AN ABSTRACT OF THE THESIS OF

Charles A. Preppernau for the degree of Master of Science in Geography presented on December 1, 2014

Title: 3D vs. Conventional Volcanic Hazard Maps: A User Study at Mount Hood

Abstract Approved:

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Bernhard J. Jenny

Volcanic hazard maps inform the public on the nature and extent of the hazards that threaten them, but these maps are often challenging for those who are not trained in map use or geology. The maps in this study focus on lahars, a dangerous, fast, and far-reaching volcanic hazard that can be avoided through preemptive evacuation, or escaped with sufficient warning and awareness of affected areas. We evaluate the effectiveness of 2D contours vs. 3D perspective for relief representation and the effectiveness of point markers vs. isochrones (lines of equal time delay) for the visualization of lahar travel time. Four maps, each with a unique combination of these variables, were tested in a user study at Mount Hood, Oregon. Each participant was given one of the maps and assigned tasks concerning: (1) terrain interpretation, (2) estimation of lahar travel times, and (3) selection of evacuation routes. Participants were then shown all four maps and asked to indicate which design they liked best and worst for each task. 34 pilot surveys and 80 regular surveys were conducted. Participants clearly liked the 3D isochrone map most and the 2D point marker map least for all tasks. Participants were better able to interpret terrain on the 3D maps, and selected better evacuation routes on 3D maps. Participants showed similar performance with point markers and isochrones when reading lahar travel times. These findings suggest that three-dimensional maps are better suited to communicate volcanic hazards than traditional contour maps.

3D vs. Conventional Volcanic Hazard Maps:
A User Study at Mount Hood

by
Charles A. Preppernau

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APPROVED:

Major Professor, representing Geography

Dean of the College of Earth, Ocean, and Atmospheric Sciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Charles A. Preppernau, Author

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I dedicate this work to the memory of my mother, Susan Eichler, 1959–2014.

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1 Introduction

Volcanoes produce a remarkable variety of hazards; some, like lava flows, are unmistakably dangerous but so easily avoided that they rarely cause fatalities (Blong 1984). At the other end of the spectrum, volcanic gases are more subtle but claim lives every year (Smets et al. 2010). Between these extremes are pyroclastic flows and lahars, which are not as widely known as lava flows or ash fall, but have high speeds and have caused the most direct fatalities in volcanic eruptions in the 20th century (Blong 1984; Baxter 1990). Pyroclastic flows are hot avalanches of ash and fragmented lava suspended in gas. They have short ranges of typically less than 12km, but their speed is often in excess of 100 km/h. Lahars, often called mudflows by non-volcanologists, are dense slurries of water, ash, and debris. They are slightly behind pyroclastic flows in terms of the number of fatalities they have caused (Rodolfo 2000). Lahars can travel for hundreds of kilometers at speeds of ~60 km/h, and contain enough kinetic energy to carry boulders several meters in diameter (Blong 1984; Baxter 1990). These two hazards have very rapid onset and give very little time for evacuation (Scott et al. 1997); lahars are especially problematic because they can occur without an eruption (Rodolfo 2000).

Volcanoes can remain quiet for centuries or millennia between eruptions, allowing people to forget the potential hazard they represent. Pyroclastic flows and lahars create smoothed slopes or flat valley floors with fertile volcanic soil, which encourages populations to concentrate in the most vulnerable areas (Blong 1984). Because keeping people away from volcanic hazards at all times is a geographic and economic impossibility, volcanologists working in crisis management have two primary goals: to forecast the timing and impact of eruptions, and to advise vulnerable populations and local governments on the best response to an eruption (Blong 1984; Newhall and Punongbayan 1996; Marzocchi et al. 2012). In the case of pyroclastic flows and lahars, evacuating the area is usually the only practical option (Scott et al. 1997).

Newhall and Punongbayan (1996) noted that while government-directed evacuations drastically reduced the number of lives lost during the eruptions at Mount St. Helens and Mount Pinatubo, these successes were partly due to luck and favorable timing. Volcano monitoring agencies have thus made it a priority to educate vulnerable populations on volcanic hazards so that individuals can take action on their own. This approach proved successful in 1994 when Rabaul volcano in Papua New Guinea erupted with only 12 hours of precursory activity. Residents of the area, who had been introduced to volcanic hazards in an outreach program in the 1980s, recognized the signs of an imminent eruption and began self-evacuating; the evacuation of surrounding villages and Rabaul Town was well underway before the official evacuation alert was issued. Despite the very short precursory period and the presence of 45,000 people in the area at risk, only four fatalities resulted from the eruption. (Dent et al. 1994).

Volcanic hazard maps are one of the primary tools volcanologists use to communicate their findings and raise awareness among local populations. The maps, however, are not always optimized to serve as public communication tools, leading to confusion or skepticism regarding the warnings on hazard maps (Newhall 2000; Cronin et al. 2004; Haynes et al. 2007; Marzocchi et al. 2012). Volcano monitoring agencies thus attempt to supplement hazard maps with videos of volcanic hazards (Newhall and Punongbayan 1996), outreach programs (Driedger and Scott 2008), and participatory hazard planning (Cronin et al. 2004). Newhall (2000) suggested that, with contemporary advances in GIS technology, future hazard maps could make use of 3D perspective as an alternative to topographic contours.

Initial studies on the effectiveness of 3D maps generally supported Newhall's statements, though the performance of 3D maps relative to 2D maps is highly sensitive to the context in which they are being used, and 3D maps are not ideally suited to all tasks (Savage et al. 2004; Petrovič and Mašera 2005; Haynes et al. 2007; Schobesberger and Patterson 2007). In addition, 3D maps are expensive to make, require specialized training and software, and present their own cartographic challenges (Schobesberger and Patterson 2007).

Newhall and Punongbayan (1996) pointed out that the abstract depiction of volcanic hazards on maps, combined with popular misconceptions about the relative dangers of lava flows and other volcanic hazards, also contributed to the inefficiency of hazard maps as communication tools. Some recent hazard maps display the time available to evacuate or the time required to reach safety (Pierson 1998; Schilling et al. 2008; Wood and Schmidtlein 2013). This approach simplifies the information in order to convey what is most important to the user: where the hazard will strike, and how long it will take to do so.

If 3D maps are to replace 2D contour maps for volcanic crisis management, they must show a significant improvement in their effectiveness over 2D maps in order to justify their cost. For volcanic hazard maps, these improvements are measureable by the user's ability to read terrain, locate their position, and plan escape routes. The cartographic techniques used to portray the temporal aspects of volcanic hazards must also be tested to ensure that this information is conveyed in an unambiguous manner. These are measureable by users' interpretation of lahar travel time and speed, as well as their choices of evacuation routes. Here we present the results from a user study that evaluates the effectiveness of 2D contours vs. 3D perspective for relief representation and the effectiveness of point markers vs. isochrones (lines of equal travel time) for the visualization of lahar travel time. Lahars are terrain-controlled hazards and evacuees need to know where they are in order to effectively plan an escape route, so we revisited questions on the effect of 2D and 3D maps on the reader's ability to interpret terrain and location. We examined whether the use of isochrones rather than point markers for lahar travel time changes readers' perceptions of lahar speeds in a hypothetical eruption of Mount Hood, Oregon. We also evaluated choices of evacuation routes to determine whether 2D vs. 3D maps or point markers vs. isochrones affect readers' response to lahar hazards.

2 Previous Research

The effectiveness of volcanic hazard map design gained increasing scrutiny after two significant eruptions. One occurred in 1985 when Columbia's Nevado Del Ruiz generated several large lahars. These devastated several towns and killed 22,942 people (Baxter 2000), despite a newspaper including a hazard map that correctly predicted the extent of the lahars (Herd 1986; Marzocchi et al. 2012). The other major event was the 1991 eruption of Mount Pinatubo in the Philippines, where it was discovered that contemporary hazard maps were relatively ineffective in communicating hazards to diverse groups such as local residents, government officials, and US air force base personnel (Newhall and Punongbayan 1996). Later, Newhall (2000) suggested that although traditional volcanic hazard maps using 2D contours made sense to volcanologists, they might be difficult for non-experts to read, and future map designs should use improvements in GIS technology to incorporate 3D perspectives. Newhall also pointed out that hazard maps should make fewer assumptions about reader's understanding of geology and volcanic hazards.

2.1 2D vs. 3D maps

Most volcanic hazard maps represent landforms with elevation contours, which are challenging to read for those without training in the interpretation of contour lines (Phillips et al. 1975; Collier et al. 2003; Haynes et al. 2007). Several cartographers have tested the readability of 2D contour maps against 3D maps in different usage scenarios, focusing on different aspects of their performance.

Savage et al. (2004) tested a filled grayscale 2D contour map against a map that was identical in all respects except for the use of a 3D perspective view. To study the effect of shape alone, no relief shading was applied to the 3D map. The performance of participants in this user study was either the same on both maps, or worse on the 3D map for all tasks (measuring distance and elevations, and determining downhill flow directions). Because there was no shading in the 3D map, there was no clear distinction between ridge tops and the features behind them, which may have led to the 3D map's poor performance relative to the 2D map.

Petrovič and Mašera (2005) performed an online user study among experienced map users, in which a 2D topographic map was compared to three 3D map designs: a topographic map draped over 3D terrain, a grayscale orthophoto draped over 3D terrain, and a stylized 3D map using generalized 3D models for structures and forests. Users performed best with the 2D map when judging distances, relative heights, and orientation. Feature recognition was best with the stylized 3D map and worst with the draped orthophoto, and user preference favored the 3D topographic map (47.9%) over the stylized 3D map (34.5%).

Haynes et al. (2007) tested the relative efficacy of 2D and 3D volcanic hazard maps on the Caribbean island of Montserrat. Two user groups were interviewed; one group was given a 2D contour map, and the other group was given a set of 3D maps. Both user groups were also shown oblique aerial photos after viewing the initial maps. The 3D map consisted of a gray 3D terrain with draped hazard data from the 2D map. Participants using the 3D map performed marginally better at identifying landmarks and noting the relationship between terrain and hazard areas, but the best performance was seen with the use of the photographs over either type of map. This was suggested to be due to user's ability to recognize familiar visual cues on the aerial photos without having to interpret abstract cartographic symbols.

Schobesberger and Patterson (2007) looked into users' performance with and preference for simple 2D vs. 3D trailhead maps in Zion National Park. Preference was equally split. Users of 3D maps did not perform significantly better than users of 2D maps in interpreting cartographic information. Subjects were better able to locate themselves on the 3D map than on the 2D map, and tended to view the 3D maps for longer periods of time. User preference between 2D and 3D was equally split, which might be explained by the similarity of the maps used in this study. Schobesberger and Patterson (2007) note a number of disadvantages with 3D perspective maps. 3D maps are more costly and time-consuming to produce than 2D maps, they do not allow for a constant scale, they complicate the clear portrayal of line features, and they are prone to occlusion of important low-lying features by higher features.

Progressive projection, where the foreground and focus of the map are viewed at a steep angle and the background is viewed nearly parallel to the line of sight, offers a solution to the problem of terrain occlusion (Jenny et al. 2010). Progressive projection gives a sense of 3D perspective while minimizing the occlusion of valleys and canyons in the area of interest. The minimal tilting of terrain in the foreground also reduces the influence of variable scale (Seipel 2013).

