Communication of Lava Flow Hazards

at the San Francisco Volcanic Field, Flagstaff, Arizona

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
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School of Geosciences
College of Arts and Sciences
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Date of Approval:
June 16, 2015

Keywords: volcano, risk perception, distributed volcanism, monogenetic volcanism

Acknowledgments

I would first like to thank my major advisor, Dr. Charles Connor, for giving me the opportunity to study at USF, supporting my work in Flagstaff, and most importantly, not giving up on me! I am very lucky to have worked with Chuck. I also want to thank my co-major advisor, Dr. Graham Tobin, for taking me on as a student and helping to develop my project. His words of encouragement were much needed and I am deeply appreciative. I want to express my gratitude to my advisor Dr. Sylvain Charbonnier, for his guidance and expertise. Thank you for pushing me to improve my thesis. Finally, thank you to my fellow graduate students for their inspiration, Laura Connor for her encouragement and support, and Mandy Stuck for her tough love and friendship.

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Abstract

This thesis examines different methods of communicating volcanic hazards to the population of Flagstaff, Arizona using the results of a recent lava flow hazard assessment of the nearby San Francisco Volcanic Field (SFVF). Harburger (2014) determined that given a lava flow originating in the SFVF, there is a statistical probability that it will inundate the city of Flagstaff or even originate from a vent within the city limits. Based on the recurrence rates for the most recent eruptions (3×10^{-4}/year), the probability of lava flow inundation in Flagstaff is 1.1×10^{-5} per year.

This study considers the effects of three different communication methods on participants' perceived risk. The methods were administered through a questionnaire and included a statement of probability of lava flow inundation per year, a statement of probability over a 100 year period, and an interactive lava flow map derived from the results of the lava flow hazard assessment. Each method was followed by questions gauging level of concern. Questionnaires were administered to 213 Flagstaff residents over a two week period in February 2015.

Results showed that levels of concern, rated from 1 (not concerned) to 5 (very concerned), varied based on each method of communication. The method with the greatest effect on perceived risk was the simulated lava flow map, while the first method with a one year odds resulted in a statistically lower mean rating of concern. It is suggested that the best way to change levels of perceived risk when communicating lava flow hazards includes a combination of comprehensible odds and visual aids. Further studies could also include visualization of the

entire eruption scenario, including time scales and other volcanic hazards, which may have more effect on concern than a simplified visualization of lava flows.

Chapter 1: Introduction

Volcanism presents significant hazards to both human life and infrastructure. Volcanic events have been associated with hazards such as crater formation, explosive eruptions, pyroclastic flows, ash fall, volcanic gasses, and lava flows (Valentine and Gregg 2008). In distributed volcanic fields, hazard assessments are used to forecast the distribution, timing, and/or magnitude of future volcanic eruptions (Connor et al., 2009; Connor and Hill, 1995; Martin et al. 2003). These form the basis for hazard mitigation strategies (Lindsay et al., 2008; Sandri et al., 2011).

Recently, Harburger (2014) conducted a lava flow hazard assessment of the San Francisco Volcanic Field (SFVF), a monogenetic, basaltic volcanic field in close proximity to the town of Flagstaff, Arizona. The most recent eruption, Sunset Crater, occurred approximately 900 years ago and was characterized by a NE-SW trending fissure that produced effusive lava flows, fumaroles and volcanic gasses (Smiley, 1958; Alfano, 2013). It is likely that a future eruption would originate from a new vent formed in the SFVF in a similar way.

Harburger (2014) estimated the conditional probability that, given a small-volume basaltic eruption within the SFVF, a lava flow will reach the city limits of Flagstaff. Her analysis consisted of a two-part approach of a spatial density estimate of volcano distribution and Monte Carlo lava simulation. The spatial density estimate used the distribution of past vents input into a Gaussian kernel function (Connor and Connor 2009) to forecast the locations of future vents. The lava flow simulation used the spatial density results along with given input parameters such as flow thickness and volume and a digital elevation model (DEM) to pick a probable vent location and simulate the extent of a new lava flow that originates from this vent, using inputs including the volumes, lengths and thicknesses of past lava flows. This method was developed by Connor et al. (2012) to determine the probability of lava flow inundation at a nuclear facility in the Shamiram Plateau region, Armenia. The results of that study determined that 2,485 of 10,000 (24.9%) iterations reached the area of interest. The probability was 6 x 10^{-6} per year, which is high enough to be of concern due to the proximity of the volcanoes to the Armenian Nuclear Power Plant and low recurrence rate of eruptive events (Connor et al. 2012).

The results of the San Francisco Volcanic Field lava flow hazard assessment were as follows: given an eruption in the SFVF, there is a 99% chance that the future vent will be located within a 3.6 x 10^{9} m^{2} area, centered about 20 km north of Flagstaff, possibly close to Sunset Crater. For the lava flow simulation, 274 of 7,769 iterations (3.5%) inundated the limits of Flagstaff, and 88 of 7,769 vents (1.1%) formed within the city limits. Given the average recurrence rate of vent formation (3.1 x 10^{-4} vents/yr) during the Brunhes chronozone (780,000 y.a. to present) and the results of the Monte Carlo simulation, the annual probability of inundation by lava flows and/or new vent formation within the area of Flagstaff is 1.1 x 10^{-5} per year (Harburger 2014). Variations in elevation and topography affected the direction of lava flows, with lower topography between existing volcanoes affording a path for lava to flow to the city. Harburger also concluded that vents located southeast of the San Francisco Peaks were most likely to result in inundation of the town.

While Harburger's (2014) probabilistic hazard assessment is the first step of hazard mitigation, the second step is to share the results with the residents of Flagstaff, since there has been no previous formal communication of volcanic hazards to the public. In an in-person survey, participants were presented three different communication methods with hazard information, and evaluated on their subsequent levels of concern. Data from the questionnaire were evaluated to determine how each method had an effect on participants' perception of risk.

Chapter 2: Background

Distributed Volcanic Fields

Distributed volcanic fields consist of monogenetic, small-volume, usually basaltic volcanoes. Monogenetic volcanoes are formed during single episodes of volcanism, with no further eruptions, while polygenetic volcanoes erupt from the same vent repeatedly over time. Monogenetic volcanic fields can include hundreds of volcanoes spanning thousands of square kilometers. Often the alignment of vents at the surface reflects tectonic structures below (Connor and Conway, 2000), and new vents can form every 100 – 100,000 years. Eruptions last from weeks to years; a recent example was within the Michoacán–Guanajuato field in central Mexico, where Paricutin volcano erupted suddenly in 1943 and continued until 1952 (Luhr and Simkin, 1993).

Hazard assessments forecast the distribution and timing of future eruptions in monogenetic fields using the recurrence rate of eruptions and spatial distribution of past vents. The long-term recurrence rates of eruptions can be calculated from the number of vents formed over a given period of time. Table 1.1 lists the long-term average recurrence rates of eruptions in selected basaltic volcanic fields, modified from data from Valentine and Connor (2015), Lindsay et al. (2011) and Kiyosugi et al. (2009). The average recurrence rate for the San Francisco Volcanic Field (SFVF) over the past 5.6 million years is 1.1×10^{-4} per year (Valentine and Connor, 2015); however, this does not account for variations in recurrence rates over different periods of time (Connor and Conway, 2000). The most recent recurrence rate for Brunhes-aged vents (<0.78 Ma) (Tanaka et al., 1986) in the SFVF is estimated to be 3 x 10^{-4} per year (Harburger, 2014).

Table 1.1. Average Recurrence Rate of Eruptions in Volcanic Fields.

	# Vents	Age Range (Ma)	Recurrence Rate
East Eifel, Germany	100	0.45	2 x 10^{-4}
Big Pine, USA	24	1.17	2 x 10^{-5}
San Francisco, USA	606	5.6	1.1 x 10^{-4}
Auckland, New Zealand	49	0.2 – 0.26	~2 x 10^{-4}
Sabatini, Italy	45	0.21	2.1 x 10^{-4}
Abu, Japan	56	3.29	1.7 x 10^{-5}

The San Francisco Volcanic Field (SFVF)

The SFVF is a monogenetic field located in northern Arizona on the southern boundary of the Colorado Plateau (Figure 2.1) (Conway et al., 1997). The SFVF is around 5.6 million years old and consists of over 600 Tertiary and Quaternary basaltic volcanoes. The field extends over 100 km east-west and 70 km north-south, and lava flows and pyroclastic deposits cover an area of around 4,800 km^2 (Figure 2.2) (Tanaka et al., 1986). Much of the field is located within the Coconino and Kaibab National Forests and the town of Flagstaff, Arizona is located on the southern boundary. Tanaka et al. (1986) determined that volcanism is migrating towards the northeast at a rate of 2.9 cm/yr, most likely due to the southwest motion of the North American plate over the fixed mantle. In accordance with this movement, the oldest rocks in the SFVF can be found on the western side, while the most recent eruption was at Sunset Crater to the east.

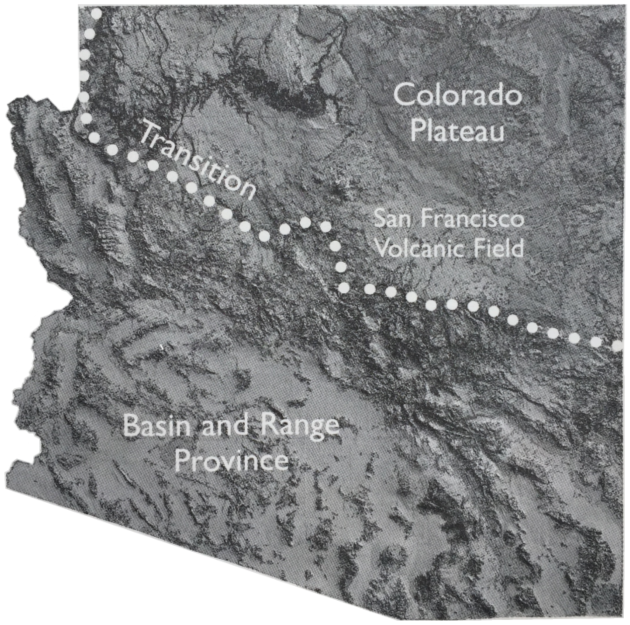

Figure 2.1. Location of the San Francisco Volcanic Field in Arizona. The SFVF is located on the southern boundary of the Colorado Plateau, north of the Transition Zone between the Colorado Plateau and the Basin and Range Province. Adapted from the Western National Parks Assoc. and MMKAA, Inc.

