. Depending on the volume and cohesiveness of the lahar, the number and location of at-risk people and property would change. Although smaller volume lahars have smaller runout distances and cross-sectional areas, they occur more frequently than larger lahars. Knowing which areas would be affected by a smaller volume, more frequent lahar would help concentrate emergency planning in the most vulnerable areas of Skagit County.

Currently, the maximum envisioned lahar zone represents the only defensible estimate of possible lahar extent available. However, more detailed analyses of spatial exposure are possible and could account for variations in lahar characteristics (e.g., volumes, origin location, cohesiveness) and surrounding topography (e.g., slope, channel morphology). Lahar models, such as LAHARZ, exist and have been applied at similar volcanoes in the Cascades (McClung, 2005; Banker, 2008; Schilling, 2014). The unavailability of similar lahar scenarios for use in this study highlights the need for such modeling efforts in the Skagit Valley. Additionally, little is known about how the presence of Baker Dam and the Lake Shannon reservoir will affect the lahar hazard from Mount Baker (Gardner *el al*., 1995). Geological investigations into how lahars and other erupted material would interact with the reservoir based on different scenarios accounting for reservoir level, flow volume, and fluid dynamics could greatly enhance recurrence interval and inundation zone estimates.

Third, a lahar of the maximum envisioned size in the Skagit Valley would carry with it extensive and intensive damage. The total loss scenario would affect over 400 km^2 of land worth billions of dollars (Table 3.2). Schools, emergency service facilities, and infrastructure networks face the possibility of severe disruption. Most importantly, such a lahar would place nearly 40,000 individuals in harm’s way. This level of lahar exposure in terms of people and property in the Skagit Valley validates the demand to prepare at a community-wide and household level. It is the importance of preparing in this context that motivates the need to understand what controls the adoption of preparedness behaviors.

CHAPTER FOUR: RISK PERCEPTION & PREPAREDNESS STUDY

The following chapter provides a brief review of the research questions guiding the social sciences component of this thesis, describes the methods used in detail, reveals relevant results, and includes a discussion of these findings. For a detailed literature review and description of objectives, refer to Chapter Two. The methods, results, and discussion sections are written in the form of a journal article with multiple authors and will be included in a subsequent manuscript for submission to a peer-reviewed journal.

Research Summary

This chapter focuses on determining how people living or working in the Skagit Valley of Washington frame and respond to risks from volcanic lahars through a place-based knowledge, risk perception, and preparedness survey. Specifically, we examine the following research questions:

1. Does a disconnect exist between awareness, risk perception, and preparedness behaviors in the Skagit Valley?

2. Which of the elements outlined in the VBN theory and PMT exert the greatest influence on preparedness behaviors?

3. Given the positive influence that public participation in risk management has on public preparedness, does participation in hazard response planning and implementation at a professional level also translate into improved household preparedness?

Results indicate that perceived response-efficacy and protective response costs fail to drive preparedness behaviors. Perceived self-efficacy and ascription of responsibility beliefs play much greater roles in determining preparedness behaviors. Professional participation in response planning and implementation only marginally improves household preparedness but successfully increases confidence in officials and perceived self-efficacy.

Methods

We conducted an anonymous, voluntary survey through the online platform Survey Monkey using a non-random convenience sampling method. The questionnaire assessed the knowledge, risk perception, and preparedness levels of individual's living or working in the Skagit Valley. The full questionnaire is presented in Appendix A.

Questionnaire Development and Content

The questionnaire developed for this thesis incorporates questions modified from previous volcanic risk studies and was designed in consultation with scientists and emergency management officials. Questions were primarily adapted from the surveys of Davis *et al*. (2006), Barberi *et al*. (2008), Johnston *et al.* (2012), and classroom pilot studies by B.D. Brand (thesis advisor). An original question asking respondents to rate the influence of potential barriers on their preparedness decisions was also included. The wording, order, and presentation of the questions and information in the survey was developed with input and review from scientists at the Cascade Volcano Observatory and GNS Science New Zealand as well as emergency management officials with the Washington State Emergency Management Division and Skagit County Department of Emergency Management. The questionnaire was tested by two individuals to identify any remaining areas of confusion and determined to take around 10 to 15 minutes to complete. The final survey questionnaire and recruitment materials were approved by Boise State University's Institutional Review Board.

Participants answered questions divided over fives sections. All questions within a section were presented on a single page. The first section included seven questions that assessed previous hazard experience as well as perceptions regarding the probability of a volcanic hazard occurring, the severity of impacts associated with various threats, and individual concern level. The first question asked participants to identify which (if any) hazardous events they had previously experienced from a list of the 11 possible hazards. Lahars and ash fall were included in the list as the primary volcanic hazards. Respondents were also given the option to select “no hazards.”

Figure 4.1: Map indicating the location of the Skagit Valley (black box) shown to participants before introducing the use of “Skagit Valley” in survey questions.

The second question determined whether or not respondents were aware that volcanic hazards have affected the Skagit Valley in the past and will do so again in the future. We prefaced this question with a map to clearly show the area that we refer to as the Skagit Valley (Figure 4.1). The third and fourth questions asked, respectively, for respondents to rate the threat posed by different natural hazards to the community in which they live and work as well as their level of concern for each hazard. Respondents were provided the option to explain their concern in greater detail as an open-ended response. The sixth question dealt with the perceived likelihood of a lahar occurring over different time frames. The final question in the first section addressed perceived lahar hazard exposure of a respondent's home, workplace, and frequently traveled roads.

Within the first section, we provided the following definitions for lahars and pyroclastic flows:

- Lahar: a mud or debris flow that moves like wet concrete and is capable of transporting large boulders. Lahars originate from the slopes of volcanoes but may be triggered for volcanic and non-volcanic (e.g., heavy rain, glacial melt) reasons.

- Pyroclastic flows: a ground-hugging current of hot gas, ash, and rock commonly created in explosive volcanic eruptions.

Alongside these definitions, we included links to videos of lahars (Apolline Project, 2012) and pyroclastic flows (Earth Uncut TV, 2014). Videos were carefully selected to be representative of the hazard, educational, and avoid eliciting a negative response.

The second section of the survey focused on the interpretation of and trust in local hazard maps. At the beginning of this section, we provided respondents with the official USGS Mount Baker and Glacier Peak volcanic hazard maps (Figure 4.2). To establish how well people interpret these maps, participants were asked to identify which hazards affect the Skagit Valley and to assess how the threat changes with distance from the volcano. They were then asked to rate the degree to which they trusted the maps as realistic representations of the hazard.

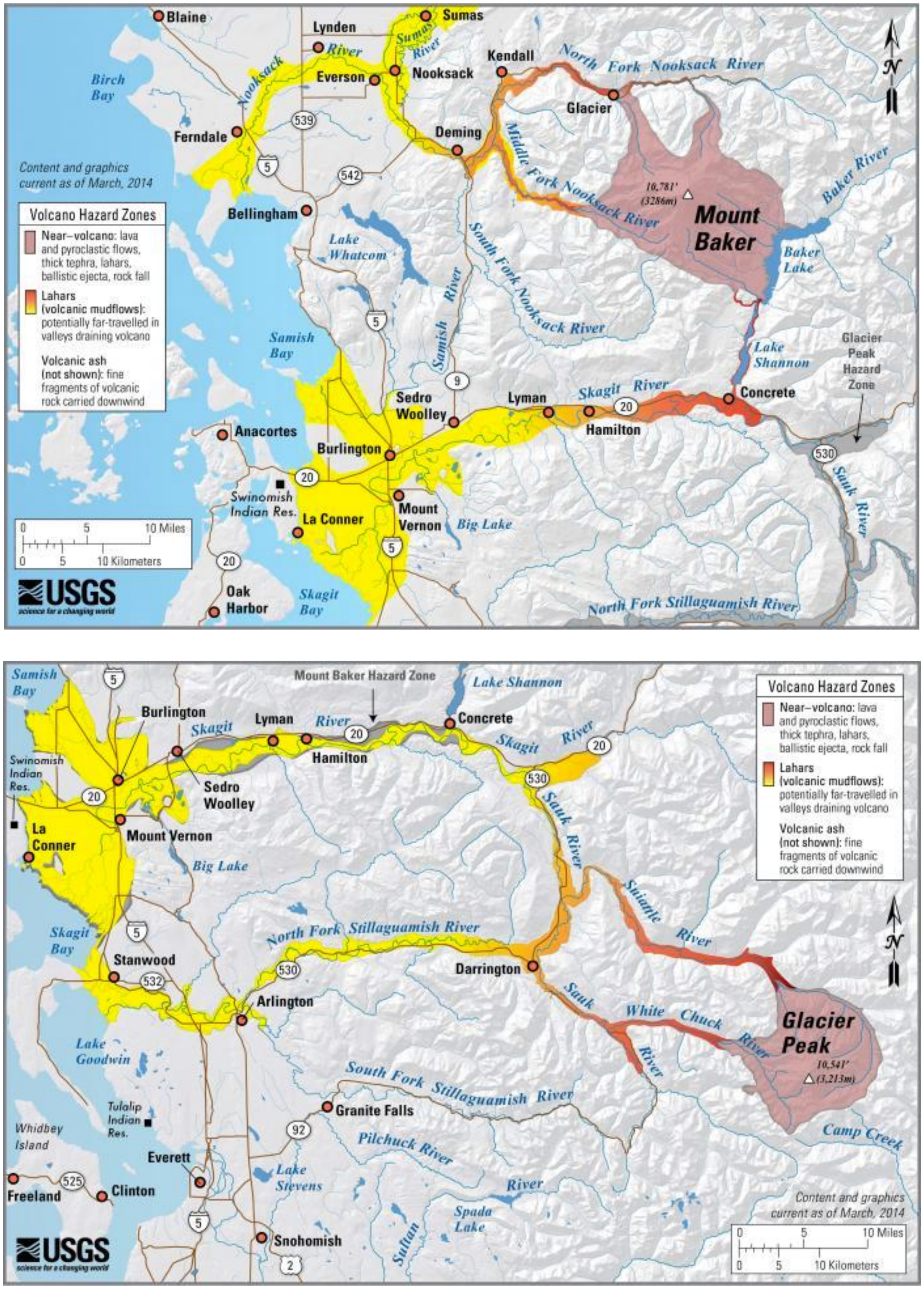

Figure 4.2: Mount Baker (top) and Glacier Peak (bottom) Volcano Hazard Maps Displayed in Online Survey (U.S. Geological Survey, 2014)

The third section of the survey dealt with information seeking behavior. We inquired whether or not a respondent had previously sought information about local volcanic hazards and the ease with which they found this information. We asked if they desired further information about local volcanic hazards, in what format they preferred to receive information, and which sources of information they trusted.

The fourth section of the survey investigated respondents' current level of household preparedness as well as issues of trust and perceived self-efficacy. The first question asked respondents to rate how responsible they felt for their own protection and provision of resources during a natural hazard. This question also asked how responsible they considered other entities—their neighbors or community members, local emergency services, FEMA, and friends and family—to be for providing protection and necessary resources.

In the second question of the fourth section, participants indicated which of 19 measures they had prepared. These measures were selected based on household preparedness recommendations from the Skagit Valley Department of Emergency Management, Washington State Emergency Management Division, Red Cross, and Ready.gov websites. Respondents were then asked to rate the extent to which nine proposed barriers prevented them from adopting further preparedness actions. The final question in the section inquired as to the respondent's confidence in their own knowledge, skills, and abilities as well as their confidence in the accuracy of scientific hazard assessments, official response capacity, and their community's ability to recover. We asked this last question after providing respondents with the list of recommended preparedness activities and items. Thus, responses to the last question may have been influenced by how people responded to the second question in this section or awareness gained from seeing the list of recommended preparedness actions.

The final section of the survey collected demographic data including zip code, occupation, age, sex, highest level of science education, household income, living arrangement, and length of residency. In addition to occupation, respondents were asked to indicate if they work as a first responder or in a leadership role within the local city government, hospitals, school districts, Red Cross, or utilities, transportation, or water companies. Those who responded yes are referred to in this study as response professionals as they are likely currently involved in hazard mitigation, planning, and/or response implementation.

Questionnaire Distribution Procedure

Survey respondents were recruited using a non-random convenience sampling method. For one week in August 2014, the research team distributed approximately 10,000 postcards throughout the Skagit Valley to advertise the survey (see Appendix C Figure C.1). We approached individuals at local farmer's markets, community events, and the county fair to briefly describe the project and, if interested, provide them with a postcard. The Skagit County Department of Emergency Management assisted in the promotion of the survey at the county fair, helping distribute postcards at their emergency preparedness information booth. Postcards were also placed on car windshields and stacks were left at local businesses, libraries, and town halls. Between August and December 2014, the research team identified all local hospitals, first responder agencies, churches, schools, and town government offices using an online search, collected business cards from local business advertising boards, and identified numerous social organizations through local websites. We contacted these entities by email and phone to request their participation in the survey and their assistance in sharing the survey with other members of their community. Posts on local social media boards, such as the Skagit Emergency Management and Skagit Breaking Facebook pages, as well as an article in the local paper, the Skagit Valley Herald, also helped recruit respondents.

As an incentive and to raise awareness for natural hazard preparedness, we provided survey respondents with links to educational material on hazard preparedness at the end of the survey. Participants were also offered the option of entering a drawing to win a 7” Double Power tablet as an additional incentive for participation. In total, 51 percent of participants entered the drawing with one person winning the tablet.

Participant Characteristics

Between August and December 2014, 507 individuals participated in the survey. Since these participants represent a nonrandom, convenience sample, no response rate can be calculated. Table 4.1 shows select demographic information for the survey participants compared to local census data (U.S. Census Bureau, 2015). Groups slightly overrepresented in the sample population include people aged 25 to 64 years and those with household incomes between $50,000 and $99,999. Women are the most overrepresented group in the sample while men and people aged 65 years and older are the most underrepresented groups.

Table 4.1 Survey Participant Demographic Compared to Skagit County Population

Sex:[1] *n = 455*	Survey Participants	County Population*
Female	63%	50.8%
Male	36%	49.6%
Transgender, Prefer not to say, Other	1%	---
Age: *n = 451*		
18 to 24	8%	11%
25 to 34	18%	16%
35 to 44	21%	15%
45 to 54	20%	17%
55 to 64	22%	18%
65+	12%	23%
Income: *n = 435*		
Under $20,000	6%	45%
$20,000 to $29, 999	9%	
$30,000 to $39,999	10%	
$40,000 to $49,999	13%	
$50,000 to $74,999	26%	20%
$75,000 to $99,999	18%	13%
$100,000 to $149,999	14%	14%
$150,000 and above	4%	7%

* 2014 American Community Survey 5-year estimates
[1] Sex operationalized as gender within survey questionnaire.

Data Analysis

Data analysis was conducted using R 0.98.1091 (R Core Team, 2014) and a combination of statistical methods based on the various data types collected. Percentages and frequency distributions show raw response data (Appendix B). For statistical tests, p-values less than or equal to 0.05 are considered statistically significant with increasing levels of significance denoted with asterisks (*p < 0.05, **p < 0.01, ***p < 0.001).

The questionnaire mainly included a combination of nominal and 5-point Likert-type questions. The Likert-type questions, with some variation, asked participants to rate their agreement with statements on a scale of 1 (strongly disagree) to 5 (strongly agree). Where necessary, an “I don’t know” category was included.

When using Likert data, it is important to distinguish between Likert-type items and Likert scales as each have different statistical assumptions and require different analytical methods. Likert-type items are single questions for which respondents answer on a given scale, such as 1 to 5 or strongly agree to strongly disagree. Likert-type questions produce ordinal data and should be analyzed using techniques appropriate for ordinal data. Likert scales, on the other hand, refer to a set of four or more related Likert-type questions that seek to measure a single underlying variable. Likert-type items can be summated or averaged to create a Likert scale that can be analyzed as a continuous variable (Clason & Dormody, 1994; Boone & Boone, 2012). Both Likert-type items and Likert scales are included in this study.

Given the mixture of nominal, ordinal, and continuous data collected, we analyze the questionnaire responses using a combination of statistical methods including the following: chi-square tests, Kendall's tau-b tests, a proportional odds cumulative logit regression (POLR) model, t-tests, and analysis of variance (ANOVA) tests. Chi-square tests examine goodness-of-fit or provide a test for independence between two variables. Chi-square tests of independence compare observed response frequencies with those expected if no relationship exists and the two variables are independent. A statistically significant p-value indicates that a relationship exists between the two variables; however, chi-square tests do not reveal the direction or magnitude of this relationship (Berman & Wang, 2011). Chi-square tests were used to compare two nominal variables or a nominal and an ordinal variable. For ordinal Likert-type responses, we combined the 1 and 2 rankings as well as the 4 and 5 rankings to ensure minimum expected values greater than five.

The Kendall's tau-b correlation coefficient provides a measure of association between two variables when at least one of the variables is binary or ordinal. The correlation coefficient indicates both the direction and magnitude of the association: a coefficient of -1 represents perfect inversion (perfect negative association), a coefficient of 0 indicates no correlation exists, and a coefficient of +1 denotes perfect agreement (perfect positive association). For example, in a hypothetical comparison of respondent perception of lahar threat and respondent concern for lahars, a Kendall's tau-b coefficient of +1 would indicate that as the perceived threat of lahars increases, the respondent's concern level increases the same amount. The coefficient is determined by pairing the data, taking the difference between the number of concordant and discordant data pairs, and normalizing this based on the total number of pairs as well as the number of tied pairs (The Pennsylvania State University, 2016). While the Spearman's rho correlation coefficient also applies to ordinal data, the ability of Kendall's tau-b to handle tied data pairs makes it the more appropriate method for this study.

POLR models are designed to model ordinal data by examining the degree to which the response to one ordinal dependent variable can be predicted based on responses to other independent variables. The impact of changing one independent variable is modeled while holding all other independent variables constant. POLR models indicate the degree to which the dependent variable is likely to be large (or small) using coefficients that represent cumulative proportional logits (log-odds). In some circumstances, the value of these coefficients can provide a relative ranking scheme. We used a POLR model to rank the relative importance of expressed barriers to preparedness. For additional information on POLR models see Agresti (2002).

Means were calculated for continuous responses (e.g., age) and summated Likert scales. T-tests were used to determine if a statistically significant difference exists between the means of two groups. To compare the means of three or more groups, we used ANOVA tests with subsequent Bonferroni pairwise multiple comparisons of means tests to isolate which group pairs were statistically different. The null hypothesis for both t-tests and ANOVAs is that no difference exists between the means of the groups in question. The alternative hypothesis states that the means of the various groups are different.

Measurement Scales

Preparedness

Measuring the complex concept of household preparedness poses a significant challenge for risk researchers, and appropriate methods for doing so remain poorly defined. Herein, we develop a new method for measuring household preparedness based on the preparedness actions that emergency management and response organizations recommend. These recommendations typically include (1) making a plan, (2) gathering supplies, and (3) seeking information. We refer to these as the planning, supplies, and action categories.

Survey participants were asked to indicate, based on a list of six activities and 14 supply items, which activities they had undertaken or items they had prepared. Two activities fell within the planning category and four within the action category. The number of activities and items that a respondent selected in each category were summed and normalized into three preparedness indicators—planning, supplies, action—measured on scales of 0 to 1. These indicator scores were then summed and normalized to generate a normalized composite preparedness (NCP) score for each participant.

Table 4.2 Optimization Model of Possible Normalized Composite Preparedness Scores Given Different Indicator Scores

Indicator			Normalized Composite Preparedness Score
A	B	C	
1	1	1	1
0	1	1	0.667
0	0	1	0.333
0	0	0	0

Using optimization modeling, we determined the corner solutions for the NCP score and examined how the NCP score changes with different indicator scores (Table 4.2). When a respondent adopts all recommended preparedness behaviors, all indicator scores and the NCP score equal 1. When we minimize one indicator score and maximize the remaining two, the NCP score drops to 0.667. Minimizing two indicator scores and maximizing the third results in a NCP score of 0.333. Thus, any individual who fails to adopt preparedness behaviors in at least one indicator category cannot have a NCP score higher than 0.667. Those who fail to adopt preparedness behaviors in two of the indicator categories cannot have a NCP score higher than 0.333. In situations where all indicator scores equal 0, meaning the respondent did not adopt any of the recommended preparedness behaviors, the NCP score equals 0.

This method substantially increases the importance of the planning and action indicators. These two indicators consist of two to four activities but each accounts for a third of the final NCP score. This is compared to the supplies indicator, which has 14 items. We assume that making plans and information seeking actions are equally as important as gathering supplies and designed the NCP score to reflect this assumption.

Overall, the NCP score provides (1) a continuous variable for measuring household preparedness, (2) a means for comparing household preparedness across individuals and groups, and (3) a measure that places less emphasis on individual supplies and more on planning and information seeking actions than would a simple count of how many measures they adopt.

Threat and Concern

We created summated Likert scales for two variables discussed in this study—perceived severity of threat and concern—and used Cronbach alpha to estimate the reliability or internal consistency of these scales. The perceived severity of threat scale was created by summing and normalizing respondent ratings of the threat (e.g., property damage, loss of life) posed by lahars, earthquakes, tsunamis, wildfires, and severe storms to the communities in which they live and work (alpha = 0.716; Table 4.3). The concern scale results from summing and normalizing of concern ratings for the same five natural hazards (alpha = 0.812; Table 4.4). Alpha values greater than 0.7 indicate an acceptable level of internal consistency for these two scales (Nunnally, 1978), meaning that the variables that make up these scales likely measure the same underlying concept (Tavakol & Dennick, 2011). By aggregating concern ratings across hazards, we measure a concept known as risk sensitivity, which refers to a respondent's predisposition to consider hazards risky. Some individuals simply tend to feel a higher level of anxiety or risk across all hazards compared to other individuals (Sjöberg, 2000).

Table 4.3 Cronbach Alpha Results for Perceived Severity of Threat Scale

	Means	Standard Deviation	Item Total Correlation	Alpha if Item Deleted	Cronbach Alpha
Perceived Severity of Threat					0.716
Threat posed by lahars	3.43	1.305	0.446	0.681	
Threat posed by floods	4.34	0.997	0.446	0.680	
Threat posed by earthquakes	4.16	0.954	0.518	0.663	
Threat posed by tsunamis	2.71	1.352	0.428	0.689	
Threat posed by wildfires	3.45	1.221	0.446	0.679	
Threat posed by severe storms	3.77	1.033	0.456	0.677	

Note: variables coded on a 5-point scale from “Strongly Disagree” (1) to “Strongly Agree” (5).

Table 4.4 Cronbach Alpha Results for Concern Scale

	Means	Standard Deviation	Item Total Correlation	Alpha if Item Deleted	Cronbach Alpha
Concern					0.812
Concern for lahars	2.58	1.354	0.515	0.797	
Concern for floods	3.82	1.158	0.553	0.787	
Concern for earthquakes	3.79	1.151	0.638	0.769	
Concern for tsunamis	2.42	1.304	0.543	0.789	
Concern for wildfires	3.02	1.280	0.583	0.780	
Concern for severe storms	3.42	1.138	0.623	0.772	

Note: variables coded on a 5-point scale from “Strongly Disagree” (1) to “Strongly Agree” (5).

Results

<u>The Disconnect Between Risk Perception, Awareness, and Preparedness</u>

To determine how a respondent's threat appraisal, or risk perception, influences preparedness in the Skagit Valley, we examine the following questions:

- Are those who perceive a higher probability of exposure better prepared?
- Are those who believe hazards pose a greater threat to property and lives better prepared?
- Are those who are inherently more concerned about risks better prepared?

We examine perceived probability of hazard exposure based on two questions. The first measures respondent awareness of past and potential future impacts of volcanic events in the Skagit Valley (Table 4.5). The second gauges perceived exposure to lahar hazards at a respondent's home, workplace, or on frequently traveled roads (Table 4.6). Respondents were not shown hazard maps prior to answering these questions nor were they asked to revise their earlier responses after seeing the map. However, the survey tool did not preclude the option of returning to a previous page and changing responses.