A review of this research suggests a number of improvements to 3D maps for further research into their effectiveness. The results of Savage et al. (2004) emphasize the importance of shading as a depth cue in showing landforms. The findings of Haynes et al. (2007) suggest that the combination of 3D maps with aerial imagery will be more effective than the exclusive use of either design. Schobesberger and Patterson (2007) highlighted the need to solve the problem of terrain occlusion. This is addressed by Jenny et al. (2010) in a way that gives a steep viewing angle in the foreground as recommended from the findings of Seipel et al. (2013), but retains occlusion and a horizon as a depth cue elsewhere as recommended by the findings of van Schooten et al. (2010).

2.2 Volcanic Hazard Representation on Maps

Cronin et al. (2004) found that communities on Ambae Island, Vanuatu, had difficulty interpreting existing volcanic hazard maps because they included many technical elements that were irrelevant for warning purposes, such as geological data, or used terminology and classifications that assumed the readers had a background in volcanology.

Montserratian study participants in Haynes et al. (2007) often interpreted red zones on the experimental hazard maps as lava flow hazards. D'Ercole and Rançon (1994) and Leone and Lesales (2009) observed a similar misconception about expected hazards on the island of Martinique. Newhall and Punongbayan (1996) stressed that misconceptions about volcanic hazards are more problematic than a mere confusion of terminology; those expecting light ashfall and lava flows will often become skeptical when they hear dire warnings based on the unfamiliar hazards of pyroclastic flows and lahars. This was well illustrated at Pinatubo, where abstract descriptions on hazard maps were not sufficient to convey the threat of these relatively unknown hazards, and it was not until the various groups of stakeholders were shown video of pyroclastic flows and lahars that they began to take the threat seriously. It may be that the difficulties described by Haynes et al. (2007), D'Ercole and Rançon (1994), Leone and Lesales (2009), and Newhall and Punongbayan (1994) in avoiding misconceptions about lethal hazards may not be an easily solvable problem on a paper map; the mobility and power of pyroclastic flows and lahars are not clearly evident unless they are seen in motion.

A focus on travel time for volcanic hazards might be a more effective alternative to attempting to represent the nature of volcanic hazards on maps. At Mount Hood Oreon, the greatest threat is from lahars, so the current official hazard maps include minimum estimates of lahar travel time for the largest plausible eruption at the volcano (Scott et al. 1997). These estimates were determined for discrete points along lahar channels at 30 minute intervals. Wood and Schmidtlein (2014) presented another method for portraying temporal aspects of hazards with the use of isochrones. Their maps of showed the time required to evacuate to high ground in the event of a tsunami based on a cost-distance analysis.

3 Methods

This study tested user response to two variables with two states; 2D contour vs. 3D perspective base maps, and point markers vs. isochrones for indicating lahar travel time. Two base maps were created. The first map uses a 2D orthographic view with elevations indicated by contour lines, relief shading, and hypsometric tints (Figure 1a). The second map uses a 3D terrain draped with high-resolution orthoimagery (Figure 1b).

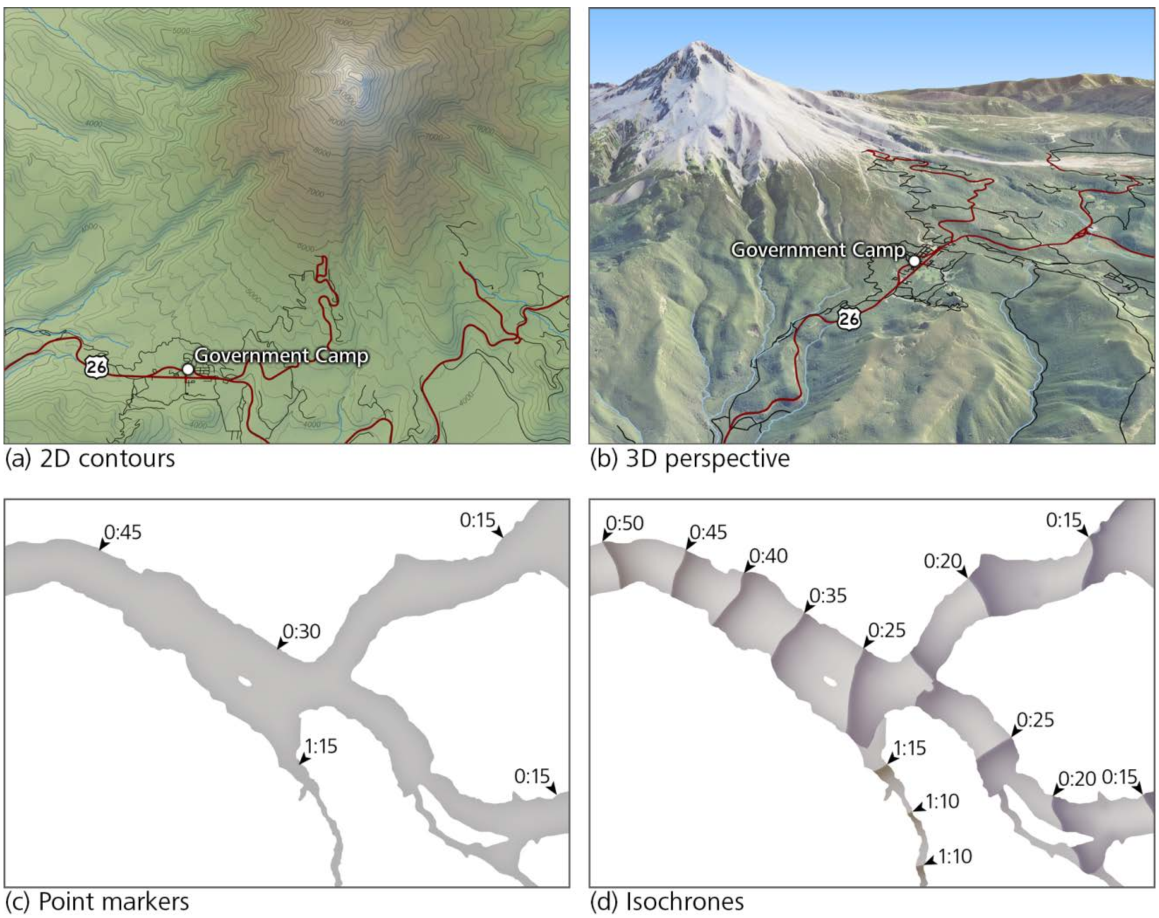


Figure 1: The two base maps (A and B) before being paired with the two lahar representation methods (C and D).

The first method for lahar travel time representation (see Appendix A for details on the model used to derive lahar travel time) is based off the method used for the official USGS volcanic hazard map for Mount Hood (Scott et al. 1997), with markers at discrete points indicating the lahar travel time. The 30-minute interval in the official map was too large for the map scale used in this study and was changed to 15 minutes (Figure 1c). The second method uses isochrones, which are a continuous representation of lahar travel time, and visualize the behavior of the lahar in wide stream channels and river confluences, which is not possible with point markers. (Figure 1d). To ensure a more continuous representation of travel time, the interval between isochrones was set to five minutes.

The two base maps were paired with the two hazard representation methods to produce four test maps. These maps were used to test the following hypotheses:

H1: Users prefer 3D perspective maps over 2D contour maps for terrain representation, and prefer isochrones over point markers for travel time indicators.

H2: Users more accurately judge relative elevation and slope on 3D maps than on 2D maps.

H3: Users more accurately locate themselves on 3D maps than on 2D maps.

H4: Users more accurately interpret lahar travel time and speed with isochrone maps than with point marker maps.

H5: Users choose more successful evacuation routes with 3D maps or isochrones than with 2D maps or point markers.

3.1 Study Area and Study Maps

Mount Hood is the northernmost of the major Oregonian Cascade peaks, and is closest to Portland, a major population center. Its last known eruption occurred about 200 years ago. This eruption consisted of multiple cycles of lava dome growth and collapse at what is now Crater Rock, just south of the summit. The collapse events created pyroclastic flows, which in turn triggered lahars. The deposits of these lahars form the flat floor of the Sandy River Valley (Scott et al. 1997). The chief hazard at Mount Hood is the potential for generation of pyroclastic flows on the south-west face, which would in turn generate lahars. These would travel down the Salmon and Sandy River valleys, eventually reaching the Columbia River near Troutdale (Scott et al. 1997)(Figure 2). The communities most likely to be threatened along this path are Government

Camp and Mount Hood Village, which is a collection of small villages near the confluence of Sandy, Zigzag, and Salmon Rivers, built on the deposits of the previous lahars (Scott et al. 1997; 2013).

The hazard zones delineated in Figure 2 are from the official hazard map (Scott et al. 1997) and are divided into three zones based on probability and level of threat. The proximal zone is defined as the area potentially impacted within 30 minutes of eruption onset and will therefore be evacuated before an eruption if unrest indicates an eruption is likely (Scott et al. 1997). The large-scale maps created for this study focus on Mount Hood Village, most of which is within the distal hazard zone lahar channels for a worst-case eruption (Schilling et al. 2008).

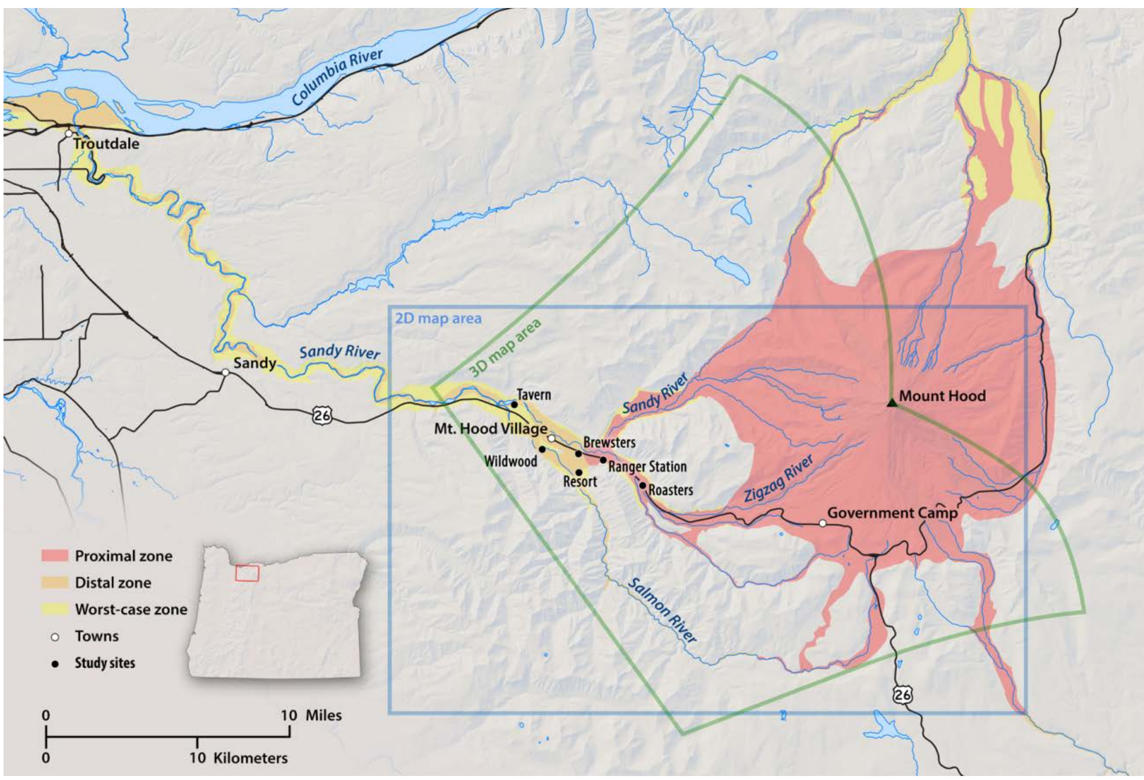


Figure 2: Mount Hood, Oregon, with communities and mudflow hazards. The survey sites and areas covered by the survey maps are also shown. Volcanic hazard data were obtained from Schilling et al. (2008).

