THE PERFORMANCE OF 2D AND 3D TSUNAMI EVACUATION MAPS: A CASE STUDY FOR SEASIDE, OREGON

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ABSTRACT

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Tsunami evacuation maps are intended to inform the public about the geographic extent of the hazard and where to evacuate, but these maps can be difficult to interpret for people unfamiliar with cartographic semiology. This study focuses on the performance of tsunami evacuation maps and how the tsunami hazard is represented cartographically, as at-risk communities must be able to act quickly, and effectively understand tsunami maps to remain aware of the hazard and adequately evacuate. This study investigated the use of static three-dimensional (3D) perspective maps and travel time to safety representation (shown using point markers and choropleth symbology), as alternative ways to help mitigate tsunami disaster. The performance of, and preference for, static 3D tsunami evacuation maps were compared to conventional two-dimensional (2D) evacuation maps using a user survey and a set of test maps for the area of Seaside, Oregon. Each participant was given either a 2D or 3D map showing travel times as either point markers or choropleth symbology, and asked to complete a series of tasks concerning terrain and positional judgment, and evacuation travel time estimation. Participants were also shown all four maps and asked to determine which map was best for completing the tasks mentioned above. There were 84 survey respondents, and the results indicated that the 3D

maps were preferred, overall. 3D maps performed best for judging terrain but showed no difference in performance when judging position. There was no difference in performance between 3D maps using choropleth symbology and 2D maps using point markers when estimating travel times. The results indicate that 3D maps perform the same or better than 2D maps and are preferred, suggesting the use of 3D maps for tsunami evacuation planning and education.

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KEY TERMS

Between-Subject Design: An experiment where two or more groups are tested by a different testing factor at the same time.

Choropleth Symbology: The use of different colors or shading within defined areas that indicates similar values or quantities.

Hypsometry: This is the measurement and depiction of elevation relative to sea level.

Mann-Whitney U-Test: A statistical test that is used to compare the means of two groups from the same population if both samples are not normally distributed. Two advantages of this test are that the two sample groups do not need the same number of observations to be valid and there is an effective two-tailed version.

Point Marker Symbology: An icon or symbol denoting a value or characteristic.

Rupture (Geologic): The event that creates seismic energy when a geologic fault moves or slips from a static position.

Subsidence (Geologic): The sinking and settling of the ground.

Symbology (with reference to maps): This describes the way map information is encoded using visual symbols, such as shapes, colors, patterns, etc.

Two-Sample T-Test: A statistical test used to determine if there is significant difference between the means of two normally distributed independent populations.

Visualization: The visual presentation of information generally in a graphic form.

Within-Subject Design: An experiment where all participants are exposed to the same test with the same set of factors.

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INTRODUCTION

A tsunami is a set of ocean waves that are propagated by a disturbance, which usually occurs when an oceanic earthquake displaces the sea floor (Bernard et al. 2006). When these waves move onshore, they can devastate coastal communities, adversely impacting socio-economic and ecological systems, and disrupting livelihoods (Alexander 1993). Geologists have historically paid less attention to these events given their infrequency compared to other hazards (Bryant 2014). However, this lack of interest began to change in 2004, when the Great Sumatra-Andaman tsunami caused unparalleled damage, and an estimated 283,000 casualties throughout the Indian Ocean region (Levy and Gopalakrishnan 2005). Then in 2011, a significant earthquake occurred off the coast of northeast Japan, creating massive tsunami waves (referred to as the Tohoku tsunami) that caused substantial destruction to Japan's densely populated eastern seaboard. Approximately 400 square kilometers were inundated, and a maximum wave height of 39 meters was reported at Miyako, causing some of the most dramatic destruction (Mori et al. 2011). There was also damage to the Fukushima Daiichi Nuclear Power Plant, which resulted in the leakage of lethal contaminates that will have effects for decades to come (Earthquake Engineering Research Institute 2011). These powerful tsunamis represent extreme disasters, as they affected large populations and areas of substantial infrastructure. They also left very little time for evacuation, with virtually no warning for those impacted by the tsunami in 2004 (McAdoo et al. 2006; Suppasri et al. 2013). The

tragic and lasting consequences of these events emphasized a global need for greater assessment of the tsunami hazard and related disaster prevention.

Tsunami waves can travel long distances, affecting coastal areas in various ways both near and far from their origin (Bryant 2014). Therefore, it is essential to recognize the differences between local causes (near-field sources) and distant causes (far-field sources), as they can pose distinct challenges for hazard response (Darienzo et al. 2005). When far-field sources propagate tsunamis, waves may take many hours to reach distant coastlines, leaving time for proper hazard response (Wang et al. 2015); in this situation, a response may only relate to locations where emergency protocols and warning systems are in place. On the other hand, local events often pose far more risk, as tsunamis can reach earthquake damaged shores within minutes (Darienzo et al. 2005). Alert systems are now available to help notify communities about incoming tsunamis, such as the Pacific Tsunami Warning Center (PTWC), which tracks seismic and tsunami activity in the Pacific region. Unfortunately, alerts for local events may not give enough lead-time to be effective (Katada et al. 2006). The most common and pragmatic method in limiting loss of life, especially for near-field tsunamis, is immediate evacuation to higher ground (Couling 2014; Priest et al. 2016).

Tsunami evacuation procedures vary between communities, as does the potential impact tsunamis can have regarding flooding, damage to infrastructure, and loss of life. Wood et al. (2015) have noted that public education on tsunamis is essential for limiting risk, and in dealing with variation in community vulnerability for evacuation success. Likewise, the National Tsunami Hazard Mitigation Program (NTHMP) recognized the

importance of education on the tsunami hazard and found that there was minimal planning for tsunami response in many communities along the West Coast of the United States (Jonientz-Trisler et al. 2005). The program has since helped vulnerable U.S. communities develop better mitigation strategies that avoid only relying on response after an event and focus on precursory ways to remain aware of tsunamis and avoid harm (Bernard 2005). Some of these strategies include informational brochures, evacuation signage and maps, evacuation route planning, newsletters, and other community-specific events (Jonientz-Trisler et al. 2005). These educational strategies have been successful in increasing tsunami hazard awareness throughout coastal Washington, Oregon, and Northern California (Dengler 2005). Similar educational approaches have proved successful abroad, as a focus on education and outreach helped some communities avoid more significant loss of life during the 2011 Tohoku tsunami (Suppasri et al. 2013). The areas that evacuated most quickly were those that had a history of tsunami disasters, which are events, kept in the collective memory of some communities through tsunami festivals, memorial parks, and other social countermeasures (Suppasri et al. 2013).

Two-dimensional (2D) paper maps are often used as a primary tool to educate people about local tsunami impacts and evacuation procedures. However, Kurowski et al. (2011) have shown that these maps involve cartographic choices that may not be effective for communicating tsunami risk and evacuation information to the public. Some efforts have been taken to eliminate discrepancies in tsunami hazard communication among communities, as Oregon and Washington have made progress in standardizing tsunami maps statewide. Before this standardization, mapping was left to the discretion of

communities, producing variable levels of cartographic quality, and inconsistencies in the types of information provided (Kurowski et al. 2011). The ability of maps to communicate tsunami risk to a public audience cannot be understated, as maps are an optimal medium for explaining the spatial nature of many natural hazards (Dransch et al. 2010). To be effective, however, tsunami hazard maps must function for public use, because inadequate forms of visual communication can adversely affect tsunami awareness and disaster response times (Schafer et al. 2008). To explore the potential for limiting problems conveying important tsunami information, and to encourage progress in risk communication, it has been suggested that future mapping efforts take advantage of three-dimensional (3D) visualization (Lonergan and Hedley 2015).

There are numerous types of 3D maps, which can broadly be categorized as static, interactive, or augmented (i.e. virtual reality). Static 3D maps depict features using an oblique or tilted perspective on a flat surface, such as on a printed map. Interactive 3D maps are generally viewed on the web and can be manipulated on-screen to see features from different perspectives or angles. Augmented 3D maps allow users to become immersed in a virtual environment using specialized hardware that can simulate an experience or a place. The development of interactive and augmented 3D maps in the field of cartography is relatively new, but static 3D maps have long been used to lend a more realistic perspective, such as on panoramic ski maps and the work of Austrian cartographer Heinrich Berann (see Figure 1).

Unlike interactive and augmented 3D maps, static 3D map displays are a familiar and established medium, and do not require any type of specialized equipment or

Figure 1. Heinrich Berann's 3D panorama of Mount Denali (Circa 1995).

experience, making them a practical option for public use. From a cartographic standpoint, static 3D maps can more effectively show the shape and depth of landforms and terrain (Jenny et al. 2015). They also have been shown to hold user attention better than 2D maps, potentially improving map communication (Schobesberger and Patterson 2008). The perceived strengths of using static 3D techniques for tsunami mapping may present an alternative perspective that is more expressive and effective in communicating information, which could influence how tsunamis are perceived and understood, and how evacuation procedures are acted upon.

3D tsunami hazard maps have rarely been evaluated for their performance in communicating risk to the public, but general studies on 3D maps have highlighted some broad considerations. Some of the most important considerations are that 3D maps may not be ideal for all map-reading tasks and that their performance is often subject to the context in which they are viewed (Savage et al. 2004; Petrovic and Masera 2005; Haynes et al. 2007; Schobesberger and Patterson 2008). Also, 3D maps are typically more expensive and time-consuming to create compared to 2D maps and can present unique cartographic problems, such as feature concealment (i.e. where tall features obstruct the view of lower elements), which may deter their production and use (Schobesberger and Patterson 2008). Although these are important factors for those interested in producing 3D maps, issues related to the challenges and costs of 3D map production do not inherently affect the map user's ability to glean valuable information, or better interpret map features.

The abstract nature of maps, or the use of visual symbols to code spatial information, can be complicated for some people to understand (Handmer and Milne 1981). However, recent research focused on natural hazard science from a community-oriented perspective has revealed new ways to convey tsunami information that may improve risk communication. Wood and Schmidtlien (2013) have investigated the use of pedestrian travel time to safety representation for tsunami evacuation maps. This type of approach shows map users what areas are most vulnerable, and how much time is available to reach safety. Unlike conventional tsunami evacuation maps that show areas inside and outside a hazard zone, using travel times to safety conveys a stronger sense of

appropriate action, which can be a benefit for evacuation planning and natural hazard education (Wood and Schmidtlien 2013).

Most conventional tsunami evacuation maps are created in 2D, with few examples in 3D (Lonergan and Hedley 2015). Research on the comparative performance between 2D and 3D tsunami evacuation maps appears limited, with a lack of information on the ability of tsunami maps to communicate risk to a general audience or promote participation in tsunami hazard awareness. However, effective public education on the tsunami hazard remains critical for disaster mitigation (Dengler 2005). Therefore, the purpose of this study was to determine preference for, and the performance of, 3D maps in comparison to 2D maps for helping people interpret and perceive the tsunami hazard, and to evaluate which is more effective for understanding pedestrian travel time to safety: using choropleth symbology or point markers. The main objective was to gather and analyze user feedback on the performance of, and preference for, 3D maps and travel time representation, in direct comparison to conventional 2D tsunami hazard maps and their symbology. To accomplish this evaluation four hypotheses were developed, which included: (H1) overall, map users prefer 3D tsunami evacuation maps to 2D maps, (H2) map users more accurately interpret position and relative elevation change on 3D maps over 2D maps, (H3) map users more accurately interpret pedestrian travel times on 3D maps, represented using choropleth symbology, and (H4) map users prefer the use of pedestrian travel times on 3D maps, represented using choropleth symbology. To test the hypotheses, 2D and 3D maps were developed, printed, and given alongside a questionnaire style survey to participants at three public locations in Seaside, Oregon,

which is a large town located in the coastal northwest that is highly vulnerable to tsunami impacts (see figure 2). By studying the preference for, and the performance of, 2D and 3D maps, and the use of pedestrian travel time representation, this study sought insights into how different tsunami evacuation map designs can assist vulnerable communities. Ideally, the results presented here could help stakeholders, such as community groups and agencies that oversee emergency planning and response, better develop map products for tsunami preparedness and evacuation.

Figure 2. Map showing the location of Seaside, Oregon.

LITERATURE REVIEW

Natural Hazard Evacuation Mapping: 2D and 3D Map Design

Most 2D hazard evacuation maps (e.g. volcanic, flooding, and tsunami hazard maps) use similar types of symbology to represent physical and anthropomorphic features, as well as hazard and evacuation information (Kurowski et al. 2011). For example, contours (i.e. lines of equal elevation) and/or subdued relief shading are often used to represent height differences and landform shapes on a variety of hazard maps, which can be critical for understanding where to locate areas of higher and lower elevation (Savage et al. 2004). These types of landform representation can be difficult for novice map users to understand, or correctly interpret. (Haynes et al. 2007; Kurowski et al. 2011). Lonergan and Hedley (2015) have recognized the potential to improve map symbology and user interpretation of tsunami risks, explaining that 3D representations may better display tsunami and terrain information, especially when visually translating complex scientific tsunami data. Numerous studies have been conducted to describe the perceived benefits and issues of 2D and 3D cartographic representation, and how hazard risks are shown visually within these perspectives. The focus of these studies has mostly involved a series of map reading tasks for general map users and their understanding of variably represented information.

Stefan Seipel (2013) examined how 2D and 3D maps perform for assessing geographic position and distance. The study identified *weak 3D* visualizations as those

that project a 3D surface within a static 2D context, allowing for a specific set of spatial cues for the observer; this view is subject to perspective distortion, or a lack of constant scale. *Strong 3D* was also used in the assessment and can be described as the augmented reality perspective, or spatial cues given as the viewer perspective changes. The assessment tested users' judgment of positions and distances between locations on maps using 2D, weak 3D, and strong 3D perspectives. The results showed that a weak 3D map with a 35-degree pitch is just as effective as the 2D perspective. The conclusion of the study suggested that 3D maps are a suitable alternative to 2D representation. Strong 3D perspectives are believed to be most effective for displaying complex 3D data but can often cause visual fatigue for users immersed in an augmented reality environment.

Petrovic and Masera (2005) developed an online survey for expert map users. They compared a 2D topographic map to multiple 3D maps, which included a 3D terrain overlaid with a topographic map, a 3D terrain overlaid with an orthophoto, and a 3D scene containing stylized physical and urban features. The results of the study showed that most expert map users were able to determine distance, relative height, and orientation best on the 2D topographic map. However, users recognized features best on the stylized 3D scene, with a visual preference for the 3D topographic map over the stylized 3D view.

Preppernau and Jenny (2015) studied the comparative performance of 2D contour and stylized 3D volcanic hazard evacuation maps for Mount Hood, Oregon. Their research was conducted by developing a survey and a set of 2D and 3D test maps that were administered on location to the public. The results of their study showed that 3D

maps are more effective when judging terrain than 2D maps and that people prefer the use of 3D maps with isochrones (i.e. lines of equal time) versus 2D maps with point markers representing time for different tasks, such as judging terrain, position, and the travel time of volcanic debris flows known as lahar. It was also noted that many participants were surprised at the speed at which volcanic lahars can travel, supporting the use of time indication when trying to convey the movement of a hazard in relation to evacuation procedure. Overall, their findings indicated that 3D maps are better for communicating volcanic hazards to the public than traditional 2D contour maps.