Table 4.5 Comparison of Average NCP Score Based on Awareness of Past and Future Volcanic Hazard Risk

		Dependent Variable: NCP Score			
Independent Variable	Respondents	Mean	Standard Deviation	t-value	p
Aware of past volcanic impacts	*n = 454*			-2.11	0.036
Yes	65%	0.49	0.27		
No	35%	0.44	0.28		
Aware of future volcanic impacts	*n = 453*			-1.71	0.089
Yes	83%	0.48	0.27		
No	17%	0.42	0.29		

Response frequencies show that the majority (65%) of respondents are aware that volcanic hazards occurred in the past in the Skagit Valley, and even more (83%) are aware of the potential for future volcanic events (Table 4.5). T-tests were used to compare the average preparedness of those aware and unaware of past and future volcanic hazard impacts. A statistically significant increase in average NCP score of 0.05 occurs when respondents are aware of past volcanic hazards. However, respondents who are aware that volcanic hazards will impact the Skagit Valley in the future fail to achieve significantly different ($p > 0.05$) preparedness levels. Thus, awareness does not consistently result in improved preparedness.

Table 4.6 Comparison of Average NCP Score Based on Perceived Hazard Exposure

Question: Do you live in a lahar zone, work in a lahar zone, or cross a road within a lahar zone when driving between home and work?

			Average NCP Score	
Live in a lahar zone***				*n = 462*
	Yes	20%	0.47	
	No	48%	0.53	
	Don't Know	33%	0.40	
Work in a lahar zone***				*n = 458*
	Yes	20%	0.47	
	No	48%	0.52	
	Don't Know	31%	0.41	
Cross a road within a lahar zone when driving between home and work***				*n = 456*
	Yes	35%	0.53	
	No	33%	0.49	
	Don't Know	32%	0.40	

***ANOVA results: difference between means statistically significant at the level of $p < 0.001$. Bonferroni post-hoc tests indicate for each category that no difference exists between the preparedness of those who answer yes and those who answer no.

Next, we examine the extent to which respondents believe they are at risk from lahars (i.e., perceived exposure) and any impact this belief carries in terms of preparedness (Table 4.6). Perceived exposure is based on whether or not respondents believe that their home, workplace, or the roads they travel between each lie within a lahar hazard zone. Analysis of variance (ANOVA) tests reveal that statistically significant differences exist between mean preparedness level and perceived hazard exposure (Table 4.6). Bonferroni pairwise multiple comparisons of means tests indicate that respondents who believe they are exposed to lahars prepare no differently than those who believe they are not. This trend is evident across all three locations listed: home, workplace, and commonly traveled roads. The group means differ only when comparing the average preparedness of that those who believe the roads they travel are within the lahar zone and those who answered "I don't know."

Table 4.7 Kendall's Tau-b Correlation Between Preparedness Scores and the Perceived Severity of Threat and Concern Scales

	Perceived:	
Preparedness Measure	Severity of Threat	Concern
Planning	0.06	0.10*
Supplies	0.07*	0.06
Action	0.13***	0.11**
NCP Score	0.10**	0.11**

*Correlations significant at the p < 0.05 level. **Correlations significant at the p < 0.01 level. ***Correlations significant at the p < 0.001 level. Note: n varies from 405 to 426 due to missing values.

Finally, we examine how perceived severity of threat and concern affect preparedness behaviors (Table 4.7). Kendall's tau-b correlation coefficients show a weak but statistically significant positive correlation exists between perceived severity of threat and NCP score ($\tau_b = 0.10$, $p < 0.01$). This difference stems from statistically significant increases in the supplies ($\tau_b = 0.07$, $p < 0.05$) and action ($\tau_b = 0.13$, $p < 0.001$) indicator scores with increasing perceived severity of threat. A similarly weak, positive association exists between concern and NCP score ($\tau_b = 0.11$, $p < 0.01$); however, this difference results from statistically significant, positive correlations with the planning ($\tau_b = 0.10$, $p < 0.05$) and action ($\tau_b = 0.11$, $p < 0.01$) indicator scores.

Summary

Ideally, higher risk perception would motivate greater adoption of preparedness actions. However, comparing preparedness measures to the three elements of PMT's threat appraisal process—perceived exposure (i.e., perceived probability), perceived severity of threat, and concern (i.e., fear)—indicates that a disconnect exists between perception and preparedness in the Skagit Valley. Awareness of the potential for future volcanic events and perceived exposure to lahar hazards fail to motivate preparedness actions (Table 4.5 - 4.6). An increase in perceived severity and concern correlates with an increase in preparedness actions, but the correlation is weak (Table 4.7). Perceived severity and concern appear to function as influential but not controlling factors for preparedness.

These findings support the claim that no direct causal link exists between risk perception and preparedness (Sims & Baumann, 1983; Paton *et al.*, 2008; Wachinger *et al.*, 2013). An individual will not prepare if they lack awareness of the hazard, an understanding of the threat's severity, and some degree of concern for subsequent impacts. In this sense, a positive threat appraisal is necessary for motivating preparedness behaviors. Yet, as our results and those of previous studies show, a positive threat appraisal alone is not sufficient to motivate preparedness behaviors (Grothmann & Reusswig, 2006). Other factors mediate the step between perception and action (Paton, 2003). People assess their coping abilities and face tangible barriers that prevent action.

Table 4.8 Suggested Barriers to Preparedness and Concepts Measured

Suggested Barrier to Preparedness:	Wording in Questionnaire:
Barriers that reflect perceived protective response costs and lack of ability or resources	
Cost	Cost (too expensive)
Time commitment	Too time consuming
Lack of hazard knowledge	Not knowing what hazards could affect me
Lack of preparedness knowledge	Not knowing what to prepare
Barriers that reflect perception of scientific hazard assessments	
Accuracy and accessibility of scientific hazard information	Inaccurate, uncertain, or difficult to understand science, information, or maps
Barriers that reflect perceived probability of a hazard event	
Perceived likelihood of impact	I don't think a natural hazard is likely to affect me
Barriers that reflect perceived response-efficacy	
Perceived response-efficacy	Items will not help me protect myself
Barriers that reflect ascription of responsibility to others	
Altruism of others	My neighbors/community members have these items and will assist me
Reliance on emergency services	Emergency services provides necessary items and assistance

Barriers to Further Preparedness Behaviors

PMT argues that the elements of the coping appraisal process—perceived response-efficacy, self-efficacy, and protective response costs—largely control the adoption of preparedness behaviors (Grothmann & Reusswig, 2006). VBN theory posits that awareness of a hazard's consequences and the ascription of responsibility to one's self for the prevention of said consequences also affect the decision to prepare (Stern *et al.*, 1999; Stern, 2000; Slimak & Dietz, 2006). We examine the role that the coping appraisal, awareness of consequences, and ascription of responsibility processes play in motivating and preventing preparedness actions. To assess conscious barriers to preparedness and respondent opinions regarding what influences their preparedness choices, respondents were asked to rate the extent to which they agreed or disagreed, on a 5-point Likert scale, with a series of suggested barriers (Table 4.8).

Table 4.9 Response Frequencies and Ranking of Suggested Barriers to the Adoption of Further Preparedness Actions

Suggested Barrier	Agree[a]	Neutral	Disagree[b]	Relative Importance[+]
Not knowing what hazards could affect me	35%	27%	38%	1
Cost (too expensive)	26%	37%	37%	2
Too time consuming	23%	41%	36%	3
Not knowing what to prepare	28%	28%	44%	4
Inaccurate, uncertain, or difficult to understand science, information, or maps	13%	40%	47%	5
I don't think a natural hazard is likely to affect me	14%	23%	63%	6
My neighbors/community members have these items and will assist me	6%	26%	68%	7
Items will not help me protect myself	7%	22%	71%	8
Emergency services provides necessary items and assistance	3%	14%	83%	9

[a] Responses of 4 or 5 on a 5-point Likert scale. [b] Responses of 1 or 2 on a 5-point Likert scale.
[+] Ranking determined based on proportional odds cumulative logit regression model. Note: n varies from 459 to 463 due to missing values.

We determined the relative importance of these barriers using a POLR model (Table 4.9) and examined the influence of various factors on barrier ratings (Table 4.10). Overall, responses to 23 factors (e.g., initial preparedness level, demographics, trust, past experience, and self-efficacy) were compared to suggested barrier ratings using chi-square (Figure D.1) and Kendall's tau-b correlation analyses (Tables 4.9, D.1, & D.2). The most relevant results are presented herein with the full correlation tables and results available in Appendix D.

While none of the proposed barriers to preparedness actions garner a majority of respondent support (Table 4.9), the top four still form barriers for 35 to 23 percent of the survey population. A lack of hazard knowledge is the most frequently cited barrier to preparedness; over a third of respondents agree that not knowing which hazards could affect them prevents them from adopting further preparedness actions. Cost, time commitment, and lack of preparedness knowledge are the second, third, and fourth most significant barriers that people face, respectively; around one quarter (23-28%) of respondents considered these barriers to household preparedness. The top four barriers represent perceived protective response costs as well as actual resources people may lack. Even though cost and resource related barriers represent the most frequently cited barriers to preparedness, the majority of respondents (77-62%) indicate that, overall, protective response costs do not hinder preparedness behaviors.

Table 4.10 Kendall's Tau-b Correlations Among Select Factors and Suggested Barriers to Preparedness Actions

			Responsibility for Personal Safety				
Suggested Barriers	I	CO	RC	RP	RES	RF	RFF
Not knowing what hazards could affect me	-0.11**	-0.03	-0.02	-0.08	0.08*	0.17***	0.05
Cost (too expensive)	-0.21***	-0.07	-0.04	-0.10*	0.04	0.03	0.06
Too time consuming	0.01	-0.03	-0.03	-0.06	0.07	0.08	0.02
Not knowing what to prepare	-0.09*	0.03	0.01	-0.11*	0.13**	0.17***	0.06
Inaccurate, uncertain, or difficult to understand science, information, or maps	-0.02	0.02	0.01	-0.13**	0.03	0.08*	0.04
I don't think a natural hazard is likely to affect me	0.01	0.09*	-0.05	-0.12**	0.08	0.09*	-0.05
My neighbors/ community members have these items and will assist me	-0.00	0.19***	0.20***	-0.18***	0.12**	0.12**	0.15***
Items will not help me protect myself	-0.01	0.14***	0.07	-0.17***	0.04	0.05	0.03
Emergency services provides necessary items and assistance	-0.04	0.24***	0.03	-0.23***	0.15***	0.16***	0.06

Note: I = income, CO = confidence in ability of officials to provide timely and effective instructions, response, or evacuation, RC = fellow community members responsible, RP = self responsible, RES = local emergency services responsible, RF = FEMA responsible, RFF = friends and family responsible. *Correlations significant at the $p < 0.05$ level. **Correlations significant at the $p < 0.01$ level. ***Correlations significant at the $p < 0.001$ level. Note: n varies from 428 to 461 due to missing values.

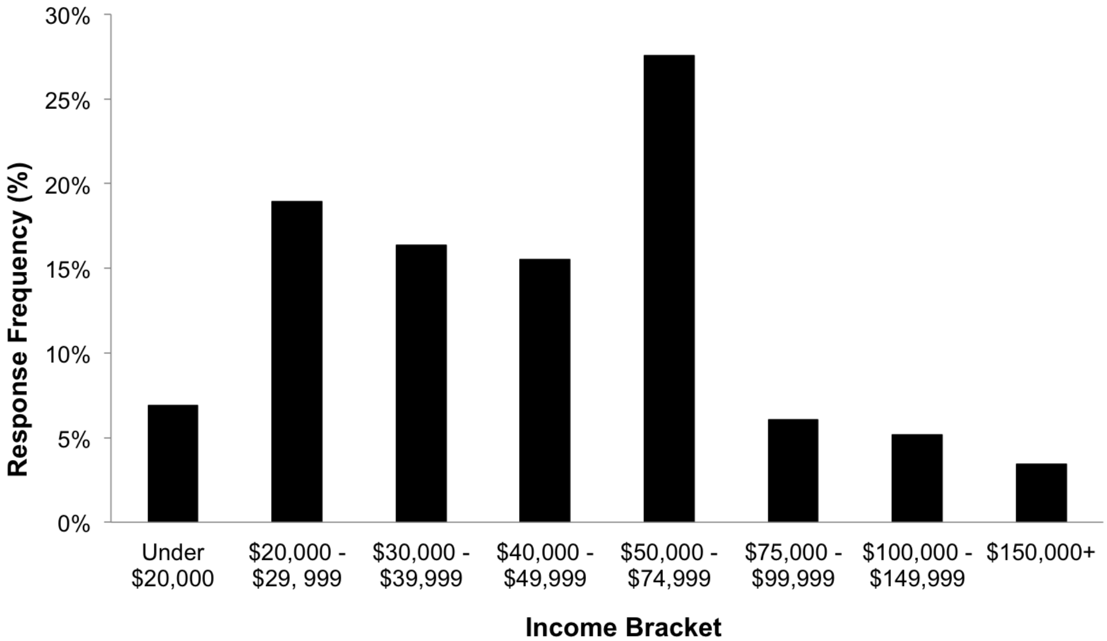

Figure 4.3: Income distribution of respondents for whom cost represents a barrier to preparedness. Some respondents from higher income brackets continue to cite cost as a barrier. For wealthier respondents, the expense associated with preparing may represent a perceived protective response cost. However, for those from lower income brackets, cost may form an actual barrier to preparedness. For reference, the median income in Skagit County is $54,917. Note: n = 116.

As noted, the monetary cost associated with preparing forms a barrier to the adoption of preparedness actions for 26 percent of respondents. For some, cost represents a barrier resulting from an actual lack of resources. For others, cost represents a barrier resulting from perception; individuals may perceive, perhaps wrongly, that the cost of preparing exceeds their means or outweighs any potential benefits. In this analysis, we do not distinguish between perceived and actual response costs; however, we note that respondents who consider cost a barrier to preparedness exhibit a range of economic backgrounds (Figure 4.3). The median household income in Skagit County is $54,917. The majority of respondents who select they “agree” that cost prevents them from preparing have incomes that fall below the bracket containing the median income ($50,000 - $74,999). Of respondents who consider cost a barrier, 28 percent fall within the median income bracket and at least 15 percent have an income higher than the median. Additionally, correlation analyses indicate that cost barrier ratings are negatively associated with income ($\tau_b = -0.21$, $p < 0.001$), meaning that cost becomes less of a barrier when the respondent is wealthier (Table 4.10).

Reliance on emergency services for resources and assistance was rated the least important barrier (Table 4.9). Among respondents, 43 percent disagreed and 40 percent strongly disagreed with the concept that a reliance on emergency services prevented them from preparing further. The idea that people stop preparing due to a reliance on other community members and neighbors for assistance, likewise, garnered little support as a barrier to preparedness. Only 6 percent of respondents indicated that this influenced their preparedness choices.

Table 4.10 shows that both of these barriers are negatively associated with personal responsibility (altruism of others: $\tau_b = -0.18$, $p < 0.001$; emergency services: $\tau_b = -0.23$, $p < 0.001$) and positively associated with confidence in the abilities of officials (altruism of others: $\tau_b = 0.19$, $p < 0.001$; emergency services: $\tau_b = 0.24$, $p < 0.001$), ascription of responsibility to local emergency services (altruism of others: $\tau_b = 0.12$, $p < 0.01$; emergency services: $\tau_b = 0.15$, $p < 0.001$), and ascription of responsibility to FEMA (altruism of others: $\tau_b = 0.12$, $p < 0.01$; emergency services: $\tau_b = 0.16$, $p < 0.001$). The altruism of others barrier is also positively correlated with ascription of responsibility to other community members ($\tau_b = 0.20$, $p < 0.001$) and friends and family members ($\tau_b = 0.15$, $p < 0.001$). These results indicate that respondents who accept greater responsibility for their own safety and provision of resources are more likely to state that a reliance on others does not prevent their preparedness. Alternatively, those who ascribe greater responsibility to others are more likely to support these two barriers. Finally, as respondents become more confident in officials, they are more likely to believe (1) emergency services will provide necessary resources and assistance during a hazardous event and (2) that this belief prevents them from adopting further preparedness actions.

The barriers assessing perceived likelihood of impact ("I don't think a natural hazard is likely to affect me") and perceived response-efficacy ("Items will not help me protect myself") were not considered important barriers to preparedness. Ranking sixth and eighth, respectively, the majority of respondents disagreed with these barriers. Only 14 percent of respondents felt the former belief prevented them from preparing and only six percent of respondents felt the latter belief prevented them from preparing. Few respondents indicate that concern over scientific hazard information accuracy and availability prevents them from adopting further preparedness actions (13%). Yet, less than half of respondents express disagreement with this as a barrier (47%). Around 40 percent of respondents selected a neutral, neither agree nor disagree, response (Table 4.9).

Table 4.11 Comparison of Average Preparedness Scores Based on the Level of Responsibility for Safety and Provision of Resources that Respondents Ascribe to Themselves

		Dependent Variable: NCP Score			
Independent Variable	Respondents	Mean	Standard Deviation	t-value	p
Respondent feels "very responsible" for their own protection and provision of resources:	*n = 460*			-3.64	0.0004
Yes	83%	0.50	0.27		
No	17%	0.37	0.27		

In addition to asking respondents to rate the importance of individual barriers, we examined how ascription of responsibility and perceived self-efficacy influence preparedness scores. All respondents consider themselves more responsible than any other entity (e.g., local emergency services, FEMA, community members) for their own safety; however, not all participants rate themselves as “very responsible” for their own safety, a rating of 5 on the Likert scale (Table 4.11). Approximately 17 percent of respondents select a lesser response of 2, 3, or 4. None of the respondents selected 1, or “not responsible.” T-test results indicate that a statistically significant difference exists between the preparedness levels of those who consider themselves “very responsible” and those who do not. The former have an average NCP score 0.12 points higher than the latter.

Table 4.12 Kendall’s Tau-b Correlations Among Ascription of Responsibility and Normalized Composite Preparedness Score of Respondents

	Ascribes Responsibility to: [a]				
	Self	Community Members	Local Emergency Services	FEMA	Friends & Family
NCP Score [b]	0.11**	0.05	-0.13***	-0.13***	0.08*

*Correlations significant at the $p < 0.05$ level. **Correlations significant at the $p < 0.01$ level. ***Correlations significant at the $p < 0.001$ level. [a] Responses rated on a five-point scale with 1 = not responsible and 5 = very responsible. [b] Continuous variable on a scale of 0 to 1.

Respondents also rated how responsible their fellow community members, local emergency services, FEMA, and friends and family are for their personal safety and the provision of resources. Kendall’s tau-b correlations reveal that the degree of responsibility an individual places on all entities, other than their fellow community members, significantly influences the adoption of preparedness behaviors (Table 4.12). The positive correlation between the variables self and NCP score ($\tau_b = 0.11$, $p < 0.01$)

supports the finding that those who feel more personally responsible prepare more. The level of responsibility placed on local emergency services and FEMA are both negatively associated with NCP score (both: $\tau_b = -0.13$, $p < 0.001$), indicating that respondent preparedness decreases when the level of responsibility that a respondent attributes to local and federal emergency services increases.

Table 4.13 Kendall's Tau-b Correlations Between Perceived Self-Efficacy Statements and Preparedness Scores

Statement	NCP Score	Planning	Supplies	Action
1. I have the knowledge and skills to ensure that I am prepared for a natural hazard:	0.35***	0.25***	0.36***	0.34***
2. I have the ability to protect myself and/or others from the effects of a ***flood***:	0.22***	0.11**	0.25***	0.25***
3. I have the ability to protect myself and/or others from the effects of a ***lahar***:	0.17***	0.10**	0.17***	0.18***
4. I am confident that I will know what to do during and after a ***flood***:	0.29***	0.20***	0.27***	0.31***
5. I am confident that I will know what to do during and after a ***lahar***:	0.25***	0.18***	0.25***	0.24***

*Correlations significant at the p < 0.05 level. **Correlations significant at the p < 0.01 level. ***Correlations significant at the p < 0.001 level. Note: n varies from 457 to 460.

Table 4.13 presents correlations among ratings for several self-efficacy statements (statements 1-5) and preparedness scores. Responses on all perceived self-efficacy statements correlate positively with NCP scores, meaning those who rate their knowledge, skills, and abilities higher also tend to be better prepared. This is true across all indicator variables, especially the supplies and action categories. Additionally, correlations between preparedness and self-efficacy are stronger when considering a frequently occurring hazard (flooding) as opposed to a rarer hazard (lahars). Stronger correlations are also found between preparedness and self-efficacy when the statement considered refers to preparedness (statement 1) rather than response and recovery activities (statements 2-5).

Summary

We find that protective response costs are the most frequently cited barriers to preparedness. Yet, those respondents indicating that response costs prevent them from preparing remain in the minority. For most, a lack of knowledge, money, or time does not dissuade them from preparing. Additionally, knowledge that volcanic hazards will affect the Skagit Valley in the future (Table 4.5) and awareness of lahar exposure (Table 4.6) appear to have no affect on actual preparedness levels. Low perceived response-efficacy likewise does not pose a barrier to preparedness according to respondents.

Opinions expressed by respondents indicate they do not consider ascription of responsibility beliefs to be important determinants of preparedness choices. In general, respondents state that a reliance on outside entities (i.e., neighbors, community members, or local emergency services) for their protection and the provision of necessary resources does not prevent them from preparing (Table 4.9). Such opinions, however, contradict evidence of actual changes in preparedness levels based on ascription of responsibility measures. Respondents who assign a high degree of responsibility for their personal safety to local emergency services and FEMA prepare less than respondents who consider themselves highly responsible for their own safety (Tables 4.11 & 4.12). High perceived self-efficacy also correlates with increased preparedness (Table 4.13).

Professional Participation's Influences on Household Preparedness & Personal Beliefs

To test the influence of professional participation in hazard response planning and implementation on household preparedness, we compare responses from 73 self-identified response professionals and 383 members of the general public on questions related to preparedness, hazard knowledge, information seeking behavior, trust, ascription of responsibility, and perceived self-efficacy.

Table 4.14 Response Professional and General Public Preparedness in Indicator Categories

	Response Professional	General Public
Planning Indicator		
Plan for contacting family members	44%	40%
Emergency contact person outside the area*	56%	43%
Supplies Indicator		
Flashlight and extra batteries	77%	71%
Water: 1 gallon/person/day for 3 days	49%	51%
Non-perishable food for 3 days	67%	63%
Non-electric can opener	82%	78%
Portable radio and extra batteries	48%	48%
Fire extinguisher	68%	69%
Smoke detector*	84%	72%
First aid kit	89%	81%
Essential medicine	47%	49%
Sturdy shoes	74%	64%
Whistle	42%	42%
Wrench or pliers to turn off utilities	67%	60%
Local maps	38%	35%
Blankets or sleeping bags	84%	74%
Action Indicator		
Bought additional insurance (e.g., home)	16%	23%
Sought out information on local volcanic hazards***	44%	23%
Someone in the family has learned to provide first aid***	85%	59%
Know who in your neighborhood or community may need additional help (e.g., elderly, families with small children)***	62%	35%

Note: n varies from 455 to 451 due to missing values. *Correlations significant at the $p < 0.05$ level. **Correlations significant at the $p < 0.01$ level. ***Correlations significant at the $p < 0.001$ level.

Chi-square tests were used to compare the number of recommended preparedness activities respondents adopt or supplies they acquire (Table 4.14). Results show that statistically significant differences exist between response professionals and the general public for five of the 20 preparedness measures listed. Compared to members of the general public, 13 percent more response professionals have identified an emergency contact person outside the Skagit Valley and 12 percent more have a smoke detector. The largest and most significant differences are the 21 percent increase in information seeking behavior among response professionals and the approximately 26 percent increase in knowledge of first aid and who in their neighborhood or community may need additional help. Interestingly, no statistically significant difference is present between response professionals and the general public for the remaining 15 recommended household preparedness measures.