The hazard maps were created using digital elevation models from the National Elevation Dataset, combined with orthoimagery from the National Agricultural Imagery Program (NAIP) and road networks from OpenStreetMap. Digital volcanic hazard data for Mount Hood were obtained from Schilling et al. (2008).

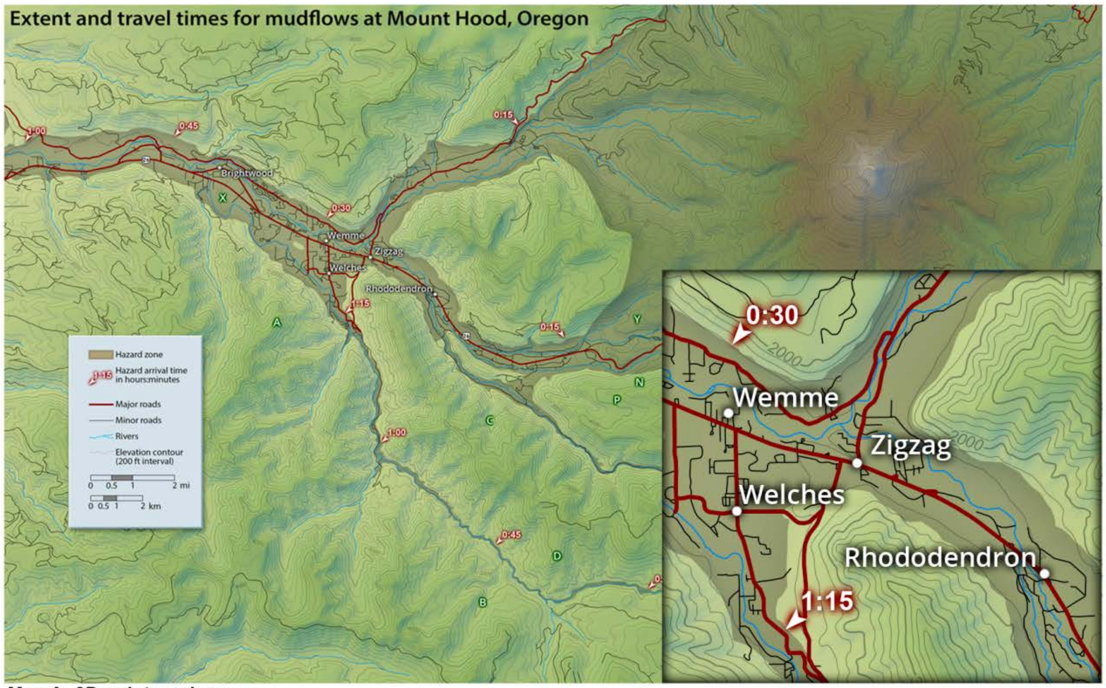
The current official hazard maps for Mount Hood (Scott et al. 1997) include lahar travel times at discrete points, which were estimated using the model described by Pierson (1998). Unlike numerical models such as LAHARZ (Schilling 1998) or TITAN2D (Patra et al. 2005), this model is an analytical approach based on observations of lahar travel time at volcanoes similar to those of the Cascades. For the maps in this study, Pierson's model was modified to use gridded data as inputs to produce a raster of lahar travel time in minutes. This raster was then used to generate the point markers and isochrones used in this study. The procedure for generating the lahar travel time raster is described in detail in Appendix A.

While the workflow for creating the 2D maps was based on standard GIS and graphics editing software, the creation of the 3D maps involved a 3D modeling and animation package called Cinema 4D. This software is designed for artists, contains a number of advanced rendering and shading options, and its scripting languages allowed the creation of a multi-resolution terrain tiling system within the software. This system automated the process of scaling and positioning terrain tiles, as well as loading elevation and imagery data (See Appendix B).

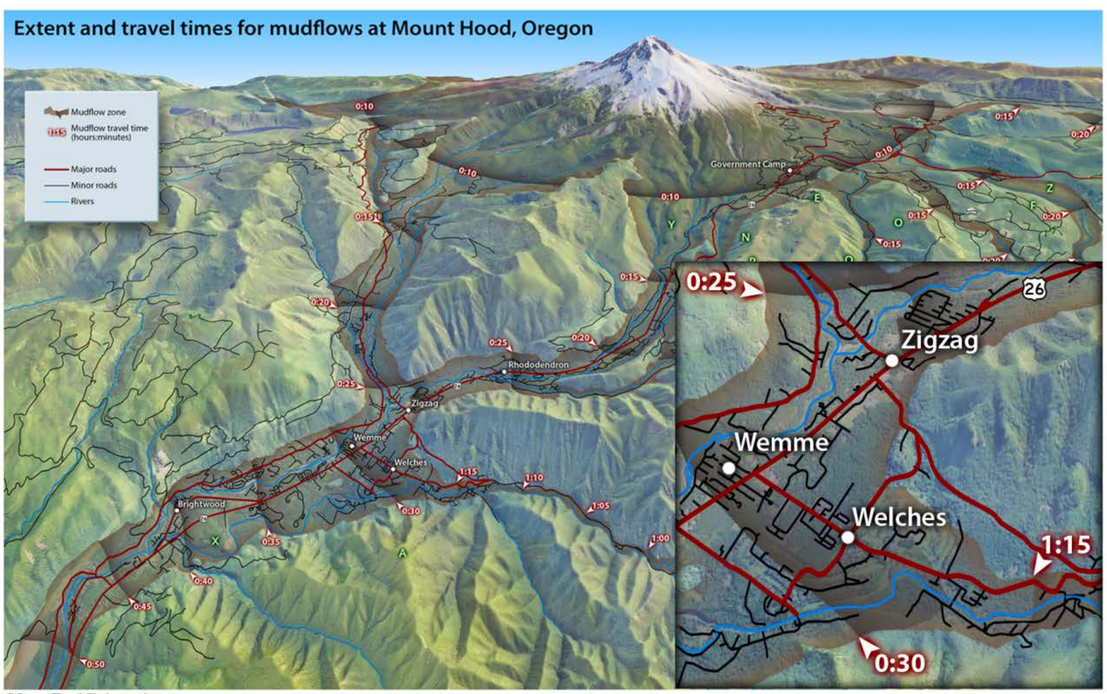
Road and stream networks were converted into 3D tubes to address some of the issues with line features on 3D maps discussed by Schobesberger and Patterson (2008). The tubes follow the terrain and stay half-in, half-out of the ground. Their slight height above the terrain surface makes them less likely to be occluded by shallow depressions or slopes dipping away from the camera, resulting in a road network representation that is easier to read than with standard texturing. Appendix C describes the procedure applied.

The terrain tiles, roads, and rivers were deformed so that Mount Hood Village was in the foreground at a steep viewing angle and Mount Hood occupied a prominent position on the horizon, with no tile edges showing and as little screen space wasted as possible. Appendix D documents design considerations and tools applied. Rendering this three-dimensional scene produced a set of layers for different elements of the map, which were brought into Photoshop for cartographic finishing.

The first of the four test maps, Map A, is closest to the design traditionally used in volcanic hazard maps: 2D contours for terrain, with uniform coloration of the hazard area, and lahar travel times indicated with point markers in 15 minute intervals (Figure 3, top left). Map B uses a 3D perspective for terrain and isochrones for lahar travel times, with five minute intervals (Figure 3, top right). Map C uses a 3D map with point markers (Figure 3, bottom left), and Map D uses a 2D map with isochrones (Figure 3, bottom right). Larger versions of the maps are available in Appendix E.