Haynes et al. (2007) examined the effectiveness of 2D and 3D volcanic hazard maps on the island of Montserrat. The study tested one user group on their ability to interpret terrain and hazard information on a 2D contour map and the other group on their ability to understand the same information using a series of 3D maps. Subsequently, both groups were given oblique air photos after looking at the other maps to measure their effect. The results of the study showed that respondents using the 3D maps were able to better identify landmarks and make connections between the terrain and hazard areas. However, the oblique air photos performed the best, as most respondents were able to quickly orient themselves, and identify terrain features and hazard areas. It was suggested that the higher performance of the air photos may have been the result of their ability to show more terrain detail, giving familiar visual cues to respondents that would have otherwise had to interpret more abstract cartographic symbology.

Savage et al. (2004) investigated the interpretation of contour lines on 2D and 3D maps. The study compared a 2D contour map containing elevation-based gray-scale fill

with a map providing the same information represented from a 3D perspective; shading was not included to evaluate contour shape strictly. The results of this investigation showed that participants understood distance, elevation, and downhill flow direction either the same on both the 2D and 3D maps or worse on the 3D maps. The study concluded that 2D contour maps are ideal for tasks that do not include elevation data and that there is no significant difference in user performance between the two map types when elevation data is visually represented.

Schobesberger and Patterson (2008) studied how users interacted with 2D and 3D trailhead maps in Zion National Park in Utah. Overall, their results showed that users did not interpret information on the 3D maps significantly better than the 2D maps. However, when users were asked to self-locate 3D maps did marginally perform better, with users spending more time viewing the 3D maps. The study concluded that map users were equally split for most tasks and that further studies should be conducted within other map reading contexts. Moreover, it was noted that 3D maps are generally more expensive and time-consuming to produce and do not allow for a constant scale.

Schobesberger and Patterson (2008) also described the issue of feature concealment as a crucial consideration when designing static 3D maps. This Problem occurs when the chosen 3D perspective forces lower or smaller features to be hidden by taller or larger foreground features. For 3D maps to effectively communicate information, the perspective view must be adjusted, allowing map users the opportunity to view all the essential cartographic elements. The use of progressive projection is an effective method of solving this problem (Jenny et al. 2010). In practice, this technique curves the map's

foreground, placing the middle and background of the map in a parallel line of sight. This technique produces a 3D perspective that keeps both foreground and background features within view. Patterson (2000) suggested another method to reduce feature concealment involving tilting (as opposed to curving) the projection plane towards the viewer but from a higher viewpoint. This technique places the foreground and middle ground in a direct line of sight, or a map-like view, while the background features and horizon appear more realistic (Patterson 2000).

Stefan Seipel (2013) demonstrated that static 3D maps could be just as useful as 2D maps in allowing users to judge distance and position without visual fatigue, which can be a problem when using immersive 3D maps in virtual reality. Savage et al. (2004) implied the importance of including shading on 3D maps to give a stronger sense of depth and relative height. Preppernau and Jenny (2015) showed evidence that 3D maps perform better than 2D contour maps for map-reading tasks related to volcanic hazard evacuation. Haynes et al. (2007) demonstrated that map users who may not be familiar with cartographic symbology might benefit from the use of 3D maps and imagery, or a more realistic depiction of a terrain. Lastly, Schobesberger and Patterson (2008) showed that static 3D maps might be able to hold user attention longer than 2D maps, found evidence that these maps may perform better than 2D maps for self-locating, and noted the importance of developing a useful 3D perspective view or angle-of-view.

Tsunami Evacuation Mapping: Hazard Representation

Tsunamis are a dynamic phenomenon that change over time and space (Geist et al. 2006). The way in which potential tsunami impacts are represented on maps do not always reflect these spatiotemporal characteristics, as they generally only show zones of flooding and safety (Kurowski et al. 2011). By just displaying these zones, map users are only given enough information to know where to evacuate, and in some cases, there is little or no advice on what mode of travel during an evacuation is most effective (Kurowski et al. 2011). There is also generally no information on how much time is available for evacuation, as shown by a survey of tsunami evacuation maps for the Pacific Northwest by Kurowski et al. (2011). Giving the public more information on the nature of the threat may be worth including, considering that the way people perceive a risk often determines how they will prepare and react (Wilson et al. 2008). Couling (2014) found this to be the case, as many people in the town of Pauanui on the North Island of New Zealand had little education on tsunamis, and an inaccurate perception of tsunami risk; many people did not recognize the difference between local and distant tsunami events and underestimated the amount of time required to evacuate. This lack of education had an adverse effect on their personal risk awareness and interest in evacuation procedures. The role of tsunami hazard maps in helping people understand where to evacuate is important, but these maps may also be able to more accurately depict the physical nature of tsunamis and improve perceptions about risk and safety.

Recent research has investigated the efficacy of showing the amount of time to safety for pedestrians during a tsunami event. Wood and Schmidtlein (2013) developed methods for using pedestrian travel times to assist communities in recognizing their ability to evacuate, highlighting people in the community most at risk (e.g. the elderly, children, and the impaired), and helping the public make better evacuation decisions. Incorporating pedestrian travel times on tsunami hazard maps could potentially convey a better sense of the hazard's nature, depicting movement over time and space to show a more realistic perspective of vulnerability. One way to visually represent pedestrian travel time to safety on a map is by using isochrones, or lines denoting equal time (Preppernau and Jenny 2015; Priest et al. 2016).

Preist et al. (2016) applied travel times using choropleth symbology to an evacuation map for Seaside, Oregon, modeling minimum pedestrian travel speeds and paths using least-cost-distance analysis and data on early wave arrival times (i.e. Beat-the-Wave modeling). Their results showed that this type of modeling and mapping is most useful for communities with higher interior flooding potential, as it accounts for early flooding and not just a maximum flooding level. This capability is essential because tsunamis can flood estuaries and connected streams during the first wave arrival, potentially cutting off evacuation access. Another essential characteristic of this model is its ability to display multiple travel speeds on a single map, where other methods require numerous maps. This aspect of the model makes communicating risk to the public simpler, allowing direct comparison between travel speeds and evacuation routes, and

further suggesting the use of pedestrian travel times as an alternative to maps that only show flooding zones.

METHODOLOGY

This study used a printed questionnaire and a series of printed test maps (printed on 19”x13” sheets) to investigate two primary design concepts: (1) 3D perspective versus 2D perspective base map design, and (2) pedestrian travel time to safety representation using either choropleth symbology or point markers. This study also examined participant preference for 2D or static 3D maps and the communication potential of pedestrian travel time representation. Preference for either map type or travel time representation do not inherently indicate an ability of a map to convey information but are considered here as a factor that may influence decisions in map design and usage. The primary design concepts and their preference factor, along with previous research on 2D and static 3D map design, and travel time representation, directed the visual needs and production techniques for administering the evaluation of the maps.

All of the base maps, or the elements of the test maps used to give context to the overlaid thematic elements (e.g. tsunami flooding and pedestrian travel time information), used in this study were developed to have similar characteristics, with fundamental differences in the display perspective. For example, the 2D base maps used a planar view (i.e. vertical perspective), representing landforms with relief shading and hypsometric tints; the maps also showed hydrologic and anthropomorphic features (e.g. streams and roads), as well as labels for major features. Conversely, the static 3D maps

used a birds-eye view (i.e. oblique perspective), but also represented landforms with the same type of relief shading and hypsometric tints. Lastly, like the 2D maps, the static 3D maps included hydrologic and anthropomorphic features and major feature labels but placed all elements within a 3D context.

The most common symbological methods used to denote tsunamis on maps involves representing the hazard and safe zones with a solid line and/or color-filled area. Tsunami maps also typically include relevant anthropomorphic and physical features (e.g. roads and major streams) that are used to add geographic context and act as cues for navigating to safe zones. These map features are the convention for most tsunami evacuation maps and are officially used by the Oregon Department of Geology and Mineral Industries (DOGAMI) (see Figure 3). An additional approach for representing the tsunami hazard applies pedestrian travel time to safety data shown as isochrones, or choropleth symbology (i.e. the usage a color coding to denote areas of equal value). This method visually shows zones with different levels of risk to travel through when trying to reach safety or describe an estimated amount of time from certain locations to reach a safe zone. Pedestrian travel times are used instead of vehicular travel times because roads are assumed to be obstructed during and after a large earthquake (Priest et al. 2016). The methods for developing pedestrian travel time data are described in the following section titled “Map Design & Production.”

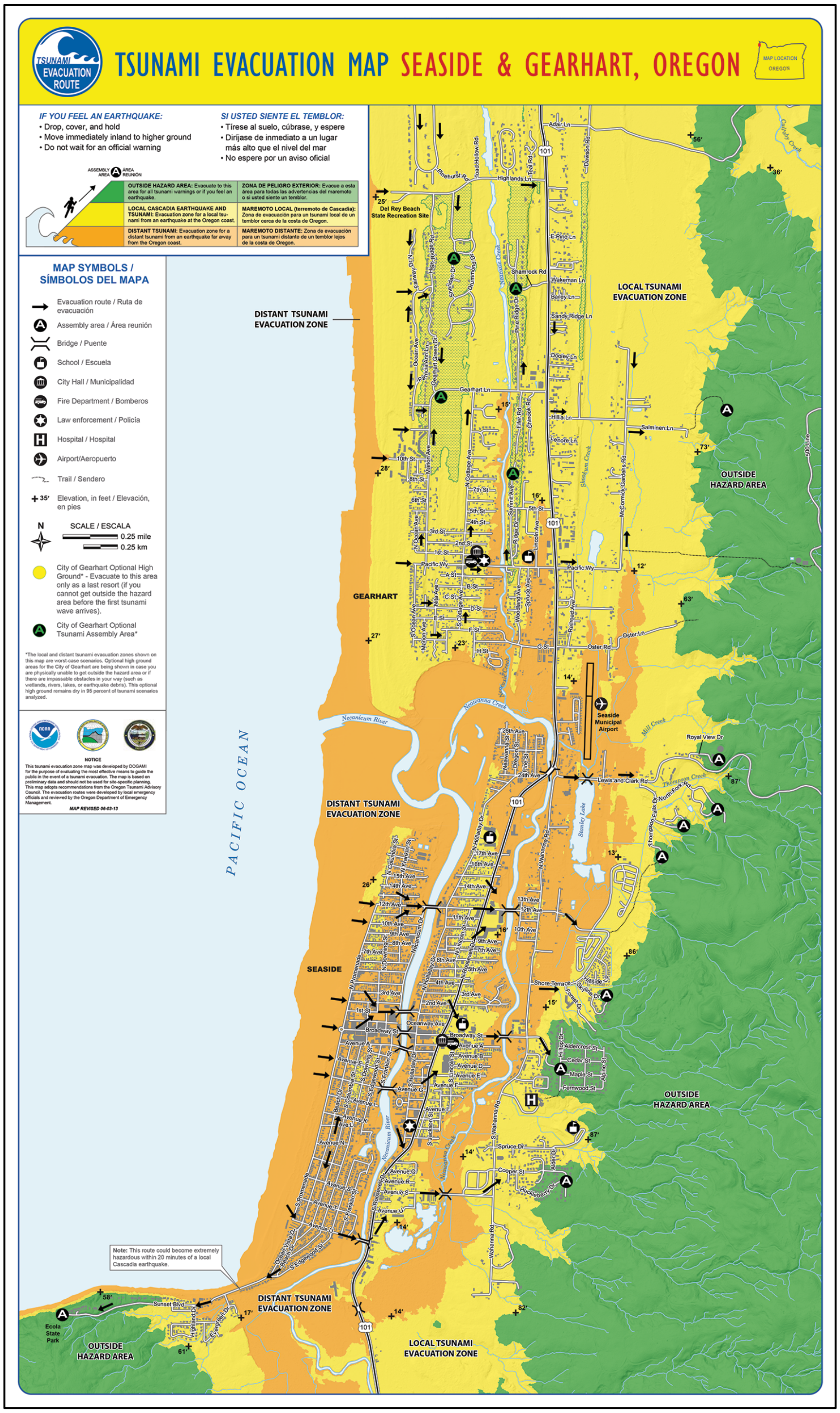


Figure 3. Official tsunami evacuation map for Seaside, Oregon.

The previously mentioned base map types were used to display the two methods for describing travel time to safety, which produced four test maps: (1) a 2D map with relief shading, anthropomorphic and physical features, flooding and safe zones, and pedestrian travel times to safety represented using choropleth symbology; (2) a 2D map with relief shading, anthropomorphic and physical features, flooding and safe zones, and pedestrian travel times to safety represented using point markers; (3) a static 3D map with relief shading, anthropomorphic and physical features, flooding and safe zones, and pedestrian travel times to safety represented using choropleth symbology; and (4) a static 3D map with relief shading, anthropomorphic and physical features, flooding and safe zones, and pedestrian travel times to safety data represented using point markers. These maps were administered alongside the survey to test the study's hypotheses.

Study Area

Tsunamis are one of the most powerful natural hazards that affect the West Coast of the United States. Coastal cities in the Pacific Northwest are some the most at risk because of their proximity to the Cascadia Subduction Zone (CSZ) (see figure 4). This zone is an active megathrust fault that has the potential, during a major rupture, to produce catastrophic earthquakes and tsunamis. The tsunamis generated by such a rupture would be considered near-field events for locations within the coastal Pacific Northwest. A major near-field tsunami would leave the least amount of time for evacuation, requiring effective emergency preparation and self-evacuation to avoid significant harm (Wood et al. 2014). This study focused on the city of Seaside, which is a highly

vulnerable area located in the northwest corner of coastal Oregon, along the central region of the CSZ (see figure 4).

According to Wood et al. (2014), the city of Seaside, which has about 6,600 full-time residents (U.S. Census Bureau), has a high level of population exposure, with one of the highest concentrations in the Pacific Northwest of residents, tourists, businesses, dependent-care facilities, and public venues within tsunami hazard zones. The primary reason for its exposure is its geography, as most of the city is situated in low-lying areas, with coastal flood-prone rivers and creeks separating much of the urban infrastructure from regions of higher elevation to the east (Priest et al. 2015). The significant level of vulnerability has remained a concern, and the Oregon Department of Geology and Mineral Industries (DOGAMI) has analyzed the problems related to evacuation procedures in Seaside (e.g. river flooding, residents at high-risk, and rapid-onset tsunamis), which has helped emergency managers make better evacuation decisions (Priest et al. 2015). One outcome of the research conducted by DOGAMI was the development of publicly available geographic tsunami data for the area, which includes, but is not limited to, modeled tsunami flood zones and wave arrival times. Given the available data, the city's sizable population, and the area's high vulnerability, Seaside was an ideal location to investigate the performance of tsunami mapping approaches.

Figure 4. Map showing the Cascadia Subduction Zone.