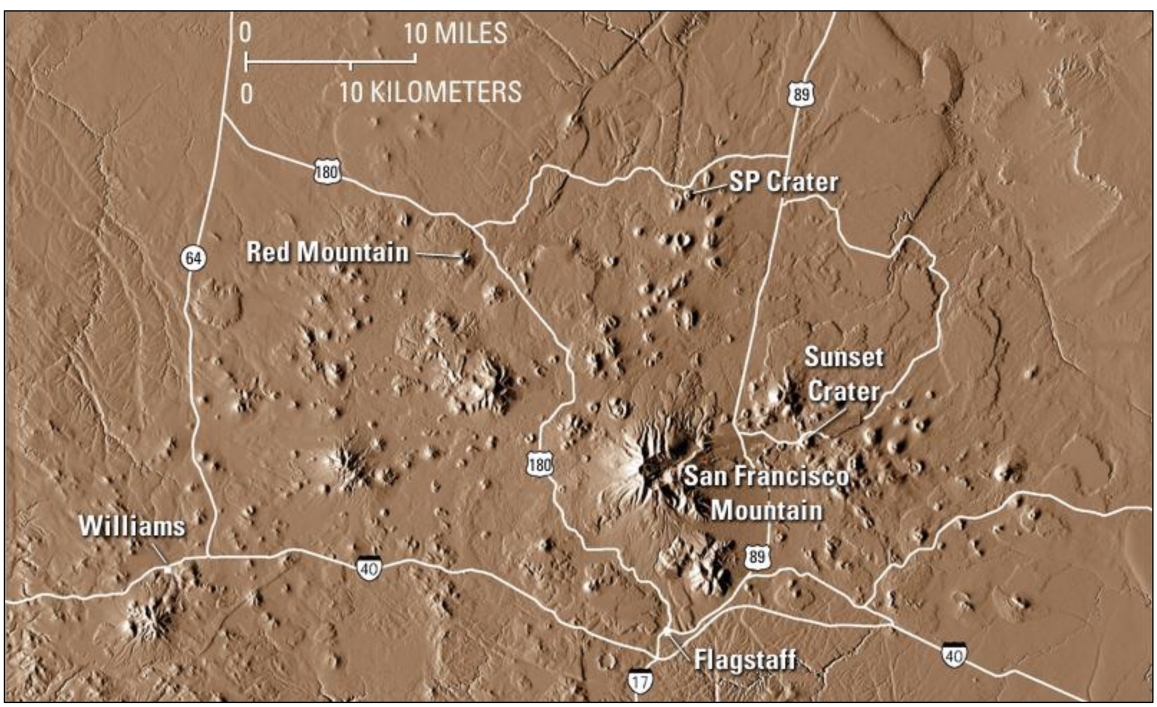

Figure 2.2. Digital Elevation Model of the San Francisco Volcanic Field. Vents are shown relative to Flagstaff, ~20 km southeast of Sunset Crater. From USGS.

Sunset Crater is the youngest volcano in the SFVF and the only Holocene volcano, dated around 1075 +/- 25 A.D. (Ort et al. 2002). It is located about 20 km northeast of Flagstaff. The eruptive history of Sunset Crater began with the formation of a NE-SW trending fissure that produced effusive lava flows, ranging in thickness from 2 m at the margins to 30 m at parts of the Bonito flow. This was accompanied by tephra explosions, fumaroles and volcanic gasses (Smiley, 1958)

The local Native American communities were greatly affected by the eruption of Sunset Crater (Colton, 1932). Lava flows buried Sinagua dwellings and fields (Smiley, 1958; Elson et al., 2015), some of which have been excavated today and helped researchers further determine the date of the eruption (Elson et al., 2011). Tephra from the explosive events covered an area of over 2,100 km^2 (Fischer, 2007) and displaced Native American populations in the surrounding area (Elson et al., 2015). Today, Sunset Crater is a National Monument operated by the National Park Service. Visitors can hike on the surrounding lava flows but the crater itself is closed to the public to prevent further erosion and damage.

Area of Study

The area of study for this thesis is Flagstaff, Arizona. Flagstaff, which is located on the south side of the SFVF, was chosen as it is the closest population and the site of a recent lava flow hazard assessment by Harburger (2014). It is bordered to the north by Mount Elden and the San Francisco Peaks, which are the remains of an andesitic composite volcano (Connor and Conway, 2000) that may have reached over 4,800 m at the summit before it collapsed (Hardy, 2015; Fischer, 2007). Today, the highest point at Humphrey’s Peak stands at 3,851 m and still dominates the landscape from most areas in Flagstaff.

According to the US Census website, the population estimate of Flagstaff in 2013 was 68,667 people, with a median age of 27 years old. The city is home to Northern Arizona University (NAU), a public university with almost 20,000 students. Flagstaff is intersected by Interstate 40, the major highway that runs through Arizona connecting California to New Mexico, generating traffic from road travelers and tourists often heading to the Grand Canyon. Other important infrastructure includes telecommunications, electric power, oil and gas, banking and financial institutions, transportation networks [the Burlington-Northern Santa Fe (BNSF) Railway and historic Route 66], water supply systems, government services, and emergency services (Fuller, 2005).

Flagstaff is vulnerable to economic and physical damages given a natural disaster, although volcanic hazards have not been considered in official city hazard planning. Flagstaff's 2005 "Multi-Hazard Mitigation Plan," a fulfillment of federal hazard planning litigation, listed the primary hazards as drought, flooding/flash flooding, wildfires, and winter storms (Fuller, 2005). While volcanoes were mentioned, the related hazards were not detailed. The 2002 Arizona Geological Survey's Home Buyer's Guide declared that the main hazard related to volcanic activity for homeowners is ashfall but that there is no need for mitigation since there are no indications of magma movement below the surface of the earth. They do not recommend that future construction projects plan for volcanic hazards (Harris and Pearthree, 2002). While current city hazard plans do not consider the economic effects of volcanic eruptions, they do detail the destructive effects of wildfires, which are one of the most significant hazards and can be a result of volcanic activity such as lava flows and fire fountaining. According to estimates, the potential economic loss estimated from wildfires in the area could reach up to $896.7 million dollars in losses with 24,314 humans exposed to the risk (Fuller, 2005).

Earthquakes are another realistic hazard for Flagstaff residents. On November 30, 2014, an M 4.7 earthquake occurred about 25 km south of Flagstaff. While earthquakes are not uncommon, the proximity of this earthquake to the proposed research date may have influenced survey-takers' perceptions of risk. The earthquake was widely felt by area residents, with over 1,000 people reporting their experiences to the USGS by the next afternoon (Scott, 2014). There were no injuries or damages reported, except for a small rock fall on State Route 89A (Lee, 2014).

The National Park Service's Geologic Resource Evaluation Report of Sunset Crater recommends close monitoring of the area around Sunset Crater including seismic monitoring and GPS to track any ground deformation (National Park Service, 2005). In October 2012, the United States Geological Survey (USGS) in Flagstaff hosted the "Volcanism in the American Southwest" conference to facilitate a dialogue about planning and mitigating volcanic hazards in the region. Attendees presented research related to both geology and hazard planning.

Eruption Scenario

Volcanic eruptions are low-frequency events with high consequences (Martin et al., 2003). Hazard assessments such as Harburger's (2014) lava flow hazard assessment can quantify the probability of volcanic activity occurring in the future. Forecasting the onset of an eruption requires continuous monitoring, while visualizing the extent and style of a potential eruption depends mostly on observations from the past. One example of forecasting future eruptive scenarios is in Auckland, New Zealand.

The Auckland Volcanic Field is a monogenetic basaltic field that underlies Auckland, New Zealand, the country's most populated city, with over one million residents (Edbrooke et al., 2003). The AVF covers an area of about 360 km^2 and consists of about 50 volcanoes (Hayward et al., 2011), with the most recent and largest eruption at Rangitoto Island occurring about 600 years ago. As seen in Table 1.1, the average recurrence rate for the AVF is around 2 x 10^{-4} per year. The hazards associated with a future eruption at the AVF were considered high enough that in 2007, the New Zealand government began national preparedness with “Exercise Ruaumoko” (Lindsay et al., 2010), which simulated an eruption in the Auckland metropolitan area. This effort included forecasting the onset of a simulated eruption and considering potential eruptive activity. Lindsay et al. (2010) used the Bayesian Event Tree for Eruption Forecasting (BET_EF) techniques (Marzocchi et al., 2007) to monitor the progression of events leading up to an eruption, and provided an estimation of all possible eruptive outcomes using historical data (Lindsay et al., 2010). Lindsay et al. (2010) determined that future activity in the AVF would most likely begin with seismic unrest for several months, followed by ground uplift and ultimately a phreatomagmatic eruption, similar to past eruptions in the AVF (Allen and Smith, 1994).

The effects of a phreatomagmatic eruption in the Auckland area could be potentially destructive: blasts from explosions could reach areas within a 5 km radius of the eruptive center and debris fall could extend up to 2 km from the crater (Edbrooke et al., 2003). Effusive activity could produce scoria cones reaching 100 m in height up to 3 km from the vent, and lava flows could extend up to 10 km from the vent, with thicknesses of up to 25 m (Edbrooke et al., 2003). Ash fall hazards would affect infrastructure in areas up to 30 km from the vent and air traffic would most likely be affected (Edbrooke et al., 2003).

A future eruption in the SFVF can be visualized using data from the eruption of Sunset Crater, which occurred sometime between A.D. 1040 and 1100 (Ort et al., 2002). The explosive eruption began with a 10 km long (Self et al., 2010) northwest-southeast trending fissure (Smiley, 1958) that produced the Kana-a and Bonito lava flows, various fumaroles and spatter cones, and the 300 m tall scoria cone (Self et al., 2010) known as Sunset Crater. The scoria-fall blanket covered an area of about 500 km^2 (Alfano et al., 2013) and reached up to 60 km from the vent (Self et al., 2010). Three lava flows with thicknesses of up to 30 m covered an area of about 8 km^2 (Alfano et al., 2013), with the Kana-a flow traveling along topographic lows to a distance of 11 km from the vent (Self et al., 2010). Lava flows from other eruptions in the SFVF are similarly extensive, such as the flow at SP Crater, located 40 km north of Flagstaff, which extends 7 km from the vent with an average thickness of over 30 m (Harburger, 2014).