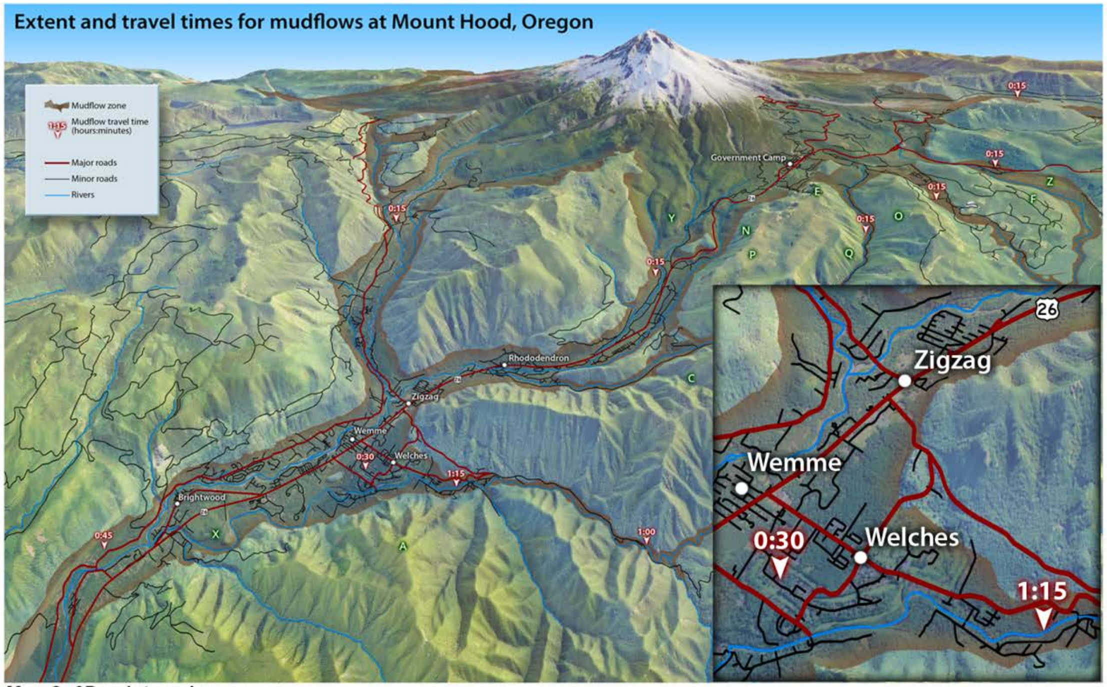


Map A: 2D point markers

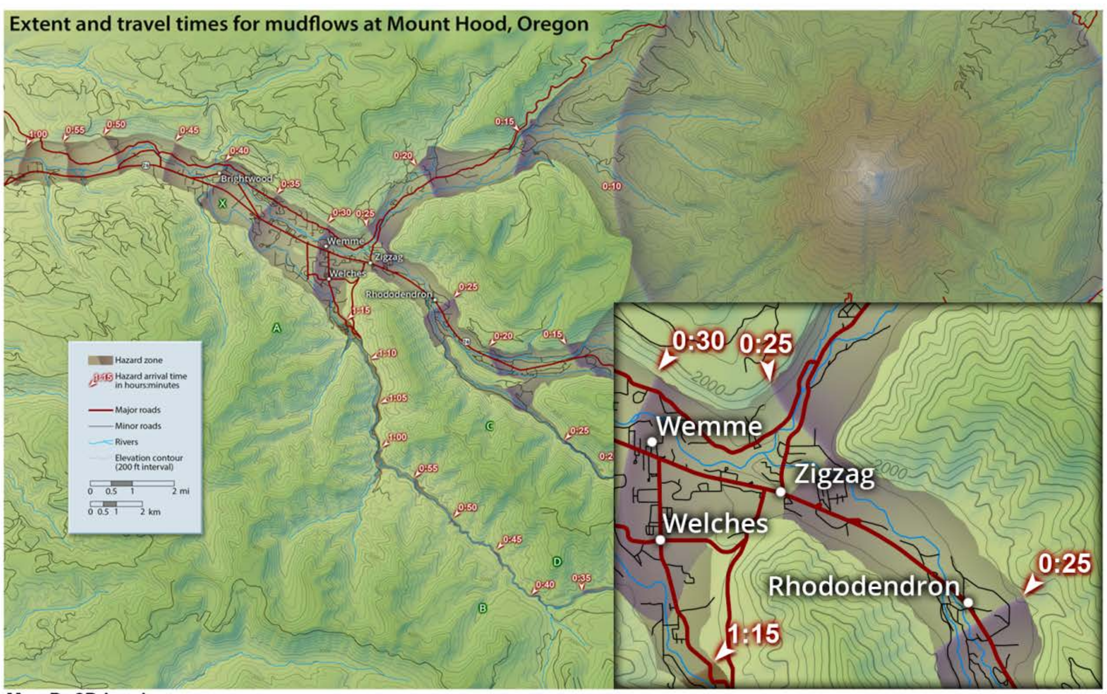


Map B: 3D isochrones

Figure 3: Reduced samples of the study maps A and B. The full-size maps were printed on 11″x17″ sheets. Insets show the confluence of the Sandy and Zigzag rivers at actual print scale.



Map C: 3D point markers



Map D: 2D isochrones

Figure 4 (continued): Samples of the study maps C and D.

3.2 User Survey

The survey was split into four sections. The purpose of section one was to determine what knowledge the participant initially had about the geographical area, measure their skill in map use, and give an indication of their familiarity with volcanic hazards. Section two was a between-groups questionnaire which dealt with interpretation of one of the maps in detail. Participants were asked to compare elevations and slopes, locate themselves, estimate lahar travel times to four points, and to plot evacuation routes from where they believed they were located while answering the questionnaire. Section three, also between-groups, was a post-treatment questionnaire designed to collect subjects' impressions once they were no longer viewing the map. Participants were asked to estimate the speed of the lahar from memory in this section. In Section four, a short within-groups questionnaire, participants were shown small versions of all four maps and asked to indicate which they liked best and worst for getting a clear understanding of terrain, for estimating mudflow travel times, and for judging escape routes. The four sections of the survey are available in Appendix F.

Surveys were conducted at six locations in Mount Hood Village: Wildwood Recreation Site, Coffee Brewsters, Mt. Hood Roasters, Zigzag Ranger Station, and Brightwood Tavern (Figure 2).

4 Results

4.1 Survey Population

Of the 80 participants in the final survey, 48 were male, 32 were female, 42 were residents of the mapped area, and 38 were visitors. Over two-thirds of the population had completed some level of college education, and more than half were over the age of 50 (Table 1). No significant differences or correlations were found between demographic groups for the various user study tasks.

Table 1: Age and education characteristics of the survey population

Age range	Number
18-20	2 (2.5%)
21-30	13 (16.3%)
31-40	7 (8.8%)
41-50	15 (18.8%)
51-60	12 (15.0%)
61 and older	30 (37.5%)

Highest education	Number
Some school	1 (1.3%)
High school / GED	7 (8.8%)
Some college	18 (22.5%)
College certificate	15 (18.8%)
Undergraduate degree	18 (22.5%)
Graduate degree	21 (26.3%)

4.2 Preference for 2D vs. 3D Maps, and point markers vs. isochrone Lahar Representation

At the end of the survey, users were shown all four maps and asked to choose which design they liked best and worst for three tasks: reading terrain, judging lahar travel time, and choosing evacuation routes. Surveys with blank responses or multiple votes were dropped from this analysis (n = 76). Table 2 shows the results. For each task, the map that each user selected as "best" was assigned a value of 1, the map selected as "worst" was assigned a value of -1, and the two other maps were assigned a value of 0. Mann-Whitney tests were run on all six pairs of maps to determine which map pairs showed a significant difference in user preference for that task. Figure 4 shows the total positive and negative votes by map for each task. Net scores show that users preferred 3D maps for terrain interpretation and evaluation of escape routes, while they preferred isochrones for judging lahar travel time. The 2D marker map was liked least for all tasks, and the 3D isochrone map was liked best for all tasks.

Table 2: User preference vote totals for all four maps. Bold text indicates the best result for each column.

Map Type	Terrain: Best	Terrain: Worst	Time: Best	Time: Worst	Routes: Best	Routes: Worst
2D markers	3	47	4	51	4	44
3D isochrones	**42**	2	**38**	**3**	**41**	**4**
3D markers	31	**1**	13	15	18	9
2D isochrones	0	26	21	7	13	19

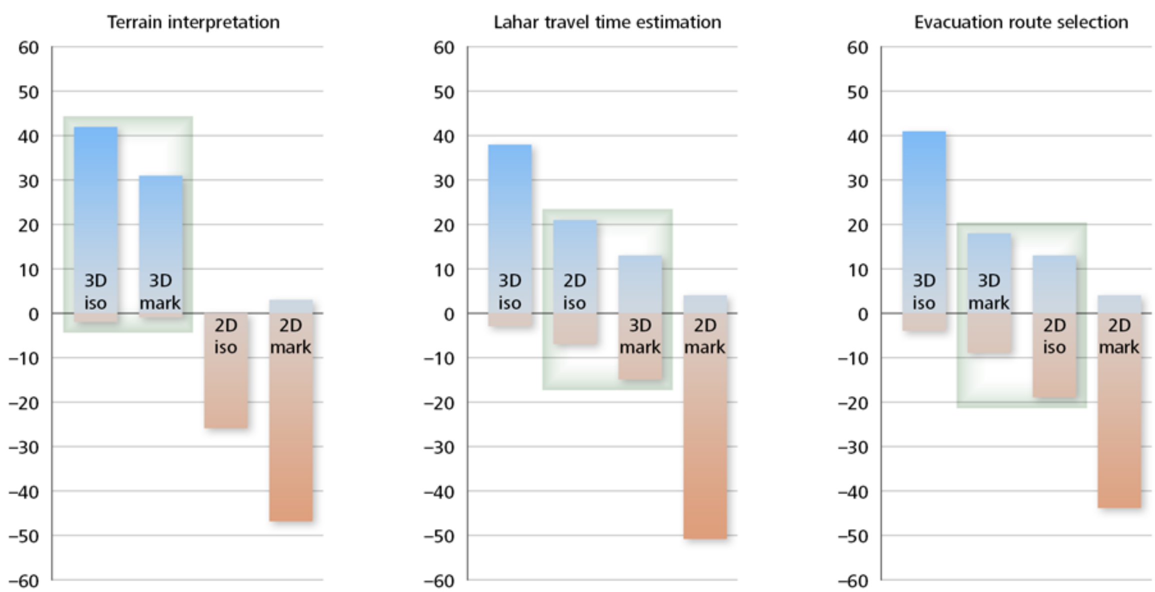


Figure 5: Positive and negative votes by map for three tasks. Map types are sorted by net votes (positive + negative) Green boxes group map types that were not significantly different ($p \geq 0.05$), which should be considered similar results.

4.3 Terrain interpretation on 3D vs. 2D maps

Participants answered two elevation comparison questions and two slope comparison questions. Participants were asked to examine pairs of points and determine which was higher, or which had the steeper slope. Answers to the questions were combined into a percentage score. There were 39 valid answers (without blanks or multiple responses) to this portion of the survey from 2D map users, and 40 valid answers from 3D map users. Scores were not normally distributed, so a Mann-Whitney U-Test (two-tailed) was used to test for significance. The test showed that the 3D map users scored higher with a two-tailed p-value of 0.03.

4.4 Self-location on 2D vs. 3D maps

Subjects were asked to mark their estimate of their current position on the map. These markings were digitized (39 for 2D maps, 40 for 3D maps) and the distances between true locations and guessed locations were measured along straight lines. These distances were not normally distributed and so were analyzed with the Mann-Whitney U-Test. No significant difference was found between map types (two-tailed p-values of 0.57 for all participants, 0.83 for residents, and 0.45 for visitors).

4.5 Lahar travel time estimation on marker vs. isochrone maps

Subjects estimated lahar travel time to three pre-chosen locations, as well as the location they marked in the self-location test, for a total of four estimates. When users gave an interval estimate, only the upper bound of the interval was used. Estimates that were not inclusively between the values of the two nearest travel time indicators were counted as misinterpretations. The numbers of misinterpretations between isochrone and point marker maps were compared using the Mann-Whitney test. No difference was observed between maps (two-tailed p-value = 0.70).

Another measure of the influence of isochrones vs. point markers was subjects' perception of lahar speed. This was measured with a Likert-scale question asking users to make a qualitative estimate of the speed of the flows by comparing it to the speed of walking, running, driving on a city street, driving on a highway, or flying an airliner. The Mann-Whitney test was used to search for differences between the two grouped marker maps and the two grouped isochrone maps. The two-tailed p-value for this test was 0.91, indicating no differences. User responses were split between city street or highway speed. City street speed (35 to 50 km/h or 25 to 30 mi/h) was the correct choice, and most errors were overestimates (Table 3).

Table 3: Totals for categorical estimated lahar speeds from users of isochrone and marker maps.

Speed	Marker maps	Isochrone maps
Walking	1	1
Running	2	3
City street	16	14
Highway	14	16
Airliner	5	4

4.6 Choice of evacuation routes

For the sake of the exercise it was assumed that users would be aware of the lahar at the moment of onset. This is unlikely in a real lahar event, as the mountain is not visible from many of the survey locations, and warnings may take as much as 20 minutes to reach endangered populations (John Ewert, Willie Scott, Thomas Pierson, Cascades Volcano Observatory, personal communication with author, January 23, 2014). The conditions affecting ease of travel along chosen evacuation routes during the evacuation scenario are not known, so the analysis of routes needed to avoid assumptions about these conditions. Another important consideration was that participants would occasionally choose routes such that they might be fleeing from the lahar during part of the route, while in a different part they would be advancing towards it in a separate lahar channel. The method chosen was to evaluate, at every point along their route, the minimum speed they must have been travelling to get to that point before the lahar. We refer to this minimum survivable speed as the critical speed. This method makes no assumptions about ease of travel along the route; rather it simply states how fast a person must travel along the route in order to stay ahead of the lahar. The lower the critical speed is, the greater the margin of safety and the more resilient that route is to adverse traffic, visibility, weather, or terrain conditions.