Table 4.15 Comparison of Average Preparedness Scores Among Response Professionals and the General Public

Independent Variable	Mean	Standard Deviation	t-value	p
	Dependent Variable: Planning Score[a]			
Response Professional	0.50	0.45	-1.47	0.15
General Public	0.42	0.44		
	Dependent Variable: Supplies Score[a]			
Response Professional	0.65	0.28	-1.17	0.24
General Public	0.61	0.29		
	Dependent Variable: Action Score[b]			
Response Professional	0.52	0.26	-5.04	< 0.001
General Public	0.35	0.28		
	Dependent Variable: NCP Score[b]			
Response Professional	0.56	0.27	-2.87	0.01
General Public	0.46	0.27		

[a] n = 455; [b] n = 450

Difference of means (t-test) analyses indicate that no statistically significant difference exists between the average planning and supplies indicator scores of response professionals and the general public (Table 4.15). However, the average action indicator score for response professionals is 0.17 points greater than that of general public respondents, a statistically significant difference. Given these indicator scores, the average NCP score for response professionals is nearly 0.10 points higher than the score for the general public, which is also a statistically significant increase.

Table 4.16 Interpretation of the Mount Baker Volcanic Hazard Map by Response Professionals and General Public Respondents

	Response Professional	General Public
Which hazards impact the Skagit Valley? (*n = 455*)		
Thick Tephra*	55%	41%
Lava	30%	27%
Lahar[1]	96%	95%
Pyroclastic Flow*	38%	25%
Rock Fall	29%	25%
Does the hazard from Mount Baker increase, decrease, or remain the same with distance downstream? (*n = 454*)		
Increase	33%	28%
Decrease	58%	60%
Remain the same	10%	12%
Overall Map Interpretation		
Correctly Identify Hazard	37%	45%
Correctly Identify Directionality of Hazard	58%	60%
Correctly Interpret Both Hazard Map Questions	27%	29%

*Response frequencies significantly different at the $p < 0.05$ level based on chi-square tests
[1]1 of 4 cells has minimum expected value less than 5

To determine how professional participation in hazard response planning and implementation influences knowledge, we examined the ability of respondents to correctly interpret local volcanic hazard maps based on two questions. After providing participants with the USGS Mount Baker volcanic hazard map, we asked participants to identify which hazards would affect the Skagit Valley and whether the hazard increases, decreases or remains the same with distance from the volcano. When interpreted correctly, respondents indicate only lahars impact the Skagit Valley and the hazard decreases downstream, away from the volcano.

Nearly all respondents in both groups correctly identify that lahars affect the Skagit Valley (Table 4.16). A higher percentage of response professionals select that thick tephra and pyroclastic flows impact the Skagit Valley. Both groups select lava and rockfall hazards at the same rate. For this question, the correct response is that only lahars affect the Skagit Valley. Given this definition, 37 percent of response professionals and 45 percent of the general public answer the question correctly, but this is not a statistically significant difference.

Response professionals and the general public also answer the second map interpretation question correctly at the same rate (Table 4.16). Nearly 60 percent of respondents in both groups correctly answer that the lahar hazard from Mount Baker decreases with distance downstream. Overall, 27 percent of response professionals and 29 percent of the general public correctly answer both questions, an insignificant difference (Table 4.16).

Table 4.17 Comparison of Information Seeking Behavior Among Response Professionals and the General Public Respondents

Information Seeking *(n=451)*	Response Professional	General Public
Sought Information***	44%	23%
Want to Learn More	82%	78%

*** Response frequencies significantly different at the $p < 0.001$ level (chi-square test)

We also compared information seeking behavior among response professionals and the general public (Table 4.17). The percent of response professionals who previously sought information about local volcanic hazards is 21 percent greater than the percent of general public respondents, a statistically significant increase. However, this difference disappears when desire to learn more about local volcanic hazards is considered. Around 80 percent of respondents in both groups desire more information.

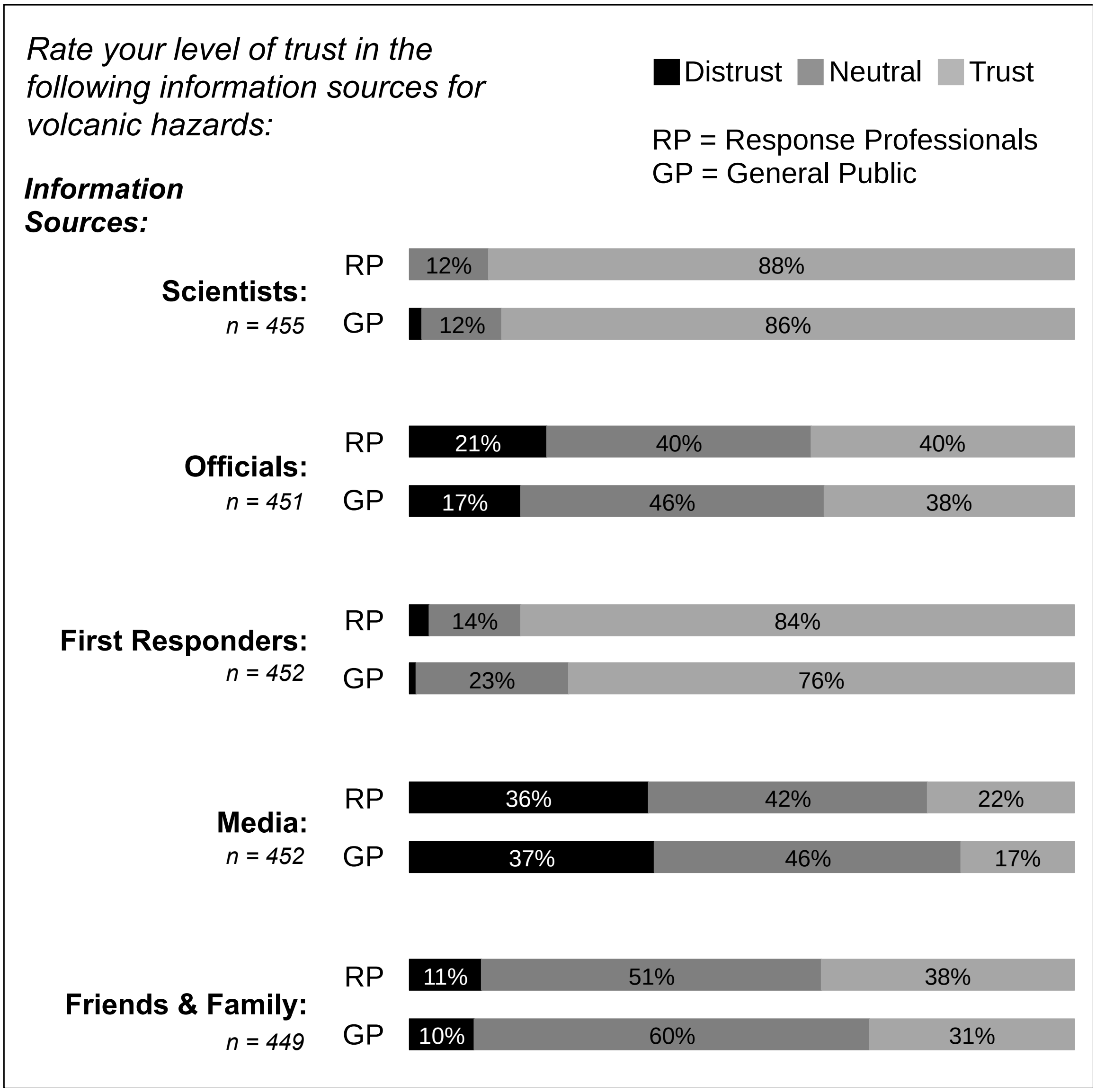

Figure 4.4: Trust levels in information sources by response professionals and the general public. Chi-square analysis indicates no statistically significant differences exist between response frequencies for the two groups. Scientists and first responders are the most trusted while the media is the least trusted information source.

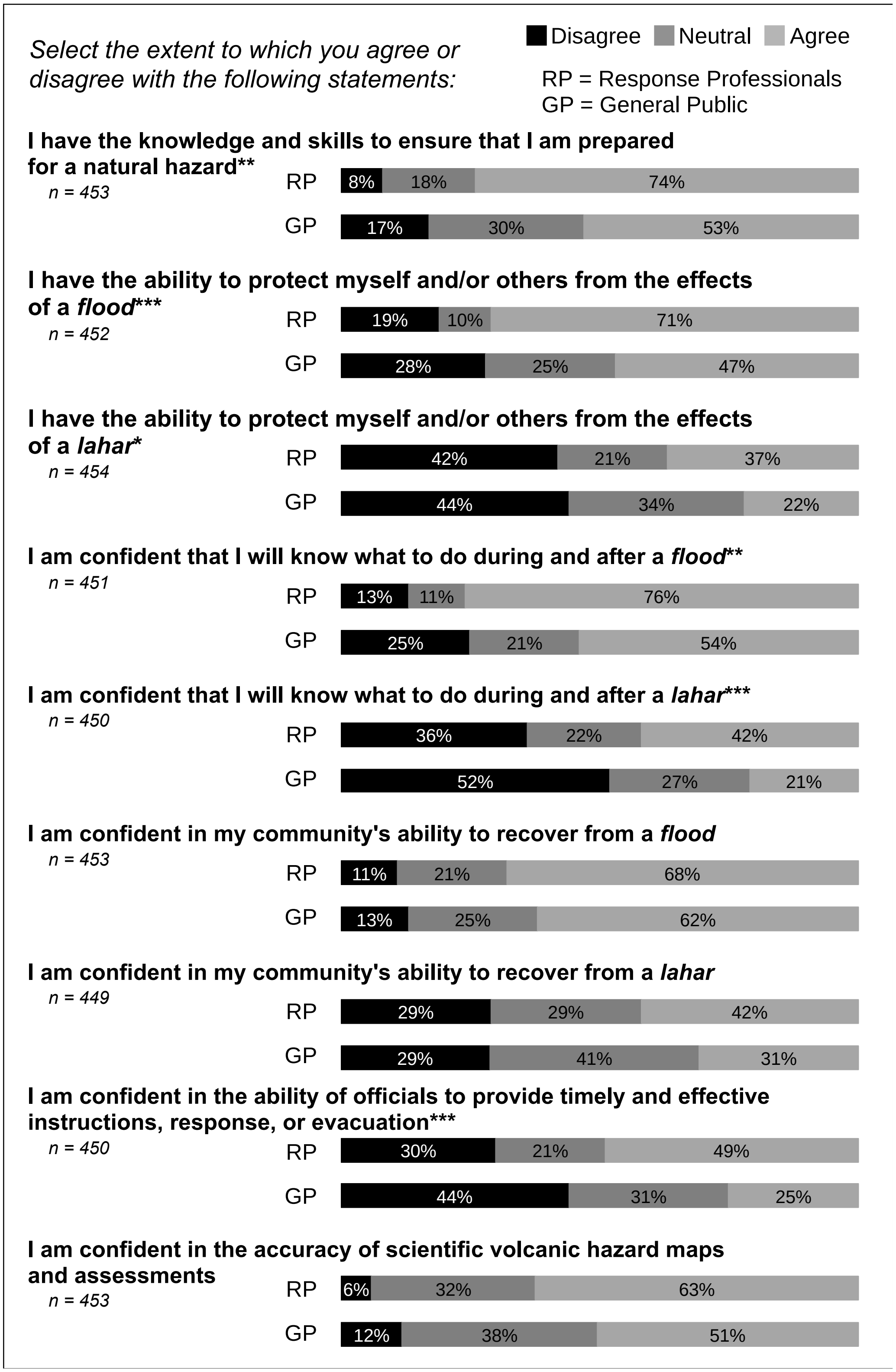

Figure 4.5: Ratings of self-efficacy and confidence statements by response professionals and the general public. Response frequencies significantly different at the levels *p < 0.05, **p < 0.01, and ***p < 0.001 (chi-square tests). Response professionals express greater perceived self-efficacy than the general public respondents.

The influence of participation on trust in information sources (Figure 4.4), confidence in officials, and confidence in scientific information (Figure 4.5) was analyzed using chi-square tests. Trust in information sources does not differ between the two groups. Both groups trust scientists and first responders most and the media least. Officials are the second least trusted sources of information. Most respondents neither trust nor distrust their friends and family members as information sources. The majority of respondents in both groups also feel confident in the accuracy of scientific volcanic hazard maps and assessments. However, response professionals express significantly more confidence in the ability of officials to provide timely and effective instructions, response, or evacuation ($p < 0.001$).

We compared the influence of professional participation on self-efficacy and confidence in personal and community abilities using the statements in Figure 4.5. Response professional and general public respondents foster similar levels of confidence in their community's ability to recover from a lahar or flood. Significantly more response professionals agree with each self-efficacy statement ($p < 0.05$). This trend holds regardless of if the statement refers to a frequent hazard (flooding) or a rare hazard (lahars). However, the increase is more pronounced when considering flooding. On average, agreement with self-efficacy statements increases by 21 percent (range: 15-24%) when respondents identify as response professionals.

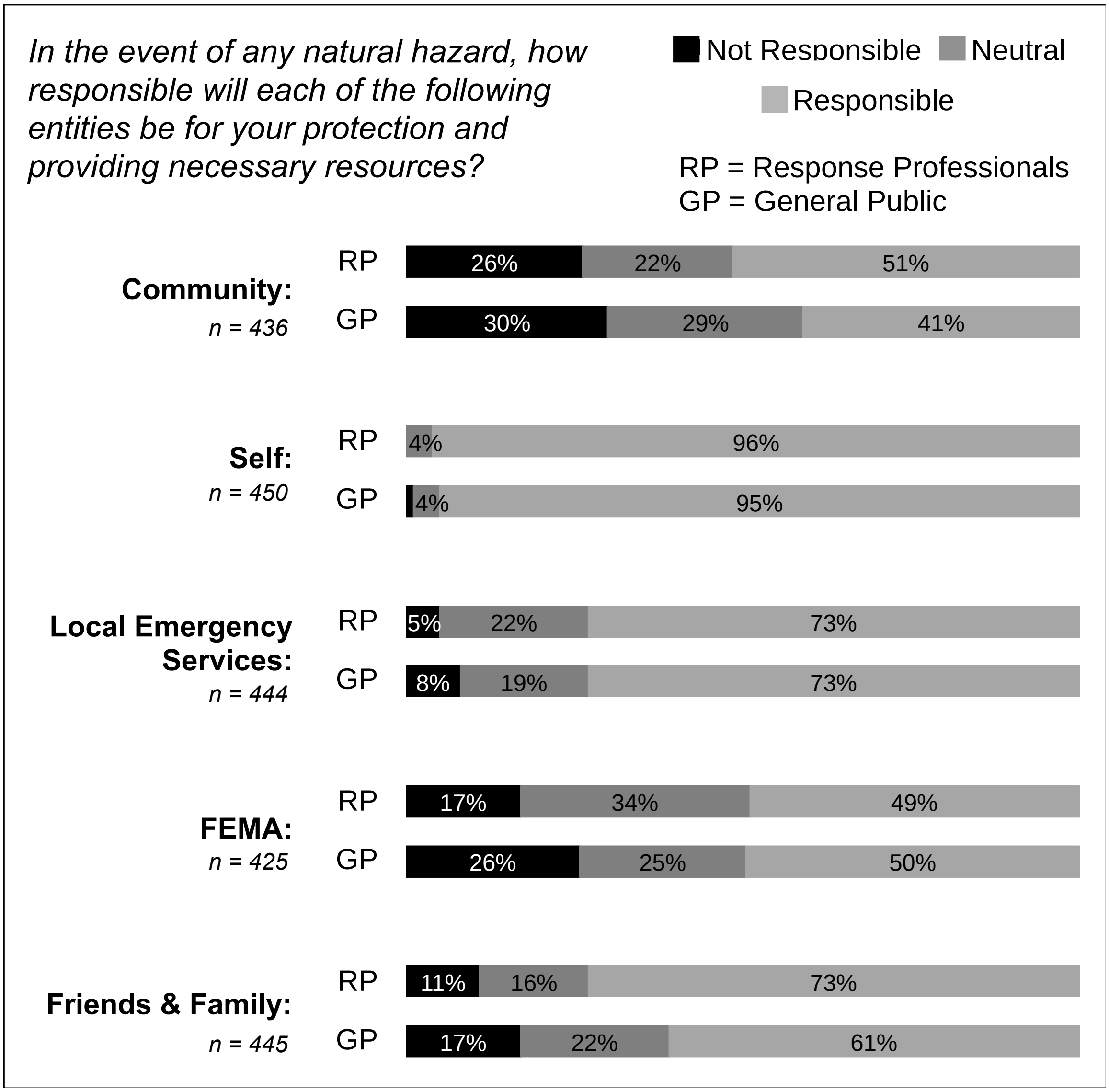

Figure 4.6: Degree of responsibility for personal safety and resource provision ascribed to various entities by response professionals and the general public. Based on chi-square tests, no statistically significant difference exists between response professional and general public ascription of responsibility. Both groups feel personally responsible for their own safety and resource provision. Respondents view local emergency services as the next most responsible entity.

The influence of participation on personal agency and the transfer of responsibility is assessed based on how much responsibility for their own safety a respondent accepts and how much they attribute to others. Statistically, both groups assign a similar degree of responsibility to all external entities (Figure 4.6). Respondents in both groups state that they, themselves, are most responsible for their personal safety during a natural hazard. They consider local emergency services and friends and family members the next most responsible. Other community members and FEMA are considered somewhat responsible.

Summary

Researchers frequently recommend increasing public participation in risk management in order to close the gap between awareness, risk perception, and preparedness. Previous studies indicate that increased public participation should positively influence preparedness levels, knowledge, trust in officials, ascription of responsibility, and perceived self-efficacy (Paton *et al.*, 2008; Wachinger *et al.*, 2013). We examined whether or not these advantages also apply to response professionals, individuals who participate in risk management at a professional level. Our results indicate the following:

- *Preparedness levels* only minimally improve with participation in hazard response planning and implementation. Response professions achieve higher NCP scores due to a higher action indicator score. In particular, more response professionals have someone in their family that has learned to provide first aid and know who in their neighborhood or community may need additional assistance during a natural hazard. To a lesser extent, more response professionals have also identified a non-local emergency contact, installed a smoke detector, and sought information about local volcanic hazards.

- *Knowledge* was assessed based on shifts in information seeking behaviors and ability to interpret local volcanic hazard maps. Nearly twice as many response professionals have previously sought out information about local volcanic hazards. However, response professionals fail to interpret local volcanic hazard maps more accurately than the general public respondents.

- *Trust in officials* as sources of information remains unchanged by participation, but response professionals are far more confident in the abilities of officials to respond to hazards in a timely and effective manner.

- *Ascription of responsibility* beliefs do not change with increased participation, but *perceived self-efficacy* is significantly higher among response professionals.

Discussion

Enhancing the understanding of what drives preparedness actions remains a cornerstone of risk perception and behavior motivation research. The majority of previous studies indicate that knowledge, awareness, and risk perception (i.e., threat appraisal) alone fail to motivate preparedness actions (Sims & Baumann, 1983 and references therein; Slimak & Dietz, 2006; Grothmann & Reusswig, 2006; Paton *et al.*, 2008; Wachinger *et al.*, 2013). Our study of lahar knowledge, risk perception, and preparedness reveals similar findings in the Skagit Valley, findings that motivate further exploration of what causes this disconnect (i.e., what barriers people face).

Grothmann and Reusswig (2006) applied PMT to explain the adoption of precautionary actions to prevent property damage from flooding in Cologne, Germany. Their results, based on phone interviews with 157 randomly selected households, indicate that coping appraisal plays a more substantial role in determining protection behaviors than threat appraisal. Our results support this conclusion. We show that perceived probability, severity of threat, and concern exhibit either no correlation or weak correlations with preparedness behaviors (Tables 4.5 - 4.7), whereas correlations between perceived self-efficacy and preparedness measures are the strongest correlations documented in this study (Table 4.13). Our findings expand upon those of Grothmann and Reusswig by investigating the influence of all three components of the coping appraisal—perceived protective response costs, self-efficacy, and response-efficacy—on behavior motivation. We also incorporate ascription of responsibility beliefs from the VBN theory into this analysis.

We find that protective response costs (e.g., knowledge, money, time) and perceived response-efficacy fail to emerge as overwhelming drivers of preparedness behavior. A third of respondents indicate that a lack of hazard knowledge prevents them from preparing and a quarter indicate that cost, time commitment, or a lack of preparedness knowledge influences their choices. Barely seven percent of respondents state that low response-efficacy beliefs ("items will not help me protect myself") prevent them from preparing further.

However, perceived self-efficacy and ascription of responsibility, while less readily recognized as barriers to preparedness, significantly affect actual preparedness levels. The vast majority of respondents (68-83%) believe that a reliance on others for assistance does not reduce their preparedness behaviors. Yet, correlations show a significant increase in the adoption of preparedness actions among respondents who express high self-efficacy and personal responsibility.

PMT and Understanding Preparedness Behaviors

Lindell and Prater (2002) examine the adoption of seismic hazard adjustments (i.e., preparedness behaviors) across three cities in California and three in eastern Washington. Terpstra and Lindell (2012) study the adoption of flood hazard adjustments in the Netherlands among residents of coastal and river floodplains. Both studies apply the Protective Action Decision Model (PADM; developed in Lindell & Perry, 1992), which is a modified version of PMT's coping appraisal. PADM explains that preparedness intentions and behaviors depend on hazard-related and resource-related attributes. Hazard-related attributes are an expansion of PMT's perceived response-efficacy that includes perceived efficacy for protecting people, perceived efficacy for protecting property, and utility of the adjustment for other purposes. Response-related attributes measure protective response costs (money, time, effort) and perceived self-efficacy (knowledge and skills). Terpstra and Lindell also give respondents the opportunity to indicate which attributes are important in their decision-making.

Both studies find that response-efficacy is the strongest predictor of preparedness intentions. Terpstra and Lindell (2012) find that 76 percent of respondents rank efficacy for protecting persons as important to their decision-making. Our findings contradict these claims with only 7 percent of Skagit Valley respondents indicating that low response-efficacy is a barrier to preparedness. However, our response-efficacy measure addresses only one aspect of response-efficacy as defined in PADM: efficacy for protecting persons. We do not examine efficacy for protecting property or utility for other uses, which should be considered in future studies.

These discrepancies in the interpreted role of response-efficacy may originate from variations in the type of hazard and location under investigation. Earthquake and flood hazards are generally more ubiquitous than lahar hazards, possibly making them more familiar to studied populations. Such familiarity affects perception (Schmidt, 2004). Terpstra and Lindell (2012) focus on the Netherlands, an area with substantial pre-existing flood defenses, whereas the Skagit Valley lacks similar lahar defenses (e.g., barriers, sirens). The extent of previously established defenses may influence the perceived effectiveness of household preparedness measures. Pre-existing defenses may legitimize the threat and support the effectiveness of preparedness measures, but they may also reduce the perceived effectiveness of smaller-scale household preparedness efforts.

Another difference may stem from how the “importance” variable is operationalized. Terpstra and Lindell (2012) frame their question in a positive manner by asking, “is it important ‘that preparations enlarge my…safety during an evacuation or a flood?’” The corresponding question in our study asks, “to what degree does the belief that protective actions ‘will not help me protect myself’ prevent preparedness actions?” This change in wording may indicate that Terpstra and Lindell examine the influence of high response-efficacy on preparedness decisions, while we study the influence of low response-efficacy on preparedness decisions. As such, our results may not contradict but, instead, complement those of Terpstra and Lindell. Terpstra and Lindell’s findings imply that high response-efficacy promotes preparedness, and our results imply that low response-efficacy does not prevent preparedness. In combination, these results suggest that perceived response-efficacy may only be predictive of preparedness behaviors when perceived efficacy is high. To test this hypothesis, future studies should examine the influence of both high and low response-efficacy on preparedness behaviors.

