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HazardReady – a geographically based natural hazard education and preparedness web application

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HAZARDREADY – A GEOGRAPHICALLY BASED NATURAL HAZARD

EDUCATION AND PREPAREDNESS WEB APPLICATION

By

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HazardReady - A geographically based natural hazard education & preparedness web application

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Abstract

Earthquakes, floods, wildfires, and other natural disasters are inevitable and costly both in terms of lives lost and money spent on recovery. Scientific research on natural hazards is widely shared within the scientific community, but is less often made more widely accessible, as methods or pathways for providing scientific natural hazard information and data in non-technical language are limited. Priorities for imparting hazard information include: 1) scientific accuracy, 2) spatial granularity, 3) integration of information about all relevant hazards, 4) nontechnical content, 5) appropriate preparedness activities, and 6) engagement with existing disaster response and mitigation capabilities. In response to these priorities, we developed HazardReady, an interactive online application that delivers location-based multihazard risk and preparedness information using graphics and natural language easily understood by nonexpert users. This paper explores the development of the prototype for Missoula County, Montana, U.S.A. called MissoulaReady. The web application is built on spatial data layers corresponding to levels of risk and historical distributions of natural hazards in Missoula County. A web user queries these data by searching on a spatial location, either an address or a map click, for which curated, location-specific, interpreted risk information is then served. We specifically address the steps required to implement all of the priorities identified, including how natural hazard data are collated, modified, and interpreted, as well as methods by which diverse stakeholders were involved in the application's creation. Focus groups and usage metrics indicate that the application meets criteria of scientific accuracy and usability.

Chapter 1: Project Introduction

1 Research Motivations

Natural disasters and the processes that control them are complex and ever changing, making them fascinating to study and impossible to predict. Geoscientists develop best estimates of hazard risks by integrating historical data and statistical methods with observations of current processes. They revise techniques when new disasters challenge previous outputs and assumptions. Efforts such as these result in science-based products like probabilistic ground shaking maps, floodplain boundaries, landslide susceptibility zones, and tsunami inundation extents among others. These products have two commonalities: 1) they are geographically based and 2) they require expertise to accurately interpret them. The first property implies that landscapes are impacted non-uniformly by disasters, which are controlled by the geomorphology, tectonics, and weather of a region. The second property presents the problem this research seeks to address. Natural disasters pose significant threat to the general public, but many individuals lack the skills to interpret and understand their risks before a disaster hits. Between 2005 and 2015 worldwide hundreds of thousands have been killed, millions have been displaced or injured, and over a trillion dollars has been spent (United Nations, 2015). As scientists improve their ability to estimate hazards risks, it is important that the broader impacts of this research be considered and strategies developed to provide critical information to relevant stakeholders. Some scientists and local governments have begun to take on this task by creating tools to communicate natural hazard risks to the public.

In recent years scientists have developed a number of natural hazard resources and games for public use. An example includes the Iowa Flood Information System (IFIS), a website that delivers flood inundation maps, real-time flood conditions, flood-related data, and interactive visualizations for Iowa residents and city officials (Demir and Krajewski, 2013). Other examples include a video game intended to enhance volcanic hazard understanding and communication (Mani et al., 2016) and a board game intended to teach decision-making and raise natural hazard awareness (Mossoux et al., 2016). The last two studies showed improved knowledge of hazards after game interaction.

Government entities are also beginning to serve natural hazard and preparedness related information to the public through games and Geographic Information System (GIS)-based data viewers. The Federal Emergency Management Agency (FEMA) and the United Nations Office for Disaster Risk Reduction (UNISDR) serve kid-targeted games to teach about hazards and how to prepare for disasters (FEMA, n.d; UNISDR, n.d.). Data viewers are typically provided on state or county government webpages and include hazard data layers that can be turned on and off with legends denoting color of overlay (Fig. 1-1).