The critical speed for each vertex in a digitized route is the cumulative distance travelled en route to the vertex, divided by the lahar travel time at the vertex. The vertex with the highest critical speed along the route represents the point at which the evacuee is most likely to be overtaken by the lahar. The critical speed at that vertex is used as the critical speed for the entire route. If, in an emergency, an evacuee could travel at an average speed greater than the route's critical speed, then their chosen route would be successful.

Critical speeds for the two 2D maps were grouped and compared to those for the two grouped 3D maps using the Mann-Whitney test. No significant differences between maps were found for evacuation routes by car. The highest critical speed for a vehicle out of all the maps was an outlier at 57.6 km/h on a very inefficient route which still would have been barely successful in good conditions. The distribution of critical speeds for the on-foot routes is shown in Figure 5. 3D maps were shown to have lower on-foot critical speeds with a two-tailed p-value of 0.026. A similar comparison for on-foot routes between marker and isochrone maps gives a p-value of 0.982, suggesting that the use of isochrones or markers made no difference in the choice of evacuation routes. Critical speeds were compared between all pairs of maps, but only the 3D isochrone map and the 2D isochrone map showed a significant difference (two-tailed p-value = 0.031)

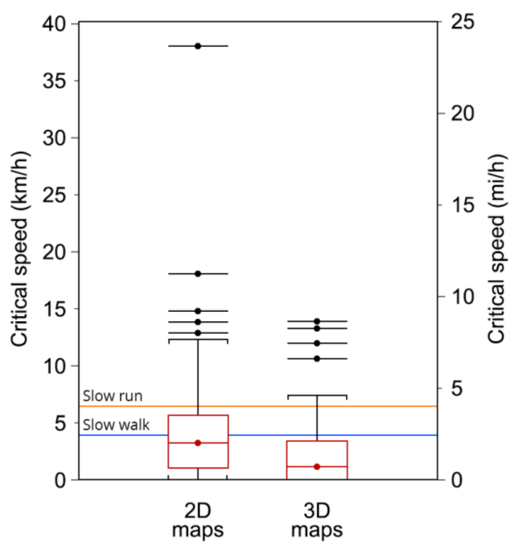


Figure 6: Box-plot of on-foot critical speeds for grouped 2D maps and grouped 3D maps, compared to the slowest and fastest on-foot evacuation speeds used in Wood and Schmidtlein (2013). Red dots indicate medians, red boxes represent the range between upper and lower quartiles, whiskers show the cutoff for outliers at 1.5 x inter-quartile range, and black bars show outliers.

5 Discussion

H1: Do Users Prefer 3D Maps and Isochrones?

We find strong evidence that users prefer 3D maps and isochrones over 2D maps and point markers.

The user preference charts show that 3D maps are overwhelmingly preferred for the purposes of terrain interpretation and to a lesser extent for evacuation route selection. User preference was stronger for isochrones than for point markers, though this result is much more ambiguous than that for 3D maps. The differences in user preference measured in this study are much greater than in Schobesberger and Patterson (2007) and Petrovič and Mašera (2005). This is likely due to the greater differences between the 2D and 3D maps in the Schobesberger and Patterson study. Factors contributing to the difference in user preference results from Petrovič and Mašera (2005) may include the use of progressive projection in our study maps, as well as the general audience in our study, whereas Petrovič and Mašera (2005) surveyed experts in geospatial science.

H2: Do users more accurately read terrain on 3D maps?

We find evidence that users are better able to read terrain on 3D maps than on 2D maps.

Terrain interpretation results suggest that map readers are able to read terrain on 3D maps more clearly than on topographic maps. Prior topographic map proficiency did not appear to affect results, although the sample size of the most inexperienced group was very small (8 for 2D maps and 11 for 3D maps). Also of note is that experienced map readers determined relative heights by counting and tracing the contours, which lengthened this part of the survey by several minutes, compared to those who were less meticulous with 2D maps, or who used the 3D maps. The implications of these data for hazard mapping are that hazard maps featuring 3D terrain are more intuitive to users than those using contour maps. With the 3D maps in this study, users more successfully read the most important information in the map: how the hazard interacts with the terrain, and how to most quickly escape from it.

H3: Do users more accurately locate themselves on 3D maps?

We find no evidence that users are better able to locate themselves on 3D maps than on 2D maps.

Self-location does not appear to be heavily influenced by any of the variations in map design; most users seem to have relied on road networks and place labels to locate themselves. This agrees with Haynes et al. (2007), where significant improvements were found in users' ability to locate places on oblique aerial photos over contour maps, while there were no significant improvements in users' ability to locate places on 3D maps without orthoimagery over contour maps.

Orthoimagery was incorporated into the 3D maps for Mount Hood with the intent of combining the advantages of aerial photos with the advantages of 3D terrain, including the freedom to select customized viewpoints. However, the scale of the map meant that the orthoimagery did not have the detail of the aerial photos in Haynes et al., and the orthoimagery was muted in order to reduce visual clutter and contrast that would have competed with road networks and hazard information. It is also worth mentioning that Haynes' map did not include any labels, specifically to avoid users finding their location by place names. While the pilot survey was unlabeled for this exact reason, it made for a frustrating or even embarrassing experience for some participants, and would have lowered the data quality of subsequent answers that depended on the user-chosen locations. Place labels were thus included in the maps used in the final version of the survey.

H4: Do users more accurately interpret lahar travel time and speed with isochrones?

We find no evidence that the use of point markers vs. isochrones had any effect on the potential to misinterpret travel time information, or on impressions of lahar speed.

The speed and extent of lahars seemed to be communicated successfully with either of the time representation methods; estimates of speed were a bit higher than that of actual lahars, but this is probably preferable to underestimates. Most user errors were within the uncertainty of the model used to derive the lahar arrival times (Thomas Pierson, Cascades Volcano Observatory, e-mail to author, August 26, 2013).

Out of the 43 users who reported in their comments that their opinions of volcanic hazards had changed after reading the map, 16 (37%) said their opinion changed because they hadn't previously realized how fast mudflows are, or had not considered mudflows as volcanic hazards.

13 (30%) said they had not previously given thought to how to escape in a volcanic emergency, or had not appreciated the difficulty of escaping in rough terrain or heavy traffic (probably due to the paucity of major roads that leave the lahar channel). 3 (7%) said they had not considered the possibility of Mount Hood erupting, or had not thought of it as an active volcano. Of the 31 people who said they did not have a change of opinion, 15 (48%) said they had already researched the hazard for themselves, and 6 (19%) stated that they had not been exposed to this information before, and thus had not formed an opinion.

The results concerning changes of opinion in light of lahar speeds, escape routes, and the volcanic nature of Mount Hood were obtained in spite of the fact that nothing in the map or survey contained any description of the nature of mudflows, and only mentioned them in the title. Thus, the significance of the mudflow hazard was successfully conveyed to the target audience in the absence of any geological information concerning lahars. This is compelling support for the inclusion of lahar travel times in hazard maps for other volcanoes prone to production of lahars.

A common misinterpretation of both time indicator types resulted from a lack of units for the times on the map; many users did not read the legend and initially believed the times represented minutes and seconds instead of hours and minutes. This misinterpretation was corrected during the survey in order to ensure validity of answers to following questions. A small minority of participants, citing the speed of the Mount St. Helens blast, believed the modeled times were too long and said that they would seem more accurate if they *were* minutes and seconds. One was adamant that the hazards would reach every point on the map in a matter of seconds.

H5: Do users choose more successful evacuation routes with 3D or isochrone maps?

We find evidence that users choose on-foot routes with a greater margin of safety when using 3D maps. We find no evidence that user's choice of evacuation routes by car are significantly affected by any of the map designs. We find no evidence that the use of isochrones or point markers affected user's choice of escape routes.

Vehicular routes were likely not significantly different due to the limited number of choices available for evacuees; the vast majority of users recognized that the ideal route was to take

Highway 26 to the west, or to the south in the case of subjects who mistook Government Camp for their location. This offered the best chance of escape combined with an assurance that they would not be stranded after the lahar passed. The result for the grouped 2D vs. 3D maps was more significant than any of the results for individual pairs of maps, raising the possibility that the lack of significance among most of the pairs is due to small sample size. It is unclear why the 2D isochrone map performed poorly in comparison to the 3D isochrone map while the 2D marker map did not. A possible cause of the 2D isochrone map's poor performance may be that it contained two sets of isolines for users to interpret, adding to the user's confusion.

6 Conclusion

We reaffirm the findings of past studies supporting the effectiveness of 3D maps over 2D maps for the purpose of terrain interpretation. 3D perspective does not appear to strongly influence users' ability to locate themselves on a map, presumably because they are accustomed to navigating by place names and road networks rather than by terrain. We also find that the use of 3D perspective improves user's choices of evacuation routes. The ability of 3D maps to effectively convey the relationship between hazards and terrain suggests that 3D perspective views may offer similar advantages over 2D topographic maps for other kinds of terrain-controlled hazards such as tsunami, floods, landslides, and fires.

The method used to portray lahar travel times does not appear to have any influence on users' ability to interpret lahar travel times or speeds, and does not affect users' choices of escape routes. While the two methods do not produce significantly different results, the focus on the temporal nature of lahar hazards successfully communicated their speed in the absence of any description of the hazard.

Many participants commented on how, after interpreting the lahar travel times, they had an appreciation for the speed of volcanic hazards that they had not had before, and most of the skepticism was associated with a belief that the modeled lahars were too slow. This suggests that lahar travel times should be included in hazard maps for other volcanoes where lahars are the principal hazard. It will also likely be beneficial to conduct surveys similar to this one in areas that have not been the sites of volcanic hazard outreach campaigns.

Future surveys may benefit from an online format. This was not possible in this study due to the self-location questions, but with the results from this study and Haynes et al. (2007), it appears that 3D maps have no effect on self-location, and this may not be a critical element in future studies. Therefore, an electronic survey targeting a larger participant pool and with a longer set of questions focusing on evacuation routes and terrain interpretation may help to quantify the influence of education and past experience with maps, which was difficult in this study due to the limited number of participants.

The process to create the 3D maps for this study is currently time-consuming and costly. Widespread adoption of these maps will require the process to be further automated, which would enable scientists or officials with limited experience in three-dimensional cartography to generate these maps. Almost every part of the process to make these maps on proprietary software is also possible in existing open-source software; porting the process to open platforms could further reduce the cost of producing these maps.