Map Design and Production

Pedestrian Travel Time to Safety Representation

Priest et al. (2015) and Witter et al. (2011) developed the pedestrian travel time and tsunami flooding data that were used for this study (originally created for Oregon Department of Geology and Mineral Industries tsunami maps). The pedestrian travel time data represent time in minutes from the shore to safe zones located in areas of higher

elevation east of Seaside. An average walking speed of four feet per second and multiple modeled tsunami flooding scenarios were primary inputs used to develop the travel time dataset, which was constructed using least-cost distance routing from a previously developed methodology by Wood and Schmidtlein (2012). Priest et al. (2015) used a modified version of this least-cost distance method for determining travel difficulty and speed, which considered certain affects to movement on foot, such as slope and land cover. It also only viewed travel paths as those accessible by foot, such as streets, sidewalks, and hard-packed pathways, excluding loose sand which has a high level of variability in computing travel difficulty. The results of this analysis produced a multi-polygon dataset describing zones of variable pedestrian travel times that were clipped to roads and other hard-packed pathways, as roads and designated pathways avoid buildings and other obstacles and are the suggested evacuation routes by Wood and Schmidtlein (2012). The zones were color-coded based on value ranges (i.e. choropleth symbology) denoting time in minutes to safety. A semi-qualitative color scheme was used to help clarify the value range for each zone, where each color was easily distinguishable, but not entirely divergent from others given that the zones described the same phenomena. A legend was used to indicate the value ranges for each color-coded zone. This representation of the pedestrian travel time data was then used to create point markers, as the zones were converted to points by calculating the centroid of each polygon. If a point marker was placed within a water feature, it was nudged to an adjacent location close to a road or intersection. The same value ranges were displayed at each point location instead of using a legend. This method of time representation has commonly been used within

volcanic hazard mapping for describing the movement of lahars and is based on research and methods used to produce volcanic hazard maps for Mount Hood (Preppernau and Jenny 2015; Scott et al. 1997). However, it is important to note that point markers, unlike choropleth symbology, only show travel times at discrete point locations, and do not denote the boundaries between areas with equal or different times. Unlike volcanic lahar, which can become channelized, traveling from point to point along a path, tsunami flooding tends to cover large areas. Therefore, the way that tsunamis travel across coastal areas may create some areas where travel time determination is more ambiguous.

Two-dimensional Map Design and Production

To produce 2D tsunami test maps (appendix, figure 17-18), this study used standard geographic information system (GIS) and graphic design applications, including ArcMap 10.1 and Adobe Illustrator and Photoshop. These map designs were principally based on a 3-meter Light Detection and Ranging (LIDAR) digital elevation model (DEM) acquired from DOGAMI. This elevation data provided the basis for relief shading, which contextualized the local hypsometry, and acted as a landform backdrop for other data; these data included roads from OpenStreetMap (OSM) and hydrologic features from the National Hydrologic Dataset (NHD). The tsunami flooding zone data were obtained from the DOGAMI natural hazard GIS database, which contains modeled flooding scenarios for numerous tsunami events. These modeled scenarios are based on hydrodynamic computer simulations that used passed tsunami flooding information, the structure of the seafloor, and numerous modeled earthquake possibilities, which were translated to multiple geospatial datasets (Priest et al. 2013). To reduce locational

uncertainty, the models used higher-resolution (LIDAR) topographic and bathymetric data and increased the severity of the rupture and subsidence potential along the Cascadia Subduction Zone for all earthquake possibilities (Priest et al. 2013). However, Priest et al. (2013) stated that some small areas within the hazard zone were deemed safe given their topographic profile (e.g. sand dunes), but could not be conclusively considered safe given the thresholds of the model and were manually eliminated given their uncertainty. Also, the model assumes that all tsunami scenarios occur during mean higher high water (MHHW), which means that any actual event not occurring during this time period would likely have a different and more uncertain outcome.

The above tsunami flooding model developed by Priest et al. (2013) was used to describe two potential scenarios on the current tsunami evacuation map for Seaside, which includes tsunami flooding patterns for major near-field and far-field events, represented as solid color-filled areas. The current map also represents safe areas, or areas outside the hazard zone using the same symbological method. The representation of hazard and safe zones are both conventional and critical elements included on tsunami evacuation maps.

The maps used in this study were created for user testing and needed to be practical for interpretation by the public. Therefore, the test maps only showed the most severe tsunami scenario, as showing multiple tsunami flooding scenarios, such as both near-field and far-field events, would have complicated the survey questionnaire, asking participants to consider more variables than necessary to test the study's hypotheses. Also, to make the test maps more readable, the tsunami flooding zone was represented

using an internal feathering effect instead of a traditional solid line or color-filled area, creating a strong sense of the hazard boundary while not obscuring other features. Unlike the current tsunami evacuation map for Seaside that does not include tsunami evacuation time information, the maps created for this study displayed pedestrian travel time to safety data, as described by Priest et al. (2015), using either choropleth symbology or point markers along roads and beach access pathways.

Besides the inclusion of base and thematic map elements, major streets and physical features were labeled to assist survey participants in using the maps to complete each map-reading task. Point markers, acquired from DOGAMI, were also used to denote time in minutes for tsunami waves to arrive at specific locations throughout the city, such as at bridge crossings and the edges of the tsunami flooding zones. These wave arrival markers were included to help survey participants better judge pedestrian travel time to safety information or to help facilitate a better understanding of the amount of time available to evacuate on foot.

Three-dimensional Map Design and Production

The static 3D maps used in this study were developed with a 3D modeling and graphics program called Natural Scene Designer 7.0 Pro, and popular GIS and graphic design applications, including ArcMap 10.1, Adobe Illustrator and Photoshop. Natural Scene Designer 7.0 Pro was developed for 3D artists and cartographers interested in creating static and animated 3D perceptive natural scenes. Most importantly, it can produce high-quality, realistic scenes, and complex perspective views, as the production

quality of the static 3D maps needed to match that of the 2D maps for useful comparison and ease-of-use.

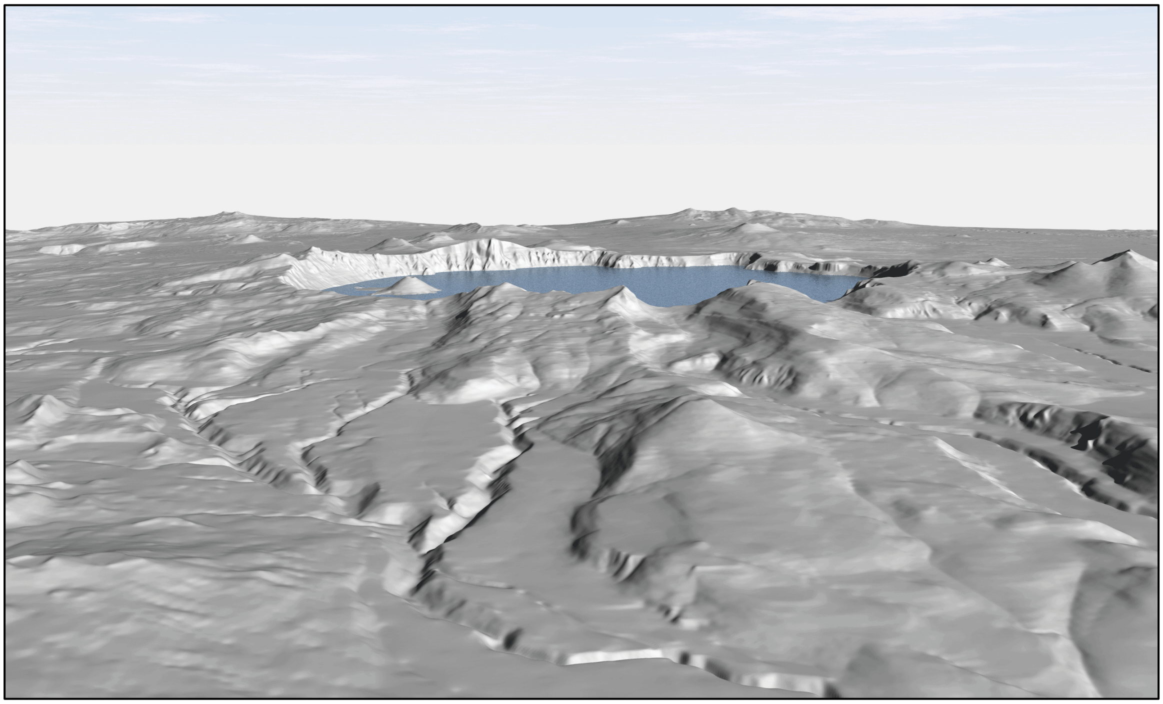
To further maintain both quality and continuity between the static 3D maps and the 2D maps it was essential to use the same datasets. This limited issues of variability in the designs and decreased the overall production time. The overlapping data between the 2D and 3D maps included the 3-meter Lidar DEM used for relief shading, and the anthropomorphic, physical, hazard, and textual elements, such as roads, hydrologic features, tsunami flooding zones, and associated labels (i.e. cities and major roads).

Unlike 2D maps, the static 3D maps required decisions to be made regarding the camera placement, or the viewer altitude, angle, and azimuth. This involved some experimentation to avoid graphical interpretation problems (see Figures 5-6). First, it was important to create a clear 3D perspective; therefore, if the camera was set too low on the horizon, the map would have a strong 3D effect, but many of the map features would be obscured (see Figure 5 - Top). Conversely, if the camera was placed at too steep of an angle, the 3D effect diminishes, or the map appears more two-dimensional (see Figure 5 – Bottom). Second, there was the issue of foreshortening or the compression of potentially important foreground features. The steepness of the oblique viewing angle and the set camera focal length primarily cause foreshortening, but the phenomenon can also be exacerbated when the camera is set too low on the horizon (see Figure 7). Lastly, it was also important to consider the amount of background terrain to include, as removing too much background terrain limits the appearance of a horizon, decreasing the 3D effect.

To create a 3D scene, the 3-meter DEM was loaded into Natural Scene Designer and after some trial and error, exploring different 3D perspective options, the camera was set at an altitude of 13,000 meters, a 40-degree angle, and a 70-degree azimuth (see Figure 6). The background terrain was also extended beyond the study area to allow for a more natural looking 3D image within the scene. Ultimately, these settings eliminated the problems of feature concealment and extreme foreshortening, while creating an explicit 3D perspective scene.

Once the camera and 3D perspective settings were set in Natural Scene Designer, the relief image was ready to be generated. There are numerous rendering options available, including shading with texture and/or photo-realistic effects. However, the final static 3D map needed to match the 2D map, so a 10% gray 3D relief scene was generated and exported as a high-resolution TIFF image (i.e. Tagged Image File Format). Using the same process, a 3D hypsometric tint image that matched the 2D map in terms of color was also generated in Natural Scene Designer, and both were combined in Adobe Photoshop and then manipulated to enhance the shading and illumination, better highlighting landform features. The anthropomorphic and thematic features, such as roads, streams, tsunami flooding zones, and the pedestrian travel time data were also imported into Natural Scene Designer as Shapefiles (i.e. a geospatial vector file format), and using the same 3D settings, were exported as a 3D SVG file (Scalable Vector Graphic). The static 3D relief image was then imported into Adobe Illustrator where it was combined with the anthropomorphic and physical elements, as well as the tsunami

wave arrival markers. The maps were then styled and labeled to match the corresponding 2D maps (appendix, Figures 15-16).



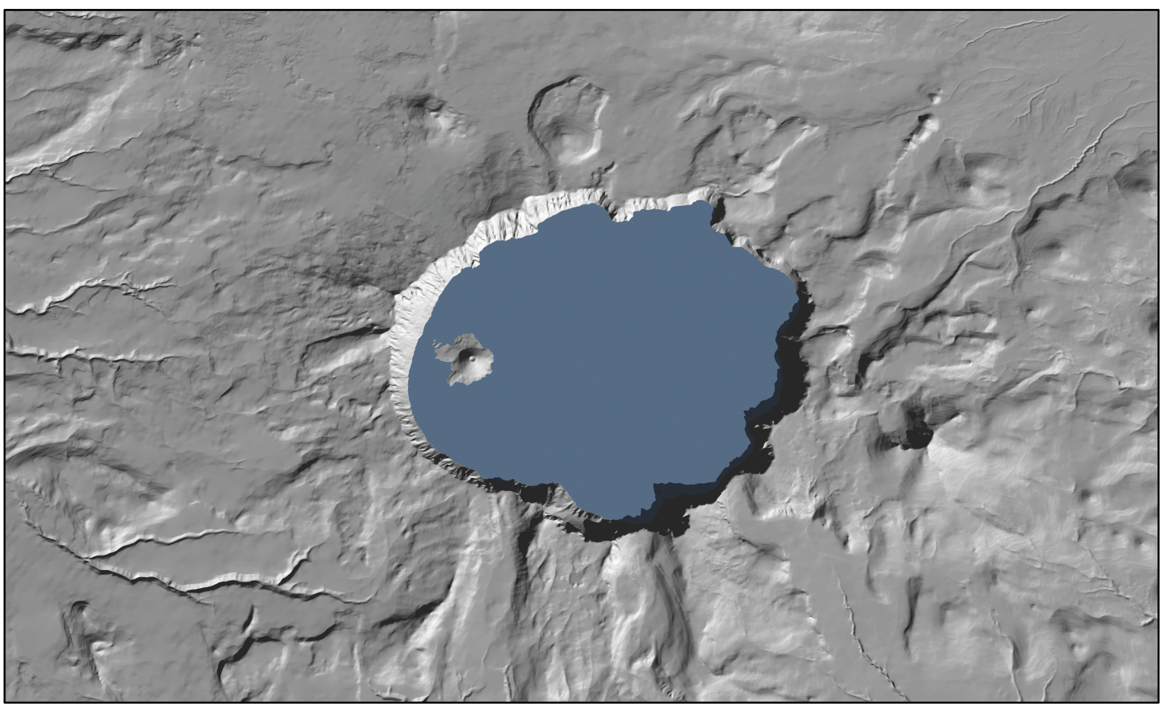


Figure 5. (Top) 3D scene of Crater Lake, Oregon, showing too shallow of a camera angle (10-degree pitch). (Bottom) 3D scene showing too steep of an angle (70-degree pitch).

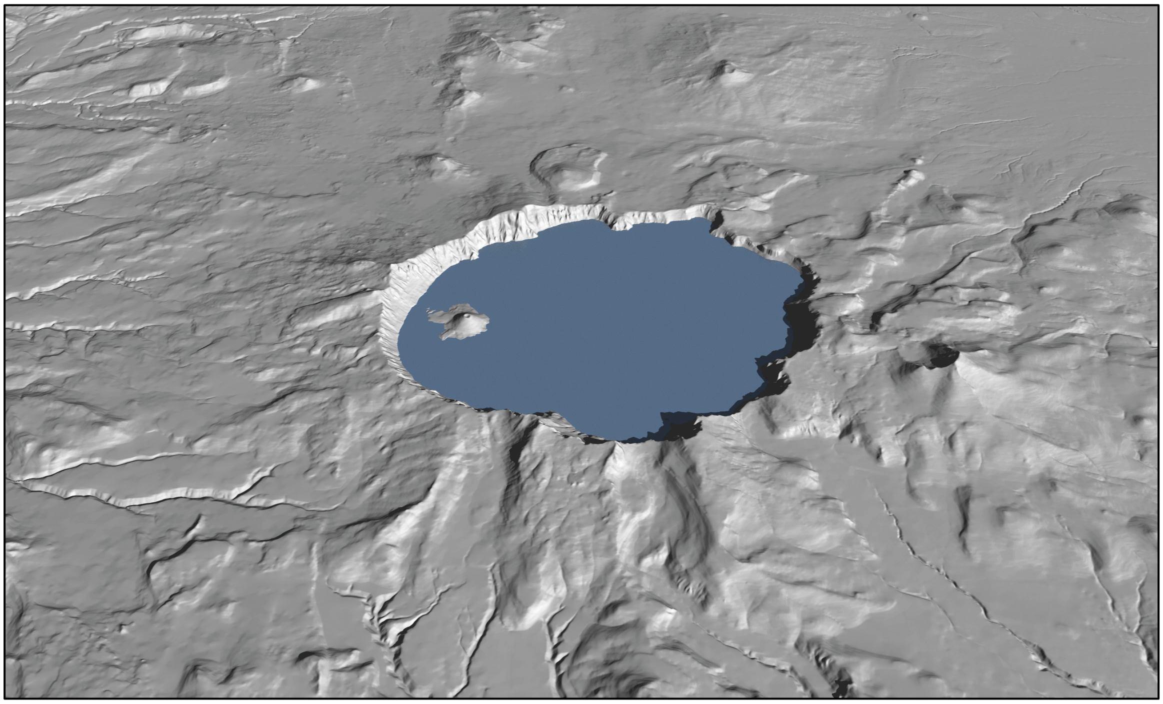


Figure 6. Example of ideal camera placement for maximizing 3D effect without obscuring important features (40-degree pitch).