The above efforts to inform and educate the public about natural hazard risks are useful, but limited in many respects. Tools with simplified content such as games or hazard

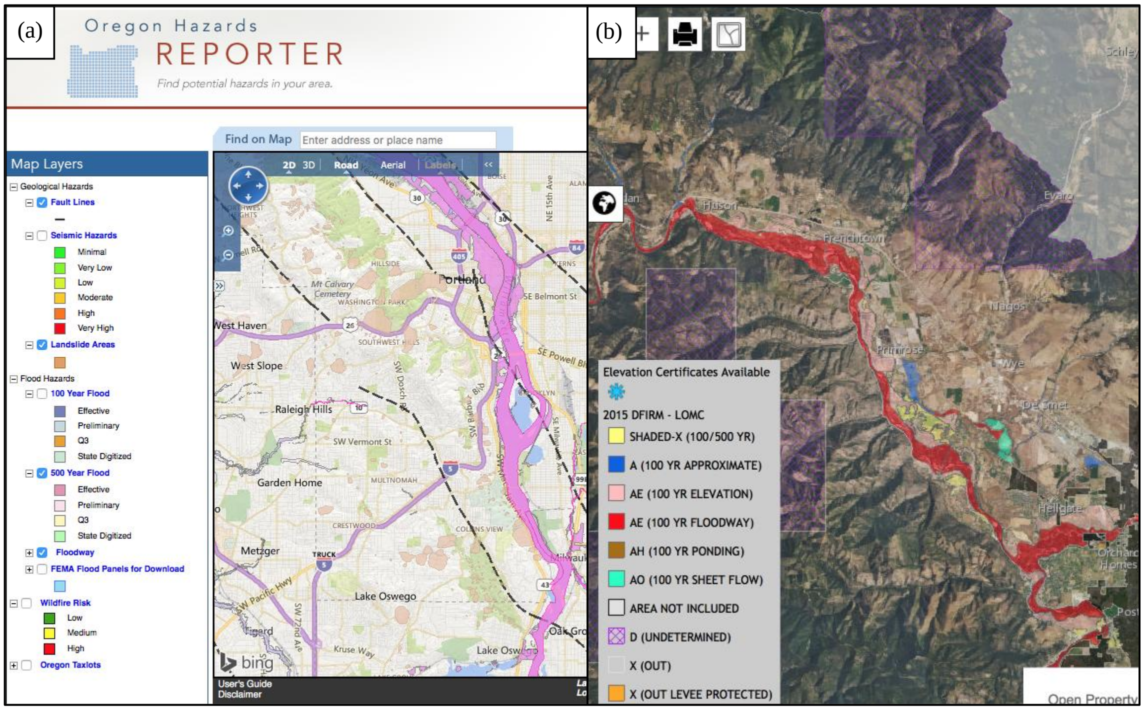

Figure 1-1. Natural Hazard data visualization tools typically have a base map overlaid with hazard-related data layers and a legend. (a) The Oregon data visualizer shows earthquake, landslide, flood, and wildfire hazard data (http://oe.oregonexplorer.info/hazards/HazardsReporter/) (b) Missoula County serves floodplain information in a similar format, but does not include all hazards (http://gis.missoulacounty.us/caps/floodplain/). Legends from both require technical understanding to interpret. These products are of limited use to the public though they are becoming standard.

awareness websites do not serve spatially specific content, though as mentioned above, disasters are geographically dependent. Geographic data viewers do contain location-specific information, but lack explanation of content that makes the information understandable to nontechnical users. These tools also tend to be single hazard specific and rarely pair risks with actionable preparedness steps. This study seeks to remedy these issues by developing a tool that is location-based, multihazard, user-friendly, and science-based. In this paper we outline a pilot study of MissoulaReady, a web-based tool, developed for Missoula County, Montana. This paper discusses how the tool and its components were developed and the workflow used for translating the technical information into easily understood text. The general tool is referred to as HazardReady.

2 Thesis Objectives

The primary goals of this study were to: 1) create a tool that provides technical natural hazard information to the public that is easily understandable and maintains scientific accuracy, 2) develop this tool such that it can be scaled in size, expanded to many localities, and include a variety of information types, and 3) to create a work flow for doing so.