Regarding perceived self-efficacy, Terpstra and Lindell (2012) argue that perceived self-efficacy does not substantially influence preparedness behaviors. In contrast, we find that self-efficacy, rather than response-efficacy, positively motivates preparedness behaviors. In fact, extensive research into behavior motivation supports the idea that perceived self-efficacy influences intentions and behaviors (Bandura, 1997 and references therein). Consequently, perceived self-efficacy measures form crucial components of numerous behavior motivation theories including the Theory of Planned

Behavior (TPB; Ajzen, 1991), Critical Awareness Theory (Paton, 2003; Paton *et al*., 2005), PADM (Lindell & Perry, 1992; Lindell & Prater, 2002; Terpstra & Lindell, 2012), and PMT (Maddux & Rogers, 1983). Meta-analytic studies on TPB (Godin & Kok, 1996; Armitage & Conner, 2001) and PMT (Floyd *et al*., 2000) demonstrate broad support for perceived self-efficacy as a predictor of behavior, and our results support this conclusion.

It must be noted, however, that challenges exist in confirming the direction of causation between self-efficacy and the adoption of preparedness actions. Grothmann and Reusswig (2006) note the possibility that current preparedness levels could influence perceived self-efficacy. For example, previous preparedness behaviors adopted by an individual make them better prepared. This knowledge increases the individual's perceived self-efficacy, creating a positive feedback loop. Since we ask participants to respond to the suite of self-efficacy statements after asking objective knowledge and preparedness questions, such a feedback system may work to inflate self-efficacy correlations. However, evidence from most studies favor self-efficacy as the causal variable (Grothmann & Reusswig, 2006; Bandura, 1997; Paton, 2003 and references therein).

The difference between our findings and those of Terpstra and Lindell (2012) likely arises from how they conceptualize self-efficacy, which remains fairly unique in the literature. Terpstra and Lindell treat self-efficacy as a trait related to the preparedness action ("the task requires little knowledge or skill"), whereas we conceptualize self-efficacy as a trait of the person ("I have the knowledge, skills, and ability to effectively cope"). We use a more standard definition of self-efficacy based on that of Bandura (1997). These two approaches, meant to measure the same concept, may result in the measurement of two different concepts, which would make direct comparisons between the two measures inappropriate. Terpstra and Lindell's self-efficacy measure may actually be more comparable with our protective response cost measures since both treat knowledge and skills as resources to expend on preparedness actions.

Our results align with those of Lindell and Prater (2002) and Terpstra and Lindell (2012) in showing that perceived protective response costs fail to control preparedness behaviors. Only a quarter to a third of respondents cite protective response costs as barriers. For these individuals, an actual or perceived lack of resources influences their preparedness decisions, but to say that protective response costs universally and entirely drive preparedness behaviors is an overstatement. Overall, the levels of support for each response-related attribute (Terpstra and Lindell, 2012) are remarkably similar to support levels for corresponding protective response cost barriers in our study (Table 4.18).

Table 4.18 Similarity between Support of Protective Response Costs as Barriers to Preparedness and Resource-Related Attributes as Important to Preparedness Decision-Making

Corwin		Terpstra & Lindell	
Protective Response Cost Barriers	Support (%)	Resource-Related Attributes	Support (%)
Lack of hazard knowledge	35%	Knowledge and Skills	36%
Lack of preparedness knowledge	28%		
Cost	26%	Cost	24%
Time	23%	Time and Effort	34%

Treating knowledge, money, and time as necessary resources for adopting preparedness actions raises the question of whether these function as perceived or actual barriers. Paton (2003), in the development of his social-cognitive preparation model (later renamed Critical Awareness Model), notes a distinction between intention and action. Paton describes how an individual's intention to prepare is mediated by factors such as a lack of resources. Grothmann and Reusswig (2006) likewise point to PMT's ability to distinguish between perceived and actual barriers. The former operate in the coping appraisal process and prevent the formulation of an intention to prepare, whereas the latter work on protection motivation, stopping the translation of these intentions into actions. Herein, we do not distinguish between the two as we do not differentiate between barriers in the intention formulation and behavior initiation phases.

The importance of distinguishing between actual and perceived barriers is evident when considering monetary barriers. Individuals with a wide range of household incomes indicate that cost prevents them from preparing further, including nearly 15 percent with incomes higher than the county's median (Figure 4.3). For those from higher income brackets, the monetary expense associated with preparing may represent a perceived protective response cost rather than an actual lack of resources. In such a case, individuals may believe that the costs outweigh the potential benefits of preparing.

Other individuals, however, see the benefits and may want to prepare but lack the resources to do so. The negative correlation between household income and cost barrier ratings supports this idea (Table 4.10). Similar correlations between income and preparedness levels are documented by Edwards (1993), who questioned Memphis residents about their household preparedness for earthquake hazards. Edwards also notes that populations tend to adopt more of the cheaper and less time intensive preparedness actions. Further, Tierney *et al*. (2001) posit that preparedness behaviors typically increase with increasing household income in their overview of disaster preparedness in the United States.

VBN Theory and Understanding Preparedness Behaviors

Our findings demonstrate the importance of including ascription of responsibility measures when evaluating preparedness intentions and behaviors. Results indicate that ascription of responsibility to self correlates with higher preparedness levels, whereas ascription of responsibility to others correlates with lower preparedness levels. This supports the argument that, after becoming aware of a hazard's consequences, a feeling of responsibility for preventing said consequences is necessary to motivate an individual to act (Stern *et al.*, 1999; Stern, 2000; Slimak & Dietz, 2006). These results agree with Paton (2003) and Wachinger *et al*.'s (2013) argument: when individuals transfer responsibility for their safety to others, preparedness suffers. In such cases, individuals fail to recognize their personal agency in the preparedness and response process. Wachinger *et al*., in particular, attribute such shifts to excessive trust in officials and the mistaken exaggeration of their abilities.

VBN theory's ascription of responsibility represents an important variable not fully accounted for within PMT's current structure. Perceived self-efficacy represents the component of PMT that most closely resembles the ascription of responsibility variable; however, the two concepts are distinct. Self-efficacy deals specifically with the question of, "am I able to respond effectively?" whereas ascription of responsibility asks, "am I responsible for responding?" The failure of respondents to recognize the significance of this variable serves to highlight the need for incorporating ascription of responsibility measures into protective behavior motivation studies.

Professional Participation's Influence on Household Preparedness & Personal Beliefs

Professional participation appears to improve information seeking habits, confidence in officials, and self-efficacy. Yet, response professionals largely mirror the public in terms of their household preparedness levels, ascription of responsibility beliefs, and ability to read and interpret hazard maps. These results indicate that differences exist in how public and professional participation affect an individual's preparedness behaviors and personal beliefs. This raises the question: why do both types of participation positively affect information seeking behavior, confidence in officials, and self-efficacy, while only public participation positively influences household preparedness, knowledge, and ascription of responsibility?

Self-efficacy and confidence in officials appear to improve regardless of the type of participation (e.g., public or professional) in which an individual engages. Wachinger *et al*. (2013) posit that an individual's self-efficacy and confidence in officials improve as they interact more with emergency officials. Both public and professional participation facilitates such interaction. The former increases interactions between the public and officials, while the latter increases interactions among officials. Additionally, it seems logical that response professionals foster higher self-efficacy—the belief in their ability to prepare and respond to hazards effectively—since they elected to pursue careers where their abilities are constantly tested.

Regarding ascription of responsibility, Wachinger *et al.* (2013) highlight the role that participation in hazard management could play in helping people take greater responsibility for their own safety. Wachinger *et al.* note that interactions with officials help the public gain a more realistic understanding of their own abilities and the abilities of officials. Members of the public become better acquainted with the measures they can take to prepare, as well as what officials will expect them to bear personal responsibility for during an event. Similarly, Paton *et al*. (2008) emphasize the need for officials to "empower" the public to take personal responsibility for their safety. Given this emphasis on public participation's positive influence on personal responsibility, the similarity between the ascription of responsibility beliefs of response professionals and the general public in our study seems to contradict expectations. However, it is important to note that general public respondents in the Skagit Valley already feel primarily responsible for their own safety. With 95 percent of general public respondents already claiming that they are responsible for their own safety, there is not much room for improvement among the response professional community.

In terms of household preparedness, response professionals appear better prepared than the general public based on their average NCP score, but a closer analysis of preparedness indicator scores reveals that response professionals are only significantly more prepared in the action indicator category. This difference results because more response professionals have someone in their family who knows first aid and are aware of vulnerable people living in their community. Both of these recommended preparedness actions are strongly tied to professional responsibilities, particularly for first responders and hospital administrators. Thus, it may be more reasonable to attribute increases in these two measures to occupational requirements rather than voluntary preparedness behaviors induced by participation in response planning. All other variations in preparedness of individual measures are minor or not significant. This fact is emphasized by the lack of statistically significant differences in the average planning and supplies indicator scores.

The lack of improvement in household preparedness among response professional respondents may originate because public and professional participation in hazard management represent fundamentally different types of participation. While both aim to improve overall community preparedness and hazard response capabilities, each takes a different approach with separate objectives. Public participation programs tend to be geared toward improving household preparedness or ensuring that hazard plans align with community values. In contrast, trainings for response professionals might only discuss household preparedness as a minor component of a program largely focused on occupational responsibilities for whole community preparedness and response.

For example, one way the public participates in hazard management in the Skagit Valley is through the Community Emergency Response Team (CERT). CERT training teaches individuals about relevant local hazards, preparedness options, and basic disaster response skills (e.g., fire safety, light search and rescue, team organization, and disaster medical operations; Federal Emergency Management Agency, 2016). Participating individuals are encouraged to get involved in community preparedness projects. Professional participation activities, on the other hand, focus more on developing an individual’s professional competencies—knowledge and skills that allow their organization to respond effectively within the broader emergency management framework. Household preparedness may increase among the public because participation programs specifically and strongly emphasize how an individual can protect their home and family.

Although response professionals may be acquainted with recommended household preparedness measures, they may still fail to adopt these measures at home. For many response professionals, household preparedness measures do not directly benefit them since they are actively responding to a hazard. However, preparedness measures can help their families, and public health professionals admit that one of their primary concerns during a hazard event is the protection of their family (Slepski, 2007). Such concerns can cause distraction or even prevent response professionals from reporting for work (Blessmann *et al*., 2007). Thus, rather than focusing training programs on what to prepare and why, training should focus on *how* household preparedness can specifically benefit response professionals. Training programs should take a ‘whole community’ approach—emphasizing how household preparedness protects family members, helps response professionals better perform their job duties, and strengthens the whole community. Additionally, we agree with Blessmann *et al*.’s (2007) recommendation to focus on providing response professionals with small, easily accomplishable steps.

Finally, the fact that response professional and general public respondents foster similar preparedness levels has implications for previous studies of response professionals. The low levels of preparedness previously found among public health employees (Blessmann *et al.*, 2007; Rebmann *et al.*, 2013) and first responders (Federal Emergency Management Agency, 2016) may be indicative of low levels of preparedness among the public in general. A more representative survey examining a random sample of response professionals and the general public would be necessary to confirm this argument. Additionally, we combined a variety of professions into the group “response professionals," but the type of participation performed by a first responder may differ substantially from that of a utilities, school, or hospital administrator. Future studies would benefit from more narrowly defining the "response professionals" category or creating sub-classes within the category defined by profession.

Advantages and Disadvantages of Survey Methodology

Several limitations to the internal and external validity of the results exist due to the sampling method. First, a convenience sample lacks randomness; thus, selection bias may affect the sample, reducing the generalizability of the results. Since a response rate cannot be determined with this method, we cannot account for an individual's inherent interest or willingness to participate. Second, using an online platform limited the number of responses from those without access to a computer or sufficient computer literacy to navigate the survey. The accessibility of the survey tool limited responses from the elderly and those from lower socio-economic backgrounds. Third, the survey was only available in English, which limited the participation of non-native English speakers, particularly among the Spanish-speaking population. In Skagit County, 5.1 percent of the adult (18+) population speaks Spanish or Spanish Creole at home (U. S. Census Bureau, 2015). Thus, the survey responses likely underrepresent the views of Spanish-speaking residents. These factors limit the representativeness of the survey sample.

Although limitations exist, using an online survey with a convenience sampling design provided an inexpensive, straight-forward, and relatively rapid means of collecting responses. This method was consistent with previous risk perception and preparedness studies (e.g., Siegrist & Cvetkovich, 2000; Bird *et al.* 2010). While nonrandom sampling limits the ability to extrapolate trends to the broader population, such surveys still provide valuable information on perception and preparedness among the surveyed population. Identified trends demonstrate risk perception and preparedness levels among a portion of the community and may be indicative of broader trends that a future randomized sample survey could investigate.

Additional Theoretical and Practical Implications

From this work, a number of additional theoretical implications arise for future research into preparedness barriers and the benefits of hazard management participation. Our use of respondent opinions in evaluating preparedness barriers reveals the need to refine these questions in terms of framing and format. When asking respondents to indicate the degree to which different factors prevented them from preparing, we framed each option as a potential barrier. In contrast, Terpstra and Lindell (2012) asked respondents which factors were most important in their preparedness decision-making. Their framing did not assume these factors were barriers or promoters of preparedness, but simply factors influencing decisions.

In terms of format, our study expanded upon Terpstra and Lindell's (2012) use of a dichotomous variable by allowing respondents to express a range of support for different barriers. Based on these ratings, we were able to construct a relative ranking of the barrier importance. In addition to this ordinal design, we recommend that future studies allow respondents to personally rank the relative importance of each barrier or, as in the model of Terpstra and Lindell, protective action to provide even greater insight into respondents' thoughts.

Second, this research highlights the need for mixed question formats in the analysis of preparedness behavior adoption. Studies should allow respondents to express their opinions regarding what motivates their preparedness choices and, where possible, include corresponding independent measures to compare with preparedness levels. Our study shows that correlations can contradict expressed preferences. Including both methods provides insight into how respondents perceive of different barriers and the extent to which these barriers actually correlate with behavior.

A number of implications also exist for the operationalization of response costs and knowledge in future surveys. As noted, the response costs component of the coping appraisal incorporates measures such as cost and time that can be either perceived or actual barriers. It would be useful to distinguish between the two in future studies. One way to accomplish this is by inserting language into the survey questions that define the question's object as preparedness intention (protection motivation) or action (Paton, 2003); perceived costs influence intentions whereas an actual lack of resources influences actions. Additionally, language could be included that distinguishes between costs that prevent people from preparing even though they desire to and costs that people believe outweigh potential benefits, preventing the desire to prepare.

In terms of knowledge assessment, a third of the respondents who are aware that volcanic hazards exist in the Skagit Valley still indicate that a lack of hazard knowledge prevents them from preparing. This highlights the need to identify what specific knowledge respondents feel they are missing. A general awareness that volcanic hazards exist may feel insufficient. Respondents need to understand what a hazardous event will mean for them personally because understanding the personal impacts of a hazard influences preparedness motivation (Lindell & Perry, 2012). People also need to know where to access hazard information. Nearly 23 percent of the survey population found that current information was difficult to find or understand and 29 percent felt information was easy to find but unclear. Paton *et al*. (2008) emphasize that providing information consistent with population needs, values, and beliefs helps emergency managers strengthen trust, reduce uncertainty, and improve the acceptance of information. By determining what specific information the public lacks and desires, as well as how best to present this information, emergency managers can better tailor educational efforts to ensure that the messages and information disseminated are appropriate for their community.

Finally, our results underscore the need for more detailed studies of hazard knowledge, risk perception, and preparedness among the response professional community. Studying response professionals is important because they play a significant role in the success of hazard response efforts and can act as role-models for the broader community. Training programs often introduce response professionals to the concept of household preparedness, yet to date, the household preparedness behaviors and personal beliefs of response professionals remain largely unstudied. Increased program evaluation would provide a clearer understanding of whether or not professional training translates into household readiness. Additionally, comparative studies of response professionals and the general public could offer a means of measuring the success of training programs and provide a more extensive understanding of whole community preparedness.

Furthermore, analyses based on occupation could identify different types of professional participation and how each influences household preparedness and personal beliefs. Such studies could isolate elements shared between the most effective training programs within and across professional boundaries. The goal of these efforts being to increase household preparedness and reduce possible distractions facing response professionals. If response professionals feel confident in the safety of their families, they can feel comfortable responding, which ultimately benefits the whole community. Overall, the results presented here reveal the important role that participation type plays in determining household preparedness actions.

In terms of practical implications, the findings presented herein will be provided to local and state emergency managers to assist in the development of improved public education programs, professional training programs, and response plans. We support the recommendation of Paton *et al*. (2008) that emergency managers should strive to empower the public. Managers should help individuals recognize their own agency during hazard events and improve their self-efficacy, both of which clearly and positively influence preparedness behaviors. Hazard management participation efforts should also be expanded given the positive impact that participation appears to have on self-efficacy and feelings of responsibility, impacts which do not appear to be tied to specific types of participation. For response professionals, household preparedness measures should be presented as small, easily achievable steps that will benefit their family and help them better perform their response duties.

This research will be shared with the Cascade Volcano Observatory (CVO) as well. The CVO's input in the design of the survey questionnaire ensured the collection of information relevant to their design of volcanic hazard maps. The current hazard maps successfully communicate the main details of the hazard, but more nuanced elements are not as easily conveyed.

CHAPTER FIVE: CONCLUSIONS

This thesis presents a two-part analysis of volcanic hazard risk in the Skagit Valley of northeastern Washington (U.S.). By incorporating both the physical and human dimensions of hazard risk, this research provides a more comprehensive examination of how volcanic activity at Mount Baker or Glacier Peak could impact surrounding communities. Using USGS delineated volcanic hazard zones and data on the built environment, risk maps were generated in GIS to deliver insight into the potential costs (i.e., life, property, and financial losses) of a maximum envisioned lahar. Subsequently, a survey of people living or working in the Skagit Valley was conducted to gather information on current knowledge, risk perception, and preparedness levels in these communities. The conclusions drawn from each component, when integrated, reveal a stronger picture of the current state of volcanic hazard exposure and readiness in the Skagit Valley as well as opportunities for future collaboration between the sciences.

To summarize the results of this study, risk maps reveal that a total loss scenario places nearly 40,000 lives and 15,000 homes at risk. Hundreds of kilometers of agricultural land would be rendered useless and monetary losses from property alone would escalate to over $5 billion. The subsequent loss of nearly $62 million dollars in tax revenue to the county would present further challenges for a recovering community.

Realistically, however, this total loss scenario forms an upper estimate of possible lahar effects because the lahar hazard decreases with increasing distance downstream and elevation above the valley floor. More detailed geologic hazard modeling in the Skagit

Valley as well as investigations into how lahars impact reservoirs would be needed to provide more complex loss scenarios that are both realistic and defensible. Such scenarios use various lahar characteristics to indicate possible lahar paths, which would help emergency managers identify the most vulnerable areas of Skagit County. By using geologic mapping tools and accounting for the built environment, this thesis identifies a number of gaps in the existing understanding of Skagit Valley lahars that can be addressed with further research in the geosciences.

The extent of lahar hazard exposure in the Skagit Valley justifies the social sciences component of this thesis. The findings presented herein confirm that awareness and risk perception (i.e., threat appraisal) fail to control hazard preparedness behaviors in the Skagit Valley. Rather, perceived self-efficacy and ascription of responsibility beliefs play more significant roles in driving preparedness actions. These findings demonstrate the value of including VBN theory’s ascription of responsibility concept in examinations of preparedness behaviors. Including ascription of responsibility measures in addition to PMT’s coping appraisal could assist in explaining preparedness in future studies, but a regression analysis should be used to account for interaction effects. Protective response costs and perceived response-efficacy failed to emerge as strongly influential barriers to preparedness.

Results from investigating the link between participation and preparedness in a professional context, indicate that an increase in self-efficacy, information seeking behavior, and trust in officials appear to occur regardless of the type of participation. The increase likely stems from the fact that any type of participation facilitates increased interactions with officials. Such interactions are often tied to the recognition of personal agency, strengthened trust in officials, and a more accurate understanding of the abilities of officials. In contrast, household preparedness appears to depend on factors unique to specific types of participation. This is perhaps due to different styles and objectives of training programs. Further analysis of household preparedness levels in comparison with occupation (e.g., first responder, administrator, emergency manager) and specific training programs could help identify traits that promote the adoption of household preparedness measures.

Overall, the Skagit Valley population is moderately prepared for a natural hazard event. The average NCP score among respondents is 0.47. The average supplies indicator score is 0.62, which indicates that respondents previously prepared eight to nine of the recommended items on average. The five most commonly prepared items included a first aid kit (81%), non-electric can opener (78%), blanket or sleeping bag (75%), smoke detector (74%), and flashlight with extra batteries (71%). At least half of respondents stated they had sufficient water (one gallon/day/person) for three days and 63% had non-perishable food for three days. However, this does not indicate whether or not people have these readily accessible. In terms of planning, 40% of respondents had a plan for contacting family members and 46% had identified an emergency contact person outside the local area. Nearly 63% of respondents have someone in their family who knows first aid.

Additionally, while only a quarter of the population previously sought out information about local volcanic hazards, over three-quarters are interested in learning more about local volcanic hazards. Most desire to receive this information via printed materials (e.g., newspapers, brochures, pamphlets, magazines) or the internet.

Respondents also foster strong feelings of personal responsibility; every respondent indicated that they are the entity most responsible for their safety and provision of necessary resources during a hazard event.

Finally, nowhere is the relevance of this study more obvious than in the comments left by survey respondents. Ninety-three respondents wrote additional comments at the end of the survey and the vast majority are overwhelmingly positive. The following presents a sample of the comments received:

- “Thanks for doing this. Great way to increase awareness. Maybe it will push me to finally make a emergency kit.”
- “I have been learning about emergency preparedness but hadn't considered volcano because we live so far from them. I'll look into that further now.”
- “I've never heard of the term Lahar and have lived in the valley my entire life. I'm very curious how big a threat it is currently.”
- “Glad to see this survey! I hope it encourages a serious look at the area's lack of preparedness and prompts changes and more communication about those changes.”
- “I had no idea of the lahar risk in this area but the maps make sense. I only thought of the volcanic ashfall. It would be very good to have more community awareness and education re all potential natural disasters esp earthquake, lahars, floods, volcanic eruption.”
- “Thank you for this survey - it certainly got me to thinking about hazards other than flooding from heavy snow melt and rainfall. The eruption of Mt St Helens was the last time I really thought about ash fall or a mudflow from our volcanoes.”
- “I think this is SUPER important and interesting. Workshops and community events might raise awareness and, since volcanoes are super interesting, there might even be decent turn out!”

In total, twenty-three respondents used the comment section to express their thanks to the research team for conducting this research and increasing hazard awareness. Many respondents stated that they found the survey both interesting and informative, and others indicated an intention to learn more about local hazards. Respondents expressed an interest in further educational material, community workshops, and hoped to learn the outcomes of this study. The results of this study will be made available to local and state emergency management and the Cascade Volcano Observatory. The local newspaper, the Skagit Valley Herald, will be contacted regarding a follow-up story to share these results with the general public.

In conclusion, this thesis demonstrates an interdisciplinary approach to natural hazards research that helps advance research in both the geosciences and the social sciences. By combining and building upon insights from various academic disciplines, it is possible to create a more robust understanding of human-environment interactions. Geology provides knowledge of the extent and dynamics of volcanic hazards while monitoring activity to provide advanced warning. Social sciences provide an understanding of the built environment and human behaviors. Both components, the physical and the human, are necessary to establish effective hazard mitigation, preparedness, response, and recovery plans that will protect communities in the Skagit Valley and worldwide. As long as the goal of hazards research remains the protection of life and property, interdisciplinary research, such as presented here, represents an effective means of reaching that goal.

REFERENCES

Agresti, A. (2002). *Categorical data analysis.* Hoboken, New Jersey: John Wiley & Sons.