Like the potential eruption in the AVF, an eruption in the SFVF would be indicated weeks to months in advance by seismic activity and possibly ground deformation. The eruption would most likely begin with the formation of a fissure like that of Sunset Crater, leading to explosive eruptions of scoria and ash and effusive lava flows. The duration could range from weeks to years; estimates for the duration of the Sunset Crater eruption vary from a few months (Colton, 1945; Elson et al., 2002) to 100-200 years (Shoemaker and Champion, 1977; Holm and Moore, 1987). Most likely, the eruptive period will last from weeks to a few years (Ort et al., 2008). Lava discharge calculations show that Sunset Crater’s Kana-a flow, which occurred throughout the eruptive period, was emplaced over a period of weeks to three months (Ort et al., 2008; Elson et al., 2015). Correspondingly, Ort et al. (2002) notes that modern cinder cone eruptions usually have eruptive periods lasting under one year and that only one cinder cone eruption, Cerro Negro in Nicaragua, has been documented to erupt for over 100 years (Hill et al., 1998).

Harburger (2014) outlines the hazards associated with a potential eruption in the SFVF. One of the most destructive processes is vent/crater formation, which would destroy infrastructure at and around the site of the vent (Harburger, 2014). With temperatures over 1,000 degrees C, lava flows following topographic lows will burn or bury everything in their path and lead to road obstructions and wildfires (Harburger, 2014). Tephra fallout can travel several hundred kilometers and build up on structures, leading to roof collapse (Harburger, 2014). There are also disastrous long-term effects that can take decades to become evident such as acid rains, climate change, destruction of vegetation and animal habitats, and long-term devastation of area landscape (Elson et al., 2015). Elson (2006; 2015) estimates that the almost 600 km^2 area affected by tephra deposits over 15 cm lost most vegetation and remained barren for several years after the eruption.

Hazard, Risk, and Risk Communication

Effective mitigation requires "an understanding of public knowledge and perception of hazard and risk" (Bird, 2009). Hazard and risk, however, are commonly used terms that are not often clearly defined and sometimes used interchangeably (Tobin and Montz, 2009a; Tobin and Montz, 1997). A hazard is a source of potential harm to humans. In this case, volcanic hazards represent the interaction between humans and extreme volcanic events (Tobin and Montz, 2009b; Tobin and Montz, 1997). In the Comparative Glossary for Core Terms of Disaster Reduction (2004), a hazard can "cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can be single, sequential or combined in their origin and effects (Montz and Tobin, 2013; Tobin and Montz, 2009b). Each hazard is characterized by its location, intensity and probability" (Thywissen, 2004).

“Risk,” as pertaining to the geosciences, “indicates the degree of potential losses in urban places due to their exposure to hazards” (Thywissen, 2004). Risk is determined by both the probability of hazard occurrence and the vulnerability of the affected society (Tobin and Montz, 2009b). Vulnerability is considered a human condition determined by exposure to the hazard and the availability of resources (Tobin and Montz, 2009b). Vulnerability often varies based on socioeconomic differences (Tobin and Montz, 2009b), shaped by both behavioral choices and population exposure (Tobin and Montz, 2009a). “Risk assessment” is defined as “the assessment on both the probability of natural disaster occurrence and the degree of danger caused by natural disasters” (Thywissen, 2004).

Risk perception is an individual concept based on one’s understanding of the probability of a hazard occurring and how that probability is interpreted (Paton et al., 2007; Slovic, 2000). Therefore, perceived risk can be considered a combination of technical risk, the nature of the hazard, and the context of the perceiver (Adler and Kranowitz, 2005). There are many factors that affect an individual’s perception of risk, including the nature of the risk, the nature of the potential consequences, and individual and social characteristics (Tobin and Montz, 1997; Slovic, 1987). Acceptable risk is determined when the benefits of reducing risk are compared with the costs (Tobin and Montz, 1997) and deemed acceptable to live with.

Risk communication is the process of informing the public about potential risks related to hazards (Adler and Kranowitz, 2005) before they occur., The key to good risk communication, as affirmed by the U.S. Department of Health and Human Services, “is to determine what information is crucial to convey and then to convey that information before a controversy develops (Adler and Kranowitz, 2005). Risk communication requires an exchange of information between experts and members of the community, but there is often a gap in communication between scientists and the public (Tobin and Montz, 2009a). In order to convey risk appropriately, risk communicators must first define the public's initial level of understanding and the way that they are affected by and perceive hazards and then determine how to communicate effectively.

Chapter 3: Methods

The purpose of this study was to investigate ways to communicate the probability of lava flow inundation in Flagstaff to residents and gauge their level of concern about volcanic hazards. The way that people usually investigate hazard communication is through a questionnaire. However, when communicating probabilities of lava flow inundation to the public, it is important to present hazard information in a way that is understandable and useful. Adler (2005) emphasized that "the best language to use in communicating risks is simple and non-technical." For that reason, the questionnaire used simplified communication methods, including probability estimates presented as odds rather than orders of magnitude, and a visualization of a simulated lava flow in Flagstaff.

Questionnaire Design

In 2013, Leathers (2014) used an in-person questionnaire to gather information about risk perception of Hawaiian residents in the Puna District exposed to hazards from Kilauea volcano. Leather's (2014) questionnaire was adapted from Lachman and Bonk's 1960 Kapoho survey of residents affected by the 1960 Kilauea eruption (analyzed by Gregg et al., 2008). Leathers' (2014) questionnaire included survey questions from Lachman and Bonk (1960) as well as questions about hazard knowledge and trust in the government (Leathers, 2014). Results from 2013 were compared to results from 1960 (Gregg et al., 2008) to see if there was a statistically significant difference between participants' responses 53 years apart.

For this study, it was determined an in-person questionnaire similar to Leathers (2014) would be an effective tool to evaluate Flagstaff residents' levels of concern about volcanic hazards. The advantages of in-person questionnaires are higher response rates and the ability to control the sequence of questions and use visual prompts (Bird, 2009). The questionnaire was approved by USF's Institutional Review Board and contained a statement of informed consent explaining the purpose for the study and contact information for Dr. Graham Tobin at USF. Like Leathers' (2014) survey, the questionnaire itself included questions about volcanic hazard perception followed by a section collecting basic demographic information.

The first section of the questionnaire consisted of six questions. The first question asked participants to identify the major environmental concern(s) in Flagstaff from a list of several natural hazards, including earthquakes, volcanoes, wildfires, flooding, drought, hurricanes, and winter storms. The next question asked participants to rate initial concern about volcanism specifically on a scale of 1 (not concerned) to 5 (very concerned). Then, participants were presented with three methods (labeled A, B and C) depicting the results of the hazard assessment in three different ways and again evaluating level of concern from 1 to 5. After that, an open-ended question allowed respondents to include their comments and concerns. The questionnaire concluded with a section collecting demographic information (Appendix A).

The main goals of the questionnaire were to present the probability of lava flow inundation in Flagstaff to residents in an understandable way and to determine which method best raises levels of concern. The hazard assessment determined that the probability of lava flow inundation in Flagstaff is 1.1×10^{-5} per year (Harburger, 2014). Although stating probability with an order of magnitude is standard for many scientists, it may not work for the general public. Slovic (2000) wrote frankly, "there is widespread agreement that casting individual risks in terms such as 10^{-x} per year is not helpful to people." Instead, probability estimates using orders of magnitude require analogies and communication tools to help the public translate the numbers into something they can easily understand. Therefore, the 10^{-5} probability was translated into odds of "1 in 100,000" per year and "1 in 1,000" over a period of 100 years. The three descriptive methods used in the questionnaire were as follows:

1. Method A: One year statement of probability. *"According to scientists, the odds of a lava flow reaching Flagstaff are 1 in 100,000 per year."* This number was developed directly from the 2014 hazard assessment's probability of 1.1 x 10^{-5} per year. The orders of magnitude widely used in risk assessment (10^{-x} per year) were not used since they are often unfamiliar or confusing to the public.

2. Method B: Statement of probability over a 100 year period. *"Scientists also said that there is a 1 in 1,000 chance of a lava flow reaching Flagstaff any time in the next 100 years."* These are the same odds as the one year statement of probability, calculated for a longer time interval, but still short enough to be conceptualized. Also considered was a 30-year time period (Bell, 2007) with a 0.033% chance, but a 100-year period was ultimately chosen because it is a consistent with the odds in the first question.

3. Method C: Lava flow example. The final method presented an interactive map on Google Earth showing a potential lava flow (Figure 3.1) developed through computer simulation (Connor et al., 2012). No odds were provided along with this method; rather, it relied on the individuals' interpretation of the simulation output.

To create the simulated flow, a potential vent was picked that was consistent with the spatial density estimate of probability of new vent formation, and an eruption of lava was simulated, using a Digital Elevation Model (DEM). The DEM was georeferenced with Google Earth and digitally drawn on as a layer. The vent itself chosen was located southeast of the San Francisco Peaks, so that the lava flow would reach the Flagstaff town limits. The simulated flow reached several kilometers into suburban eastern Flagstaff, inundating several residential neighborhoods and crossing Routes 66 and 40. Table 3.1 lists input parameters for the lava flow simulation in Harburger's (2014) Monte Carlo simulation as well as for Method C, the single lava flow scenario.

Table 3.1. Input Parameters for the Lava Flow Simulation and Scenario.

	Harburger, 2014	Lava Flow Scenario	Notes
Vent location (km)	Various	446.03 E, 3896.92 N	One vent chosen for lava flow scenario
Modal lava thickness (m)	1.4 – 197.5	50	Uniform distribution
Lava flow volume (m^3)	$10^7 – 10^9$	4.8×10^7	Log-normal distribution
Iteration volume (m^3)	10^6	10^6	
Number of simulations	7,769	1	

The lava flow scenario was presented using Google Earth (Figure 3.1) on an iPad so that the map could selectively display the boundaries of Flagstaff, the boundaries of the area of interest for the lava flow code, the locations of the San Francisco Volcanic Field and Sunset Crater in reference to Flagstaff, and various identifying landmarks such as NAU and Route 40.

Participants could also use the iPad to identify their current location within the map and determine whether or not they lived in the lava flow zone.