3 Research Methodology

This research is innovative and interdisciplinary so no accepted methods currently exist for completing it. Instead, a workflow was developed that includes three phases, 1) needs assessment, 2) tool development, and 3) product testing and revision (Fig. 1-2). These three phases involve assimilating currently available information and data, synthesizing the available materials, and developing methods to translate scientific content for public consumption. An important aspect of this project was involving stakeholders before, during, and after development to ensure the tool was useable and contained relevant information. Specifics on tool concept and design can be found in chapter two while data management and processing are described in detail in chapter three.

4 Concluding Remarks

The resulting product developed in this study can be implemented in other regions with different hazards and datasets making it useful for hazard education and mitigation in any region. The methods for translating scientific information and data into a simple format can also be used in future studies. Community and local government interest in this product suggests that tools like this are needed and that timing is right. With science communication becoming a popular topic, especially surrounding global warming and other issues at the intersection of science and society, this tool provides a new avenue and can be utilized with any type of geographic data.

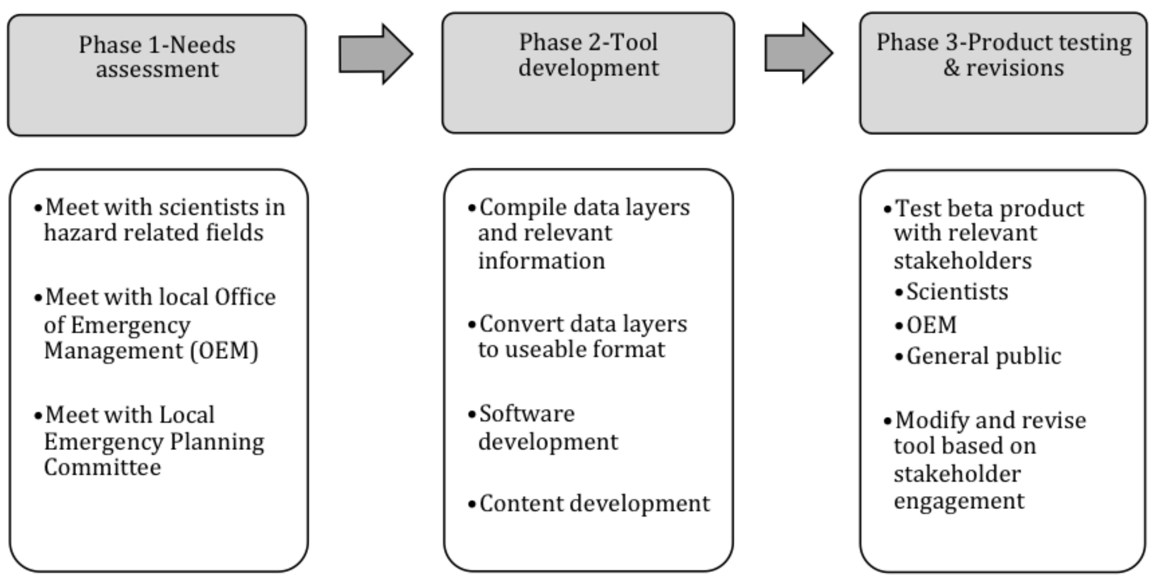

Figure 1-2. Project phases and components overview. Web developers hired for this project completed the software development aspect of this project with guidance from myself.

5 References

Demir, I. and Krajewski, W. F.: Towards an integrated Flood Information System : Centralized data access, analysis, and visualization, Environ. Model. Softw., 50, 77–84, doi:10.1016/j.envsoft.2013.08.009, 2013.

FEMA: Disaster Master and Build a Kit, https://www.ready.gov/kids/games, last access 5 July 2016. n.d.

Mani, L., Cole, P. D. and Stewart, I.: Using video games for volcanic hazard education and communication, NHESS Discuss., doi:10.5194/nhess-2016-23, 2016.