Ajzen, I. (1991). The theory of planned behavior. *Orgnizational Behavior and Human Decision Processes, 50*, 179–211. doi:10.1016/0749-5978(91)90020-T

Armitage, C. J., & Conner, M. (2001). Efficacy of the Theory of Planned Behaviour: A meta-analytic review. *The British Journal of Social Psychology, 40*, 471–499. doi:10.1348/014466601164939

Apolline Project (2012, January 29). *Lahars in Japan.* Retrieved from https://www.youtube.com/watch?v=kznwnpNTB6k

Ballantyne, M., Paton, D., Johnston, D., Kozuch, M., & Daly, M. (2000). *Information on volcanic and earthquake hazards: The impact on awareness and preparation.* Institute of Geological & Nuclear Sciences Limited, Lower Hutt, Science Report, 2000/2.

Bandura A. (1997). *Self-efficacy: The exercise of control.* New York: W.H. Freeman and Company.

Banker, S. R. Z. (2008). *Utilizing geographic information systems to identify potential lahar pathways in proximity to Cascade stratovolcanoes* (Master's thesis). Retrieved form http://www.nwmissouri.edu/library/theses/2008/BankerSamantha.pdf

Barberi, F., Davis, M. S., Isaia, R., Nave, R., & Ricci, T. (2008). Volcanic risk perception in the Vesuvius population. *Journal of Volcanology and Geothermal Research, 172*(3-4), 244–258. doi:10.1016/j.jvolgeores.2007.12.011

Barclay, J., Haynes, K., Houghton, B., & Johnston, D., (2015). Social Processes and Volcanic Risk Reduction. In H. Sigurdssson, B. Houghton, H. Rymer, J. Stix, &

S. McNutt (Eds.), *Encyclopedia of Volcanoes* (pp. 1203-1214). Cambridge, Massachusetts: Academic Press.

Beget, J. E. (1982). *Postglacial volcanic deposits at Glacier Peak, Washington, and potential hazards from future eruptions.* U.S. Geological Survey Open-File Report, 82-830.

Beget, J. E. (1983). Glacier Peak, Washington: A potentially hazardous cascade volcano. *Environmental Geology, 5*(2), 83–92. doi:10.1007/BF02381101

Berman, E. & Wang, X. (2011). *Essential Statistics for Public Managers and Policy Analysts.* Thousand Oaks, California: Sage Publications.

Bird, D. K., Gisladottir, G., & Dominey-Howes, D. (2010). Volcanic risk and tourism in southern Iceland: Implications for hazard, risk and emergency response education and training. *Journal of Volcanology and Geothermal Research*, *189*(1-2), 33–48. doi:10.1016/j.jvolgeores.2009.09.020

Blessman, J., Skupski, J., Jamil, M., Jamil, H., Bassett, D., Wabeke, R., & Arnetz, B. (2007). Barriers to at-home-preparedness in public health employees: Implications for disaster preparedness training. *Journal of Occupational and Environmental Medicine*, *49*(3), 318–326. doi:10.1097/JOM.0b013e31803225c7

Boone, H.N., & Boone, D.A. (2012) Analyzing Likert Data. *Journal of Extension, 50*(2).

Carlino, S., Somma, R., & Mayberry, G. C. (2008). Volcanic risk perception of young people in the urban areas of Vesuvius: Comparisons with other volcanic areas and implications for emergency management. *Journal of Volcanology and Geothermal Research*, *172*(3-4), 229–243. doi:10.1016/j.jvolgeores.2007.12.010

Clason, D. L., & Dormody, T. J. (1994). Analyzing Data Measured By Individual Likert-Type Items. *Journal of Agricultural Education*, *35*(4), 31–35. doi:10.5032/jae.1994.04031

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). *Social vulnerability to environmental hazards. Social Science Quarterly, 84*(2), 242–261.

Davis, M, Johnston, D., Becker, J., Leonard, G., Coomer, M., & Gregg, C. (2006). Risk perceptions and preparedness: Mt Rainier 2006 community assessment tabulated results. GNS Science Report, 2006/17.

Diefenbach, A. K., Wood, N. J., & Ewert, J. W. (2015). Variations in community exposure to lahar hazards from multiple volcanoes in Washington State (USA). *Journal of Applied Volcanology*, *4*(1), 4. doi:10.1186/s13617-015-0024-z

Donovan, A. R., & Oppenheimer, C. (2011). The 2010 Eyjafjallajökull eruption and the reconstruction of geography. *The Geographical Journal*, *177*(1), 4–11. doi:10.1111/j.1475-4959.2010.00379.x

Douglas, M. & Wildavsky, A. (1982). *Risk and culture: An essay on the selection of technological and environmental dangers.* Berkeley, California: University of California Press.

Dragovich, J. D., & McKay, D. T. J. (2000). Holocene Glacier Peak lahar deposits in the lower Skagit River Valley, Washington. *Washington Geology*, *28*(1/2), 19–21.

Earth Uncut TV (2014, January 21). Extreme Pyroclastic Flows At Sinabung Volcano, Indonesia 21st Jan 2014 火砕流. Retrieved from https://www.youtube.com/watch?v=95bYATFIOxs

Edwards, M.L. (1993). Social location and self-protective behavior: Implications for earthquake preparedness. International Journal of Mass Emergencies and Disaster 11: 293-304.

Federal Emergency Management Agency (2016, March 8). Community Emergency Response Teams. Retrieved from http://www.fema.gov/community-emergency-response-teams

Federal Emergency Management Agency. (n.d.). Ready Responder: Emergency planning for first responders and their families. Retrieved from https://www.ready.gov/sites/default/files/documents/files/RRToolkit.pdf

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S. & Combs, B. (1978). How safe is safe enough? A psychoometric study of attitude towards technological risks and benefits. *Policy Science, 9,* 127-152.

Floyd, D. L., Prentice-Dunn, S., & Rogers, R. W. (2000). A Meta-analysis of research on protection motivation theory. *Journal of Applied Social Psychology, 30*(2), 407-429. doi:10.1111/j.1559-1816.2000.tb02323.x

Flynn J., Slovic, P., & Mertz, C.K. (1994). Gender, Race, and Perception of Environmental Health Risks. *Risk Analysis, 14*(6), 1101-1108.

Gardner, C. A., Scott, K. M., Miller, C. D., Myers, B., Hildreth, W., & Pringle, P. T. (1995). *Potential Volcanic Hazards from Future Activity of Mount Baker, Washington.* U.S. Geological Survey Open File Report, 95-498.

Gardner, J. E., Carey, S., & Sigurdsson, H. (1998). Plinian eruptions at Glacier Peak and Newberry volcanoes, United States: Implications for volcanic hazards in the Cascade Range. *Bulletin of the Geological Society of America, 110*(2), 173–187. doi:10.1130/0016-7606(1998)110<0173:PEAGPA>2.3.CO;2

Godin, G., & Kok, G. (1996). The theory of planned behavior: A review of its applications to health- related behaviors. *American Journal of Health Promotion, 11*(2), 87–98. doi:10.4278/0890-1171-11.2.87

Grothmann, T., & Reusswig, F. (2006). People at Risk of Flooding: Why Some Residents Take Precautionary Action While Others Do Not. *Natural Hazards*, *38*(1-2), 101–120. doi:10.1007/s11069-005-8604-6

Handmer, J.W. (1980). Flood hazard maps as public information: An assessment within the context of the Canadian flood damage reduction program. *Canadian Water Resources Journal*, *5*(4), 82-110.

Haynes, K., Barclay, J., & Pidgeon, N. (2008). Whose reality counts? Factors affecting the perception of volcanic risk. *Journal of Volcanology and Geothermal Research*, *172*(3-4), 259–272. doi:10.1016/j.jvolgeores.2007.12.012

Hildreth, W. (2007). *Quaternary magmatism in the Cascades--geologic perspectives.* U.S. Geological Survey Professional Paper, 1744.

Hyde, J. H., & Crandell, D. R. (1978). *Postglacial volcanic deposits at Mount Baker, Washington, and potential hazards from future eruptions.* Geological Survey Professional Paper, 1022-C.

IPCC (2013). Summary for Policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P.M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1-30). Cambridge, United Kingdom: Cambridge University Press. doi:10.1017/CBO9781107415324.004.

Johnston, D. M., Bebbington Chin-Diew Lai, M. S., Houghton, B. F., & Paton, D. (1999). Volcanic hazard perceptions : comparative shifts in knowledge and risk. *Disaster Prevention and Management*, *8*(2), 118.

Johnston, D. M., Orchiston, C., & Becker, J.S. (2012). Eastern Washington resident perceptions of natural hazard risks. GNS Science Report, 2012/05.

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., Kasperson, J.X., Ratick, S. (1988). The Social Amplification of Risk: A Conceptual Framework. *Risk Analysis*, *8*(2), 177–187. doi:10.1111/j.1539-6924.1988.tb01168.x

Kasperson, J. X., Kasperson, R. E., Pidgeon, N., & Slovic, P. (2003). The social amplification of risk: assessing fifteen years of research and theory. In N. Pidgeon, R.E. Kasperson, & P. Slovic (Eds.), *The social amplification of risk* (pp. 13-46). Cambridge, United Kingdom: Cambridge University Press.

Kovanen, D. J., Easterbrook, D. J., & Thomas, P. A. (2001). Holocene eruptive history of Mount Baker, Washington. *Canadian Journal of Earth Sciences, 38*, 1355–1366. doi:10.1139/e01-025

Lindell, M. K., & Perry, R. W. (1992). *Behavioral foundations of community emergency planning.* Washington, DC: Hemisphere Press.

Lindell, M. K., & Perry, R. W. (2012). The protective action decision model: Theoretical modifications and additional evidence. *Risk Analysis, 32*(4), 616-632.

Lindell, M. K., & Prater, C. S. (2002). Risk area residents' perceptions and adoption of seismic hazard adjustments. *Journal of Applied Social Psychology*, *32*(11), 2377–2392.

Maddux, J. E., & Rogers, R. W. (1983). Protection motivation and self-efficacy: A revised theory of fear appeals and attitude change. *Journal of Experimental Social Psychology, 19*, 469–479. doi:10.1016/0022-1031(83)90023-9

Marris, C., Langford, I. H., & O'Riordan, T. (1998). A quantitative test of the cultural theory of risk perceptions: comparison with the psychometric paradigm. *Risk Analysis : An Official Publication of the Society for Risk Analysis*, *18*(5), 635–647. doi:10.1111/j.1539-6924.1998.tb00376.x

Mastin, L., & Waitt, R. (2000). *Glacier Peak - history and hazards of a cascade volcano.* U.S. Geological Survey Fact Sheet, 058-00.

McClung, S. C. (2005). *Lahar hazard mapping of Mount Shasta, California: A GIS-based delineation of potential inundation zones in Mud and Whitney Creek basins* (Master's thesis). Retrieved from http://dusk.geo.orst.edu/djl/theses/steve/mcclung_thesis.pdf

Morrow, B. H. (1999). Identifying and mapping community vulnerability. *Disasters, 23*(1), 1–18. doi:10.1111/1467-7717.00102

Mouginis-Mark, P. (n.d.). *Mount Pinatubo, Philippines: 5. Lahars.* Retrieved from: http://eos.higp.hawaii.edu/ppages/pinatubo/5.lahars/index.html

Nunnally, J. C. (1978). *Psychometric theory.* New York: McGraw-Hill.

Parker, C. L., Barnett, D. J., Fews, A. L., Blodgett, D., & Links, J. M. (2005). The Road Map to Preparedness: A competency-based approach to all-hazards emergency readiness training for the public health workforce. *Public Health Reports, 120*(5), 504–514.

Paton, D. (2003). Disaster preparedness: a social-cognitive perspective. *Disaster Prevention and Management*, *12*(3), 210–216. doi:10.1108/09653560310480686

Paton, D., Smith, L., Daly, M., & Johnston, D. (2008). Risk perception and volcanic hazard mitigation: Individual and social perspectives. *Journal of Volcanology and Geothermal Research, 172*(3-4), 179–188. doi:10.1016/j.jvolgeores.2007.12.026

Paton, D., Smith, L., & Johnston, D. (2005). When good intentions turn bad : promoting natural hazard preparedness. *The Australian Journal of Emergency Management, 20*(1), 25–30.

Pierson, T. C. & Scott, K. M. (1985). Downstream dilution of a lahar: Transition from debris flow to hyperconcentrated streamflow. *Water Resources Research, 21*(10), 1511-1524.

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Rayner, S. (1988). Muddling through metaphors to maturity: A commentary on Kasperson et al., The social amplification of risk. *Risk Analysis, 8*(2), 201-204.

Rayner, S. (1992). Cultural theory and risk analysis. In S. Krimsky & D. Golding (Eds.), *Social Theories of Risk,* (pp. 83-115). Westport: Praeger.

Rebmann, T., Strawn, A. M., Swick, Z., & Reddick, D. (2013). Personal disaster and pandemic preparedness of U.S. human resource professionals. *Journal of Biosafety Health Education, 1*(1), 1–7. doi:10.4172/jbhe.1000102

Rodolfo, K. S. (2000). The hazard from lahars and jökulhlaups. In H. Sigurdssson, B. Houghton, S. McNutt, H. Rymer, & J. Stix (Eds.), *Encyclopedia of Volcanoes* (pp. 973-995). Academic Press.

Rogers, R. W. (1983). Cognitive and physiological processes in fear appeals and attitude change: A revised theory of protection motivation. In B.L. Cacioppo & L.L. Petty (Eds.), *Social Psychophysiology: A Sourcebook* (pp. 153- 176). London, UK: Guilford.

Rogers, R.W. & Prentice-Dunn, S. (1997). Protection motivation theory. In D.S. Gochman (Ed.), *Handbook of Health Behavior Research I: Personal and Social Determinants* (pp. 113-132). New York, New York: Plenum.

Rowe, G. & Wright, G. (2001). Differences in expert and lay judgments of risk: Myth or reality? *Risk Analysis*, *21*, 341-356.

Rubinstein, J.L. & Mahani, A.B. (2015). Myths and facts on wastewater injection, hydraulic fracturing, enhanced oil recovery, and induced seismicity. *Seismological Research Letters*, *86*(4), 1-8. doi: 10.1785/0220150067

Savadori, L., Savio, S., Nicotra, E., Rumiati, R., Finucane, M., & Slovic, P. (2004). Expert and public perception of risk from biotechnology. *Risk Analysis*, *24*(5), 1289–1299. doi:10.1111/j.0272-4332.2004.00526.x

Savage, I. (1993). Demographic influences on risk perceptions. *Risk Analysis*, *13*(4), 413–420.

Schilling, S. P. (1996). *Digital data set of volcano hazards for active Cascade Volcanos, Washington.* U.S. Geological Survey Open-File Report, 96-178. http://pubs.er.usgs.gov/publication/ofr96178

Schilling, S. P. (2014). *Laharz_py—GIS tools for automated mapping of lahar inundation hazard zones.* U.S. Geological Survey Open-File Report, 2014-1073, http://dx.doi.org/10.3133/ofr20141073.

Schmidt, M. (2004). Investigating risk perception: A short introduction. In Schmidt, M., *Loss of agro-biodiversity in Vavilov centers, with a special focus on the risks of genetically modified organisms (GMOs).* (pp. 1-16). Doctoral dissertation, Vienna

Schwarz, M. and Thompson, M. (1990). Divided we stand: Redefining politics, technology and social choice. Philadelphia: University of Pennsylvania Press.

Scott, K., Hildreth, W. & Gardner, C. (2000). *Mount Baker - living with an active volcano.* U.S. Geological Survey Fact Sheet, 059-00.

Siegrist, M., & Cvetkovich, G. (2000). Perception of Hazards: The Role of Social Trust and Knowledge. *Risk Analysis*, *20*(5), 713–720. doi:10.1111/0272-4332.205064

Siegrist, M., & Gutscher, H. (2006). Flooding Risks: A Comparison of Lay People's Perceptions and Expert's Assessments in Switzerland. *Risk Analysis*, *26*(4), 971–979. doi:10.1111/j.1539-6924.2006.00792.x

Sims, J. H., & Baumann, D. D. (1983). Educational programs and human response to natural hazards. *Environment and Behavior, 15*(2), 165-189.

Sjöberg, L. (1999). Risk perception by the public and by experts: A dilemma in risk management. *Human Ecology Review*, *6*(2), 1–9.

Sjöberg, L. (2000). Factors in Risk Perception. *Risk Analysis : An Official Publication of the Society for Risk Analysis*, *20*(1), 1–11. doi:10.1111/0272-4332.00001

Sjöberg, L. (2002). The allegedly simple structure of experts' risk perception: An urban legend in risk research. *Science, Technology, & Human Values, 27*(4), 443-459.

Skagit County (2014). Digital Data Warehouse [SCDDW]. (accessed May 1, 2014) http://www.skagitcounty.net/Departments/GIS/Digital/main.htm

Slepski, L. A. (2007). Emergency preparedness and professional competency among health care providers during Hurricanes Katrina and Rita: Pilot study results. *Disaster Management & Response*, *5*(4), 99–110. doi:10.1016/j.dmr.2007.08.001

Slimak, M. W., & Dietz, T. (2006). Personal Values, Beliefs, and Ecological Risk Perception. *Risk Analysis*, *26*(6), 1689–1705. doi:10.1111/j.1539-6924.2006.00832.x

Slovic, P. (1987). Perception of risk. *Science, 236*, 280-285. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3563507

Slovic, P. (1999). Trust, emotion, sex, politics, and science: Surveying the risk-assessment battlefield. *Risk Analysis, 19*(4), 689-701.

Slovic, P., Fischhoff, B., & Lichtenstein, S. (1982). Why study risk perception? *Risk Analysis*, *2*(2), 83–93. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1539-6924.1982.tb01369.x/full

Stern, P. C. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues*, *56*(3), 407–424. doi:10.1111/0022-4537.00175

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. a., & Kalof, L. (1999). A value-belief-norm theory of support for social movements: The case of environmentalism. *Human Ecology Review*, *6*(2), 81–97. doi:10.2307/2083693

Tansey, J., & O'Riordan, T. (1999). Cultural theory and risk: A review. *Health, Risk & Society*, *1*(1), 71–90. doi:10.1080/13698579908407008

Tavakol, M. & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53–55.

Terpstra, T., & Lindell, M. K. (2012). Citizens' perceptions of flood hazard adjustments: An application of the Protective Action Decision Model. *Environment and Behavior, 45*(8), 993–1018. doi:10.1177/0013916512452427

The Pennsylvania State University (2016). *18.3 - Kendall Tau-b Correlation Coefficient* [Course Lesson]. In STAT 509: Design and analysis of clinical trials. Retrieved from https://onlinecourses.science.psu.edu/stat509/node/158

Thompson, M., Ellis, R. & Wildavsky, A. (1990). *Cultural theory*. Boulder: Westview Press

Tierney, K.J., Lindell, M.K., & Perry, R.W. (Eds.). (2001). *Facing the unexpected: Disaster preparedness and response in the United States.* Washington D.C.: National Academy of Science.

Trenberth, K.E. (2012). Framing the way to relate climate extremes to climate change. *Climate Change. 115*(2), 283-290.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, *185*(4157), 1124–1131. doi:10.1126/science.185.4157.1124

U.S. Census Bureau (2015). 2010-2014 American Community Survey 5-Year Estimates. (accessed March 2, 2016) http://www.census.gov/programs-surveys/acs/

U.S. Department of Agriculture (n.d.). USDA Forest Service Pacific Northwest Region: Geographic Information Sets. (accessed May 1, 2014) http://www.fs.fed.us/r6/data-library/gis/

U.S. Geological Survey (2014, March). *Cascade volcanoes simplified hazard maps.* Retrieved from http://volcanoes.usgs.gov/vsc/multimedia/cvo_hazards_maps_gallery.html

Vallance, J.W. (2000). Lahars. In H. Sigurdssson, B. Houghton, S. McNutt, H. Rymer, & J. Stix (Eds.), *Encyclopedia of Volcanoes* (pp. 601-616). Academic Press.

Volcano Hazards Program, U.S. Geological Survey (1998, Oct 6). *Photo Information*. Retrieved from: http://volcanoes.usgs.gov/Imgs/Jpg/Ruiz/30410135_071_caption.html

Volcano Hazards Program, U.S. Geological Survey (2016, Jan 19). *Hazards: Lahars*. Retrieved from: http://volcanoes.usgs.gov/vhp/lahars.html

Wachinger, G., Renn, O., Begg, C., & Kuhlicke, C. (2013). The risk perception paradox--implications for governance and communication of natural hazards. *Risk Analysis : An Official Publication of the Society for Risk Analysis*, *33*(6), 1049–65. doi:10.1111/j.1539-6924.2012.01942.x

Waitt, R. B., Mastin, L. G., & Beget, J. E. (1995). *Volcanic-Hazard Zonation for Glacier Peak Volcano, Washington.* U.S. Geological Survey Open File Report, 95-499.

Walder, J. S., Watts, P., Sorensen, O. E., & Janssen, K. (2003). Tsunamis generated by subaerial mass flows. *Journal of Geophysical Research*, *108*(B5), 1–19. doi:10.1029/2001JB000707

Washington Department of Natural Resources (WA-DNR) (2016). *North Cascades.* Retrieved from http://www.dnr.wa.gov/programs-and-services/geology/explore-popular-geology/geologic-provinces-washington/north-cascades

Washington State Department of Transportation (2010). WSDOT GeoData Distribution Catalog. (accessed May 1, 2014) http://www.wsdot.wa.gov/Mapsdata/GeoDataCatalog/default.htm

Wildavsky, a., & Dake, K. (1990). Theories of risk perception: Who fears what and why? *Daedalus*, *119*(4), 41–60. doi:10.2307/20025337

APPENDIX A

Survey Questions

Page 1

Skagit River Valley Natural Hazard Survey
Welcome to My Survey

Individuals living within the Skagit River Valley (between the towns of Concrete and La Conner, Washington) who are over the age of 18 are invited to participate in an online survey regarding natural hazards that may affect your community (e.g., earthquakes, volcanoes, storms, floods). This survey is an important part of a Masters-level research project being conducted at Boise State University. Your participation is greatly appreciated!

Upon completion you will have the option to enter a drawing to win a Blue Double Power 7" Tablet with Android 4.2 OS.

At the end of the survey you will also be given information on simple ways to prepare for natural hazards that someday may occur in your community. You may be surprised how easy it is to protect ourselves and our families.

The survey should take about 10-15 minutes to complete.

BENEFITS
For taking part in the survey, you will receive information on what natural hazards affect the Skagit River Valley and how to prepare for a potential hazardous event. Also, at the end of the survey you may enter a drawing to win a Blue Double Power 7" Google-Certified Tablet with Android 4.2 OS.

PARTICIPATION
Your participation in this survey is completely voluntary. You may decline to answer any question or choose to withdraw from the survey at any time.

RISKS
Survey responses are anonymous. There are no foreseeable risks involved in participating in this study and you are free to decline to answer any question or exit the survey at any time.

CONFIDENTIALITY
Your participation in this research is confidential. No personally identifiable information is required, requested, or collected during the survey process. If you choose to enter the tablet drawing, the email address provided will be stored separately from all survey responses.

For more information, contact:
Kimberley Corwin – kimberleycorwin@u.boisestate.edu (Masters research student) Dr. Brittany Brand – brittanybrand@boisestate.edu (Research advisor – http://earth.boisestate.edu/brittanybrand/)

If you have questions about your rights as a research participant you may contact the Boise State University Institutional Review Board (IRB), which is responsible for the protection of volunteers in research projects. You may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling (208) 426-5401 or by writing: Institutional Review Board, Office of Research Compliance, Boise State University, 1910 University Dr., Boise, ID 83725-1138.

Select:
○ I consent to the participate in the following survey and have read the above information.

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Have you experienced any of the following events in your lifetime? (Check all that apply).