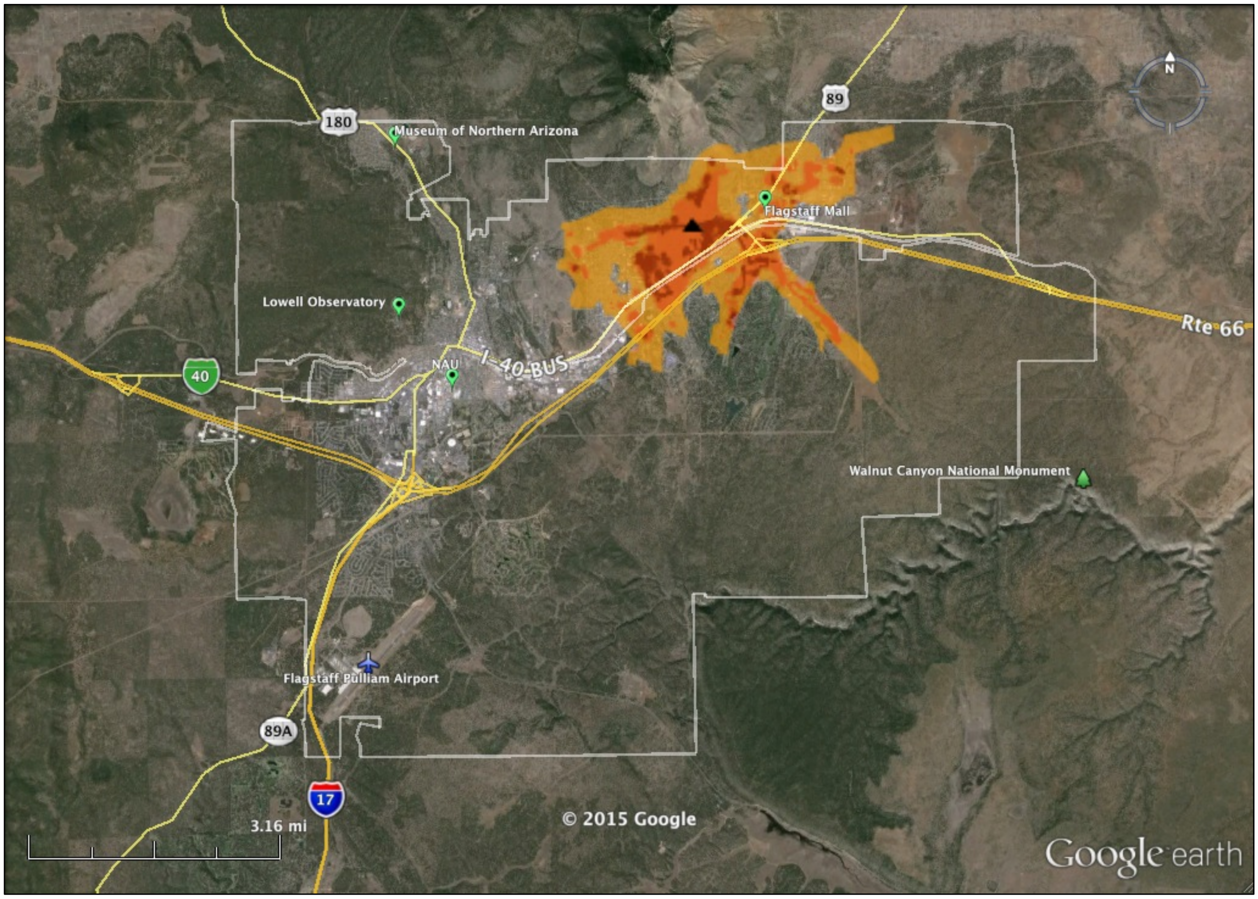

Figure 3.1. Method 3: Google Earth Map with example lava flow. Vent is marked by black triangle. This map was interactive and allowed the user to point out current location as well as local landmarks.

After each lava flow hazard scenario (A-C) was presented, participants were asked to rate their level of concern on a scale of 1 (not concerned) to 5 (very concerned). A final, open-ended question ("is volcanism a concern in Flagstaff?" allowed participants to voice any comments or concerns. The second section of the survey included optional demographic questions pertaining to age, years lived in Flagstaff, zip code, education level, income, and homeownership.

Data Collection

A total of 213 questionnaire surveys were completed during a two week period in February 2015, administered in-person at various gathering places around Flagstaff including NAU, the Flagstaff Mall, Safeway, the Sonesta hotel, the Coconino Ranger Station and Sunset Crater Visitor Center, the USGS Astrogeology building, and a variety of local parks and businesses, both inside and outside the simulated lava flow zone. The following table summarizes basic information for each interview location, including whether the area was located in the zone of the simulated lava flow, the number of surveys collected at that location, and percent of total number of surveys.

Table 3.2. Interview Locations.

	Lava Flow Zone	***N* Surveys**	**%**
Northern Arizona University (NAU)	No	95	44.6
Flagstaff Mall	Yes	24	11.3
Sonesta ES Suites	Yes	13	6.1
Home Depot	Yes (On the edge)	8	3.8
Best Buy	Yes (On the edge)	6	2.8
Buffalo Park	No	6	2.8
Museum of Northern Arizona	No	6	2.8
Sunset Crater	No	6	2.8
Wheeler Park	No	6	2.8
Hwy. 89 Safeway	Yes	5	2.3
Target	No	4	1.9
Eat ‘N Run	Yes	3	1.4
Flagstaff Visitor’s Center	No	3	1.4

Table 3.2. Interview Locations (Continued).

Fort Tuthill County Park	No	3	1.4
Flagstaff Toyota	Yes	3	1.4
USGS Astrogeology	No	3	1.4
Aspen Sports	No	2	0.9
Chamber of Commerce	No	2	0.9
Crystal Magic	No	2	0.9
Enjoy Jesus Coffee House	Yes	2	0.9
Mike and Ronda's	No	2	0.9
Office Max	Yes	2	0.9
Old Hwy. Trading Post	No	2	0.9
World Market	Yes (On the edge)	2	0.9
89A Gas Station	No	1	0.5
Cedar Safeway Starbucks	Yes	1	0.5
Coconino Ranger Station	Yes	1	0.5
Total	70 in lava flow zone, 143 not in lava flow zone	213	100

Participants were adults, ages 18 and up. Individuals were approached and asked if they would be willing to complete a questionnaire about natural hazards in Flagstaff for a Master's Thesis project. If they agreed, this was followed by the statement of informed consent, and rejections were noted. Most questionnaires took less than five minutes to complete and data and comments were recorded by hand.

Chapter 4: Results

Demographics

Participants were invited to complete a brief set of questions about their demographics, including gender, years lived in Flagstaff, zip code, home ownership, age, level of income, and level of education. Every individual who completed the first part of the questionnaire agreed to complete the demographics section, although many excluded their income.

The demographics results are as follows: 58.7% of the sampled participants were female and 41.3% male (Table 4.1). About 72% of participants had lived in Flagstaff for less than five years and 28.2% had lived in Flagstaff for at least 5 years or more (Table 4.2), with the longest residency in Flagstaff being 58 years. The predominant zip codes of residence were 86001 (32.4%), 86004 (30.1%), 86011 (19.7%), and 86005 (5.6%), and 12.2% of participants listed their zip codes as areas outside Flagstaff (Table 4.3). Around 82% of participants rented their homes (Table 4.4). The predominant age group was 18-24 years (64%), followed by 25-34 (14.6%), 55-64 (7.5%) and 35-44 (6.6%). Both the age ranges of 45-54 and 65+ consisted of 4.7% of the total (Table 4.5). Around 58% of participants listed their education level as "Some College," while 17.8% listed a Bachelor's Degree and 9.9% listed an Associate's Degree. Over 9% of participants listed a High School Degree or GED, and 4.2% listed a Graduate Degree (Table 4.6). Participants listing an income of less than \$20,000 per year accounted for 47% of the total. The remainder of the income results included \$20,000 - \$30,000 (8.5%), \$35,000 - \$50,000 (8%), \$65,000 - \$80,000 (4.7%), over \$100,000 (2.8%), and \$50,000 - \$65,000 (2.4%). No participants listed their income as $80,000 - $100,000 (Table 4.7), and around 27% elected "Prefer Not to Answer."

Table 4.1. Gender.

	N	%
Male	88	41.3
Female	125	58.7
Total	213	100

Table 4.2. Years Lived in Flagstaff.

	N	%
< 5 years	153	71.8
> or = 5 years	60	28.2
Total	213	100

Table 4.3. Zip Code.

	N	%
86001	69	32.4
86004	64	30.1
86011	42	19.7
86005	12	5.6
Other	26	12.2
Total	213	100

Table 4.4. Home Ownership.

	N	%
Own	39	18.3
Rent	174	81.7
Total	213	100

Table 4.5. Age.

	N	%
18 – 24	132	62.0
25 – 34	31	14.6
35 – 44	14	6.6
45 – 54	10	4.7
55 – 64	16	7.5
65+	10	4.7
Total	213	100

Table 4.6. Level of Education.

	N	%
Some High School	1	0.5
High School or GED	20	9.4
Some College	124	58.2
Associate's Degree	21	9.9
Bachelor's Degree	38	17.8
Graduate Degree	9	4.2
Total	213	100

Table 4.7. Income.

	N	%
Under 20,000	100	47.0
20,000 – 35,000	18	8.5
35,000 – 50,000	17	8.0
50,000 – 65,000	5	2.4
65,000 – 80,000	10	4.7
80,000 – 100,000	0	0
Over 100,000	6	2.8
Prefer Not to Answer	57	26.8
Total	213	100

Over 50% of the respondents in this study were students at the University of Northern Arizona. Most of these students had lived in Flagstaff for less than five years, lived in the 86001 or 86011 zip codes, fell within the "18 – 24" age range, selected an education level of "some college" and had an income of less than $20,000 per year.

Questionnaire Data

The part of the questionnaire concerning lava flow hazards consisted of six questions. The first question was a multiple choice question, followed by four ordinal questions evaluating concern on a scale of 1 (not concerned) to 5 (very concerned). The final question was an open-ended question asking whether participants think that volcanism is an issue in Flagstaff.

Question 1: What do you think is the major natural hazard in Flagstaff?

This was a multiple-choice question with responses constrained to seven natural hazards: earthquakes, volcanoes, wildfires, flooding, drought, hurricanes, and winter storms. Participants were required to select one answer, but many picked more than one. Since the number of chosen hazards is not the same across all surveys, this makes analysis difficult. However, the overwhelming majority of participants (81.2%) included "wildfires" as one of their answers. 26.3% of participants included "winter storms" and 18.8% included "drought;" 17.8% of participants selected "flooding" as one of their answers and 16.9% selected "earthquakes." Finally, 8.9% of participants included "volcanoes" as a main concern. No participants selected "hurricanes" as an option, which was expected, and makes sense given that Flagstaff is far from any area susceptible to hurricanes.