There are many hazards besides lahars that are not entirely understood by non-volcanologists, and while these hazards are usually preceded by warnings, this is not always the case. Even pyroclastic flows can on rare occasions be generated in conditions indistinguishable from "background" activity, as the recent eruption of Mount Ontake in Japan has demonstrated (Chappell 2014). While volcano monitoring techniques have improved dramatically over the last decades, volcanic crisis management has too many variables to guarantee successful evacuations. Even the most successful cases are sometimes attributed to luck, as circumstances beyond the control of volcanologists can nullify the benefit of even the most accurate forecasts (Newhall and Punongbayan 1996). There will thus continue to be a need for effective communication of hazards so that people can minimize their own vulnerability. In the course of this user study we have found reason to believe that 3D hazard maps with a focus on hazard impact or travel time can serve this function well. We recommend that future research in the cartography of natural hazards continues to explore the effectiveness of different 3D map designs, building on the lessons learned from the strengths and weaknesses of past attempts. We also recommend that cartographers and GIS technicians research more efficient and streamlined procedures for creating these maps.

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Appendices

A: Lahar Travel Time Raster

A raster of lahar travel time in minutes was required in order to extract 15-minute points for the marker maps and five-minute isochrones for the isochrone maps. Pierson (1998) introduced a model for determining lahar travel times for volcanoes like those found in the Cascades. The model is based on the very close fit ($R^2 \geq 0.9$) of two-degree polynomial curves to plots of distance traveled vs. travel time for observed lahars. The shape of the curve varies according to the initial discharge of the lahar. Thus, if the size of an expected lahar can be estimated, then the model can be used to predict the time it will take the lahar to travel a given distance. The lahar travel times for Mount Hood provided in Schilling et al. (2008) were created with this model, using the largest credible initial discharge for an eruption at Mount Hood, and manual distance measurements to specific points (Thomas Pierson, Cascades Volcano Observatory, e-mail to author, August 20, 2014). This model can also be used as a raster calculation in GIS software to convert a raster of distance from source to a raster of travel time.

Stream networks generated from DEMs produce the best results for measuring distance along lahar channels, though a modification to the DEM is necessary to account for the behavior of pyroclastic flows and lahars. These hazards have enough kinetic energy to climb and overtop ridges (Nakada 2000), so drainages not hydrologically connected to the origin of the lahar can still serve as lahar channels. To model this phenomenon, we draw inspiration from a simple method for determining pyroclastic flow extent in rugged terrain. This approach models the gravitational potential energy of the flow as an "energy cone". The apex of the energy cone is the origin of the flow, the slope of the cone is negatively correlated to the volume of the flow, and the cone's intersection with the terrain is the expected extent of the flow (Malin and Sheridan 1982). For the purpose of creating a lahar travel time raster, the cone is not used to quantitatively model kinetic energy, but to make streams ignore topographic barriers near the source. The cone parameters are approximated by matching the cone's extent to the hazard zones provided by Schilling et al. (2008). The lahar travel times in Scott et al. (1997) were based on a summit source for the north-moving lahars, and a source near Crater Rock for the south and west-moving lahars. Because these two locations are only 500 m distant from each other, and the location of future vents is uncertain, the decision was made to use the summit as the source of all flows. The cone was created as a raster DEM and combined with the Mount Hood DEM. To encourage formation of higher-order streams on the cone, two additional surfaces were added to the cone: radial furrows created with a sine function of the cone's aspect, and traces of the original topography (Figure 6). Stream networks generated from this DEM radiate out from the origin, travelling in relatively straight lines and ignoring ridgelines below the surface of the cone, similar to the behavior of a pyroclastic flow. Where the cone intersects the terrain, streams begin following the river valleys. This approximates the combined behavior of pyroclastic flows and the lahars generated from them.

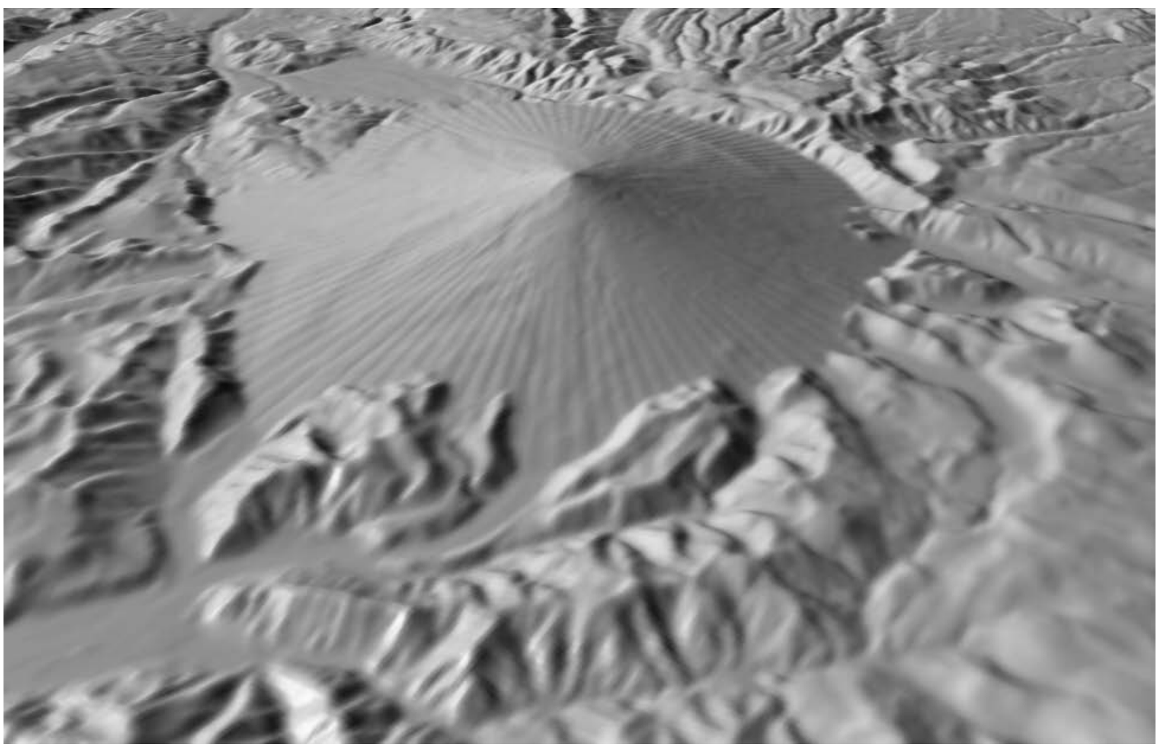


Figure 7: Energy cone added as a DEM to the terrain of Mount Hood.

Streams that did not correspond to the lahar channels defined by Schilling et al. (2008) were deleted from the network, and the minimum distance from source was calculated for each vertex in the remaining polylines. Spline interpolation was used to build a distance raster from these points, with barriers at channel confluences to prevent the creation of gradual transitions in travel time where channels join together.

The distance raster was used to compute lahar travel times with Pierson's model. To calibrate the model for the new distance measurement method, values for the distance raster were plotted with travel times from Schilling et al. (2008), and a quadratic curve was fit to these points. The curve was constrained to pass through the origin to avoid negative travel times near the source. The equation of the resulting curve, which provides lahar travel time in minutes, was $(0.0003285728d^2 + 0.013534772d)*60$, where d is the value of the distance raster in kilometers. The greatest deviation between the lahar travel time raster and the points from Schilling et al. (2008) was seven minutes. Considerable uncertainties exist concerning the location of the lahar origin, the delay between eruption onset and lahar formation, and the actual behavior of the lahar, so these deviations are likely insignificant (Tom Pierson, Cascades Volcano Observatory, e-mail to author, August 26, 2013). Isochrones were constructed from this raster by clipping the raster to the lahar boundaries in Schilling et al. (2008) and applying a contouring algorithm with a five-minute interval. The point markers were created by manually placing markers along the isochrones in 15-minute intervals.

B: Terrain Tiling in Cinema 4D

The elevation and imagery data for the region affected by lahars from Mount Hood are large datasets, and much of this data is outside the viewing area of any given 3D perspective. Loading the entire dataset to create a 3D map is thus inefficient and places prohibitive demands on memory usage and processor time. The solution is to load only those pieces of information that are being displayed, at the minimum resolution necessary to achieve satisfactory results. To achieve this in Cinema 4D, the Mount Hood hazard region was split into 20 x 20 km tiles, and each tile was given an index number (Figure 7). The index number was composed of the x and y offset of the center of each tile from the center of the Mount Hood hazard region.

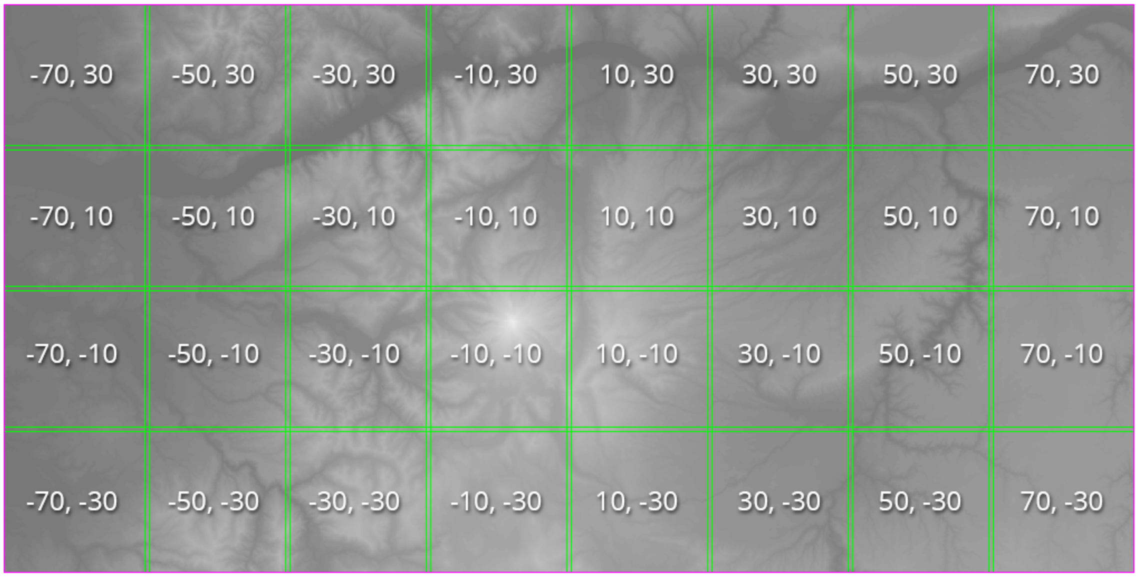


Figure 8: DEM for the Mt. Hood hazard region, divided into 20x20 km tiles (outlined in green).

A Python script was used to generate the tiles, along with custom metadata documents bearing the names of the tiles. While the index contains the horizontal position of the tile, the metadata contains the information that Cinema 4D needs in order to correctly scale and offset the elevation values. This is done with two scripting languages native to Cinema 4D. COFFEE (a false acronym) is a programming language similar to Java, while XPresso is a visual scripting language that uses a set of function nodes, whose inputs and outputs can be visually connected to other nodes.

In Cinema 4D each instance of a tile object contains the script functions necessary to position and load the tile data, allowing the user to load, position, and scale the tile by specifying values of only four variables: the x index, the y index, and the resolution of the terrain and imagery. Once these parameters are chosen, they are fed into an XPresso script. XPresso handles most functions necessary for processing the tiles, while the COFFEE script is called in order to read the metadata.