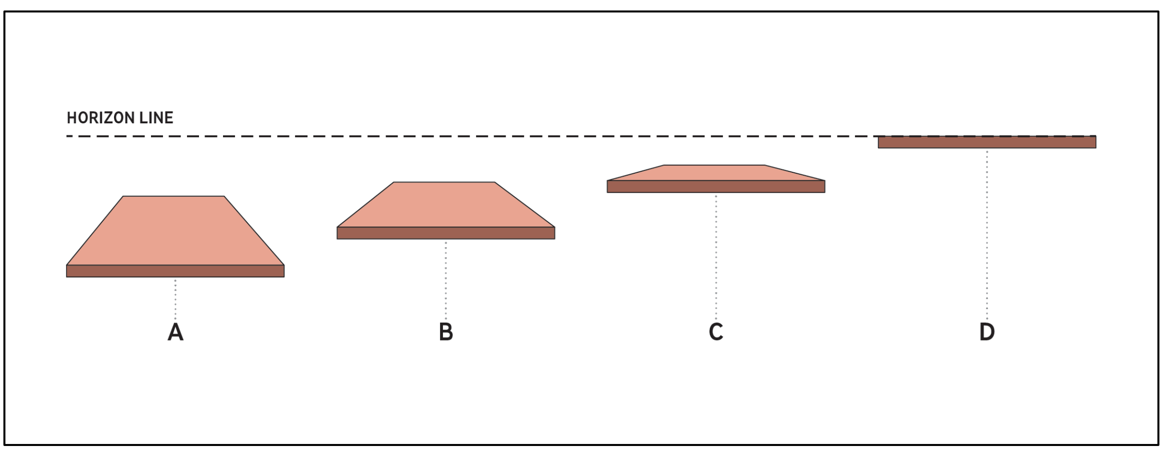


Figure 7. The foreshortening effect shown on a flat plane. (A) shows the least amount of foreshortening and (C) shows the most dramatic amount of foreshortening, as the viewing position moves closer to the horizon line.

Survey Design and Rationale

The survey included both map preference questions and those intended to measure each map's performance for different tasks. The survey also gathered information on participant demographics, map-reading ability, familiarity with the local tsunami hazard, association with the community of Seaside, and preparedness for a local tsunami event. The purpose of determining map preference and performance was to evaluate the study's hypotheses and cross-reference the results to understand better how participant preference for a particular map style correlated with each map's performance in communicating tsunami evacuation information. In other words, this study was interested in gauging public interest in 3D map displays, and if any of the perceived benefits of using 3D tsunami evacuation maps corresponded with how they performed. Likewise, the purpose of gathering survey population information was to determine any possible correlations or trends between participant characteristics and survey responses or to provide better insight into why certain outcomes occurred potentially.

The survey had a total of 26 questions, with 11 of the questions requiring the use of one or more of the test maps. These questions were separated into four parts that correlate with the study's hypotheses: (1) association with the local community, and knowledge of the tsunami hazard and map-reading (appendix, Figures 19-20); (2) map-reading tasks for performance testing (appendix, Figure 21-22); (3) impressions of the maps (appendix, Figures 22); and (4) map preference and demographics (appendix, Figures 23-24). Part one and the final section of the survey did not have a direct

connection to the study’s hypotheses but were intended to define the characteristics of the survey population. However, the answers to part two of the survey (i.e. questions 2.1-2.3) were used to evaluate two hypotheses: (H1) overall, map users prefer 3D tsunami evacuation maps to 2D maps, and (H2) map users more accurately interpret position and relative elevation change on 3D maps over 2D maps. Part three and the beginning of part four of the survey (i.e. questions 2.4, 4.1-4.3) were used to evaluate the last two hypotheses: (H3) map users more accurately interpret pedestrian travel times on 3D maps, represented using choropleth symbology, and (H4) map users prefer the use of pedestrian travel times on 3D maps, represented using choropleth symbology.

The final survey design was estimated to take approximately fifteen minutes to complete based on a pilot survey given to ten consenting participants at Humboldt State University. Each section was ordered based on the importance of the collected answers for completing the study’s analysis to reduce the potential effects of fatigue during the final survey, or the chance of questions not being answered. Also, each question was ordered based on any dependencies on other questions or map-reading tasks. The final survey was administered along the city’s Promenade, at the Seaside Public Library, and in the Safeway parking lot during a local craft event (see Figure 8).

For part one, participants were asked if they were a resident of Seaside, working in the city, or visiting, and if they were a resident, for how long have they resided. The second and third questions in this section asked how well participants believed they understood the local tsunami hazard, and if they believed they were currently standing in a tsunami hazard zone. These questions were used to determine the likeliness of

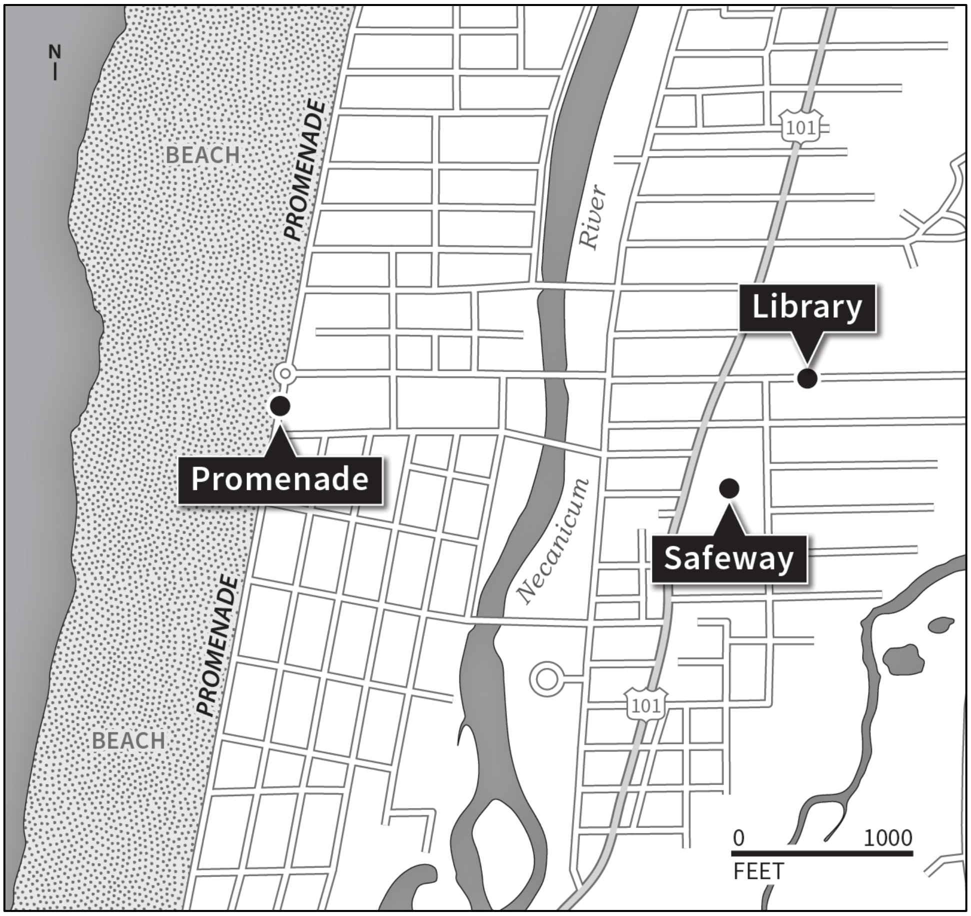


Figure 8. Map showing survey locations in Seaside, Oregon.

participant knowledge of the local geography and examine their confidence in understanding the local tsunami threat. The next question was used to determine the actions participants have taken to understand the tsunami threat and prepare for an occurrence, by asking a series of “Yes” or “No” questions separated by participant association with the area (i.e. residing or visiting). For example, this included asking participants whether they have read a local tsunami map and if participating residents are familiar with the local tsunami evacuation plan. The final question of this section asked

participants to determine which points were higher in elevation on two given maps: a map with only contours and another with only shaded relief. The purpose of this part of the survey was to gauge prior participant map-reading knowledge for comparison with the survey's other map-reading related questions and tasks.

Part two used a between-subject design, where each participant was only shown one randomly assigned map. This design was chosen to help eliminate bias and decrease the amount of time required to complete the survey. This section also included a confidence assessment after each question, asking participants to mark along a Likert scale, the level of certainty for each answer. This task helped judge whether the correct answers were made with confidence or guesswork. Moreover, the questions in this section were used to examine the performance of the 2D and static 3D maps, requiring participants to read one of the four test maps and make a series of determinations for relative elevation, current location, safe zone location, evacuation time estimation, and pedestrian travel speed estimation. The first question asked participants to locate which point was higher within three pairs of points. The purpose of this question was to examine the performance of 2D and 3D maps when trying to determine relative elevation differences. The next two questions had participants mark where they believed they were currently standing on the test map, and where they thought the tsunami safe zone was located. These questions were used to examine the performance of 2D and static 3D maps when trying to self-locate and find safety, which is both necessary tasks when using an evacuation map. The final two questions required informed estimates to be made for pedestrian travel time and speed. Participants were asked to use the map's symbology and

corresponding legends to estimate the amount of time from given locations to safe zones, and choose, given a set of qualitative choices, the speed at which a person would have to travel at to reach safety (e.g. walking, jogging, or running). The purpose of these questions was to examine the performance of choropleth symbology and point markers in representing time to safety on 2D and static 3D maps.

The third part of the survey asked participants about their impressions of the maps, and how well they represented tsunami evacuation information. The first question required a written answer, as it asked participants whether the map changed their opinion of the local tsunami hazard, and why or why not. The subsequent three questions required "Yes" or "No" responses, asking participants if the map helped them understand where to evacuate, better recognize the amount of time needed to evacuate, and if the map gave adequate information for evacuating. The final question asked participants to explain what they would like to see on the map if they believed the map did not give sufficient information. This section of the survey was a post-treatment given after the participants were no longer viewing a map, utilizing participant opinions to examine how well participants received the maps, and gauge each map's perceived utility for helping people evacuate on foot.

For the fourth part, the survey used a within-subject design, where participants were shown all four test maps and were asked to complete five questions to determine their overall map preference and their map preferences for specific tasks. Each task-specific question required a selection of the best and worst map for the given task. The questions asked participants to choose a map for understanding terrain, interpreting travel

time to safety, and judging position. The final question asked what map was preferred, overall, and why the map was chosen. The purpose of this section was to examine which maps the participants believed performed best, or which maps were chosen for other non-performance-based reasons. This section was followed by a series of demographic questions, asking participants their gender, age, and educational attainment. The purpose of these questions was to understand better the survey population, which were placed at the end of the survey because the answers were not pertinent to the study's analysis and could be left blank if necessary.

Statistical Analysis

To analyze the survey responses, all answers from each part of the survey were collected and categorized in a spreadsheet by the type of map used and their corresponding question. Questions with responses that appeared to favor a specific outcome overwhelmingly or were not in the map-reading or map preference sections were filtered by similar response and assigned a percentage score based on the number of like answers out of the total number of responses per question. Comparisons were then made between scores for each question.

Two sections of the survey elicited answers that were used to test the study's hypotheses, which did not result in a comparative analysis but were statistically examined. The answers to survey questions 4.1-4.4 (appendix, Figure 18) were used to test the first hypothesis or, overall, map users prefer static 3D tsunami evacuation maps to 2D maps. The answers to survey questions 2.1-2.3 (appendix, Figure 16) were used to

test the second hypothesis or, map users more accurately interpret position and relative elevation change on static 3D maps over 2D maps. The answers to survey questions 2.4 and 2.5 (appendix, Figure 16-17) were used to test the third hypothesis or, map users more accurately interpret pedestrian travel times on static 3D maps, represented using choropleth symbology. Lastly, the answers to survey questions 4.2 and 4.4 (appendix, Figure 18) were used to test the fourth hypothesis or, map users prefer the use of pedestrian travel times on static 3D maps, represented using choropleth symbology.

The between-subject section of the survey or the section that involved map-reading tasks and the first part of the within-subject section (i.e. map type preferred for completing map-reading tasks) used either the Mann-Whitney U-Test or the Two-Sample T-Test to determine the significant difference between responses. A single test was unable to be used throughout the study given differences in the distribution of each set of responses, and the required assumptions for each statistical test. The Mann-Whitney U-Test is powerful in examining independent groups with an ordinal dependent variable but requires that each set of observations are not normally distributed (Corder and Foreman 2014; MacFarland et al. 2016). On the other hand, the Two-Sample T-Test is effective for testing for significant difference between two independent sets of observations that are normally distributed (Welkowitz 2012). To determine which test should be used for each set of responses, summary statistics were calculated in Microsoft Excel, and the kurtosis and skewness values were used to indicate whether the data was normally distributed. If these values were between -2 and +2 and/or if the mean and median values were similar, then the data were considered normally distributed (George and Mallery 2010).

In this study, two groups were viewing different map types (i.e. 2D or static 3D), and the answers to the map performance questions within part two of the survey were able to be ranked based on a calculated (i.e. the summation of correct answers) and assigned ordinal value. Likewise, in the first part of the map preference section participants viewed all four maps, but chose two maps for each category (i.e. the best and worst map), creating paired choices that were designated a ranked value. Given the ordinal characteristics of the collected data, the use of separate test groups, and the independence of observation between groups, the Mann-Whitney U-Test was applied for each set of responses that were not normally distributed using Minitab statistics software. The result of this test produced a p-value (a value between 0-1), which is the probability of sampled data supporting that the null hypothesis is true (MacFarland et al. 2016). High p-values, or those greater than 0.05 if a 95% confidence interval is used, indicate a failure to reject the null hypothesis, and low values (less than or equal to 0.05) indicate acceptance of the null hypothesis (MacFarland et al. 2016).

The use of a 95% confidence interval (i.e. 0.05 p-value) is an individually set probability threshold (i.e. different values can be used such as 0.01), where a p-value of 0.05 means that if a null hypothesis or evaluated claim is true then there is the likelihood that the same result could be expected at least 5% of time. In this case, if there is only a 5% chance of getting a particular result for an assumed claim, then it is fair to suggest that the claim is false. Therefore, this study used a 95% confidence interval for all tests, considering this value to be a strong enough threshold to assert significant difference and either accept or reject the null hypotheses. Furthermore, MacFarland et al. (2016)

explained that a two-tailed Mann-Whitney U-Test with a 95% confidence interval (i.e. p-value of 0.05) is ideal in limiting the chance of bias towards an effect in one direction. For example, this version of the test allowed for the possibility to indicate a difference in performance between map types in either direction. In other words, the two-tailed test indicated if the 3D maps performed better or worse than the 2D maps, opposed to only being able to tell if they performed better.