Question 2: On a scale of 1 (not a risk) to 5 (high risk), how much of a risk is volcanism to the population of Flagstaff?

The second question asked participants to evaluate perceived risk of volcanic activity in Flagstaff on a scale of 1 (not a risk) to 5 (high risk). Of the total responses (N = 213), the mean score was 1.99 and the modal value was 2. There were 49.3% respondents selecting number 2, followed by 29.6% for option 1. Of the remaining respondents, 15% chose number 3, 5.2% chose number 4, and only 0.9% chose number 5. The distribution of answers is illustrated in Figure 4.1.

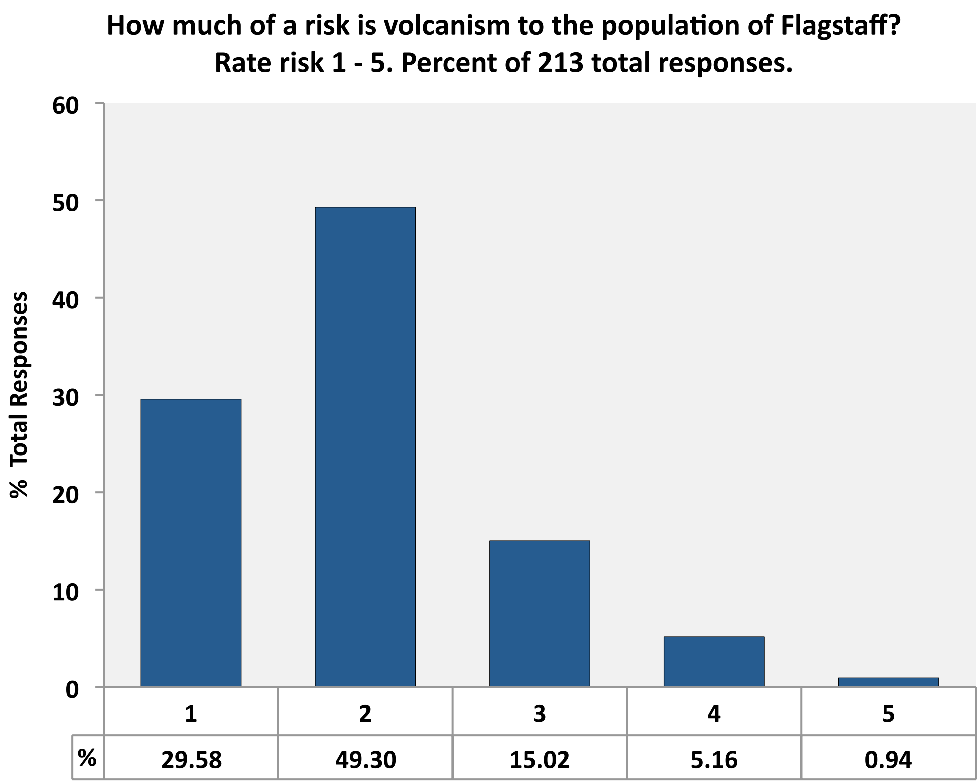

Figure 4.1. Question 2: Perceived Risk of Volcanism in Flagstaff. Participants were asked to rate the risk of volcanism to the population of Flagstaff, from 1 (no risk at all) to 5 (high risk).

Method A: According to scientists, the odds of a lava flow in Flagstaff are 1 in 100,000 per year. On a scale of 1 (not concerned) to 5 (very concerned), how concerned are you about lava flows affecting Flagstaff?

Method A presents the first method of communication with the 2014 hazard assessment simplified from 1.1×10^{-5} to odds of approximately 1 in 100,000 per year. This question presents the odds of 1 in 100,000 then asks participants to rate their level of concern on a scale of 1 (no concern) to 5 (very concerned). Of the total responses (N = 213), the mean score was 1.62 and the mode was 1, with 51.2% responses of number 1, followed by 2 at 39%; 6.6% of participants chose number 3, and 3.3% chose number 4. There were no answers of number 5 (very concerned). The distribution of answers is illustrated in Figure 4.2.

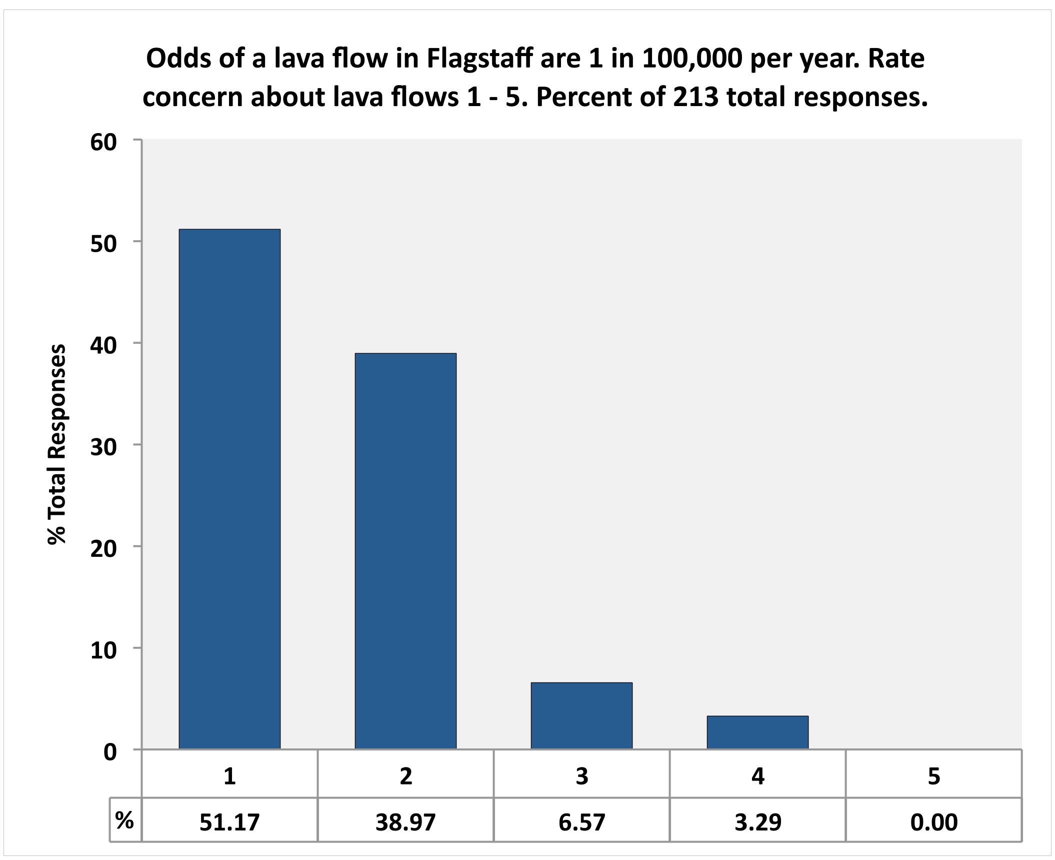

Figure 4.2. Level of Concern for Method A. This method presented the odds of inundation of 1 in 100,000 per year. Participants were asked to rate their concern from 1 (not concerned at all) to 5 (very concerned).

Method B: Scientists also said that there is a 1 in 1000 chance of a lava flow in Flagstaff any time in the next 100 years. On a scale of 1 (not concerned) to 5 (very concerned), how concerned are you about volcanic hazards affecting Flagstaff?

In this method, participants are presented with another scenario that rephrases the same odds into a 100-year probability of 1 in 1000. Just as before, participants are asked to rate their level of concern on a scale of 1 (no concern) to 5 (very concerned). Of the total responses (N = 213), the mean was 2.10 and the mode was 2. About 48% of participants selected 2 and 26.8% selected 1, followed by 3 at 16.4%, 4 at 6.6%, and 5 at 2.4%. The distribution of answers is illustrated in Figure 4.3.

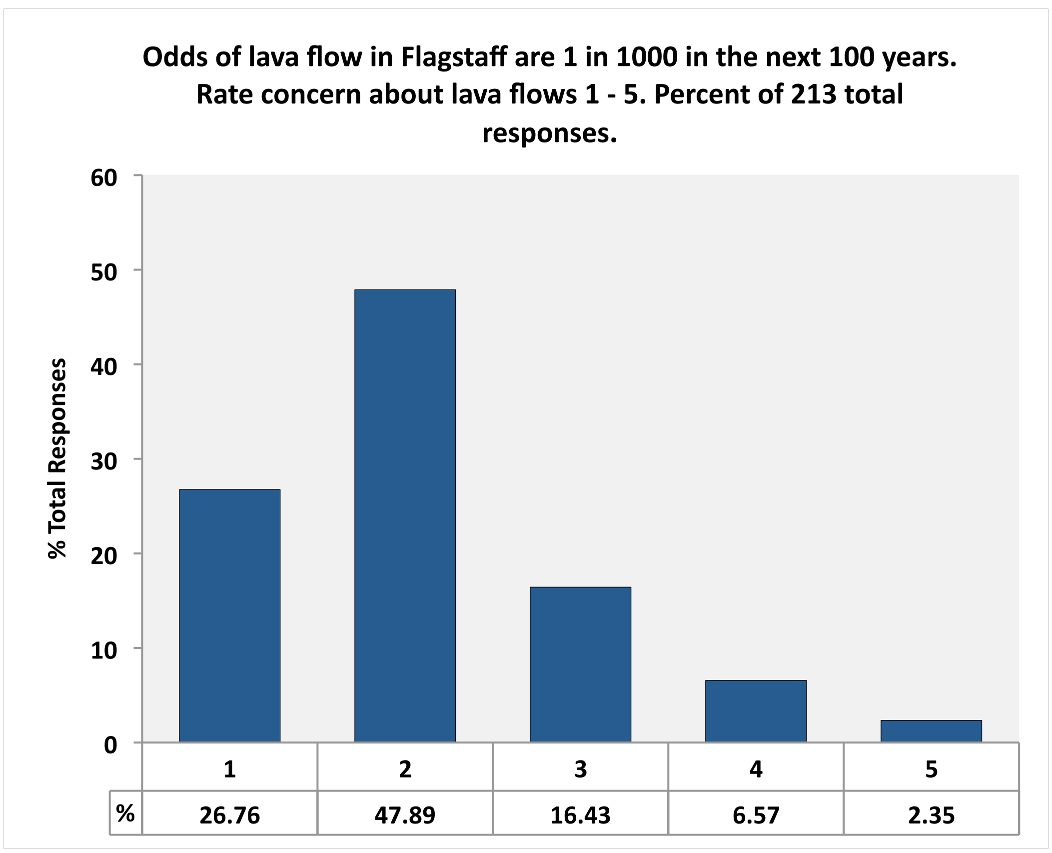

Figure 4.3. Level of Concern for Method B. This method presented the odds of inundation of 1 in 1,000 in the next 100 years. Participants were asked to rate their concern from 1 (not concerned at all) to 5 (very concerned).