C: 3D Mapping of Linear Features

When linear features such as roads and rivers are portrayed on 3D terrain using draped line rasters, the rendered image often has a poor appearance unless the raster resolution is quite high, creating additional resource demands. In addition, draped linear features have no vertical thickness and thus follow every convolution of the terrain. This means that every dip or tilt of the terrain away from or toward the camera will alter the local appearance of the line feature to a much greater extent than is desirable for cartographic display. Drawing lines on the rendered map is more desirable for purposes of consistent display, but this can be very time-consuming and ignores the effect of orientation and distance on the apparent size of the feature, which is an important depth cue.

A solution that solves both problems is to convert line features into 3D tubes that are rendered with the terrain. This was done with the Mount Hood map using a "sweep" operator in Cinema 4D. The operator sweeps a profile vector (a flattened circle in this case), along a path vector, creating 3D geometry. The road and river vectors were projected onto the terrain and used as paths for the sweep, creating a network of tubes (Figure 8).

Figure 8: Roads and rivers near Government Camp rendered as 3D tubes over a flat white plane. Each class of line feature has a different color and radius. Terrain is absent but the shadows on the "floor" give an indication of relative feature height.

These tubes follow the terrain and stay half-in, half-out of the ground surface, so they are not affected by the slope and aspect of the terrain in the way that draped rasters are. Their slight height above the terrain surface makes them less likely to be occluded by slopes tilted away from the camera. They also have a smaller apparent size at a distance, and because of the slight flattening of their profile shape, they appear narrower when oriented perpendicular to line of sight than when oriented parallel to it (Figure).

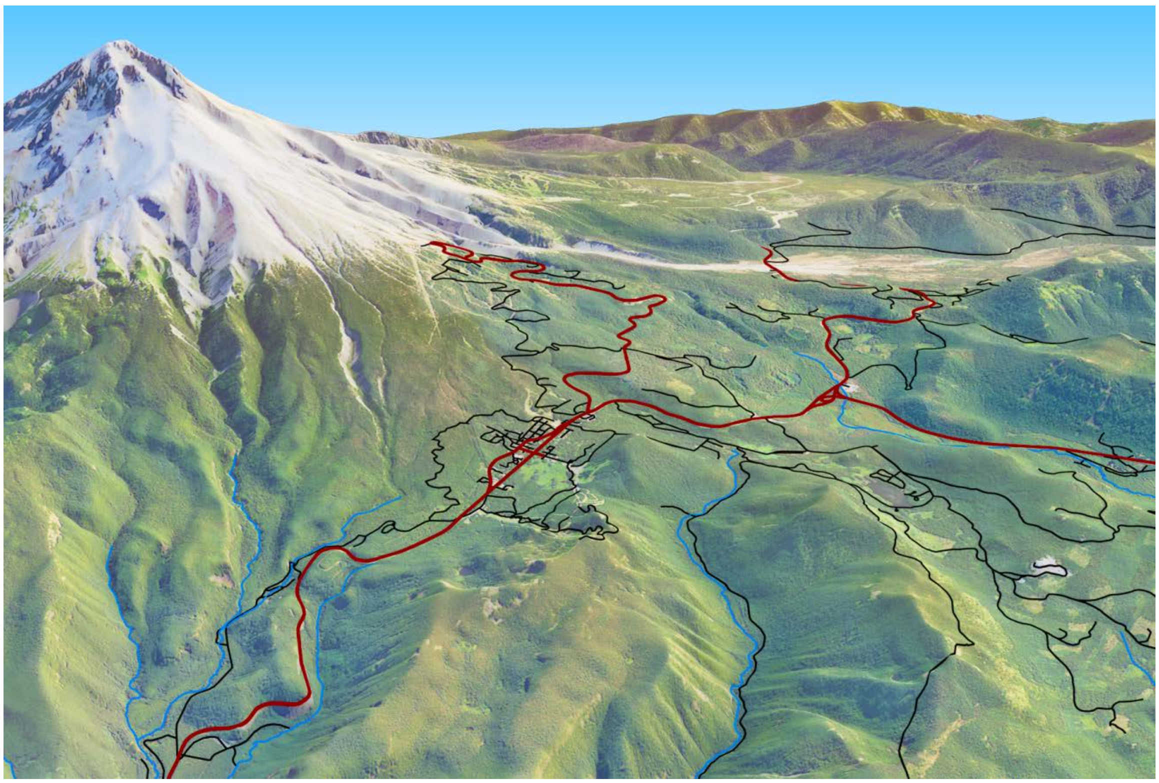


Figure 9: Final result for 3D roads and rivers near Government Camp. The flattened-tube profile results in roads that are occluded by hills, but have a consistent and smooth appearance even in rugged terrain, with a slight perspective effect.

D: Progressive Deformation

Schobesberger and Patterson (2007) explain that a potential problem of 3D maps is the occlusion of significant features in lowlands and valleys and the distortion of scale. This is especially problematic for 3D visualizations of lahar and debris flow models, as they typically take place in the bottom of steep-sided river valleys (John Ewert, Willie Scott, Thomas Pierson, Cascades Volcano Observatory, personal communication with author, January 23, 2014). This problem can be resolved with the use of progressive terrain bending, a technique for showing the foreground of a 3D map at a steep angle, while the background is viewed at a nearly parallel angle, resulting in a horizon and a view of the sky (Jenny et al. 2010).

Some 3D modelling software contains deformers which can be used to achieve this effect. The deformer is often represented as a 3D lattice that initially has a cuboid shape. The deformer tracks the displacement of each vertex in the lattice from its starting position, and a smoothed interpolation of this displacement is applied to the object being deformed. In Cinema 4D, the terrain tiles and 3D tubes were grouped together and modified with a deformation lattice that rendered Mount Hood Village at a nearly vertical angle, while Mount hood itself formed part of the horizon. The Mount Hood edifice and Government Camp were slightly enlarged to keep the perspective from diminishing the size of these important areas of the map.