- ❑ Flood
- ❑ House Fire
- ❑ Wildfire
- ❑ Lahars* (mud and debris flows)
- ❑ Volcanic ash fall
- ❑ Landslides
- ❑ Other (please specify) ________________________
- ❑ Tsunami
- ❑ Earthquake
- ❑ Chemical spill or gas leak
- ❑ Severe Storm (e.g., tornado, hurricane, winter storm)
- ❑ Pandemic
- ❑ No events

**LAHAR: a mud or debris flow that moves like wet concrete and is capable of transporting large boulders. Lahars originate from the slopes of volcanoes but may be triggered for volcanic and non-volcanic (e.g., heavy rain, glacial melt) reasons. (link)*

***PYROCLASTIC FLOW: a ground-hugging current of hot gas, ash, and rock commonly created in explosive volcanic eruptions (link)*

For the remainder of the survey, Skagit River Valley refers to the area within the black box:

Figure A.1 Location map of Skagit Valley (black box) shown in online survey

Please describe the extent to which you agree or disagree with each of the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Volcanic hazards have impacted the Skagit River Valley in the **past**	❑	❑	❑	❑	❑
Volcanic hazards may impact the Skagit River Valley in the **future**	❑	❑	❑	❑	❑

Rate the threat level (property damage and loss of life) of the following natural hazards to the community where you currently live and work? (one box per line)

	Not a Threat 1	2	3	4	Very Serious Threat 5	Don't Know
Ash Fall	❑	❑	❑	❑	❑	❑
Lahar* (mud or debris flows)	❑	❑	❑	❑	❑	❑
Lava Flow	❑	❑	❑	❑	❑	❑
Pyroclastic Flows**	❑	❑	❑	❑	❑	❑
Flood	❑	❑	❑	❑	❑	❑
Earthquake	❑	❑	❑	❑	❑	❑
Tsunami	❑	❑	❑	❑	❑	❑
Wildfire	❑	❑	❑	❑	❑	❑
Severe Storm	❑	❑	❑	❑	❑	❑

**LAHAR: a mud or debris flow that moves like wet concrete and is capable of transporting large boulders. Lahars originate from the slopes of volcanoes but may be triggered for volcanic and non-volcanic (e.g., heavy rain, glacial melt) reasons. (link)*

***PYROCLASTIC FLOW: a ground-hugging current of hot gas, ash, and rock commonly created in explosive volcanic eruptions (link)*

On a scale of 1-5, how concerned are you about the effect of the following hazards in the future to you or your local family, friends, and neighbors? (Check one box per line)

	Not Concerned 1	2	3	4	Very Concerned 5	Don't Know
Lahar*	❑	❑	❑	❑	❑	❑
Flood	❑	❑	❑	❑	❑	❑
Earthquake	❑	❑	❑	❑	❑	❑
Tsunami	❑	❑	❑	❑	❑	❑
Wildfire	❑	❑	❑	❑	❑	❑
Severe Storm	❑	❑	❑	❑	❑	❑

Please feel free to explain your concern more fully below:

On a scale of 1-5, in your opinion, what is the chance of a major lahar* occurring in the Skagit River Valley in the next: (Check one box per line).

	Not Possible 1	Unlikely 2	Somewhat Likely 3	Highly Likely 4	Don't Know 5
1 year	❑	❑	❑	❑	❑
10 year	❑	❑	❑	❑	❑
50 years	❑	❑	❑	❑	❑
100 years	❑	❑	❑	❑	❑
>100 years	❑	❑	❑	❑	❑

Do you:

	Yes	No	Don't Know
Live in a lahar* zone	❑	❑	❑
Work in a lahar* zone	❑	❑	❑
Cross a road within a lahar* zone when driving between home and work	❑	❑	❑

**LAHAR: a mud or debris flow that moves like wet concrete and is capable of transporting large boulders. Lahars originate from the slopes of volcanoes but may be triggered for volcanic and non-volcanic (e.g., heavy rain, glacial melt) reasons. (link)*

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Below are the United States Geological Survey volcano hazard maps for Mount Baker and Glacier Peak volcanoes:

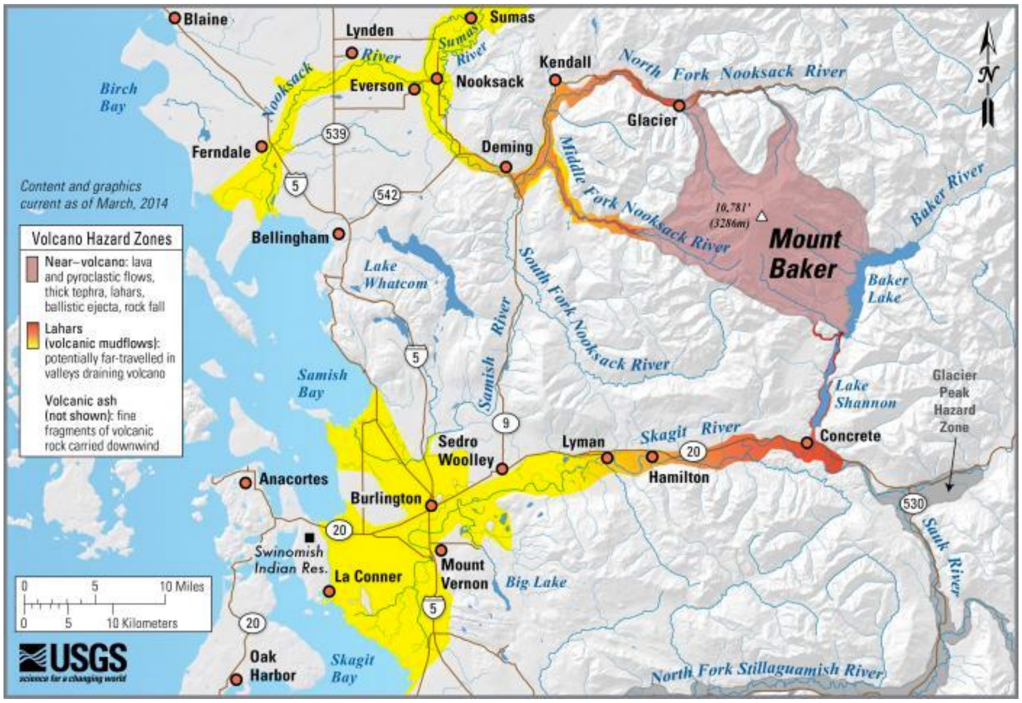

Figure A.2 Mount Baker volcano hazard map displayed in online survey

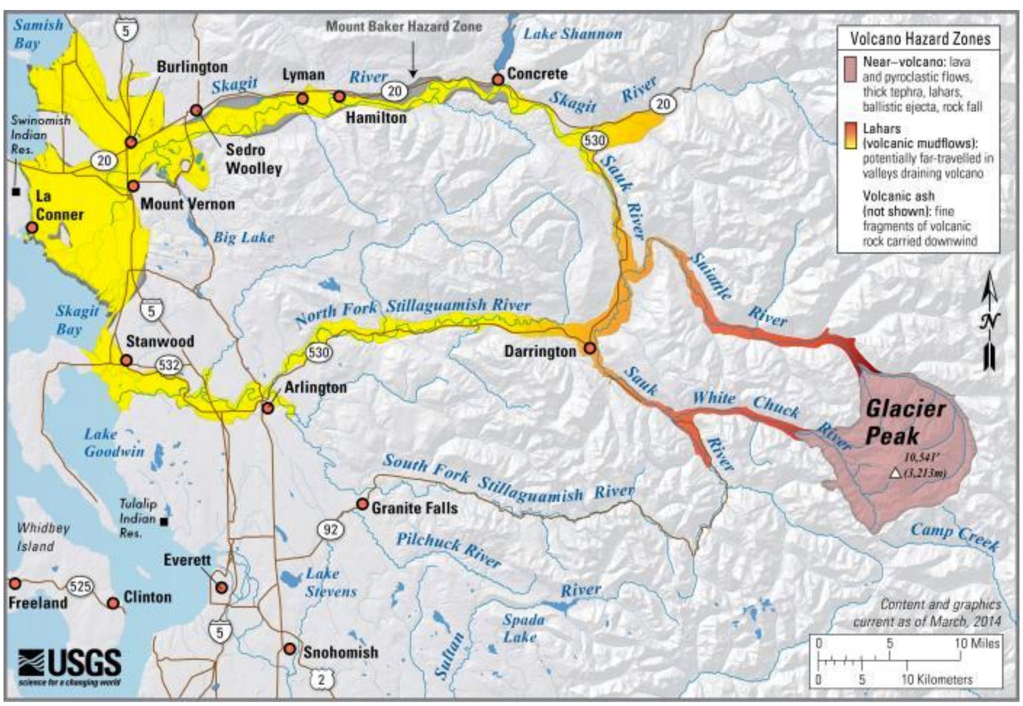

Figure A.3 Glacier Peak volcano hazard map displayed in online survey

Based on these maps, which volcanic hazard affects the Skagit River Valley?

- ❑ Thick Tephra (ash fall)
- ❑ Lava Flow
- ❑ Lahar* (mud or debris flow)
- ❑ Pyroclastic Flows**
- ❑ Rock fall

Does the lahar hazard increase, decrease, or remain the same moving from the town of Concrete to La Conner for Mount Baker and Glacier Peak volcanoes?

	Increase	Decrease	Remain the Same
Mount Baker	❑	❑	❑
Glacier Peak	❑	❑	❑

Please rate the extent to which you trust or distrust these maps as realistic representations of the volcanic hazards in the community where you live and work.

Strongly Distrust	Distrust	Neither Distrust nor Trust	Trust	Strongly Trust
❑	❑	❑	❑	❑

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Have you sought information about volcanic hazards in the community where you live and work?

- ❑ Yes
- ❑ No

If you have sought information, was it:

- ❑ Difficult to Find
- ❑ Easy to Find but Unclear
- ❑ Easy to Find and Understand
- ❑ Haven't Sought Information

Are you interested in learning more about volcanic hazards in your community and how to prepare?

- ❑ Yes
- ❑ No

If you answered yes above, what is your preferred way of receiving more information? ***(Select all that apply)***

- ❑ Printed media (newspapers, brochures, pamphlets, magazines)
- ❑ Public forums (meetings, workshops)
- ❑ Internet
- ❑ Television
- ❑ Other (please specify) ______________________

Rate your level of trust in the following information sources for volcanic hazards:

	Strongly Distrust	Distrust	Neutral	Trust	Strongly Trust
Scientists:	❑	❑	❑	❑	❑
Officials:	❑	❑	❑	❑	❑
First Responders:	❑	❑	❑	❑	❑
Media:	❑	❑	❑	❑	❑
Friends & Family	❑	❑	❑	❑	❑

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In the event of any natural hazard, how responsible will each of the following entities be for your protection and providing necessary resources?

	Not Responsible 1	2	3	4	Very Responsible 5	Don't Know
Neighbors/Community	❑	❑	❑	❑	❑	❑
Myself	❑	❑	❑	❑	❑	❑
Local Emergency Services	❑	❑	❑	❑	❑	❑
Media	❑	❑	❑	❑	❑	❑
Friends & Family	❑	❑	❑	❑	❑	❑

Have you or your family prepared any of the following items in case of emergency?

- ❑ Plan for contacting family members
- ❑ Emergency contact person outside the area
- ❑ Flashlight and extra batteries
- ❑ Water: 1 gallon/person/day for 3 days
- ❑ Non-perishable food for 3 days
- ❑ Non-electric can opener
- ❑ Portable radio and extra batteries
- ❑ Fire extinguisher
- ❑ Smoke detector
- ❑ First aid kit
- ❑ Essential medicine
- ❑ Sturdy shoes
- ❑ Whistle
- ❑ Wrench or pliers to turn off utilities
- ❑ Local maps
- ❑ Blankets or sleeping bags
- ❑ Bought additional insurance (e.g., home)
- ❑ Someone in the family has learned to provide first aid
- ❑ Know who in your neighborhood or community may need additional help (e.g., elderly, families with small children)

Please select the extent to which you agree or disagree with each of the following as a factor preventing you from preparing items in the above question. ***(Check one box per line)***

	Strongly Disagree	Disagree	Neither Disagree nor Agree (Not a Factor)	Agree	Strongly Agree
Cost (too expensive):	❑	❑	❑	❑	❑
Too time consuming:	❑	❑	❑	❑	❑
Inaccurate, uncertain, or difficult to understand science, information, or maps:	❑	❑	❑	❑	❑
Not knowing what to prepare:	❑	❑	❑	❑	❑
Not knowing what hazards could affect me:	❑	❑	❑	❑	❑
I don’t think a natural hazard is likely to affect me:	❑	❑	❑	❑	❑
My neighbors or other community members have these items and will assist me in an emergency:	❑	❑	❑	❑	❑
Preparing these items will not help me protect myself during a natural hazard:	❑	❑	❑	❑	❑
Emergency services provides necessary items and assistance quickly, I won’t need these items personally:	❑	❑	❑	❑	❑

Please select the extent to which you agree or disagree with the following statements: ***(Check one box per line)***

	Strongly Disagree	Disagree	Neither Disagree nor Agree (Not a Factor)	Agree	Strongly Agree
I have the knowledge and skills to ensure that I am prepared for a natural hazard	❑	❑	❑	❑	❑
I have the ability to protect myself and/or others from the effects of a lahar*	❑	❑	❑	❑	❑
I have the ability to protect myself and/or others from the effects of a flood	❑	❑	❑	❑	❑
I am confident that I will know what to do during and after a lahar*	❑	❑	❑	❑	❑
I am confident that I will know what to do during and after a flood	❑	❑	❑	❑	❑
I am confident in the ability of officials to provide timely and effective instructions, response, or evacuation	❑	❑	❑	❑	❑
I am confident in the accuracy of scientific volcanic hazard maps and assessments	❑	❑	❑	❑	❑
I am confident in my community's ability to recover from a lahar*	❑	❑	❑	❑	❑
I am confident in my community's ability to recover from a flood	❑	❑	❑	❑	❑

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***PYROCLASTIC FLOW: a ground-hugging current of hot gas, ash, and rock commonly created in explosive volcanic eruptions (link)*

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Demographics:

Zip Code: _________

Occupation: ________________

Do you work as a first responder or in a leadership role within the local city government, hospitals, school districts, red cross, or utilities, transportation, or water companies?

- ❑ Yes
- ❑ No

Age: ______

Gender:

- ❑ Female
- ❑ Male
- ❑ Transgender
- ❑ Prefer not to say
- ❑ Other (please specify) ___________________

Highest level of science education:

Geology/Earth Science

- ❑ Elementary/Middle School
- ❑ High School
- ❑ College/University
- ❑ Vocational/Trade School
- ❑ Associates Degree in Scientific Field
- ❑ Bachelor’s Degree in Scientific Field
- ❑ Some Graduate Level Coursework
- ❑ Master’s Degree in Scientific Field
- ❑ Ph.D. Degree in Scientific Field

Other Sciences (e.g., Biology, Physics, Chemistry, Astronomy)

- ❑ Elementary/Middle School
- ❑ High School
- ❑ College/University
- ❑ Vocational/Trade School
- ❑ Associates Degree in Scientific Field
- ❑ Bachelor’s Degree in Scientific Field
- ❑ Some Graduate Level Coursework
- ❑ Master’s Degree in Scientific Field
- ❑ Ph.D. Degree in Scientific Field

Household Income

- ❑ Under $20,000
- ❑ $20,000 to $29,999
- ❑ $30,000 to $39,999
- ❑ $40,000 to $49,999
- ❑ $50,000 to $74,999
- ❑ $75,000 to $99,999
- ❑ $100,000 to $149,999
- ❑ $150,000 and above

In the Skagit River Valley, do you:

- ❑ Own a home, condo, or apartment
- ❑ Rent a home, condo, or apartment
- ❑ Live with Family/Friend
- ❑ Other (please specify) _______________

How long have you lived in the Skagit River Valley: ________________

How did you hear about this survey?

- ❑ Farmer's Market
- ❑ Skagit County Fair
- ❑ Library
- ❑ Grocery Store or Gas Station
- ❑ Friends or Family
- ❑ Received link via email

Are you a current student, faculty, or staff member at Skagit Valley College?

- ❑ Yes
- ❑ No

Do you have any additional comments or questions that you would like to share:

APPENDIX B

Response Frequencies & Open Response Text

Have you experienced any of the following events in your lifetime? (Check all that apply).

Event *n = 504*	Response Frequency
Flood	252
House Fire	58
Wildfire	88
Lahars* (mud and debris flows)	18
Volcanic ash fall	101
Landslides	77
Tsunami	9
Earthquake	373
Chemical spill or gas leak	56
Severe Storm (e.g., tornado, hurricane, winter storm)	276
Pandemic	18
No events	44

Please describe the extent to which you agree or disagree with each of the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Don’t Know
Volcanic hazards have impacted the Skagit River Valley in the **past** *n = 498*	22	27	70	156	160	63
Volcanic hazards may impact the Skagit River Valley in the **future** *n = 497*	13	10	35	192	215	32

Rate the threat level (property damage and loss of life) of the following natural hazards to the community where you currently live and work? (one box per line)

	Not a Threat 1	2	3	4	Very Serious Threat 5	Don’t Know
Ash Fall *n = 500*	41	109	130	102	88	30
Lahar* (mud or debris flows) *n = 492*	46	76	113	107	131	19
Lava Flow *n = 490*	158	130	87	39	38	38

Pyroclastic Flows** *n = 487*	116	119	88	48	49	67
Flood *n = 501*	10	24	57	102	304	4
Earthquake *n = 499*	3	30	79	145	236	6
Tsunami *n = 496*	114	116	103	73	71	19
Wildfire *n = 495*	32	87	120	128	118	10
Severe Storm *n = 495*	7	53	124	159	145	7

On a scale of 1-5, how concerned are you about the effect of the following hazards in the future to you or your local family, friends, and neighbors? (Check one box per line)

	Not Concerned 1	2	3	4	Very Concerned 5	Don't Know
Lahar* *n = 496*	135	119	92	73	58	19
Flood *n = 501*	24	56	85	158	175	3
Earthquake *n = 501*	21	49	116	139	174	2
Tsunami *n = 493*	151	136	100	48	50	8
Wildfire *n = 493*	65	123	127	93	82	3
Severe Storm *n = 495*	28	79	139	148	97	4

Please feel free to explain your concern more fully below: Open Response *n = 87*

- Given that major subduction earthquakes have occurred in this area roughly every 300 years; were due for another one any time now. I dont think were very well-prepared for an event of that magnitude.
- We love about 70 miles away from Mt. Baker which is a volcano that has shown signs of volcanic activity several times in the past. We are also very close to the water; on the Pacific coastline. We get storms every fall; some causing a lot of damage from fallen trees; loss of power as a result.
- An earthquake has affected my house in 2001. Another can effect us and the house.
- Based on my past knowledge of living in Skagit Co. since 1978, what I've seen most of & been involved in is floods w/an occasional earthquake thrown in.
- The nearby town Arlington, WA recently experienced a Lahar. 30 people were killed, and many homes were destroyed. Hillsides with the same potential for hazard are numerous in Skagit County. ------- I believe however that it is unlikely that I will experience in my lifetime a severe earthquake, flood, or severe storm at my location.
- I'm aware but not staying up at night worrying.
- In the Alger area, there is very little concern for floods, tsunamis or lahars. For the others. I'm sure that at some point they'll happen, but I feel prepared to deal with them.
- They are all possible.
- we've had floods we've had earthquakes. these events are only concerning if we have the "big one" and there's a reason its a one in 500year chance for those things, its not likely.
- I would hate for something horrible to happen to myself and I understand the golden rule and naturally feel I would hate for something to happen to someone else especially my neighbors or friends
- continental plats shifting at the subduction zone is a strong concern. It is at its max time for the event. I am out of the impact area for the strong effects of the tsunami. Mtn. Baker has an area on the south side that has shown activity in the past and has developed a rapid thaw of the glacial pack in that area. The power company with the use of dams has deter any real threat, however if mt Baker is affected by the plate movement at an more extreme level, it could cause a quick thaw and the skagit river next to my home would be a perfect flow for the lahar. However, with the current rate of receeding glacial pack, the main concern for the near future within 10 years is a drought with no glacial recovery. If yellowstone goes, we will experience a glacial phase, which would help the snow pack return to the mountains in Washington. It is pine trees everywhere here, so a fire would be a threat.
- well the flood on the river is a common thing here, storms are common and earthquakes are a possibility
- excessive tree cutting and rising tides for those who live near water are concerns that limited support for hillside and erosion raise risk to homes at base of hills and near waters edge (see swinomish channel and issues in shelter bay).
- We live close to the river and surrounded by an active volcano
- live too far from ocean.
- After the serious mudslide in Oso, Lahar has become a real concern of mine. I never used to consider it a problem before.
- 100 year earthquake is due.
- Many people living near the river have no outlet if Hwy. 20 is blocked or damaged.
- Family farm is on Fir Island. Biggest threat is a flood.
- we live close to a volcano and a river

- Flood damage not so important to us because we live 300 feet above the flood plain of Skagit River.
- If the volcano were to erupt and the dams broke everyone would be under water and there would be a huge loss.
- Living in Shelter Bay with trees and wild Blackberry dried out vines all around fire concerns me most. However I understand a Tsunami would go up the valley past us and catch us on the way back to the sea.
- Not concerned about my individual home - I live on the large stable hill in Mount Vernon. However, my community is most definitely at risk for some of these things.
- The overall lack of preparedness we all have the knowledge that this can occur, yet we don't want to face the reality by preparing.
- High risk of earthquake, wildfire and severe storms in this area given history what I have lived through thus far and potential for in the future
- We have already experienced significant episodes of flooding with no real effort to improve conditions on the Skagit, we should be concerned about future flooding.
- Concern is high because the likelihood of these disasters occuring is high, and I don't think we are as equiped to deal with it as we would like. The public is not either.
- I am so concerned that I have paid serious money to get my house up to code regarding earthquakes.
- Our private road owned by the owners (road assocation), Has decided not to renforce a 80 foot drop off up the side of Mountain. On which we live on the top. 1 owner who is from California has convinced the people below not to upgrade the hillside. Winter there is alot of rain.
- Just the history of our valley this is a huge floodplain
- Concerned about living very close to Mt. Baker in the dam if the dam let go the whole valley would flood.
- I consider 'concern' something that is often in my mind/troubling, and this isn't the case with these, which is why I'm not 'very concerned' about any of these...
- Earthquake/severe storms/ flood, IMO, can create huge problems in our area. Power outages, roads blocked, bridges destroyed, infrastructure damage.
- We just moved here a couple years ago so I am unaware of hazards.
- I have perused Washington State's Volcanic Activity site. It scared the shit out of me!
- Too many persons are I'll knowledged, under prepared, or just don't care.
- The river be flooding like crazy. I think the government is using concretion's to test alien studies. Them people up river never look a man in the eye. Thats because uncle sam is testing those alien probes on em.
- our home is high above the swinomish channel.
- The Skagit river floods every year. Some years worse than others.
- FDlood is a known hazard here and one dealt with every year. Earthquake is one that most structures here can withstend. Lahar is such that we have bigger problems than you can reasonably prepare for and the last two really aren't relevant to the Skagit county Area.
- Most people probably don't have enough stored food and water. I myself don’t know of the scenarios and what to do if Mt. Baker erupts.
- The NW relies heavily on bridges. If there were a major event like a quake, people in the valley would be instantly cut off from one another and rescue or supply vehicles. For instance I have to cross or go under one or two bridges to get to work. The closest grocery store is two bridges, and a railroad crossing away, depending on my route.