Mossoux, S., Delcamp, A., Poppe, S., Michellier, C., Canters, F. and Kervyn, M.: Hazagora : will you survive the next disaster ? – A serious game to raise awareness about geohazards and disaster risk reduction, , 16, 135–147, doi:10.5194/nhess-16-135-2016, 2016.

UNISDR: Stop disasters! – A disaster simulation game from the UN/ISDR, http://www.stopdisastersgame.org/en/home.html, last access: 5 July 2016. n.d.

United Nations: Sendai Framework for Disaster Risk Reduction 2015-2030, 2015.

Chapter 2: HazardReady - A geographically based natural hazard education & preparedness web application

C. MacPherson-Krutsky and R. Bendick

Abstract. Earthquakes, floods, wildfires, and other natural disasters are inevitable and costly both in terms of lives lost and money spent on recovery. Scientific research on natural hazards is widely shared within the scientific community, but is less often made more widely accessible, as methods or pathways for providing scientific natural hazard information and data in non-technical language are limited. Priorities for imparting hazard information include: 1) scientific accuracy, 2) spatial granularity, 3) integration of information about all relevant hazards, 4) nontechnical content, 5) appropriate preparedness activities, and 6) engagement with existing disaster response and mitigation capabilities. In response to these priorities, we developed HazardReady, an interactive online application that delivers location-based multihazard risk and preparedness information using graphics and natural language easily understood by nonexpert users. This paper explores the development of the prototype for Missoula County, Montana, U.S.A. called MissoulaReady. The web application is built on spatial data layers corresponding to levels of risk and historical distributions of natural hazards in Missoula County. A web user queries these data by searching on a spatial location, either an address or a map click, for which curated, location-specific, interpreted risk information is then served. We specifically address the steps required to implement all of the priorities identified, including how natural hazard data are collated, modified, and interpreted, as well as methods by which diverse stakeholders were involved in the application's creation. Focus groups and usage metrics indicate that the application meets criteria of scientific accuracy and usability.

1 Introduction

In 2016, there are more data and information available than ever before to quantify and assess natural hazard risks and to inform mitigation practices. Natural hazard scientists are continuously adding to the understanding of hazards whether through developing channel migrations estimates (Boyd, 2009), incorporating geodetic slip rates in seismic hazard analysis (Ozener et al., 2013), or creating new models for wildfire risk assessment (Thompson et al., 2015). Though this research is being done, it is typically inaccessible to the general public. This is due to both physical (hard to locate) and technical (hard to understand without prior knowledge) inaccessibility (Hassol, 2008; Haynes et al., 2007). Findings are published in journals or remain in the researcher's possession. Because different entities generate data on different types of hazards, technical products are spread out amongst different agencies (Table 2-1). Even if the data are downloadable, technical skills and tools like ArcGIS are needed to interpret and understand them. In the U.S., data are compiled as part of disaster mitigation and preparedness requirements on U.S. municipalities to obtain Federal grants (FEMA, 2015), but even these products are difficult for residents to find and use. It follows that communities are left without accurate information and therefore an ability to prepare efficiently for disasters.

Table 2-1. Agencies responsible for collecting and serving natural hazard information are varied and numerous.

Natural Hazard	Data	U.S. Agency
Atmospheric (hurricane, cyclone, tornado, lightning)	Predictions, hazard maps, historic information	NOAA
Earthquake & Tsunami	EQ Hazard Maps	USGS
Floods	Floodplain Maps, Forecasting, Historic information	FEMA/NOAA/ USGS
Landslides	Landslide Hazard Maps	USGS
Volcanoes	Volcanic Hazard Maps	USGS/NOAA
Wildfires	Fire Hazards, Burn Probability and Flame Length Maps	USFS