The Two-Sample T-Test was applied in Microsoft Excel for each set of responses that were normally distributed. The survey data in this study met the major assumptions of this test, including that there were two independent sets of unpaired responses, that the data were normally distributed, and that there was the same number of responses in each population to create equal variance (Welkowitz 2012). Similar to the version of the Mann-Whitney U-Test used in this study, this test shared the same probability threshold, was two-tailed, and presented test results using a p-value, where the null hypothesis is rejected if the p-value is less than or equal to the significance level.

RESULTS

Survey Population: Demographics

Surveying yielded 84 participants, with 40 (49%) men, 41 (51%) women, and 3 participants declining to answer the question. Most of the participants were 51 years and older, with only 35% of the population between the ages of 21 and 50 (see Table 1). Out of the total population, 13% were full-time residents, 5% were seasonal residents, and 82% participants were visiting. Over 75% of the survey population had either completed a college degree or had attended college at some point (see Table 1). There were no significant differences or correlations found between any demographic group for the map reading tasks or map preference questions.

Table 1. Participant age range and highest educational attainment.

Age	**Number**	**Education**	**Number**
18-20	0 (0%)	Some school	0 (0%)
21-30	9 (11%)	High school / GED	4 (5%)
31-40	12 (15%)	Some college	12 (15%)
41-50	7 (9%)	College certificate	9 (11%)
51-60	23 (29%)	Undergraduate degree	27 (34%)
61 and older	29 (36%)	Graduate degree	27 (34%)
Declined to answer	4 (0%)	Declined to answer	5 (0%)

Survey Population: Knowledge of the Local Tsunami Hazard

Besides gathering demographics, the survey asked participants about their knowledge of the local tsunami hazard, including how well they believed they understood the hazard based on a set of Likert scale choices. There were 83 (n=83) usable responses for this question, with most participants, or 64% responding that they understood the tsunami hazard “well” or “moderately,” 22% responding that they understood the hazard “very well,” and 14% responding that they “minimally” understood the hazard. This section also asked participants whether they believed they were currently standing in a tsunami hazard zone. There were 84 (n=84) usable responses, with 89% marking “yes” among all survey locations, 7% marking “no,” and 4% were “not sure.” Lastly, this survey attempted to determine the actions participants have taken to understand the tsunami threat and prepare for an occurrence, by asking a series of “Yes” or “No” questions separated by participant association with the area. Since most participants were visiting, the answers to this question were dropped, as there were too few. However, the question asking whether participants had read a local tsunami map was posed to visitors and residents and had a full response rate. This question had 84 (n=84) usable responses, with 43% marking “yes,” 57% marking “no,” and out of the 13% that were full-time residents, only one participant had not read a local tsunami evacuation map. Based on these responses, there were no correlations found between participant knowledge of the city, the local tsunami hazard, and the map reading tasks (see Figure 9).

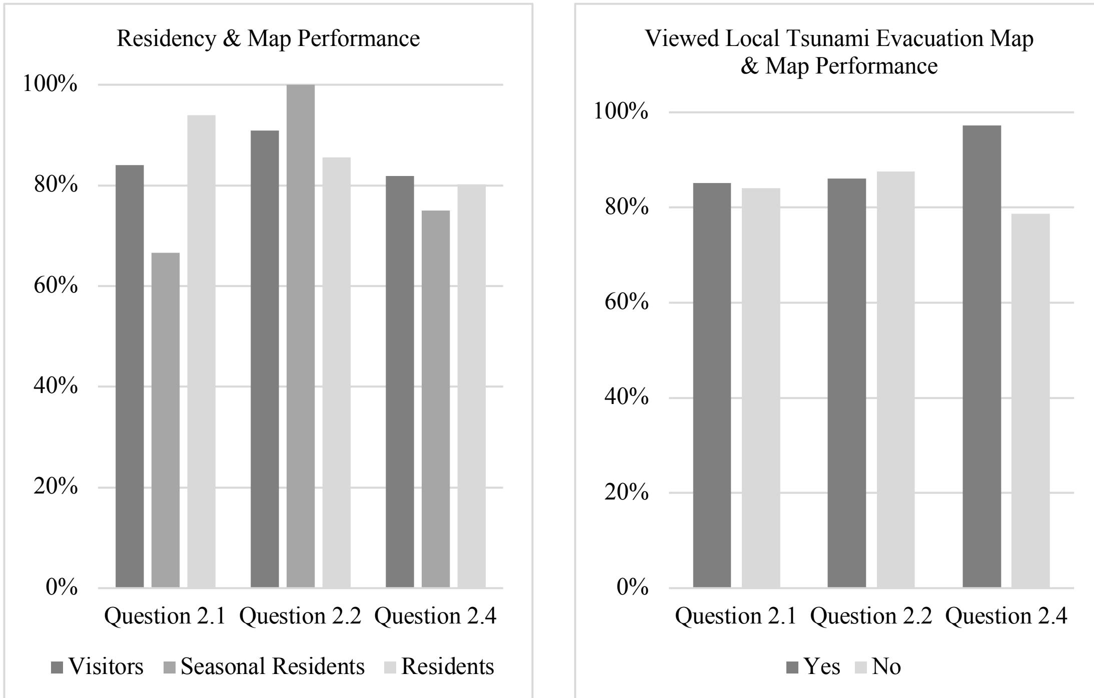


Figure 9. (Left) The percentage of correct responses for each map-reading task separated by type of residency. (Right) The percentage of correct responses for each map-reading task separated by whether or not participants viewed a local tsunami map.

Hypothesis 1 and Hypothesis 4: 2D vs. Static 3D Map Preference

The fourth section of the survey asked participants to view all four maps and choose the maps they thought were best and worst for completing all map-reading tasks, including judging terrain, locating their current position, and interpreting travel time to safety. There was a variable number of dropped responses for each question, as participants either left the question blank or gave an inappropriate answer. In total there were 81 (n=81) usable responses for the terrain interpretation question, and 77 (n=77) usable responses for the travel time and position determination questions, which were sorted by task and then assigned ordinal values depending on the map chosen. Maps

voted best were assigned a 1, those voted worst were given a -1, and the remaining maps were assigned a 0. Total votes were calculated for each map type to determine which map was voted the best and worst in each category (see table 2). To then examine which map pairs indicated a significant difference in participant preference for each task, the Mann-Whitney U-Test was used. A quick examination of the data showed overwhelmingly that 3D maps were preferred over 2D maps for judging terrain; however, a statistical examination was still completed to remain consistent in analyzing this part of the survey. Therefore, combined scores showed a preference for static 3D maps when judging terrain with a p-value of .00001, while there was no significant difference in preference for self-locating with a p-value of 0.65 (see Figure 10). There was also no significant difference between 2D and static 3D maps using either type of symbology for judging travel time to safety, with a p-value of 0.76 between the 3D map with choropleth symbology and the 2D map with point markers, and a p-value of 0.30 between the same 3D map and the 2D map with choropleth symbology (see Figure 10).

The second question in the map preference section asked participants to select the map that they preferred best, overall. There were 78 (n=78) usable responses, which were sorted by the map chosen (i.e. choosing between maps 1 through 4), and given a percentage score based on the number of times each map was selected. Participants overwhelmingly preferred static 3D maps over 2D maps, or 66% chose one of the two 3D maps. Between the two static 3D maps, which either displayed pedestrian travel time to safety information using choropleth symbology or point markers, participants most preferred the static 3D map displaying choropleth style symbology (see Table 3).

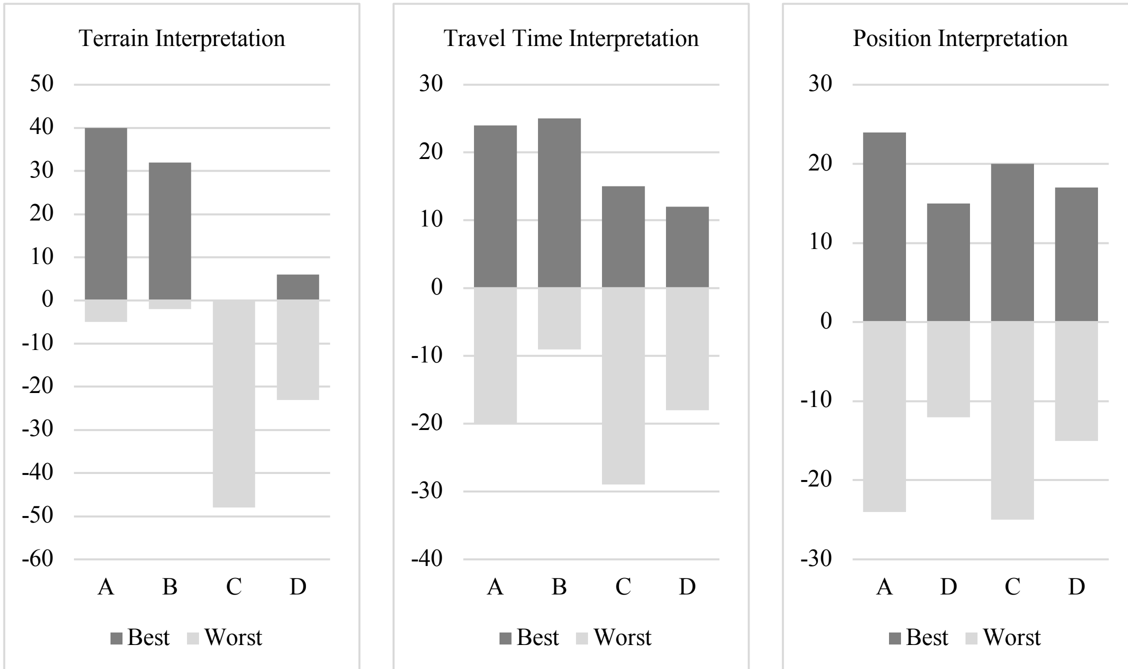


Figure 10. Best and worst votes by map for all mapping-reading tasks. (A) 3D choropleth map, (B) 3D point marker map, (C) 2D choropleth map, and (D) 2D point marker map.

Table 2. Participant preference vote totals for all test maps. The highlighted values indicate the best result for each category.

Maps	**Terrain** Best	**Terrain** Worst	**Time** Best	**Time** Worst	**Position** Best	**Position** Worst
3D Choropleth	40	5	24	20	24	24
3D Markers	32	2	25	9	15	12
2D Choropleth	6	23	12	18	17	15
2D Markers	0	48	15	19	20	25

Table 3. Map preference results for 2D vs. static 3D comparison by percentage.

Maps	Selections (n)	Percentage	Net Percentage
3D map 1	30	38%	3D maps (66%)
3D map 2	22	28%	-
2D map 3	11	14%	2D maps (34%)
2D map 4	15	19%	-

The survey also asked participants why they preferred the map they chose for all map-reading tasks. Most participants who selected a static 3D map said that the 3D terrain was more clearly depicted. For example, it was stated that the static 3D maps were "easier to read," or "easier to interpret." Only two participants mentioned that the 3D terrain was more difficult to read, noting that "3D is confusing," or that the 2D makes it "easy to see current location and hazard areas." Regarding pedestrian travel time representation, the most common response for those who used a map with choropleth symbology was that the color-coding more clearly depicted the zones. Two participants commented that the "colors are easier to read," or simply that they "like color-coded zones." Those who selected a map with point markers found this type of representation to be helpful, as a few participants appreciated not having to refer to a legend. Furthermore, multiple participants suggested combining both choropleth symbology and point markers, with one of the comments noting to "combine both symbol concepts."

Hypothesis 2: Terrain and Location Interpretation on 2D and Static 3D Maps

The second part of the survey asked participants to answer a series of questions related to judging elevation differences and determining their current location on 2D and 3D maps. For the section of the survey dealing with elevation comparison, participants were given three pairs of points and were asked to choose which point in each pair was higher in elevation. The answers were collected into a single score between 0 and 3, where 0 meant they did not get any of the questions correct, and 3 indicated they answered all the questions correctly. There were 84 (n=84) usable responses, with 42 appropriate answers for each group of participants who used either 2D or 3D maps. The scores were not normally distributed, so a two-tailed Mann-Whitney U-Test was used to test for a significant difference. The test indicated that participants who used the static 3D maps scored higher with a p-value of 0.025 (see Figure 11).

The terrain interpretation part of the survey was proceeded by an initial pre-treatment question to determine participant knowledge and ability to read terrain on maps using either contours or shaded relief (appendix, Figure 20). Similarly, this task had participants identifying which point was at a higher elevation between pairs of points for both maps. The answers to these questions were collected and categorized by map. Overall, participants were able to correctly identify which point was at a higher elevation for each set of points for each map. The results of the pre-treatment did not show any relationship between a participant’s general ability to read terrain on maps and their judgment of elevation differences on the test maps.

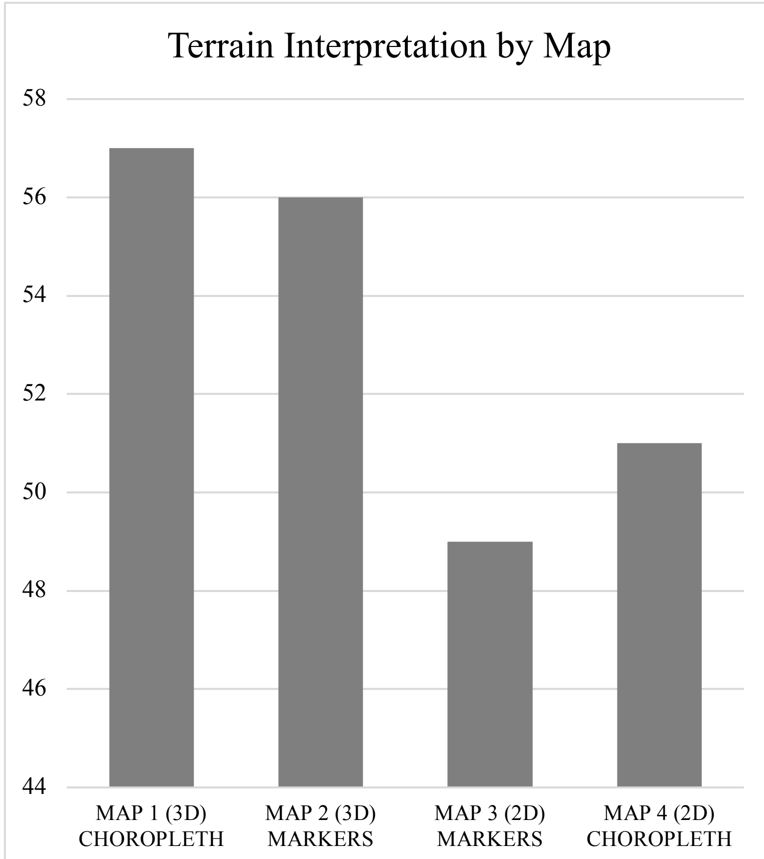


Figure 11. The number of correct responses for judging terrain by map.