Method C: This is a map of Flagstaff showing the extent of a potential lava flow from a new vent. On a scale of 1 (not concerned) to 5 (very concerned), how concerned are you about volcanic hazards affecting Flagstaff?

Instead of a probability estimate, the third method included the presentation of an interactive map of Flagstaff showing the output of a lava flow simulation. After viewing the simulated lava flow displayed on an interactive map, participants are asked to again rate their level of concern on a scale of 1 (no concern) to 5 (very concerned). Of the total responses (N = 213), the mean for this question was 2.62 and the mode was 2, with 37.1% of responses of number 2, followed by 3 at 28.6%, 4 at 18.3% and then 1 at 12.68%. 3.29% chose number 5. The distribution of answers is illustrated in Figure 4.4.

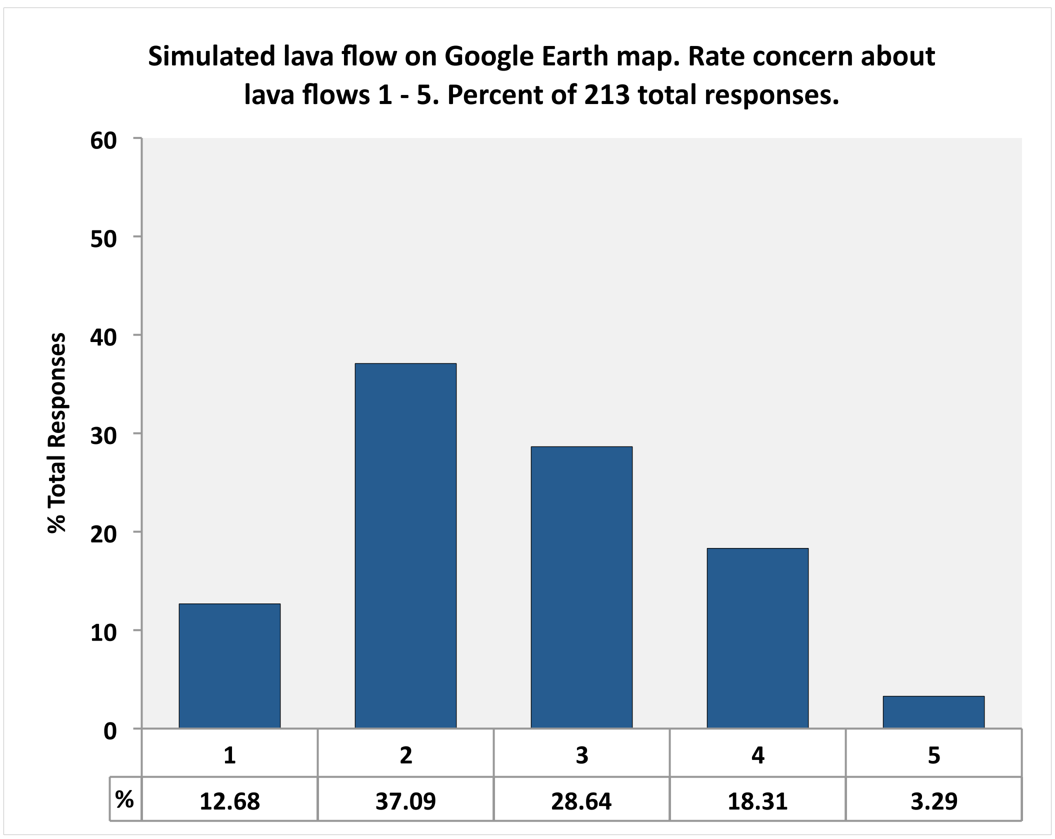

Figure 4.4. Level of Concern for Method C. This method included the example lava flow on Google Earth. Participants were asked to rate their concern from 1 (not concerned at all) to 5 (very concerned).

Question 6: In general, do you think volcanism is an issue in Flagstaff?

This final question was open-ended and participants were encouraged to state their comments or concerns. Answers for this question included the definitive yes ("Yes, I'm scared of volcanism in Flagstaff now") and no ("I have no concerns and I have lived in Flagstaff for a long time"), as well as responses of uncertainty, concern about property, and having faith in governmental warnings.

Many participants were either unaware of volcanism in the area, or aware but unconcerned. An employee at the Flagstaff Visitor's Center remarked that she didn't know volcanoes existed near Flagstaff, while several students at NAU admitted the same. Many participants commented that although they were aware of volcanism, they were not concerned considering the time scale ("I know they exist but do not think they would erupt during my lifetime;" "no concern for the next several hundred years; "it hasn't been an issue here in thousands of years.").

A number of participants misunderstood the nature of volcanism in the SFVF, specifically, the potential for eruptions from new vents. Participants stated "I am not concerned because the volcanoes are inactive," "the ancient volcanoes are unlikely to revive," and "no, the San Francisco peak already erupted and has been dormant for a number of years." Other participants stated that while volcanism is a potential concern, it is not an imminent threat ("maybe many many many years from now;" "we do have some risk but I think for the next 100 years I will be fine"). A local geologist stated, "my understanding of volcanism in Flagstaff is that the activity is moving to the northeast, so not much concern."

Some individuals suggested that other natural hazards such as wildfires were of more concern than volcanism at this time. A selection of their comments included "I am more worried about other disasters," "wildfires are more important," "drought is a huge problem," and "my concerns are more with wildfires and flooding."

On the other hand, some participants were concerned, and called for preventative measures. "Continuous monitoring" and "being prepared" were common sentiments. One participant stated that the city should track 'hotspot' movement and have disaster evacuation and readiness plans made. At least four people commented on potential property damage. An NAU student remarked, "If there was a lava flow in Flagstaff, the damage could be extreme" and a resident originally from Hawaii also mentioned that property damage would be her main concern.

The lava flow example in the questionnaire was met with mostly positive responses. Some participants simply found it interesting ("the odds seem really slim but the map is cool" and "it's interesting to see where the flow would impact"). A participant remarked, "I don't think volcanism is an issue but I would like to learn more about it after seeing the map." Another individual commented, "I never really worried about it but after seeing the map I guess it made it seem more real even if distant."

Location within the mapped lava flow was alarming for some participants who identified their residences or places of work within the lava flow. A small business owner and a hotel employee both expressed concern that their businesses were located within the flow. On the other hand, for some students at NAU, their location at the downtown university located outside the lava flow lessened their concern ("it could affect parts of Flagstaff but not NAU.").

Notably, several participants concluded that they were confident that there would be adequate warning if an eruption were to occur. One participant remarked, "I'm not too worried about it. I know scientists have simulated it very well and will warn everyone." Another person echoed the same sentiment: “I'm not very worried about lava flows here. I'm sure there will be plenty of warnings.” A student affirmed that volcanism “may affect certain parts of town, but with current technologies and communication everyone can be kept safe.” Most participants were optimistic: “hopefully it is able to be predicted.”

Chapter 5: Analysis and Discussion

The results for Question 2 and Methods A, B and C suggest that on average, levels of perceived risk are low. Since there has not been an eruption in the San Francisco Volcanic Field in about a thousand years, this result is not surprising and may be appropriate. It is interesting to compare this result with a 2012 survey of residents living in areas exposed to lava flow hazards around Etna Volcano. There, it was determined that despite the near-constant eruptive activity, the perceived risk of young residents was low, even “indifferent” (Mercatanti, 2013). Mercatanti (2013) relates young residents’ lack of concern to lack of experience; unlike older residents, they had never experienced eruptions that threatened their homes or property. Similarly, in Flagstaff, many residents are aware of volcanoes in the area, but they have never experienced an eruption or considered its potential hazards. In addition, the responses for Question 1, which asks the major natural hazard in Flagstaff, suggests that the perceived risk of other hazards such as wildfires, flooding, and drought is probably higher than the perceived risk of volcanism, a reasonable assessment given the probability of these events occurring. This is also supported by the comments in the final open-ended question.

Means for Question 2 and Methods A, B and C

The means, modes, and ranges of the answers for Question 2 and the three methods (N = 213) are summarized in Table 5.1. The mean level of initial perceived risk (stated as risk of volcanism) for Question 2 was 1.99 (s.d. 0.86). The three communication methods were presented to see if there was a change in the level of expressed concern as the descriptors varied. The mean for Method A, which presented the odds as 1 in 100,000 per year, was 1.62 (s.d. 0.75); that is, the level of concern decreased when the probability of lava flows was presented in this form. The mean for Method B, which presented the odds as 1 in 1000 over 100 years, was 2.1 (s.d. 1.03). The mean for Method C, showing the extent of potential lava flow in Flagstaff, was 2.62 (s.d. 1.03); that is, the level of concern increased when the lava flow simulation results were presented. The modal value for Question 2 and Methods B and C is 2. The mode for Method A, on the other hand, is 1. Finally, the range of answers on the 1-5 scale for Question 2 and Methods B and C is 1-5. The range for Methods A is 1-4.

Table 5.1. Means, Modes and Ranges for Question 2 and Methods A, B and C.

	Mean	Mode	Range
Question 2: Risk of Volcanism to the population of Flagstaff	1.99	2	1 – 5
Method A: Odds of inundation are 1 in 100,000 per year.	1.62	1	1 – 4
Method B: Odds of inundation are 1 in 1000 in next 100 years.	2.1	2	1 – 5
Method C: Example lava flow simulated on Google Earth	2.62	2	1 – 5

Not only did the visualization of the lava flow simulation have the highest mean rating, but 48% of participants raised their concern rating by at least one point from the previous rating after viewing this method. Figure 5.1 shows mean risk/level of concern ratings over the entire population (N=213). In addition, the top two response choices for the lava flow hazard simulation were 2 and 3, compared to 1 and 2 for the other questions and methods.