- Fidalgo Island could have direct impacts- flood wildfire,earthquakes, tsunami, storms and indirect impacts from lahars, lava and pyroclastic flows on the mainland.
- Not too concerned about Mt Baker because it is pretty far for the lava to travel, but the ashes will probably make their way down to Skagit Valley
- Big earthquake due will cause much disruption. Lahar is huge concern as well, but I live outside the area that would be directly affected by the lahar off Baker.
- Keeping people safe, warm, fed with safe water and dry until utilities and infrastructure can be re-established.
- some family members live on the skagit flat others live on the hill near mount vernon so that we don't have to worry about most of these issues
- I had a mudslide in 2006
- Nature is unpredictable. I can't expect everything to be safe forever.
- I live at 350' above sea level, where the flood and lahar risks are minimal, but my friends do live within those zones, so this depends on the definition of "local."
- Lahar awareness has been raised significantly since the Oso incident; flood hazards occur regularly; earthquake is just a matter of time; tsunami less severe because of some protection from Puget Sound; wildfire becoming more of a concern on the west side of the mountains, particularly with the east side burning so dramatically this season
- I don't spend much time thinking about 'what if'...I pretty much agree with the Boys Scouts motto to 'Be Prepared', so I don't waste time worrying about events that may never occur.
- one of my biggest concerns is if Mt Baker does blow, the lahar from that could take out some of the upper dams on the skagit, causing massive flooding downriver. If one of the upper dams does go, the sudden rush of water will likely take out the lower dams by force.
- 100 year flood, GI study of flood results in Skagit County will flood all of County. On a fualt line for earthquakes, Tsunami threat once in past 2 years. Recent mudslide in Snohomish County (south of Skagit) lost 44 lives this year. We have natural gas pipeline on our properties and coal trains are passing thru our valley. And refineries in our area are unsafe and have experienced explosions.
- Most of my friends and neighbors live well above the 100-year flood plain for the Skagit River and only a few within the 500-year flood plain. However, floods do pose a transportation risk for the region. Meanwhile, volcanic hazards could come from both Mt. Baker and Glacier Peak. While earthquakes and related tsunamis could easily inundate the lower Skagit.
- There are many tall trees around us. Fire or wind is always a threat.
- I don't believe that Skagit County is ready for a big earthquake.
- There is little to no discussion or planning in the county for these hazards.
- Dam breakage resulting in finding like the valley has never seen before
- I think the impact of a volcanic eruption is unknow to many and I prepare for the worst to be on the safe side.
- History past and present of these threats- OSO is a graphic and tragic example....and all the wildfires this summer. Winters seems to be more severe too the last 5 years or so.
- I see Glacier Peak as the biggest single threat to the S V. But it will give warning, if people heed. In an extreme event, it could flush the whole valley below Rockport. The Cascadia Subduction Zone could also cause severe damage due to shake, but I'm not sure if a tsunami would be able to pass through the Strait and get past the islands to cause severe damage.

- I'm personally more familiar with floods, earthquakes and storms, so they are a somewhat "known." Wildfire is frightening to me, now, as I live up against 100s of acres of forest. A lahar seems more remote, rare and exotic and I don't think I live where one could occur - same with a tsunami. But one can't know where they'll be located should any of these occur.
- My geology friend told me all about our risk for lahars and pyroclastic flow -- so interesting! And abstract to me.
- What happens, happens.
- Living under Mt Baker, I grew up watching the "steam" get released and have always been a little frightened of an eruption.
- Mt Saint Helens was an eye opener!
- I actually live outside of Anacortes, so I focus more on the dangers there. My husband and I prepared fully for natural disasters before moving to the Pacific Northwest in 2012.
- All of these hazards can impact the Skagit Valley residents.
- Don't think that very many people are ready for a major natural disaster.
- There's not much one can do about disasters of these kinds so why worry
- I live 1 block from the Skagit River in Conway and work at home
- I live in north Skagit Valley, where (I think) flood, tsunami and storm damage are more of a risk than volcanic activity.
- I'm not concerned because I don't really think about it.
- Our immediate community is south Fidalgo Island
- Sedro Woolley is a very safe place but the chance's are still high
- Severe storms can/will affect everyone , no matter elevation or distance from river, but although they can create a lot of havoc, we get very few real severe and it usually is more power outages that causes the biggest concern. Of course there are some much more serious consequences also.
- We live +/- 30 miles from an active volcano and on a historically active fault zone
- Lived with greater threats in Hawaii
- I think the earthquakes are simply a matter of when...not if.
- Flood and river overflow and possible mudslides.
- More education to prepare for hazards are needed. People also need a basic understanding of geology- flood plain means a plain or flat area that will flood; don:t build near or under a cliff; Mother Nature always wins so don:t try to take shortcuts with het
- daughter lives close to river afraid she would loose everything and maybe her life if she does not get out quick enough if flood happens;
- We live within in the 100 year flood zone; so that is always in the back of your mind although our property hasn:t experience a flood since 1917. Earthquake-wise; I have a beautiful view of Mount Rainier to the South and Mount Baker to the Northeast.
- Living on the Skagit River during any natural hazardous event.
- There is no human way to prevent natural disasters. The best solution is early warning. Using trains and buses for early evacuation would prevent road congestion and save lives.

On a scale of 1-5, in your opinion, what is the chance of a major lahar* occurring in the Skagit River Valley in the next: (Check one box per line).

	Not Possible 1	Unlikely 2	Somewhat Likely 3	Likely 4	Very Likely 5	Don't Know
1 year *n = 488*	36	233	107	18	6	88
10 year *n = 497*	16	150	167	55	23	86
50 years *n = 490*	11	64	162	103	60	90
100 years *n = 492*	9	43	118	109	121	92
>100 years *n = 481*	7	25	82	70	196	101

Do you:

	Yes	No	Don't Know
Live in a lahar* zone *n = 506*	99	241	166
Work in a lahar* zone *n = 502*	101	243	158
Cross a road within a lahar* zone when driving between home and work *n = 500*	173	167	160

Based on these maps, which volcanic hazard affects the Skagit River Valley?

Hazard *n = 485*	Response Frequency
Thick Tephra (ash fall)	216
Lava Flow	139
Lahar* (mud or debris flow)	457
Pyroclastic Flows**	137
Rock fall	126

Does the lahar hazard increase, decrease, or remain the same moving from the town of Concrete to La Conner for Mount Baker and Glacier Peak volcanoes?

	Increase	Decrease	Remain the Same
Mount Baker *n = 482*	139	288	55
Glacier Peak *n = 466*	126	200	140

Please rate the extent to which you trust or distrust these maps as realistic representations of the volcanic hazards in the community where you live and work.

n = 482	Strongly Distrust	Distrust	Neither Distrust nor Trust	Trust	Strongly Trust
	5	13	157	250	57

Have you sought information about volcanic hazards in the community where you live and work?

- *n = 478*
- Yes = 131

If you have sought information, was it:

n = 140	Response Frequency
Difficult to Find	32
Easy to Find but Unclear	41
Easy to Find and Understand	67

Are you interested in learning more about volcanic hazards in your community and how to prepare?

- *n = 478*
- Yes = 373

If you answered yes above, what is your preferred way of receiving more information? *(Select all that apply)*

n = 484	Response Frequency
Printed media (newspapers, brochures, pamphlets, magazines)	238
Public forums (meetings, workshops)	99
Internet	281
Television	133

Rate your level of trust in the following information sources for volcanic hazards:

	Strongly Distrust	Distrust	Neutral	Trust	Strongly Trust
Scientists: *n = 483*	5	6	64	240	168
Officials: *n = 478*	18	73	209	153	25
First Responders: *n = 480*	1	10	101	284	84
Media: *n = 479*	51	132	215	80	1
Friends & Family *n = 477*	11	40	270	132	24

In the event of any natural hazard, how responsible will each of the following entities be for your protection and providing necessary resources?

	Not Responsible 1	2	3	4	Very Responsible 5	Don't Know
Neighbors/Community *n = 467*	71	60	129	103	86	18
Myself *n = 465*	0	5	20	52	386	2
Local Emergency Services *n = 465*	4	29	92	158	174	8
Media *n = 465*	33	75	114	107	105	31
Friends & Family *n = 464*	32	44	95	152	135	6

Have you or your family prepared any of the following items in case of emergency?

n = 468	Response Frequency
Planning	
Plan for contacting family members	189
Emergency contact person outside the area	214
Supplies	
Flashlight and extra batteries	334
Water: 1 gallon/person/day for 3 days	235
Non-perishable food for 3 days	293
Non-electric can opener	365
Portable radio and extra batteries	226
Fire extinguisher	322
Smoke detector	345
First aid kit	379
Essential medicine	229
Sturdy shoes	305
Whistle	199
Wrench or pliers to turn off utilities	286
Local maps	169
Blankets or sleeping bags	349
Information Seeking Action	
Bought additional insurance (e.g., home)	100
Someone in the family has learned to provide first aid	294
Know who in your neighborhood or community may need additional help (e.g., elderly, families with small children)	184

Please select the extent to which you agree or disagree with each of the following as a factor preventing you from preparing items in the above question. ***(Check one box per line)***

	Strongly Disagree	Disagree	Neither Disagree nor Agree (Not a Factor)	Agree	Strongly Agree
Cost (too expensive): *n = 462*	60	111	170	95	26
Too time consuming: *n = 459*	47	118	187	95	12
Inaccurate, uncertain, or difficult to understand science, information, or maps: *n = 460*	71	146	185	51	7
Not knowing what to prepare: *n = 462*	60	141	130	121	10
Not knowing what hazards could affect me: *n = 461*	44	132	123	141	21
I don’t think a natural hazard is likely to affect me: *n = 462*	115	176	108	55	8
My neighbors or other community members have these items and will assist me in an emergency: *n = 461*	143	172	120	24	2
Preparing these items will not help me protect myself during a natural hazard: *n = 462*	155	174	102	26	5
Emergency services provides necessary items and assistance quickly, I won’t need these items personally: *n = 463*	187	199	63	12	2

Please select the extent to which you agree or disagree with the following statements: *(Check one box per line)*

	Strongly Disagree	Disagree	Neither Disagree nor Agree (Not a Factor)	Agree	Strongly Agree
I have the knowledge and skills to ensure that I am prepared for a natural hazard *n = 464*	6	68	132	211	47
I have the ability to protect myself and/or others from the effects of a lahar* *n = 465*	55	147	149	97	17
I have the ability to protect myself and/or others from the effects of a flood *n = 463*	27	99	105	206	26
I am confident that I will know what to do during and after a lahar* *n = 461*	61	167	120	92	21
I am confident that I will know what to do during and after a flood *n = 462*	24	85	91	231	31
I am confident in the ability of officials to provide timely and effective instructions, response, or evacuation *n = 461*	57	136	135	122	11
I am confident in the accuracy of scientific volcanic hazard maps and assessments *n = 464*	16	37	171	215	25
I am confident in my community's ability to recover from a lahar* *n = 460*	34	102	178	131	15
I am confident in my community's ability to recover from a flood *n = 464*	15	45	115	250	39

Demographics:

See Table 4.1 for age, sex (gender), and income data

Zip Code:

n = 459	Response Frequency
98237	29
98284	88
98273	102
98233	58
98232	18
98274	65
98257	26
98221	11
Other	62

Occupation: Open Response *n = 449*

Homemaker	Teacher	writer
Cook	Retired career firefighter; EMT	Student
Teacher	Law Enforcement	farmer/student
Laborer	Homemaker	Student
Sr lab tech	Assistant Fire Chief	retired
Safety Coordinator	community corrections	prep cook
self-employed	retired	College Instructor
social worker	service tech	warehouseman
Barista	natural gas worker	Medical Billing
civil engineer; public sector	District Manager	Student
production mechanic	Student	Biology Professor
Nurse	Retail	student
transportation	Cook	student
front desk agent	Student	Executive Assistant
student	Student	Instructional Technician
teacher	College Student	homemaker
Government	Full time Student	web editor
Caregiver; mechanic	Clinical Research	RN
paraeducator	student	Director of Marketing at the
farmer	student	Radiostation (Firefighter)
Homemaker	Security Guard	RN
Bus Driver	student	NURSE
retired	library tech	RN
SALES	Student	Certified nurse’s assistant
retired	N/A	disabled
Retired educator	Student/fulltimemom/machine	Security
Journalist	operator	CNA
Nurse	geology instructor	tutor
self employed	Pastor	Paralegal
Retired Counselor	homemaker/small farmer	RN
Retired	housewife	RN
Energy Conservation Program	busser	photographer
Manager	elected official	RECEPTIONIST

Interpreter
Fire Chief
MA
Clinical Application Support Specialist
CNA
medical assistant
medical reception
rn
RN
Certified Medical Assistant
Health Services Specialist
student
RN
HEALTH CARE WORKER
Kidney Dialysis Coordinator
HIM specialist
health information
RN
RN
College Instructor
Hospital
Student
teacher
Instructor SVC
College Faculty
Hyperbaric Tech
administration
Biomedical Technician
Medical Records
Registered Nurse
UNIT CLERK
referrals
registered nurse
Patient Registration Specialist
nurse
radiologic technologist
REGISTERED NURSE
Medical Reception
nurse
pharmacy tech
RN
Medical field
security
Information Systems CASS
RN
R.N.
CNA; nursing student
Middle Mgmt.
Dietitian
Church Administrator
Physical Therapist
Retired
PATIENT REGISTRATION SPECIALIST
office admin
Medical Assistant
Healthcare worker
RN
Dietitian
community relations
Clinical Dietitian
retired
secretary
Registered Nurse
charge capture specialist
RN
Clerical
Medical Administration
Volunteer Fire Chief/Mechanic (retired)
registered nurse
TRANSCRIPTIONIST
Disaster Response Specialist
trail crew
clerical
Medical Receptionist
pharmacy tech
Business Office Insurance specialist
medical coder
Palliative Care social worker
Registered Nurse
Endoscopy Tech
Cardiac Electrophysiology Specialist
radiologic technologist
Office
cna
RN
PHARMACY TECHNICIAN
SECRETARY
Registered Nurse
Registered Nurse
health care
RN
student
firefighter; mechanic
union carpenter
Supervisory Transportation
Security Officer
Retired contractor; fireman for 30yrs
ARNP
retail
Assistant principal
social work
Operations mgr
Office Assistant
Move seniors to retirement communities
Auditor
Librarian
emergency services
Recruiter
retired
self-employed
regional sales manager
Human Services
Retired medical assistant also volunteer for local firedepartment
disabled
Laborer
Management
retired
Forester
DISABLED VETERAN
Construction
teacher
Sales
Homemaker
driver
Parts Sales
Corrections officer
Registered nurse
pastor
Business owner
Retail Store Manager
millwright
Bookkeeper
Engineer
construction worker
School psychologist
RETIRED
attorney
stay at home dad
consultant
Retired law enforcement park ranger
Server
Not Fema or Government

RN
Librarian
Safety and Training
Coordinator
Instructor
teacher
Engineer
Hay and Forage
Harvester/Farm Operator
Chief Deputy Sheriff
sales
Nurse
Retired mechanic
records clerk
RN
Transit Planner
retired
tech svs; aerospace
Student
Delivery driver
welder
cashier
Human Resources
housewife
retired
retired shipwright
Librarian
Administrator and owner of
I.T. firm
Land Use Planner
truck driver
retired
Sales
retired
retired
General Manager
drafter
Sales Floor
Retired
Nuclear Medicine
Technologist
Compensation Analyst
RN
Supervisor
retired
retired
teacher
Lawyer
Contractor - Microsoft
At home Entrepreneur
self employed; bakery and
farmer
Doula
accountant
Educator
textile weaver
Advertising Consultant
ATP
Technology Executive
Forester
Project Manager
retired
teacher
retired
Law Clerk
Sales
retired
Banker
Physical Science Technician
Conservation Planner
retired
administrative assistant
executive
stay at home mom
retired
Teacher
Volunteer Coordinator
Program Coordinator
retired
Project Manager
instructor at Skagit Valley
College
Dental Front Office
Pastor
Retired disabled educator
Educator
public service
Facility Management
analyst
Office Manager
admin.
Lawyer
Retired
retired
retail management
government employee
Emt-Iv
Emergency Response
Self Employed
Construction Manager
farmer
Retired
Housewife
RN
blacksmith
firefighter
plant ecologist
Marketing Coordinator
Office Manager
office manager
Farmer
Teacher
Retired
Representative
Visual Information Specialist
retired RN and teacher
retired
sales
Archeologist
Architect
metalworker
teacher
Park Ranger
Executive Director
Illustrator
retired
retired
web based training creation
Homemaker
Retired
Director
consultant
Consultant
retired military
Teacher
firefighter
preschool teacher
Educator
Retail
Retired
Retired
retired National Park Ranger
Retired US Army / High
School Teacher
secretary
Corrections Deputy
Photographer
Public relations
home maker
retired
Land Conservation
retired

housewife
stay at home mom
artist
Life Skills Counselor for Swinomish Housing Authority
Sales Associate
Education
mechanic
Carpenter
Soil Scientist
Retired Farmer
Marine electronic technician
Retired
children’s ministry director
Environmental Health & Safety
Library assistant
Writer
Safety Manager
coordinator
Project Manager
teacher
Retired FF/EMT
Emergency Preparedness

Recreation Coordinator
Legal Assistant
Library Technician
Caregiver
Library Associate Burlington Public Library
Library clerk
retired R.N.
Receptionist
AmeriCorps Volunteer
retired
none
Clean offices
Accountant
Applications Analyst
artist - self employed
Veterinary Technician
College Professor
administrative assistant
manager/cook
Legal Assistant
clerk/treasurer
retired RN
librarian

Business owner
retired
Retail Manager
landscape designer
Tribal Gaming Regulatory Agent
Business owner retail
retired fisheries biologist
substitute at schools
retired
cook
Retired veterinarian
social services planner
Business Owner
Management
retail merchant
medical
Process Engineer
Retired College Professor
power plant operator
Sales Associate
disabled
Public Service

Do you work as a first responder or in a leadership role within the local city government, hospitals, school districts, red cross, or utilities, transportation, or water companies?

- ❑ *n = 456*
- ❑ Yes = 73

Highest level of science education:

	Response Frequency	
Education Level	Geology/Earth Science *n =413*	Other Sciences (e.g., Biology, Physics, Chemistry, Astronomy) *n =405*
Elementary/Middle School	8	2
High School	188	127
College/University	169	184
Vocational/Trade School	5	10
Associates Degree in Scientific Field	15	19
Bachelor’s Degree in Scientific Field	15	27
Some Graduate Level Coursework	4	13
Master’s Degree in Scientific Field	7	19
Ph.D. Degree in Scientific Field	2	4

In the Skagit River Valley, do you:

n = 456	Response Frequency
Own a home, condo, or apartment	304
Rent a home, condo, or apartment	91
Live with Family/Friend	22
Other	39

How long have you lived in the Skagit River Valley:

- *n = 424*
- Average length of residency: 20.66 years
- Median length of residency: 17 years
- Range of residency: 0-72 years

How did you hear about this survey?

n = 456	Response Frequency
Farmer's Market	33
Skagit County Fair	22
Library	15
Grocery Store or Gas Station	21
Friends or Family	9
Received link via email	80
Other	276

Do you have any additional comments or questions that you would like to share:

- Thanks for doing this. Great way to increase awareness. Maybe it will push me to finally make a emergency kit.
- Would volcanic eruptions have an impact in the Skagit river?
- limited space to store emergency equipment is a factor in not being prepared.
- yes, how is it that there is five different options under the gender question? ...I think the craziness of that question alone sums up my point.
- I do not believe at this time that scientists' assessment of our present lahar danger is complete, and that more studies need to be carried out to assess potential dangers to our communities here in the Skagit Valley.
- My family and friends are in Boise Idaho, so there is not a need for me to help family here, however I have mentioned other potential hazards to them and to be prepared. I have attempted to visit with neighbors about the potential hazards here in the Skagit Valley area. Most persons give me the same response, that they would prefer not to know. It is unsettling for them to think they have potential life threatening dangers around them constantly. Some do want to be prepared and I have asked several persons in school if they would like a plan of preparedness and they all said yes. Thank you. It is something that I am working on as well. Local officials and local information is extremely limited as is the knowledge of procedures to inform the population.
- I've never heard of the term Lahar and have lived in the valley my entire life. I'm very curious how big a threat it is currently.
- I am interested in the results of your efforts
- Hope you are able to raise awareness.

- I feel the county and state, has done a great job working with the communitys to provide assistance during major floods or disasters, (I-5 bridge for example). Because of what occured in OSO, I have no doubt that local goverment is looking to make sure we are prepared. My concern is how much money gets spent working on these types of issues. We don't put effort in preventing the problem, like, Why are people allowed to build homes in areas of high risk for floods, mud slides etc. Scientific research is present, but we allow ourselves to engineer "work arounds" to the science evidence that already exsists. Money is really the question for me. Where do we put our time and money and which issues are the priority?
- do not drive my insurance up
- I WOULD LIKE TO SEE SOME COMMUNITY EDUCATIONAL EVENTS REGARDING THIS ISSUE
- The threat from these natural disasters pales to the threat from other disasters, including man-made, e.g., economic collapse, high altitude electromagnetic pulse weapon, cyber or physical attack on power grid, coronal mass ejection, pandemic, nuclear war.
- Good Survey
- Glad to see this survey! I hope it encourages a serious look at the area's lack of preparedness and prompts changes and more communication about those changes.
- I had no idea of the lahar risk in this area but the maps make sense. I only thought of the volcanic ashfall. It would be very good to have more community awareness and education re all potential natural disasters esp earthquake, lahars, floods, volcanic eruption.
- Written mailed lists as to what to do and how to do and respond on water proof paper that can be posted for people to refer too
- thank you for doing this
- Regarding the 2 maps: map 1 showed different coloring of probable hazard in the Concrete area as does the Map 2
- would be good to get more information on how to prepare in case these events happened.
- I think Skagit County should start serving ditches on private drive ways over 1/8 of a mile
- Please pick me to win !
- Live here due to low income or would move.
- I hope your group helps people understand how, what and when to prepare for a emergency. First responders might take days to respond to their neighborhood. I have a 10 day supply of food. I also have a jump bag for my PETS. Very surprised you did not include family pets in your survey and plan. I know that it is mandatory for first responders to rescue people and their pets. Why didn't you include pets in your survey???
- I guess I'm wrong about living/working in a lahar zone... :-)
- run a Homesteader group with survival training
- I work for the local county govt. I have little faith in their ability to make good decisions. Cities seem to be better long term planners. My family and I take our personal safety and security very seriously. We have a generator, wood heat, emergency supplies, water etc. My main concerns would be harsh winter storm(ice storm) knocking out power to many for anything over a few days in winter. Many are not prepared for something this. A good sized earthquake taking out a few bridges and a gasline or two would sure be bad also
- I feel community workshops would go a long way in decimating information.
- VERY INTERESTING AND THOUGHT PROVOKING

- i have been learning about emergency preparedness but hadn't considered volcano because we live so far from them. I'll look into that further now. Thanks.
- After watching "Years of Living Dangerously" I have been thinking more about global warming and how it will affect us. Just last week I found some time to research and collect my own list of emergency preparedness supplies. I haven't collected them yet. I also just this week signed up for CPR training. My neighbor (a nurse) was by a few weeks ago to collect information for a neighborhood plan. Somehow this is all coming into my consciousness a lot in the last month. I'm glad to help you raise awareness and prepare our community.
- Floods are expected here, and all who have lived here 10 years or so are likely to have experienced one or more. Volcanic activity is rare, so no one thinks or knows much. Seems not unreasonable to live a whole life and not experience this. Do you know something we don't?!!
- GOOD LUCK AND THANK YOU!
- Fema is after my beets and carrots. They wont get em i buried them in the dirt. aint nobody gonna be able to help when bakers blows. nobody.
- Thank you for asking and doing this research.
- The first question was unclear as to whether the event was something I had been around to witness or if it had happened to me personally, eg, did my own house burn down.
- Good luck!
- Thank you for this survey - it certainly got me to thinking about hazards other than flooding from heavy snow melt and rainfall. The eruption of Mt St Helens was the last time I really thought about ash fall or a mudflow from our volcanoes.
- Good survey. Perhaps it will be used to increase knowledge of lahars!
- Larry Kunsler (sic), a local man, has made a life time study of the Skagit River including El Nino, floods, lahar, and human interventions. Kristi Carperter at the Skagit Conservation District could undoubtedly put you in contact with him.
- We cannot prevent natural disasters. We can prepare for what might happen, but we can't control nature.
- Not at this time.
- I am concerned that there is no warning system in the area where we live.
- I thought this was very interesting and definitely worth my time!
- None at this time. Thanks
- Skagit Valley Herald (above). I would be interested in learning more about how to prepare and what to expect in the case of a local volcanic eruption.
- This was very interesting. There are evacuation route signs in Burlington and I don't even know what we are supposed to evacuate from... Thanks for doing this - makes me think.
- Although we live on Fidalgo Island, which does not seem to be the focus of this survey, we have a significant connection to the Skagit River Valley for transportation, water source, utilities, supplies, etc. Our personal safety situation may be different than those in the valley but our living conditions would be severely impacted by up-river disasters.
- Given the broad valley floor/capacity to absorb water/mud downstream of perhaps Burlington I sometimes wonder if maps don't overstate likely risks to places like LaConner. I don't doubt a risk, just feel that perhaps it could be represented differently... am I missing something?
- please make results public and share your findings with residents of skagit valley. thanks and good luck!
- Good Luck!!