The next part of the survey asked participants to locate their current position on the map (i.e. self-locate) and indicate where on the map they would be outside the tsunami hazard zone (i.e. the location of the safe zone). If a participant correctly located their position within a one block radius, their answer was assigned a 1, and if they chose a location outside the same range, or if they answered incorrectly, their response was assigned a 0. A similar strategy was applied to the question asking participants to indicate any location outside the tsunami hazard zone, where answers that correctly identified safe

zones where assigned a 1, and incorrect answers were given a 0. There were 84 (n=84) usable responses for both questions, with 42 appropriate answers for each group of participants who used either 2D or static 3D maps. The scores for the question asking participants to self-locate were not normally distributed, so a two-tailed Mann-Whitney U-Test was used to test for a significant difference. The results of the test showed a p-value of 0.57, indicating that there was no significant difference between 2D and 3D maps when locating a current position for all three survey locations. For the second question that asked participants to indicate any location outside the tsunami hazard zone, all participants (n=42) who viewed the 2D maps answered the question correctly. For those who viewed the static 3D maps, all but one participant responded to the question correctly, or 98% of the participants were able to locate the safe zone (see Table 4).

Table 4. Results shown as percentages for locating position and safe zones.

Categories & Map Type	**Number (n)**	**Number Correct**	**Percentage**
Locating current position			
3D maps	42	36	86%
2D maps	42	38	90%
Locating safe zones			
3D maps	42	41	98%
2D maps	42	42	100%

Hypothesis 3: Interpretation of Pedestrian Travel Times on 2D and Static 3D Maps

The final map-reading section of the survey asking asked participants to estimate the amount of time it would take to get from four selected locations on the map, to an area outside the tsunami flooding zone using one of the four test maps. Participants were given either a 2D map with evacuation travel times represented using choropleth symbology or point markers or a static 3D map using the same two types of travel time representation. The answers were collected into a single score between 0 and 4, where 0 meant they did not get any of the questions correct, and 4 meant they answered all the questions correctly. The scores were then placed into two categories: scores taken from the maps using choropleth symbology, and those from maps using point markers. There were 84 (n=84) usable responses, with 42 appropriate answers for each group of participants who viewed a map with either type of travel time representation. The scores were normally distributed, so a Two-Sample T-Test was used to test for a difference. The test showed a p-value of 0.72, indicating that there was not a significant difference between the two types of travel time representation. The test was repeated, but with scores separated by map perspective (i.e. 2D or static 3D). The results of this test showed no significant difference, with a p-value of 0.60. Lastly, the scores for the static 3D map using choropleth symbology were compared to those of the 2D map using point markers, and the results indicated no significant difference, with a p-value of 0.90. Figure 12 shows the results by the number of correct responses by map or the type of symbology.

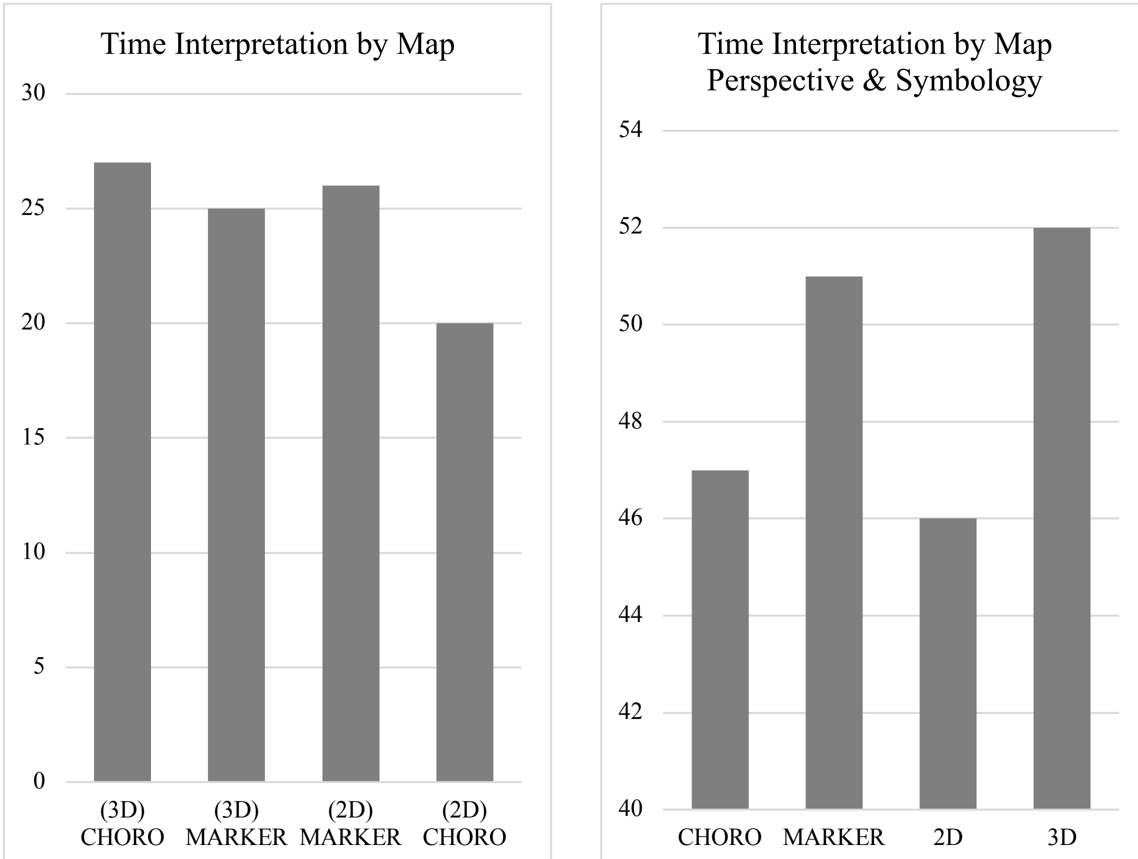


Figure 12. (Left) The number of correct responses by map type. (Right) The number of correct responses by map perspective and symbology.

DISCUSSION

Uncertainty: Maps and Survey Methods

Maps can be viewed as graphical representations of reality, and inherently produce particular types of uncertainty, which mainly derive from cartography's use of generalization, scale, projection, and symbolization (Monmonier 2006). This study produced four test maps that involved the symbolization of tsunami hazard zones,

pedestrian travel time to safety information, and other physical and anthropomorphic elements, all of which were produced to be displayed at certain scales and were, in some cases, generalized to be included on maps for public use. Therefore, it is important to note that all four test maps do not directly translate the relative size, shape, or precise extent of any map feature, but accurately describe each feature's idealized characteristics, as well as show their accurate location given the scale and projection of each map, and the accuracy and precision of the methods used to create each dataset. As new tsunami models are developed and potential changes occur among the other information included on the test maps, new maps will need to be developed to reduce uncertainty between changes on the ground (i.e. reality) and what the maps display.

There was also some uncertainty within in the methods used to conduct the survey for this study, given that the sample collected was random with no guarantee that a demographically variable population would be assessed given the overall characteristics of the total population. This study intended to limit this potential issue by choosing three different survey locations that could capture a more variable set of participants such as those visiting, seasonal residents, and full-time residents, with demographic variation within these three groups. However, most of the participants in this study were visitors to Seaside, and over half were 51 years and older. Although there were no discernable trends found between any demographic group and the performance and preference between any of the maps, it is possible that gathering a larger pool of participants from more locations could have had a different impact on the outcome of the survey. This potential effect may have been most notable among those in the community that would

have difficulty evacuating during a tsunami event, such as the elderly, those within dependent care, and others with limited mobility. Gathering a larger pool of participants that included those from groups with variable ability to evacuate could have elicited different results, especially concerning map preference and participant feedback.

Hypothesis 1: Do people prefer static 3D tsunami evacuation maps to 2D maps?

The results of this study showed strong evidence that static 3D maps are preferred to 2D maps, especially when judging relative elevation change (see Figures 13-14). This outcome was overwhelming apparent, considering that over half of the participants chose one of the two static 3D maps, and approximately 15% of the participants who used a 2D map during the survey preferred one of the 3D maps, overall. This finding was consistent with research conducted by Preppernau and Jenny (2015), where participants preferred 3D volcanic hazard maps to conventional 2D contour maps. Conversely, greater preference was shown for static 3D maps in this study than in research conducted by Schobesberger and Patterson (2007) and Petrovič and Mašera (2005). This result may have been due to differences in map and questionnaire design, as well as the context that the maps were viewed. Furthermore, in comparison to Petrovič and Mašera (2005), the participants in this study were the public, and not experts in geospatial science or a related field, which may have been a factor in the participant's map display choice.

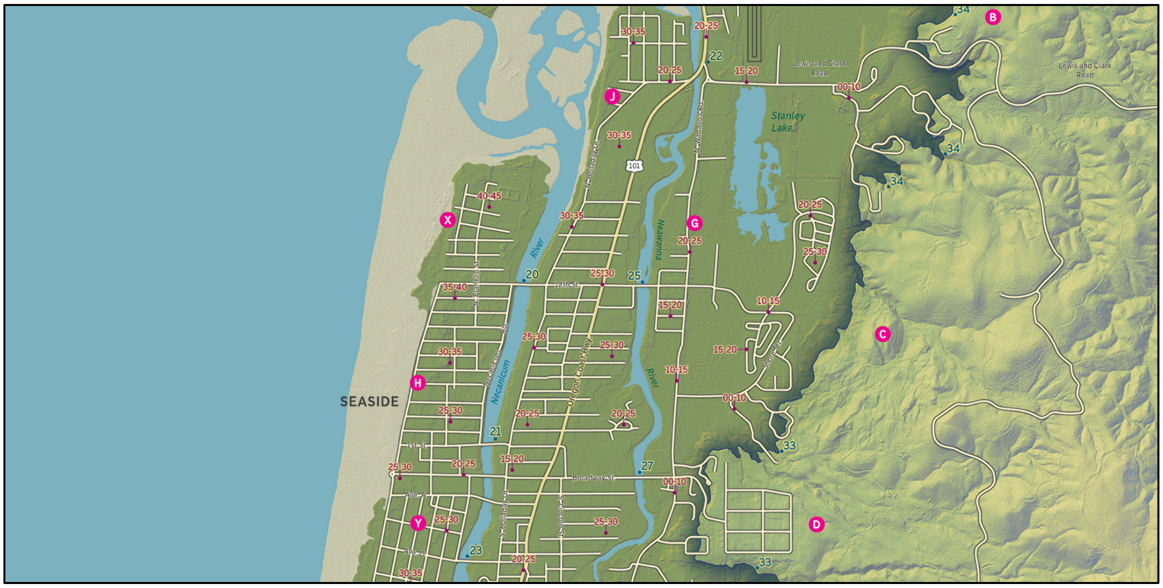


Figure 13. Example of relative elevation change, or the visual change in landform height on one of the 2D test maps.

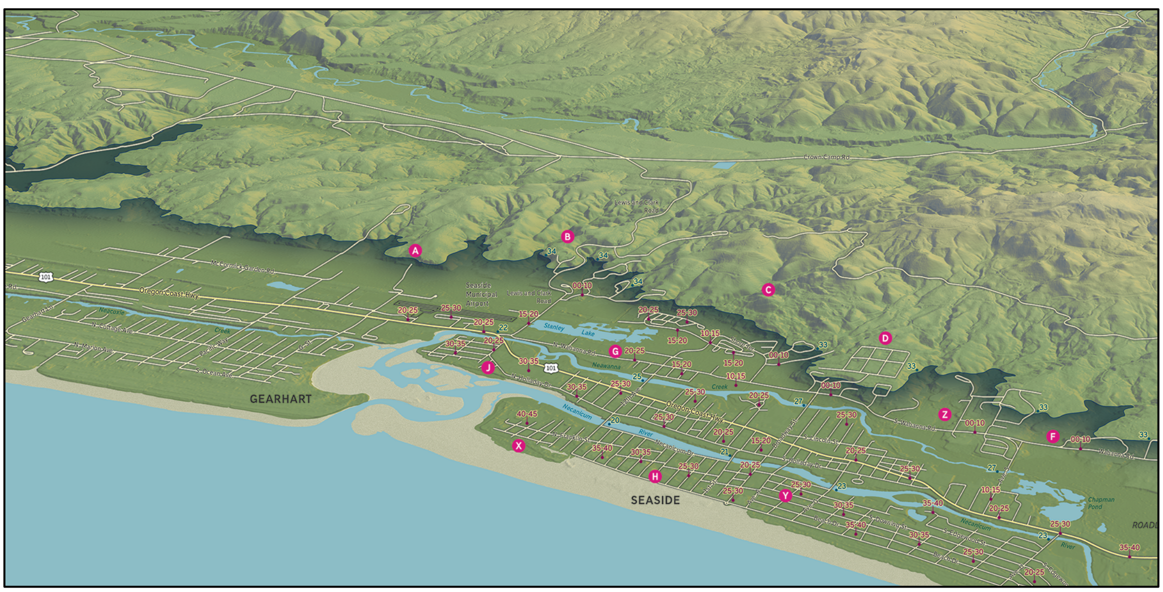


Figure 14. Example of relative elevation change, or the visual change in landform height on one of the static 3D test maps.

Hypothesis 2: Do people better interpret elevation change and more easily find their current position on static 3D maps?

The results of this study showed evidence that people better interpret elevation change on static 3D maps, suggesting that 3D terrain is more intuitively understood when compared to 2D maps for hazard mapping (see Figures 13-14 above). It is important to note that in part one of the survey, participants were asked to judge points of higher and lower elevation on two topographic maps to gauge their proficiency in map-reading. It appeared that any prior topographic map-reading experience or knowledge did not affect the results. This finding was consistent with research conducted by Preppernau and Jenny (2015). However, it is essential to consider that their 2D test maps used contours, which were an additional elevation metric not used on the maps in this study. Although the overall results were similar, this difference in map design should be noted if comparing the results of their research and those presented here.

Regarding self-location, this study showed no difference between 2D and static 3D maps, where over 85% of participants were able to find their current location between 2D and 3D maps (see Table 3 above). This result is consistent with research conducted by Preppernau and Jenny (2015) and Haynes et al. (2007), who found that most people use road features and topographic details to navigate. It was evident in this study that most participants used major land and water features, and road intersections to find their location on the maps. For those who took the survey along the Promenade, the beach was a major geographic cue to their location. However, it took markedly longer for those who

completed the survey at the other two more inland locations to self-locate. It is also important to note that the test maps showed labels for major roads and water features, which appeared to help many participants find their bearing. Labels were not included on the maps used in the Hayes et al. (2007) study, with the intention for participants to navigate using various physical and anthropomorphic features on overlaid aerial imagery and simple contour maps. However, it is both practical, and the convention for tsunami evacuation maps to display labels, such as on the official tsunami evacuation map for Seaside, and so similar labeling was used on all the test maps in this study.

Hypothesis 3: Do people better interpret pedestrian travel times on static 3D maps using choropleth symbology Vs 2D maps using point markers?