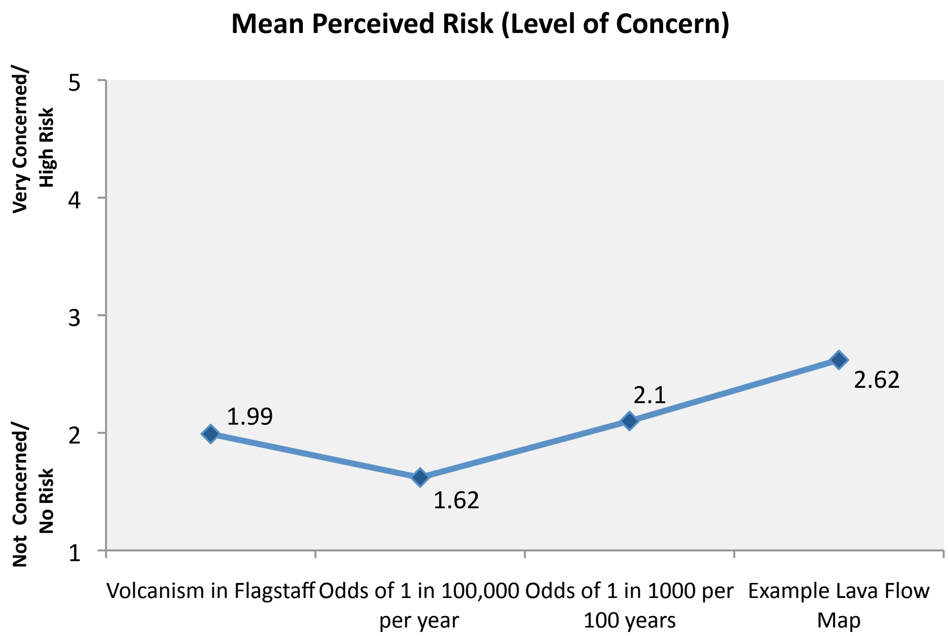

Figure 5.1. Mean Ratings for Question 2 and Methods A, B and C. For Question 2, participants were asked to rate the level of risk from 1 (no risk at all) to 5 (high risk). For Methods A, B and C, participants were asked to rate their concern from 1 (not concerned at all) to 5 (very concerned).

Statistical Analysis

A single-factor ANOVA (Analysis of Variance) test (α=0.05) determined that there was a statistically significant difference between the means across the three methods. To determine whether there was a significant difference between initial concern and each communication method, two sets of paired two-sample t-tests for means were run between Question 2 (initial evaluation of concern) and Methods A, B, and C, and between Methods A and B, and Methods B and C, with α=0.05.

Table 5.2 shows the p-values for all t-tests. The p-value is the probability that an observed result is due to chance rather than for a reason, while the level of significance (alpha value) gives the probability of rejecting the null hypothesis when it is true. If the p-value is less than the alpha, the null hypothesis, which states that no differences exist between the means of each group, is rejected. The t-tests indicated that there was a significant difference in the means ($p<0.05$) between Question 2 and Method A, and between Question 2 and Method C. There was no statistically significant difference ($p=0.052$) between the means for Question 2 and Method B. However, when considering the tests between Methods A and B and Methods B and C, t-tests showed that there was a statistical difference between the means as the methods progressed.

Table 5.2. P-Values for Paired Two Sample T-Test.

	P-Value	**Results**
Question 2 and Method A	0.000	Reject Null Hypothesis
Question 2 and Method B	0.052	Cannot Reject Null Hypothesis
Question 2 and Method C	0.000	Reject Null Hypothesis
Method A and B	0.000	Reject Null Hypothesis
Method B and C	0.000	Reject Null Hypothesis

Demographics

Results for Question 2 and Methods A, B and C were compared to demographic information to see if a statistically significant different existed between different demographic brackets; particularly between males and females, residents of different ages, and residents who had lived in Flagstaff over five years or under five years. It was determined that there were no statistically significant differences in the mean ratings between different demographic groups.

Eruption Scenario Visualization

Based on data from the Sunset Crater eruption, a future eruption in the SFVF could last weeks to a few years. There are destructive short-term and long-term hazards: fissure formation and fire fountaining would destroy any surrounding infrastructure, especially if the vent originated inside the city. The vent could produce lava flows extending several kilometers and reaching depths of tens of meters that would destroy property and block transportation routes. Tephra fall could cover an area of thousands of square kilometers, not only damaging property but devastating the landscape for years afterwards.

While the questionnaire included a brief explanation of the lava flow map, it did not include a full visualization of a potential eruption scenario in Flagstaff. Since the simplified lava flow map did produce a statistically significant increase in concern ratings, it is probable that adding a visualization of an entire eruption scenario lasting weeks to years with elements such as crater formation and tephra fallout would have further increased concern ratings, especially to those already concerned about lava flows. The participants who expressed concern in Question 6 about property damage and living in the simulated flow may find additional information useful, while the participants who were not concerned because the flow did not reach their place of residence may change their minds when they are presented with the full eruption scenario and its consequences. Subsequent studies should include visualization of a full eruption scenario to see if the method does in fact increase concern more than the simplified visualization of lava flows.

Discussion

Slovic (1987) stated that “when people lack strong prior opinions…they are at the mercy of the problem formulation. Presenting the same information about risk in different ways…alters people’s perspectives.” In this questionnaire, participants had different reactions to the same probability worded two different ways, while the strongest reaction was elicited from the visualization of the lava flow simulation. The means of the responses were determined to have statistically significant differences from each other, illustrating that each method raises different levels of concern. It is undetermined whether the levels of concern for each method should be evaluated as they each relate to the initial question, or whether they should be considered as building on one another. There is, however, a statistically significant change from one question to the next, but not between each method and the initial concern question.

Communication of Risk

Fischhoff (2005) outlined the developmental stages of risk communication in Figure 5.2.

All we have to do is get the numbers right.

All we have to do is tell them the numbers.

All we have to do is explain what we mean by the numbers.

All we have to do is show them that they’ve accepted similar risks in the past.

All we have to do is show them that it’s a good deal for them.

Show them that mitigation is good deal for them.

All we have to do is treat them nice.

All we have to do is make them partners.

All of the above.

Figure 5.2. Developmental Stages in Risk Management. From Fischhoff (2005).

As inferred in the progression above, risk communication is a challenging process that builds on itself. While quantitative assessments and probability estimates may be sufficient for experts, simply stating the numbers does not work for the public (Haynes et al., 2008). In addition, risk communicators must explain the numbers, make understandable and useful analogies, plan out mitigation strategies, and eventually begin an exchange of communication between all involved parties. However, in accordance with Fischhoff's first 2-3 stages, the hazard assessment and this subsequent study has begun that process by "getting the numbers right," "telling them the numbers," and "explaining what we mean by the numbers," though the third step needs improvement. One way is through visualization of an eruption scenario and the related hazards. Statistical analysis shows that there is a change in perception of risk when the numbers are presented in different ways and when visual aids are used, and it is predicted that a more extensive visualization of potential eruptions will produce even more effective results and aid in moving to the next stage in risk communication.

Limitations

There were limitations of the methods in this study, both in questionnaire design and data collection. Due to the progressive nature of the survey questions, it is impossible to determine whether levels of concern were determined individually for each question, or if they had been influenced by previous answers. Most likely, that depended on each participant's personal process of risk perception.

While the simplification of the probability of inundation into odds was certainly more understandable to the public, they may not have been sufficient. Both Slovic (2000) and Adler (2005) assert that it is important to include useful analogies as well as comparisons with other risks to help the public put orders of magnitude in perspective. Adler (2005) recommends creating multiple definitions of the same problem, since individuals have different definitions of issues shaped by their life experiences. The visualization of the lava flow in Method C was more effective in increasing levels of concern, but was certainly an oversimplification. It could have included more information about eruption scenarios.

The main problem with data acquisition was standardization. There were many advantages to using in-person questionnaires such as increasing response rate and controlling the order of questions; however, the interviews in this study were not all completed in exactly the same way. The presentation of each method was mostly standardized, but some participants asked questions and engaged in conversation before choosing their answers, especially with the lava flow map method. It is possible that some participants were given more information about this simulation than others, and that it affected their answers.

There was also unintended sampling bias towards a younger population of people, most notably when collecting data at Northern Arizona University. Sampling was intended to be random by approaching every third person, but most success was achieved at NAU. Quite simply, younger people were friendlier, less suspicious of the interviewer's motives, and more likely to agree to participate, especially when informed that the study was part of a graduate program.

Further Research

Further research into communication of hazards is necessary to formulate the best way to present the results of the hazard assessment to the public. It is evident that this will include some form of the probability coupled with visual aids and a full visualization of an eruption scenario in the SFVF, including eruptive style and duration. For the lava flow in particular, the map could be improved to show the numerical probability of inundation around Flagstaff using marked hazard zones or vulnerable areas. It is also recommended that a more representative and broader sample of the public take part in this research, including city officials and members of the National Park and Forest Services.

Chapter 6: Conclusions

This study investigated ways to communicate lava flow hazards to the residents Flagstaff residents and gauge levels of concern about volcanic hazards. Flagstaff residents were given a questionnaire that presented different methods of communication (two probability estimates and a lava flow map) and then asked to rate their level of concern. Results indicated that levels of perceived risk in Flagstaff are generally low, but varied with the method of communication presented to them.

When comparing the mean response ratings Methods A, B, and C to the mean initial level of concern, the probability of 1 in 100,000 in next year (Method A) decreased the mean level of concern. The probability of 1 in 1000 in next 100 years (Method B) increased mean level of concern from the lower level back to the level of initial concern. The simulated lava flow extending several kilometers into the city (Method C) further increased the mean level of concern. T-tests determined that there were statistically significant differences in the mean responses between initial concern and Methods A and C, and between the mean responses for Methods A and B, and Methods B and C.

While it could be suggested from the change of mean responses that that stating the probability as 100 year olds (Method B) was more effective than using one year odds (Method A), it appears that stating the probability alone is not sufficient to raise levels of concern to a statistically significant level. Overall, Method C, the simulated lava flow example, was most effective in raising mean levels of concern. Almost half (48%) of the participants raised their concern rating by at least one point from the previous rating after viewing this method, and the top two response choices for this method were 2 and 3, rather than 2 and 1, or 1 and 2.