- not at this time
- Good luck!
- Cool survey! :)
- Will we see the results of the survey and the researcher's conclusions?
- It was impossible for me to answer some of these questions because the computer would not "take" them.
- Need to add does not apply to all questions as some did not pertain to me.
- Thank you for this information. I had not idea about this threat.
- this was very informative. A good survey.
- Can you prevent a natural disaster? Seems to me you can only respond.
- on the first question, were those events supposed to be if you have experienced them in the Skagit River Valley or in/out of the valley? I have experienced some of them living outside of the valley...
- personally, I believe it is not a question of 'if' but, 'when'
- Our area/community is in a hazard zone for a Lahar and it has not been discussed until the Oso landslide in March of 2014. We need to be prepared!!
- Thanks for doing this and increasing our understanding
- Thanks for doing this. You might want to add the level of education (non-science) as well as an option for not stating household income.
- Thank you for bringing awareness to the Skagit valley. Your efforts may save lives should a future natural emergency occur.
- I would like information about ALL of the hazards mentioned in this survey. I would like to know what areas each would affect and how to prepare for each..
- Some questions on lahar are too assuming. The Skagit River Valley's most dangerous natural hazard is to come from flood and not volcanic mudflows. Thanks for your interest and good luck with your graduate project.
- Good luck with your Master's work, this is a very interesting topic!
- Seems like skagit officials should make the locals more aware of potential disasters. The recent disaster in Oso makes me nervous/aware of how quickly things can go bad :(
- I am thankful for your survey as I learned a few things and will look more into it'. Thank you
- Important survery- would like to see our community get more training and be prepared for things addressed in this survey!
- I feel that the smaller rural response centers are as best equipped as they presently can be, but that they are woefully short on resources should an actual emergency arise.
- I don't have much of a clue about the content of this survey, but it was interesting and has me thinking more about the forces around me. I've watched Mount Baker letting off steam for decades and am aware of what it could unleash. I especially like the Glacier Peak nod. I'd never given it a thought until a recent tv blurb about how potentially dangerous it could be. The young woman handing out these invitations was most pleasant, too. Thank you.
- I think this is SUPER important and interesting. Workshops and community events might raise awareness and, since volcanoes are super interesting, there might even be decent turn out!
- Thank you!
- Remember our National Moto and practice it. Don't spend money you don't have and don't let college damage your common sense.
- First questions answered were experienced as part of my job ff/emt 29 years Renton, wa.
- Thank you!

- Thanks for doing this!
- Good luck on your survey! I hope you educate residents about the natural disasters looming as I have found most people in the area to be completely ignorant of the dangers.
- We live with these hazards in our minds but have little fear as a community and so we have few plans.
- While I do not live in the Skagit Valley I have worked over 20 years there in the past and travel there frequently
- this is a good idea to help people see how prepared they REALLY are! thanks
- I would like to receive information on local emergency preparedness. Good luck w your research.
- thanks for informing me about this study. i lived in boise for a number of years and it holds a special place in my heart, just like skagit!!
- Good luck with your project. I look forward to reading about the results.
- I know what to do to prepare, in theory, but just never seem to get around to actually doing it!
- I hope that the survey results are made public at some time. Thanks for bringing people's attention to it.
- I am concerned that the effects of a lahar on Baker Lake & Dam with associated ripple effects is underestimated by public and elected officials.
- My wife and I recently moved to the Smokey Point area from Bellingham. We were living in Bellingham the previous three years. I also still commute to Bellingham for work.
- I've lived a long, decent life and don't fear much. I've lived with stronger threats than exist here and dealt with them, expect same here, but if I don't survive, I'm okay with it.
- Under the Preparedness section~ cost is a major factor but so is storage. A tiny apt simply does not have the room for a standard list of preparedness items.

APPENDIX C

Survey Postcard Advertisement

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BOISE STATE UNIVERSITY

Skagit Valley Natural Hazards Survey

The Skagit Valley is affected by a number of natural hazards with potentially severe impacts. A few simple steps can prepare you and your family and keep these natural hazards from becoming natural disasters.

This survey invites residents to answer a few simple questions about their awareness of and preparedness for select hazards. This survey provides educational material on natural hazards and ways to prepare. Participants also have the chance to **WIN A 7" TABLET!**

To take the survey visit: www.surveymonkey.com/s/skagithazards

Eligibility: 18 and live or work in the Skagit Valley.
Participation: This survey is completely anonymous.
Purpose: This survey is part of a Masters research study for a Boise State University graduate student.

For more information contact:
Kimberley Corwin - kimberleycorwin@u.boisestate.edu (Masters research student)
Dr. Brittany Brand - brittanybrand@boisestate.edu (Research advisor - http://earth.boisestate.edu/brittanybrand/)
Boise State University Institutional Review Board - (208) 426-5401

APPENDIX D

Barrier Correlations

The following records a detailed description of results relating to how various factors influence respondent opinions regarding the barriers that prevent them from adopting further preparedness actions:

A respondent's perception of these suggested barriers changes based on factors such as initial preparedness level, demographics, trust, past experience, and self-efficacy. Figure D.1 and Tables D.1 and D.2 show the results of chi-square and Kendall's tau-b correlation analyses, respectively, between the suggested barriers and 23 factors. Out of all 23 factors considered, initial preparedness (NCP score) correlates significantly with the greatest number of barriers. A respondent's preparedness level at the time of the survey is negatively associated with every barrier except a belief in the altruism of others. This indicates that respondents who are already well prepared view almost every barrier as less influential than do respondents who are poorly prepared.

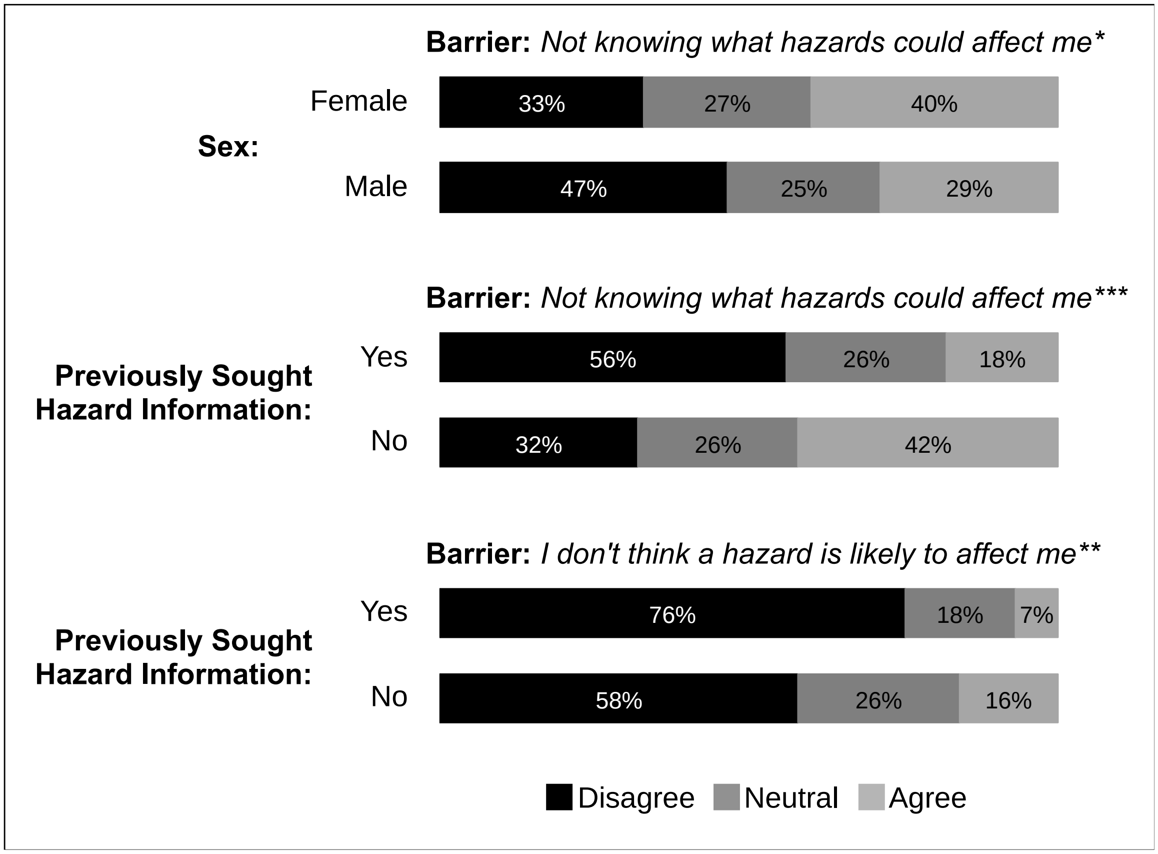

Figure D.1: Knowledge and perceived hazard probability barrier ratings based on sex and previous information seeking behavior. More female than male respondents cite a lack of hazard knowledge as a barrier to preparedness. Fewer individuals who have sought information about local hazards believe that either a lack of hazard knowledge or a belief that hazards won't affect them prevents them from preparing. Response frequencies were compared using chi-square analyses and differences were determined to be statistically significance at the level of $*p < 0.05$, $**p < 0.01$, and $***p < 0.001$.

Table D.1 Influence of Various Factors on Suggested Barriers to Preparedness Actions (Kendall's Tau-b Correlation Coefficients)

Suggested Barriers	NCPS	I	A	D	LR	AF	C	ST	CO	CS
Not knowing what hazards could affect me	-0.24***	-0.11**	-0.18***	-0.04	-0.07	-0.12**	-0.01	-0.05	-0.03	-0.13**
Cost (too expensive)	-0.14***	-0.21***	-0.21***	-0.11**	-0.06	-0.07	0.02	0.03	-0.07	-0.06
Too time consuming	-0.14***	0.01	-0.12**	-0.06	-0.01	-0.03	-0.03	-0.00	-0.03	-0.07
Not knowing what to prepare	-0.22***	-0.09*	-0.18***	-0.02	-0.02	-0.04	0.02	-0.02	0.03	-0.09*
Inaccurate, uncertain, or difficult to understand science, information, or maps	-0.09*	-0.02	-0.06	-0.01	0.03	-0.10*	0.02	-0.03	0.02	-0.23***
I don't think a natural hazard is likely to affect me	-0.25***	0.01	-0.12***	0.05	-0.03	-0.26***	-0.19***	-0.16***	0.09*	-0.06
My neighbors/ community members have these items and will assist me	0.00	-0.00	0.014	0.01	0.03	-0.12**	0.02	-0.04	0.19***	-0.03
Items will not help me protect myself	-0.10**	-0.01	-0.06	0.02	0.00	-0.14**	-0.06	-0.05	0.14***	-0.08*
Emergency services provides necessary items and assistance	-0.13***	-0.04	-0.07*	0.01	0.01	-0.21***	-0.06	-0.08*	0.24***	-0.00

Note: NCPS = normalized composite preparedness score, I = income, A = age, D = distance from vent, LR = length of residency, AF = aware of future volcanic hazard, CO = confidence in the ability of officials to provide timely and effective instructions, response, or evacuation, CS = confidence in the accuracy of scientific volcanic hazard maps and assessments, C = concern, ST = perceived severity of threat. *Correlations significant at the $p < 0.05$ level. **Correlations significant at the $p < 0.01$ level. ***Correlations significant at the $p < 0.001$ level.

Table D.2 Influence of Trust in Information Sources and Ascription of Responsibility Variables on Suggested Barriers to Preparedness Actions (Kendall's Tau-b Correlation Coefficients)

	Trust in Information Sources					Responsibility for Personal Safety				
Suggested Barriers	TS	TO	TFR	TM	TFF	RC	RP	RES	RF	RFF
Not knowing what hazards could affect me	-0.03	0.02	0.04	0.03	0.06	-0.02	-0.08	0.08*	0.17***	0.05
Cost (too expensive)	-0.03	-0.06	0.03	-0.10**	-0.01	-0.04	-0.10*	0.04	0.03	0.06
Too time consuming	-0.02	0.05	-0.00	0.03	0.02	-0.03	-0.06	0.07	0.08	0.02
Not knowing what to prepare	-0.05	0.04	0.05	0.07	0.04	0.01	-0.11*	0.13**	0.17***	0.06
Inaccurate, uncertain, or difficult to understand science, information, or maps	-0.18***	-0.04	-0.03	-0.04	0.07	0.01	-0.13**	0.03	0.08*	0.04
I don't think a natural hazard is likely to affect me	-0.13**	0.06	-0.15***	0.03	-0.02	-0.05	-0.12**	0.08	0.09*	-0.05
My neighbors/ community members have these items and will assist me	-0.16***	0.03	-0.04	0.10*	0.15***	0.20***	-0.18***	0.12**	0.12**	0.15***
Items will not help me protect myself	-0.17***	-0.00	-0.09*	0.04	0.11**	0.07	-0.17***	0.04	0.05	0.03
Emergency services provides necessary items and assistance	-0.18***	0.04	-0.14***	0.05	0.06	0.03	-0.23***	0.15***	0.16***	0.06

Note: TS = trust in scientists as an information source, TO = trust in officials as an information source, TFR = trust in first responders as an information source, TM = trust in media as an information source, TFF = trust in friends and family an as information source, RC = ascription of responsibility to fellow community members, RP = ascription of responsibility to self, RES = ascription of responsibility to local emergency services, RF = ascription of responsibility to FEMA, RFF = ascription of responsibility to friends and family members. *Correlations significant at the $p < 0.05$ level. **Correlations significant at the $p < 0.01$ level. ***Correlations significant at the $p < 0.001$ level.

Summary of the influence of factors in Figure D.1 and Tables D.1, and D.2 on suggested barriers:

1) Lack of hazard knowledge is influenced to a statistically significant level by a respondent's sex, information seeking behavior, income, age, awareness of local hazards, confidence in scientific hazard maps and assessments, and ascription of responsibility for personal safety to local emergency services and FEMA. In terms of sex, nearly 40 percent of female respondents indicate that a lack of hazard knowledge prevents them from adopting further preparedness actions as opposed to 29 percent of male respondents. Among those who have sought information about local volcanic hazards, only 18 percent view a lack of hazard knowledge as a barrier compared to 42 percent of those who have not sought information. Income ($\tau_b = -0.11$, $p < 0.01$), age ($\tau_b = -0.18$, $p < 0.001$), hazard awareness ($\tau_b = -0.12$, $p < 0.01$), and confidence in scientific maps and assessments ($\tau_b = -0.13$, $p < 0.01$) are all negatively associated with the lack of hazard knowledge barrier, which means that as these factors increase, this barrier becomes less important to respondents. Ascription of responsibility for personal safety to local emergency services and FEMA are both positively correlated with this barrier. The former is a weak correlation ($\tau_b = 0.08$, $p < 0.05$) while the latter is slightly stronger ($\tau_b = 0.17$, $p < 0.001$).

2) Cost is negatively associated with income ($\tau_b = -0.21$, $p < 0.001$), age ($\tau_b = -0.21$, $p < 0.001$), location ($\tau_b = -0.10$, $p < 0.05$), and self reliance. Cost becomes less of a barrier to preparedness when a respondent has a higher income, is older, lives further from the volcano that threatens them, or feels a high degree of responsibility for their own safety. Income and age are more strongly correlated with the cost barrier than are location and personal responsibility.

3) Time commitment is only significantly influenced by age (τ_b = -0.12, $p < 0.01$); the time commitment required to prepare forms less of a barrier among older respondents.

4) Lack of knowledge regarding how to prepare is very weakly correlated with income (τ_b = -0.09, $p < 0.05$). A stronger correlation exists with age (τ_b = -0.18, $p < 0.001$). Both are negative associations. Ascription of responsibility to self also negatively correlates with this barrier (τ_b = -0.11, $p < 0.05$) while the ascription of responsibility to local emergency services (τ_b = 0.13, $p < 0.01$) and FEMA (τ_b = 0.17, $p < 0.001$) positively correlates with this barrier. Those who place responsibility for their personal safety in the hands of emergency officials are less likely to view the lack of preparedness knowledge as a barrier.

5) Inaccurate, uncertain, or difficult to understand science, information, or maps is most strongly correlated with confidence in scientific hazard maps and assessments (τ_b = -0.23, $p < 0.001$). Those who are more confident in science view potential inaccuracies, uncertainties, and complexities associated with the science as less of a barrier to preparedness. Trust in scientists as information sources (τ_b = -0.18, $p < 0.001$) and awareness of future volcanic hazards (τ_b = -0.10, $p < 0.05$) also are negatively correlated with this barrier. A negative correlation exists with ascription of responsibility to self (τ_b = -0.13, $p < 0.01$) while a positive, albeit weak, correlation exists with the attribution of responsibility to FEMA (τ_b = 0.08, $p < 0.05$).

6) Believing that a natural hazard is unlikely to affect respondents is significantly influenced by information seeking behavior (Figure D.1), age (τ_b = -0.12, $p < 0.001$), awareness of future volcanic hazards (τ_b = -0.26, $p < 0.001$), concern (τ_b = -0.19, $p < 0.001$), perceived severity of threat (τ_b = -0.16, $p < 0.001$), confidence in officials (τ_b =

0.09, $p < 0.05$), trust in scientists ($\tau_b = -0.13$, $p < 0.01$) and first responders ($\tau_b = -0.15$, $p < 0.001$) as information sources, and ascription of responsibility for personal protection to one's self ($\tau_b = -0.12$, $p < 0.01$) and FEMA ($\tau_b = 0.09$, $p < 0.05$). Those who have sought information about local volcanic hazards consider this less of a barrier than respondents who have not sought information. Ratings of FEMA's responsibility for one's personal safety are weakly but positively correlated with this barrier; those who place greater responsibility with FEMA tend to rate this barrier as a more important. All remaining factors exhibit negative associations. The strongest correlation is with awareness of future volcanic hazards. The correlation with confidence in officials' abilities to provide timely and effective instructions, response, or evacuation is the weakest, statistically significant, negative correlation.

7) Believing the altruism of neighbors and community members negatively correlates with awareness of future volcanic hazards ($\tau_b = -0.12$, $p < 0.01$) and positively correlates with confidence in the abilities of officials ($\tau_b = 0.19$, $p < 0.001$). As awareness increases, the belief in the altruism of others becomes less of a barrier. However, as confidence in officials increases so does the belief that neighbors or community members will provide assistance during a hazard event. This barrier is also negatively associated with trust in scientists as information sources ($\tau_b = -0.16$, $p < 0.001$) and reliance on one's self for protection during hazardous events ($\tau_b = -0.18$, $p < 0.001$). Positive correlations exist between this barrier and trust in the media ($\tau_b = 0.10$, $p < 0.05$) and friends and family ($\tau_b = 0.15$, $p < 0.001$) as information sources. Positive correlations also exist with ascription of responsibility to other community members ($\tau_b = 0.20$, $p < 0.001$), local emergency services ($\tau_b = 0.12$, $p < 0.01$), FEMA ($\tau_b = 0.12$, $p < 0.01$), and friends and family members ($\tau_b = 0.15$, $p < 0.001$).

8) Low perceived response-efficacy is negatively associated with awareness of future hazards ($\tau_b = -0.14$, $p < 0.01$), personal responsibility ($\tau_b = -0.17$, $p < 0.001$), trust in scientists as information sources ($\tau_b = -0.17$, $p < 0.001$), confidence in scientific volcanic hazard maps and assessments ($\tau_b = -0.08$, $p < 0.05$), and trust in first responders as information sources ($\tau_b = -0.09$, $p < 0.05$). The latter two are extremely weak correlations. Confidence in the ability of officials to provide timely and effective instructions, response, or evacuation is positively correlated with this barrier ($\tau_b = 0.14$, $p < 0.001$). Thus, as a respondent become more confident in the abilities of officials, they become more inclined to believe that these recommended preparedness actions won't protect them. Trust in friends and family members as sources of information is also positively correlated with this barrier ($\tau_b = 0.11$, $p < 0.01$).

9) Believing that emergency services will provide necessary resources and assistance is negatively associated with awareness of future volcanic hazards ($\tau_b = -0.21$, $p < 0.001$), personal responsibility ($\tau_b = -0.23$, $p < 0.001$), trust in scientists as information sources ($\tau_b = -0.18$, $p < 0.001$), trust in first responders as information sources ($\tau_b = -0.14$, $p < 0.001$), and perceived severity of threat ($\tau_b = -0.08$, $p < 0.05$). The last is an extremely weak correlation. This barrier is most strongly and positively correlated with confidence in officials' abilities ($\tau_b = 0.24$, $p < 0.001$). As respondents become more confident in officials, they are more likely to believe (1) that emergency services will provide necessary resources and assistance during a hazardous event and (2) that this belief prevents them from adopting further preparedness actions. Similar positive correlations exist between this barrier and the ascription of responsibility for personal safety to local emergency services ($\tau_b = 0.15$, $p < 0.001$) and FEMA($\tau_b = 0.16$, $p < 0.001$).

APPENDIX E

IRB Approval Letter

BOISE STATE UNIVERSITY
RESEARCH AND ECONOMIC DEVELOPMENT

Date: July 29, 2014

To: Kimberley Corwin cc: Brittany Brand

From: Social & Behavioral Insitutional Review Board (SB-IRB)
c/o Office of Research Compliance (ORC)

Subject: SB-IRB Notification of Approval - Original - 014-SB14-106
Volcanic Risk Perception and Preparedness in Communities Within the Mount Baker and Glacier Peak Hazard Zones

The Boise State University IRB has approved your protocol submission. Your protocol is in compliance with this institution's Federal Wide Assurance (#0000097) and the DHHS Regulations for the Protection of Human Subjects (45 CFR 46).

Protocol Number:	**014-SB14-106**	Received:	7/16/2014	Review:	Expedited
Expires:	**7/28/2015**	Approved:	7/29/2014	Category:	6, 7

Your approved protocol is effective until 7/28/2015. To remain open, your protocol must be renewed on an annual basis and cannot be renewed beyond 7/28/2017. For the activities to continue beyond 7/28/2017, a new protocol application must be submitted.

ORC will notify you of the protocol's upcoming expiration roughly 30 days prior to 7/28/2015. You, as the PI, have the primary responsibility to ensure any forms are submitted in a timely manner for the approved activities to continue. If the protocol is not renewed before 7/28/2015, the protocol will be closed. If you wish to continue the activities after the protocol is closed, you must submit a new protocol application for SB-IRB review and approval.

You must notify the SB-IRB of any additions or changes to your approved protocol using a Modification Form. The SB-IRB must review and approve the modifications before they can begin. When your activities are complete or discontinued, please submit a Final Report. An executive summary or other documents with the results of the research may be included.

All forms are available on the ORC website at http://goo.gl/D2FYTV

Please direct any questions or concerns to ORC at 426-5401 or humansubjects@boisestate.edu.

Thank you and good luck with your research.

Mary E. Pritchard

Dr. Mary Pritchard
Chair
Boise State University Social & Behavioral Insitutional Review Board

1910 University Drive Boise, Idaho 83725-1139
Phone (208) 426-5401 orc@boisestate.edu

This letter is an electronic communication from Boise State University