This study found no evidence that participants better interpret pedestrian travel times on 3D maps using choropleth symbology versus 2D maps using point markers (appendix, Figures 15 and 17), suggesting that both representation methods perform similarly in communicating time to safety. Likewise, it appears that 2D and static 3D map display types do not affect how people interpret travel time using either style of travel time representation. However, it is worth noting that some of the incorrect time estimates given by participants viewing maps with choropleth symbology, may have resulted from not using the legend, or misunderstanding the purpose of the legend. In this case, the point markers may have been easier to understand for novice map-readers since the travel times were located on the map. Even though it did not appear to influence the results, it is important to remember that point markers have an inherent limitation, which is that they

only show travel times at discrete points, and do not denote the boundaries between areas with equal or different times. It is recognized that this limitation could have been improved by the proximity of the point markers to the four test locations; although, an effort was made to randomly position the test locations without the influence of travel time indicators. Lastly, the answers to question 2.5 on the questionnaire were not analyzed, as there were too many inappropriate answers. However, this question did not significantly affect the results of this study and was only a supplement to question 2.4, examining how well participants understood the use of wave arrival markers placed throughout each test map.

In the post-treatment section, participants were asked their impressions of the maps, and whether the maps helped them understand the amount of time needed to evacuate on foot. Out of the 84 responses, 74% marked "yes," or believed that the map they viewed helped them understand the amount of time to evacuate, 15% marked "no," and 7% marked that they were "not sure." These responses indicated, at least nominally, that participants found including pedestrian travel times on tsunami hazard maps helpful.

Hypothesis 4: Do people prefer the use of pedestrian travel times on static 3D maps using choropleth symbology or point markers on 2D maps?

The results of this study showed no evidence that 3D maps using choropleth symbology are preferred over 2D maps with point markers (appendix, figure 15 and 17). Unlike the strong preference for static 3D maps in judging terrain, there was no significant difference found for preference between static 3D maps using choropleth

symbology versus point markers. Likewise, there was no relationship found for preference between 2D and static 3D maps when representing travel times using either method (i.e. choropleth symbology or point markers). Participants were mostly split on their preference for the methods used to denote travel times, which could have been the result of only spending time exploring one map during the map-reading task, and not wanting to take the time to investigate the other map types when completing the map preference section of the survey.

CONCLUSION

The objective of this study was to gather and analyze user feedback on the performance of, and preference for, 3D maps and travel time representation, in direct comparison to conventional 2D tsunami evacuation maps and their symbological elements. The study's objective was accomplished by testing a set of hypotheses using a questionnaire style survey and four maps developed specifically for user testing. The results of this study reasserted the findings found in past research supporting the use of static 3D maps over 2D maps for terrain mapping, and greater preference for static 3D maps over 2D maps, overall. Unlike terrain representation, static 3D maps do not appear to perform any better than 2D maps for helping people self-locate, as most use landmarks and roads to navigate regardless of the perspective view. There was also no evidence found showing that static 3D maps affect how people interpret travel time to safety differently than on 2D maps. These results indicate that, although static 3D maps may not

perform better than 2D maps for all map-reading tasks, they also did not perform worse. Therefore, given the improved performance of static 3D maps in helping people judge terrain, and the apparent preference for this perspective view, it is not suggested that static 3D perspective maps replace 2D maps, but develop static 3D maps as companions to 2D evacuation maps and other tsunami education materials. This study also suggests using static 3D tsunami evacuation maps within popular tourist locations in communities like Seaside, where large numbers of visitors who may be unaware of the local tsunami hazard and evacuation procedures, could be more inclined to examine a more visually compelling 3D map, hopefully increasing their understanding of what to do during a tsunami event.

Unlike some volcanic hazard maps, which show lahar travel times to indicate evacuation needs, travel times are not a standard inclusion on tsunami evacuation maps. However, the results of this study suggest that they may be worth using on both 2D and static 3D perspective maps and can be displayed using choropleth symbology and point markers. Although this study was not exhaustive in testing the performance of either type of travel time representation, participants did appear to understand the purpose of including pedestrian travel time to safety information and acknowledged that both methods for displaying travel times helped them determine the amount of time needed to evacuate, with the suggestion to display both symbological types. Including pedestrian travel times on tsunami evacuation maps may help show the quick tsunami onset in some cases, and highlight the difficulty some groups within communities have in evacuating (e.g. the elderly and those in dependent care). At the moment, most tsunami evacuation

scenarios, including the scenario used in this study, assume that evacuees are mobile enough to quickly evacuate on foot, but this is not always possible. Further research on the outcomes of using travel time representation for tsunami evacuation mapping could help refine their design, and possibly improve their interpretation, increase their usage, and focus more attention on people who would need assistance during any type of evacuation situation.

Future research on this topic would likely benefit from gathering a larger sample size in a location with fewer tourists, possibly during different times of the year. This survey was administered in the summer (mid-late July), during the high tourism season in Seaside, so most participants were visitors with presumably less interest in the local tsunami hazard than residents. Although this influence did not appear to affect the results, gathering a more diverse pool of participants may elicit different outcomes. The parts of the survey that required participants to self-locate on the map, and find a safe zone, did not allow for this survey to be given online. However, as previously suggested by this study and others (Preppernau and Jenny 2015), self-locating has been shown to have little or no relationship to a map's perspective view. Therefore, future map performance testing could be more extensively conducted online, with access to a significantly broader pool of participants, and more attention to participant profiles and map design variables, such as different 3D perspectives and interactivity.

The maps designed for this study were simplified to limit participant confusion and distraction, and homogenously stylized to create a fair evaluation. Unlike these simple maps, modern static 3D map design capabilities can help create complex products,

in many cases far more complex and expressive than the maps designed for this study. As noted by Schobesberger and Patterson (2007), detailed static 3D map design comes at a higher cost compared to most equivalent 2D maps and can take much more time to produce. Developing static 3D tsunami evacuation maps on a larger scale will require production to be streamlined, possibly using already existent open-source 3D applications, which could lower production costs and expand interest in 3D displays.

The Great Sumatra-Andaman tsunami of 2004, and the 2011 Tohoku tsunami are powerful reminders of how critical it is to understand what measures are effective in reducing the loss of life. Even though places, such as Japan, have some of the most prepared communities, tsunamis can still cause massive devastation and physical harm. The 2011 tsunami in Japan showed that even with the proper evacuation procedures in place, there are many unmanageable variables that affect how tsunamis impact communities, and how people can respond. This unpredictability becomes evident when considering the effects of climate change on sea level rise, as coastal areas are likely to become more at-risk with tsunamis pushing further inland and potentially causing smaller tsunamis to have larger adverse impacts. This may influence evacuation procedures to dramatically change, or eventually become a determinant of who can live within coastal tsunami zones. Likewise, it is worth recognizing that 65% of the survey population in this study were over the age of 50, and with aging coastal populations there is greater vulnerability, as evacuation plans do not always consider the amount of time needed for the elderly, those in dependent care, or any other segment of the population who are inhibited, to quickly move to higher-ground. Nevertheless, there has been marked success

in limiting the loss of life among communities implementing preparedness and hazard education strategies, which remain the primary objectives for agencies and community groups that oversee emergency planning (Dengler 2005). Thus, there is a continuing need for research on tsunami disaster mitigation strategies that include new avenues to communicate the hazard and inform the public about their vulnerability, while also helping decision makers better understand the relationships between the tsunami hazard, current mitigation strategies, and those within coastal communities most at-risk.

This study has shown evidence that 3D maps and pedestrian travel time representation are viable options for cartographically representing the tsunami hazard, and supports findings indicating the use of 3D maps in other natural hazard situations, such as in the volcanic hazard mapping scenarios described by Preppernau and Jenny (2015). It is recommended that cartographers and GIS professionals continue to improve and streamline methods for developing 3D maps, and for future research to continue investigating the effectiveness of 3D mapping methods and the symbological representation of tsunamis, further expanding on this study and others that seek to improve how maps communicate natural hazards to the public.

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APPENDICES

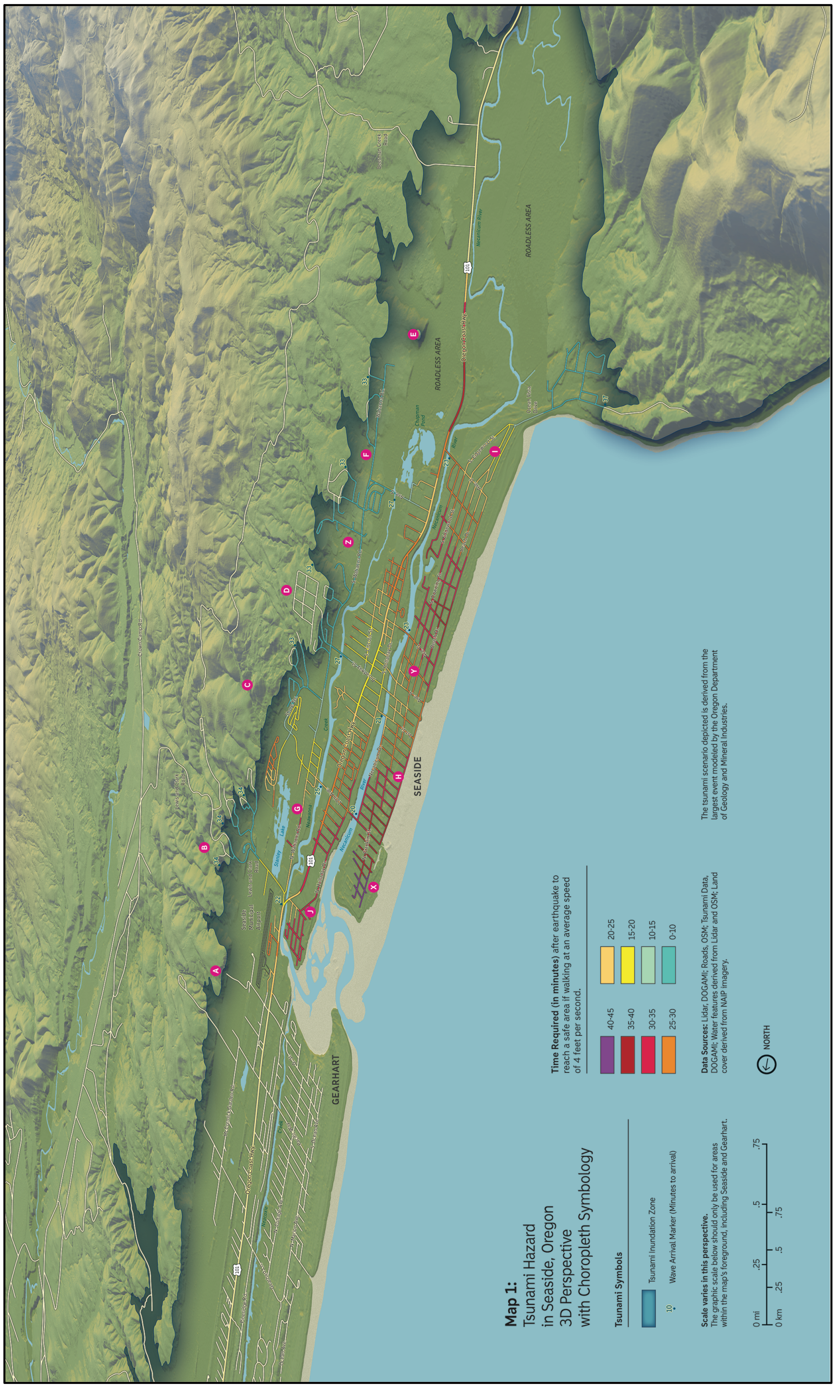


Figure 15. Survey Map 1 (3D).

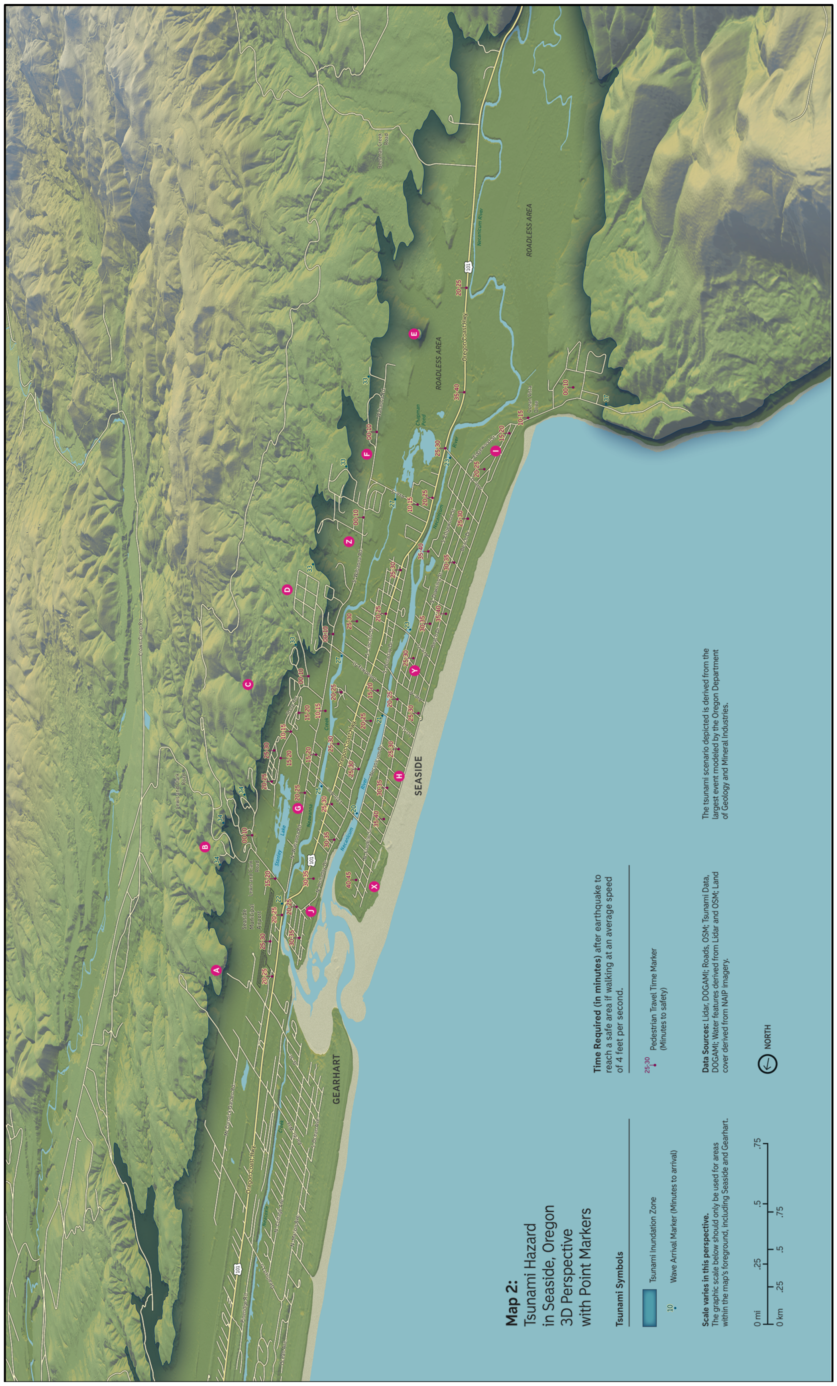


Figure 16. Survey Map 2 (3D).