Recommendations

Defining the numerical probability of inundation in the 2014 Hazard Assessment was the first step of mitigation for future eruptions in the SFVF. The next step, and the purpose of this study, was to determine different ways of communicating that number to the public and to gauge how it affects their level of concern about volcanic hazards. Further research should build on this study to develop a method that combines the probability with a visualization of the full eruption scenario. Three courses of action are recommended next to reach more members of the Flagstaff community:

1. Public outreach: Develop methods of public outreach to increase awareness about volcanism in Flagstaff and volcanic hazards. This could include an exhibit at the Museum of Northern Arizona or a pamphlet distributed at the Flagstaff Visitor's Center and Coconino Ranger Station.
2. Hazard mitigation: Include volcanism and mitigation for volcanic hazards in the next federally-mandated Multi-Hazard Mitigation Plan.
3. Auckland exercise: Modify Auckland, New Zealand's national hazard planning initiative, "Exercise Ruaumoko," for use in Flagstaff by simulating an eruption in the SFVF. This would include seismic and GPS monitoring, visualization of the potential eruption scenario, and mitigating for any hazards that may affect Flagstaff.

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Appendices

Appendix A: Flagstaff Resident Survey

Intro Statement: Hello, my name is Catie Carter. I am a graduate student at the University of South Florida studying the communication of natural hazards for my Master's Thesis project. I'd like to ask you a few questions about your concerns about hazards as a resident of Flagstaff. This survey will take no more than five minutes to complete and your participation is completely optional. You may also stop the questionnaire at any time. Your answers will be kept confidential and I will not be taking your name or any identifying personal information.

There are no known risks, but if you have any questions or would like any information about the methods or content of this survey, please contact Dr. Graham Tobin at the University of South Florida at gtobin@usf.edu or (813) 974-4580. You may also contact the Division of Research Integrity and Compliance of the University of South Florida at (813) 974-5638 if you have any questions about your rights as an individual taking part in a research study.

Thank you for your participation. Your contribution will help me learn more about communication of natural hazards and hazard mitigation here in Flagstaff.

1. First, I would like to ask you a general question. What do you think is the major natural hazard in Flagstaff? Pick the best answer from the following options:
Earthquakes Volcanoes Wildfires Flooding Drought Hurricanes Winter Storms

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2. On a scale of 1 (not a risk) to 5 (high risk), how much of a risk is volcanism to the population of Flagstaff?

No risk at all **High Risk**

1 2 3 4 5

---

3. METHOD A: Statement of Probability

Next, I want to ask you a few questions about volcanoes and lava flows. According to scientists, the odds of a lava flow in Flagstaff are 1 in 100,000 per year. *(Show first card with probability written on it).* On a scale of 1 (not concerned) to 5 (very concerned), how concerned are you about lava flows affecting Flagstaff?

Not Concerned at All **Very Concerned**

1 2 3 4 5

---

4. METHOD B: 100-Year Probability Percentage

Here's a second situation. Scientists also said that there is a 1 in 1000 chance of a lava flow in Flagstaff any time in the next 100 years. *(Show second card with 100-year probability written on it).* On a scale of 1 (not concerned) to 5 (very concerned), how concerned are you about volcanic hazards affecting Flagstaff?

Not Concerned at All **Very Concerned**

1 2 3 4 5

---

5. METHOD C: Lava Flow Map

Scientists have made computer simulations of lava flows, including one here in Flagstaff. Here's one example. *(Show Google Earth image on the iPad.)* This is a map of Flagstaff showing the extent of a potential lava flow from a new vent, chosen from scientific data and erupted on a digital model. After viewing the map, on a scale of 1 (not concerned) to 5 (very concerned), how concerned are you about volcanic hazards affecting Flagstaff?

Not Concerned at All **Very Concerned**

1 2 3 4 5

In general, do you think volcanism is an issue in Flagstaff?

(Open-ended question)

DEMOGRAPIC INFORMATION

These last questions are used to gather general information about the people being interviewed. Your personal information will be kept completely confidential.

Interviewer check off: **Male ____** **Female _____**

How many years have you lived in Flagstaff? **________ years**

What is your zip code? __________

Do you own or rent? **Own _____ Rent _____**

What is your age? **18 – 24** **25 – 34** **35 – 44** **45 – 54** **55 – 64** **65+**

What is the highest level of education you have completed?

Some High School

High school graduate or equivalent

Some college

Associate's degree

Bachelor's degree

Graduate or Professional degree

Don't know / No response

Please indicate the category which best describes your household income.

Under $20,000

$20,000 - $35,000

$35,000 - $50,000

$50,000 - $65,000

$65,000 - $80,000

$80,000 - $100,000

Over $100,000

Don't know / No response

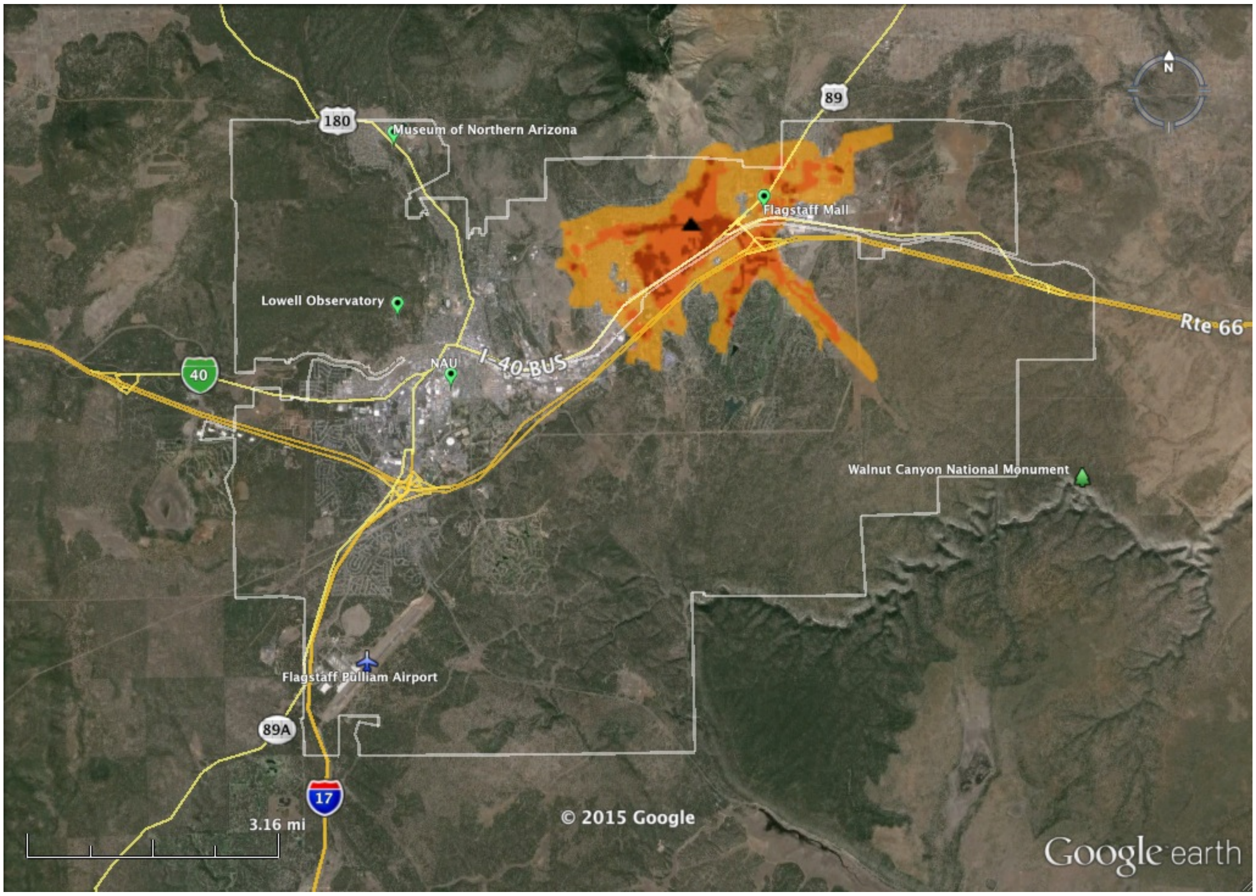
Method A: Probability per year

The odds of a lava flow in Flagstaff are 1 in 100,000 per year.

Method B: Probability Over the Next 100 Years

There is a 1 in 1000 chance of a lava flow in Flagstaff any time in the next 100 years.

Method C: Lava Flow Map



Appendix B: IRB Approval Letter

USF
UNIVERSITY OF SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813)974-5638 • FAX(813)974-7091

January 6, 2015

Catherine Carter
School of Geosciences
Tampa, FL 33617

RE: **Exempt Certification**
IRB#: Pro00020463
Title: Risk Perception and the Communication of Lava Flow Hazards in Flagstaff, Arizona

Study Approval Period: 1/6/2015 to

Dear Ms. Carter:

On 1/6/2015, the Institutional Review Board (IRB) determined that your research meets USF requirements and Federal Exemption criteria as outlined in the federal regulations at 45CFR46.101(b):

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Approved Items:

Catherine Carter IRB Study Protocol

Catherine Carter IRB Informed Consent

Your study qualifies for a waiver of the requirements for the documentation of informed consent as outlined in the federal regulations at 45CFR46.117(c) which states that an IRB may waive the requirement for the investigator to obtain a signed consent form for some or all subjects if it finds either: (1) That the only record linking the subject and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality. Each subject will be asked whether the subject wants documentation linking the subject with the research, and the subject's wishes will govern; or (2) That the research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context.

As the principal investigator for this study, it is your responsibility to ensure that this research is conducted as outlined in your application and consistent with the ethical principles outlined in the Belmont Report and with USF IRB policies and procedures.

Please note, as per USF IRB Policy 303, "Once the Exempt determination is made, the application is closed in eIRB. Any proposed or anticipated changes to the study design that was previously declared exempt from IRB review must be submitted to the IRB as a new study prior to initiation of the change."

If alterations are made to the study design that change the review category from Exempt (i.e., adding a focus group, access to identifying information, adding a vulnerable population, or an intervention), these changes require a new application. However, administrative changes, including changes in research personnel, do not warrant an amendment or new application.

Given the determination of exemption, this application is being closed in ARC. You will receive notification stating that the study has been closed; however, this does not limit your ability to conduct your research project. Again, your research may continue as planned; only a change in the study design that would affect the exempt determination requires a new submission to the IRB.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John A. Schinka, Ph.D.

John Schinka, Ph.D., Chairperson
USF Institutional Review Board