E: Test Maps

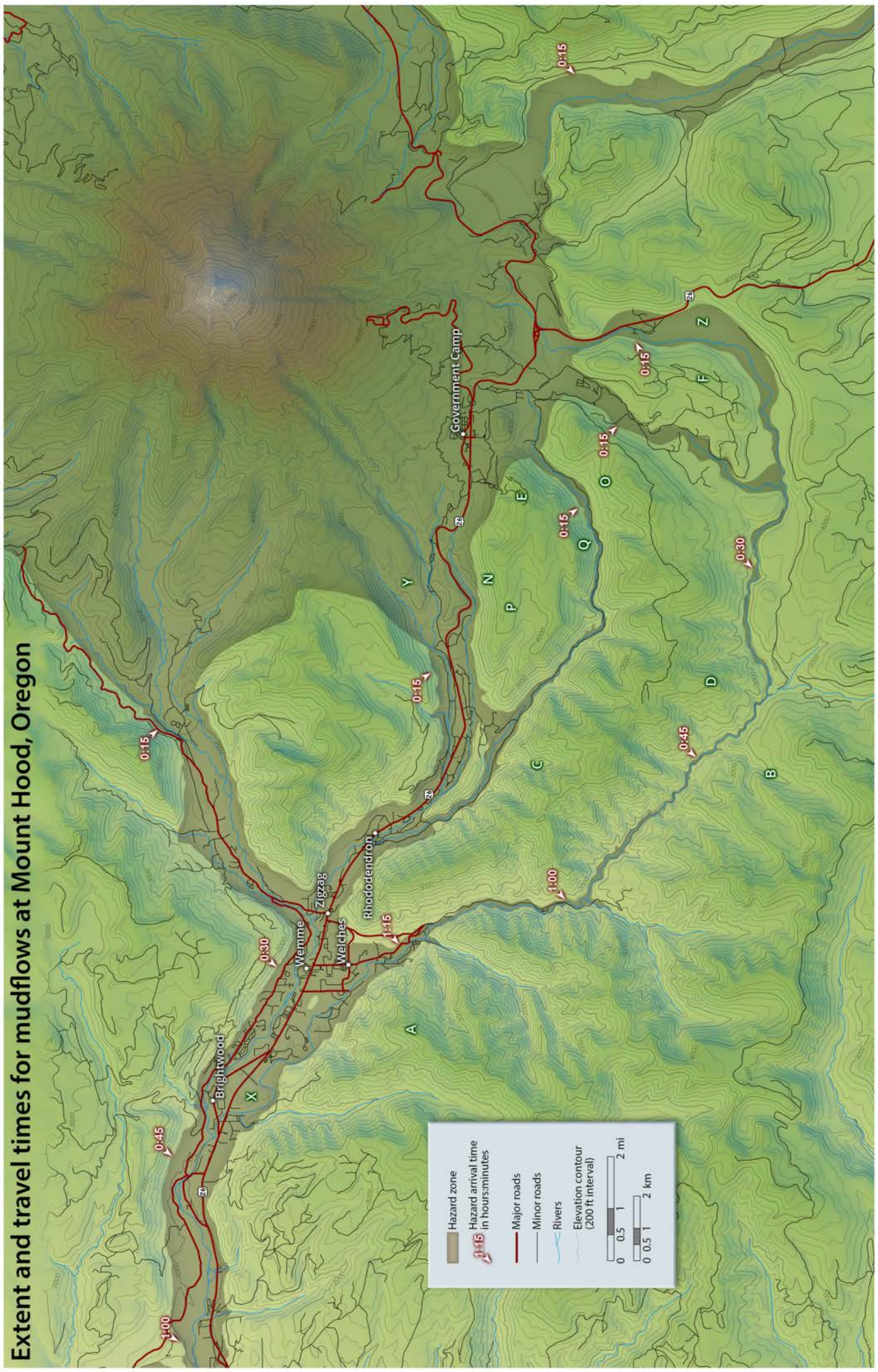


Figure 10: Map A: 2D point markers

Figure 11: Map B: 3D isochrones

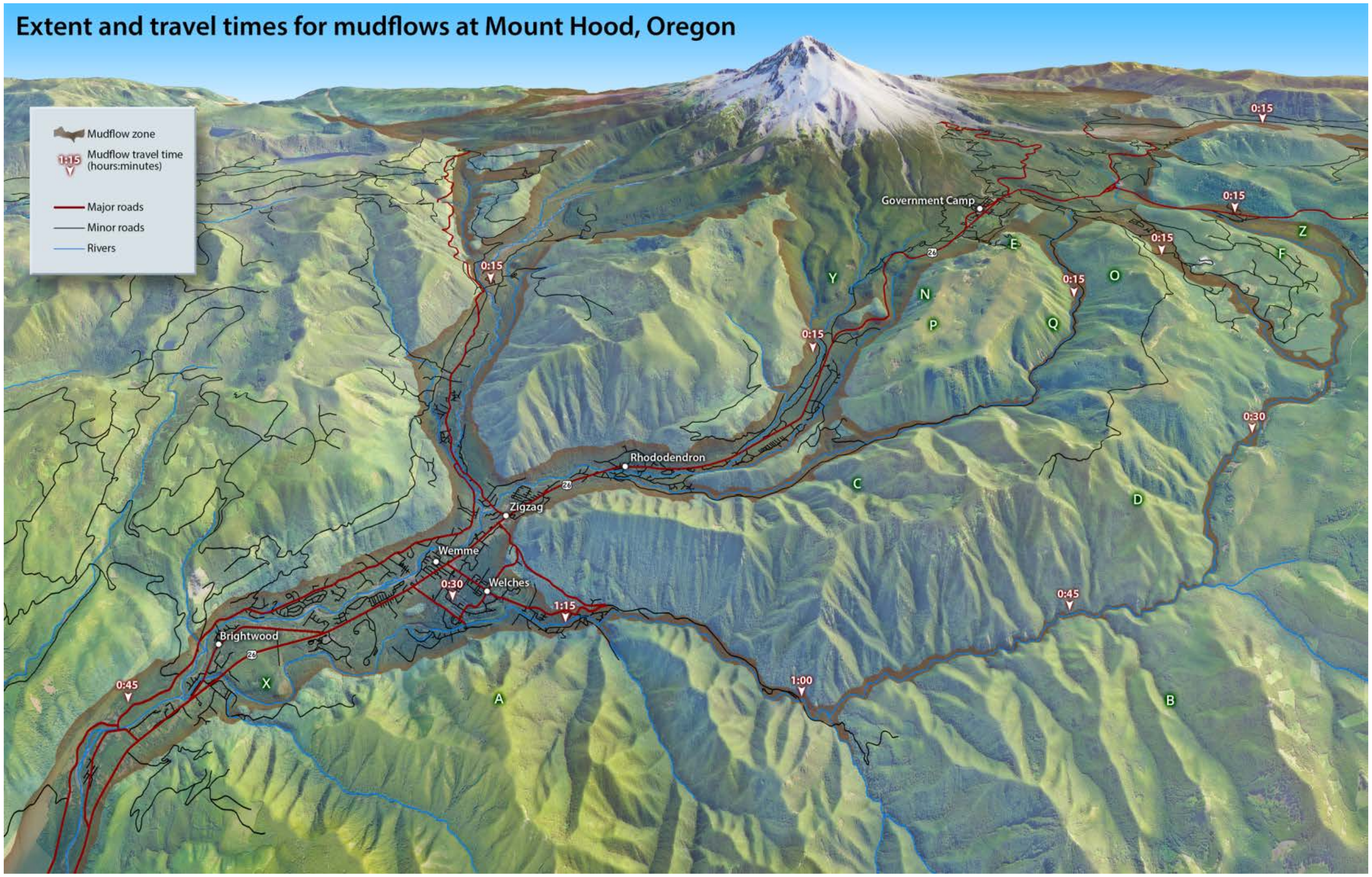


Figure 12: Map C: 3D point markers

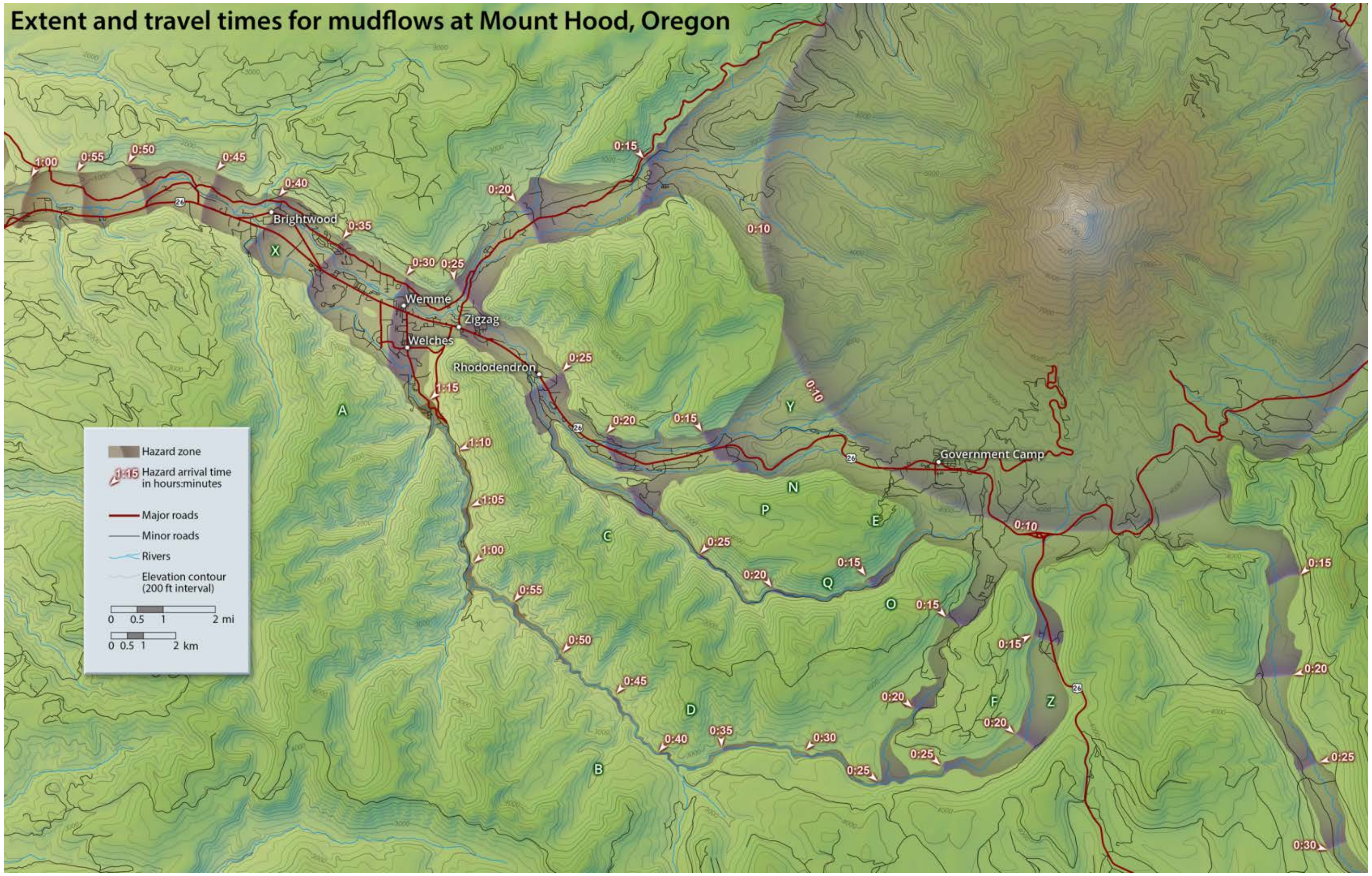


Figure 13: Map D: 2D isochrones

F: Survey Pages

Section 1: Prior knowledge

This survey is not a test of your skill; it is a test of how effective different map designs are. The questions on this page are meant to see if you already have specific knowledge about some of the things the maps are designed to show, which we need to account for when judging their effectiveness.

1.1 Are you living in the area around Mount Hood, or visiting?

☐ Living ☐ Visiting

1.2 If you are living in the area, for how many years or months?

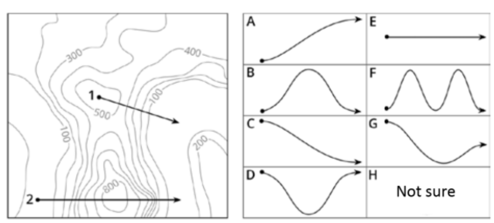
____

1.3 How well would you say you can find your way around the Mount Hood area?

With great difficulty	With difficulty	Fairly well	Easily	Very easily
☐	☐	☐	☐	☐

1.4 Below on the left is a sample topographic map with two paths. On the right are a set of profiles, which describe how elevation might change along the path.

Map Profiles



Which profile best describes how elevation changes along Path 1?

____

Which profile best describes how elevation changes along Path 2?

____

1.5 How would you rate your familiarity with volcanic hazards?

Minimal	Modest	Moderate	Well informed	Very well informed
☐	☐	☐	☐	☐

1.6 What is the nearest potentially active volcano you can name?

1.7 Which kinds of volcanic hazards do you think are the top three most serious threats to life in the Pacific Northwest?

1________________________ 2________________________ 3________________________

Section 2: Map interpretation

2.1 Elevation

Please find the locations marked A and B on the map. Which is at a higher elevation?

Please find the locations marked C and D on the map. Which is at a higher elevation?*

Please find the locations marked E and F on the map. Which is at a higher elevation?

2.2 Slope

Please find the locations marked N and O on the map. Which is on a steeper slope?

Please find the locations marked P and Q on the map. Which is on a steeper slope?

2.3 Please mark where on the map you believe we are currently located.

2.4 How sure are you that this is the correct location?

Very uncertain	Somewhat certain	Quite certain	Very certain
☐	☐	☐	☐

2.5 At our current location, as well as the locations marked X, Y, and Z, how soon after the onset of eruption could the hazard arrive? Use the map to read the arrival times.

Our current location	X	Y	Z
______________	______________	______________	______________

2.6 How sure are you of your estimates?

Very uncertain	Somewhat certain	Quite certain	Very certain
☐	☐	☐	☐

2.7 *<u>Evacuation scenario:</u> You at our current location when a loudspeaker announces that Mt. Hood has erupted and everyone needs to evacuate to high ground as quickly as possible. Let's assume your friends and family are already out of harm's way, and there's no need for you to retrieve anyone or anything from home or anywhere else.* **Please mark where on the map you would evacuate to, and the path that you would take to get there from here. Please use the blue pen for the route you would take in a car, and the red pen for the route you would take on foot.**

***Due to an error in a contour lable near one of the locations on the 2D maps, results from this question were not used in the data analysis.**

Section 3: Map impressions

3.1 Based on how far the mudflows travel in a given amount of time, how fast would you say they seem to be?

Walking speed	Running speed	City street speed	Highway speed	Airliner speed
☐	☐	☐	☐	☐

3.2 Has this map changed your opinion on volcanic hazards in this area? Why or why not?

3.3 When you were reading the map and planning your evacuation route, how accurate did you think the hazard travel times were?

Within an hour	Within 30 minutes	Within 10 minutes	Within 5 minutes	To the minute
☐	☐	☐	☐	☐

3.4 In a real eruption, would you expect to have the amount of time indicated on the map, or to have more or less time?

As indicated	More time	Less time
☐	☐	☐

Section 4: Final comments and demographics

Out of the four maps, choose the best and the worst for the following categories:

4.1 Which map gives you the clearest understanding of the terrain?

Best Worst

________________ ________________

4.2 With which map would you feel most confident about your interpretation of hazard arrival times?

Best Worst

________________ ________________

4.3 Which map is best for judging escape routes?

Best Worst

________________ ________________

4.4 What is your gender?

□ Male □ Female □ Decline to state

4.5 What is your age group?

□ 18-20 □ 41-50 □ Decline to state
□ 21-30 □ 51-60
□ 31-40 □ 60 and older

4.6 What is the highest level of education you've attained?

□ Some school □ College certificate □ Decline to state
□ High school/GED □ Undergraduate degree
□ Some college □ Graduate degree

4.7 Do you have any further comments on the maps or the research?

4.8 Lastly, do you have any questions about the research?