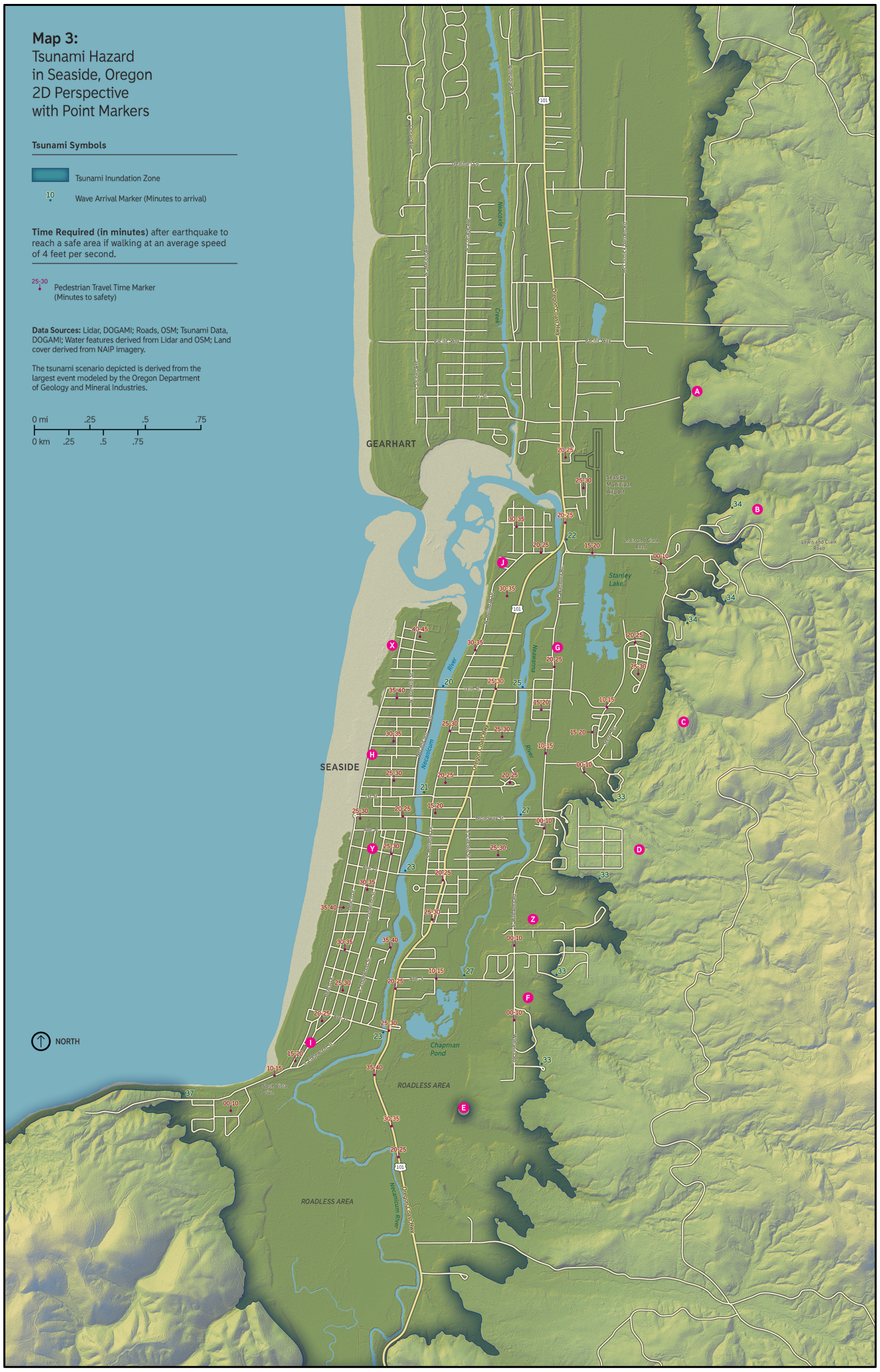


Figure 17. Survey Map 3 (2D).

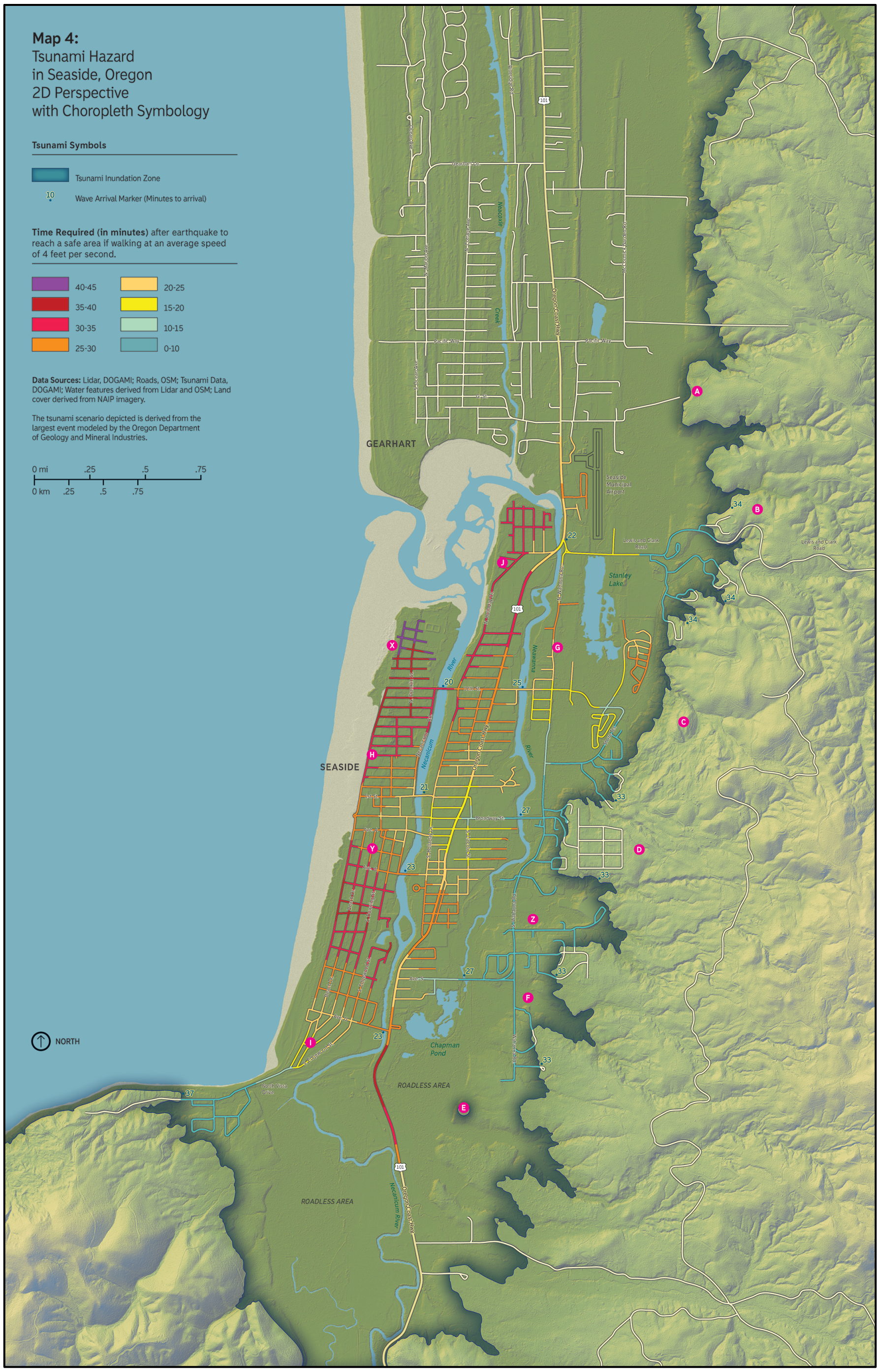


Figure 18. Survey Map 4 (2D).

Survey ID Number		Map Number	

This survey is not a test of your abilities, but is a test of how effective different map types are. Many of the following questions are intended to determine prior knowledge of some of the things that the maps show, which are needed to judge their effectiveness.

Part 1: Tsunami and map reading knowledge

1.1 Are you a resident of Seaside, a seasonal resident, just working in the community, or visiting?
" Working" refers to living outside Seaside, and commuting to the Seaside area.

☐ Full-time resident ☐ Seasonal resident ☐ Working ☐ Visiting

1.2 If you are living or working in Seaside, for how long?

☐ Less than a month ☐ 1-6 months ☐ 6 months–1 year ☐ 1 year –3 years
☐ 3–6 years ☐ 6 or more years

1.3 How well would you say you understand tsunamis and their potential hazards?
A tsunami is a set of waves that inundate a populated area, causing damage and potential injury.

☐ Minimally ☐ Moderately ☐ Well ☐ Very Well

1.4 Do you believe you are currently located in a tsunami hazard zone?

☐ Yes ☐ No ☐ I'm not sure

1.5 How prepared do you believe you are if a tsunami event occurred in Seaside?
Please answer the following questions by checking the appropriate box. If you are a resident, you only need to answer the first set of questions, and the second set if you are a non-resident.

<u>For full-time and seasonal residents</u>

Categories	Yes	No	Decline to Answer
Have a hazard emergency kit?	☐	☐	☐
Have a household emergency plan?	☐	☐	☐
Know the local evacuation plan?	☐	☐	☐
Know the local evacuation routes?	☐	☐	☐
Have read a local tsunami map?	☐	☐	☐

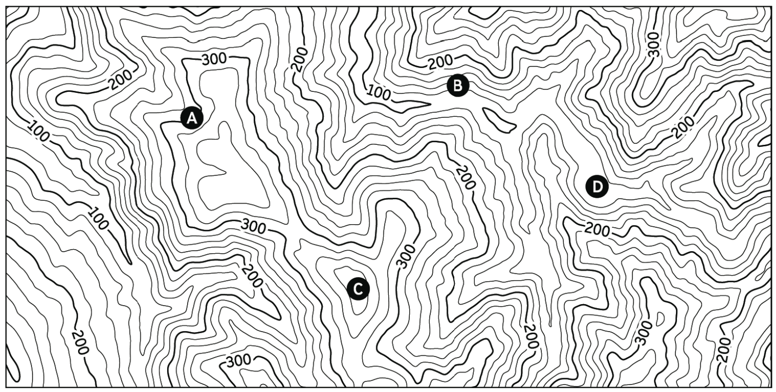
<u>For those working or visiting</u>

Categories	Yes	No	Decline to Answer
Know the local evacuation plan?	☐	☐	☐
Have read a local tsunami map?	☐	☐	☐

1

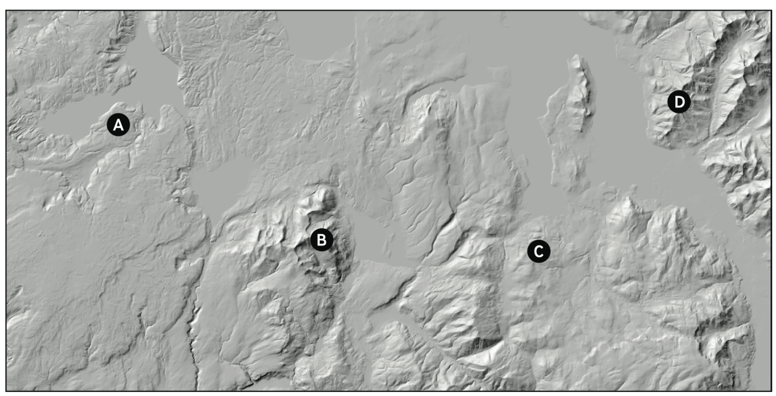
Figure 19. Administered Survey, page 1.

1.6 Below are two simple topographic maps with two sets of points, and below each map, are two questions asking which point in each pair of points is placed at a higher elevation.



Which point is at a higher elevation, **A** or **B**? ____________

Which point is at a higher elevation, **C** or **D**? ____________



Which point is at a higher elevation, **A** or **B**? ____________

Which point is at a higher elevation, **C** or **D**? ____________

2

Figure 20. Administered Survey, page 2.

Part 2: Map reading

2.1 Terrain

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

☐ A ☐ B ☐ I'm not sure

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

☐ C ☐ D ☐ I'm not sure

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

☐ E ☐ F ☐ I'm not sure

2.2 Position

Please mark where on the map you think we are currently located (*Mark using an **X***).

How confident are you that this is the correct location?

☐ Very Uncertain ☐ Somewhat Certain ☐ Mostly Certain ☐ Very Certain

2.3 Safe zone location

Please mark where on the map the evacuation safe zone is located (*Mark using a **DOT***).

How confident are you that this is the correct location?

☐ Very Uncertain ☐ Somewhat Certain ☐ Mostly Certain ☐ Very Certain

2.4 Time estimation

Using locations G, H, I, and J, how much time do you think is required to get to an area outside the hazard zone during a tsunami event? **In this scenario, a person would be walking at a normal speed of about 4 feet per second.** *Please use the map to estimate times.*

G ___________________ H ___________________ I ___________________ J ___________________

How confident are you of your estimates?

☐ Very Uncertain ☐ Somewhat Certain ☐ Mostly Certain ☐ Very Certain

3

Figure 21. Administered Survey, page 3.

<u>2.5 Pedestrian travel speed estimation</u>

From locations X, Y, and Z, at what <u>minimum speed</u> do you think you must move on foot to make it to a safe zone during a tsunami event? **In this scenario, there is a 5-minute evacuation delay after the earthquake has stopped. Also, the average walking speed for a person is ~4 feet per second.** *Please use the map to make your determinations, and choose one of the following choices below for each location:*

A. Slow Walk **B.** Normal Walk **C.** Fast Walk **D.** Jogging **E.** Running

X ________________ Y ________________ Z ________________

How confident are you of your estimates?

☐ Very Uncertain ☐ Somewhat Certain ☐ Mostly Certain ☐ Very Certain

Part 3: Map impressions

3.1 Has this map changed your opinion on tsunami hazards in this area? Why or why not?

3.2 Did this map help you understand where to evacuate?

☐ Yes ☐ No ☐ I'm not sure

3.3 Did this map help you understand the amount of time needed to evacuate on foot?

☐ Yes ☐ No ☐ I'm not sure

3.4 Did this map give adequate information for evacuating?

☐ Yes ☐ No ☐ I'm not sure

3.5 If you answered **NO** to the previous question, what information would you like to see?

4

Figure 22. Administered Survey, page 4.

Part 4: Map preference, demographics, and comments

4.1 Which maps give you the best and worst understanding of the terrain?

Best ________________________ Worst ________________________

4.2 Which maps do you think are best and worst for interpreting travel time to safety?

Best ________________________ Worst ________________________

4.3 Which maps do you think are best and worst for judging your position?

Best ________________________ Worst ________________________

4.4 Out of all the maps, which map do you prefer?

Best Overall ________________________

4.5 Why do you prefer the map you chose?

4.6 What is your gender?

☐ Male ☐ Female ☐ Decline to answer

4.7 What is your age group?

☐ 18-20 ☐ 41-50 ☐ Decline to answer
☐ 21-30 ☐ 51-60
☐ 31-40 ☐ 61 and older

4.8 What is the highest level of education you have attained?

☐ Some school ☐ College certificate ☐ Decline to answer
☐ High school/GED ☐ Undergraduate degree
☐ Some College ☐ Graduate Degree

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Figure 23. Administered Survey, page 5.

4.9 Do you have any questions about this research?

4.10 Do you have any comments on the maps or research?

If you have any further questions or comments, you can email me at:
aaron.taveras@humboldt.edu

Thank you for participating!

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Figure 24. Administered Survey, page 6.