The events surrounding a landslide in Oso, Washington in spring 2014 show the real-world repercussions associated with barriers to access for hazard data and risk information. Despite clear scientific evidence for non-trivial hazard in six decades of landslide susceptibility reports and a landslide in 2006, building codes were approved and homes were built in the path of a future landslide (Miller and Sias, 1998; Shannon and Associates, 1952; Thorsen, 1969). The landslide led to 43 deaths when a slope failed catastrophically sending mud and debris into a housing development (Lombardo et al., 2014). The event in Oso, the deadliest landslide in U.S. history, motivated geoscientists, social scientists, and emergency managers alike to understand and learn from it. Reports examining the Oso landslide recommend advancing the use of early warning systems, using remote sensing to aid in evaluating risk (LaHusen et al., 2015), clearly communicating landslide risk to the public, as well as promoting proactive preparedness measures (Keaton et al., 2014; LaHusen et al., 2015; Lombardo et al., 2014). Remote sensing was recently used in 2015 after the Gorkha earthquake in Nepal to monitor and map landslides. These efforts aided in disaster response and informed decision makers in almost real-time (Kargel et al., 2016).

In contrast to Oso, when hazard risk information is either made accessible or mitigation activities imposed on communities before an event, the potential for reducing loss of property and lives is substantial. This can be quantified by comparing fatalities for areas with strong differences in preparedness and mitigation prior to physically similar earthquakes. For example, the 2010 magnitude (M) 7 Port au Prince earthquake in Haiti and the 1996 M 7.1 Loma Prieta earthquake in the United States, were both strike-slip events in densely populated urban areas, with similar shaking intensity distributions. However, the estimated number of Haitians killed outnumbered Americans by five thousand times (USGS Earthquake Archive, 2014; Holzer, 1989). The Sumatra earthquake and tsunami of 2004 and the Tohoku, Japan earthquake and tsunami of 2011 also had similar magnitudes, tsunami magnitudes, and shaking characteristics in settings with very different levels of resident awareness and institutional preparedness, with a consequent 14-fold difference in event fatalities. Access and promotion of natural hazard information before disasters saves lives. Regions that have programs to distribute and inform the public about potential disasters have drastically less fatalities than those lacking education and preparedness platforms (Fig. 2-1).

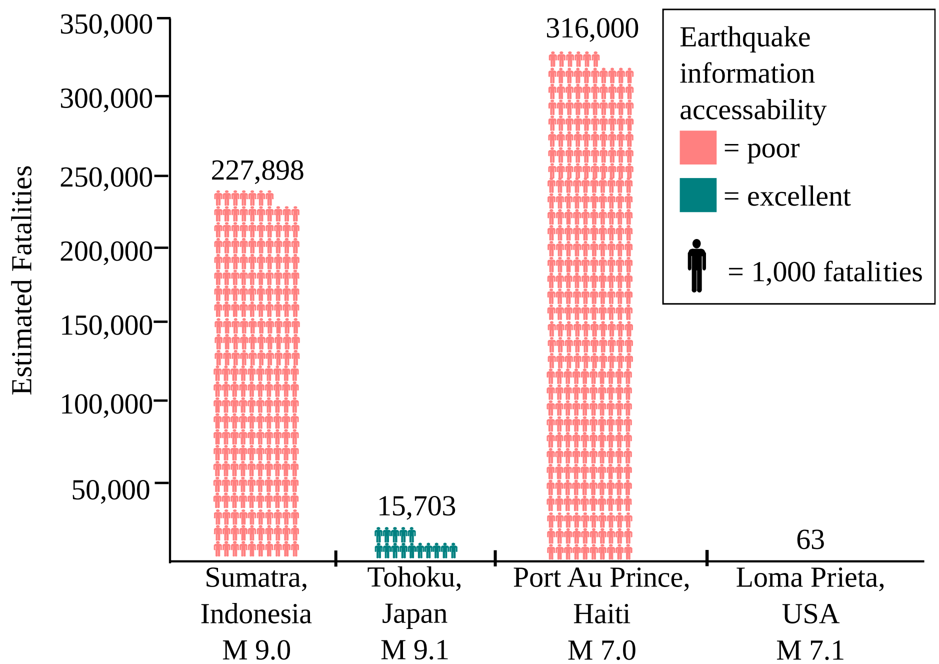

Figure 2-1. Areas where hazard education and preparation is prevalent prior to an event have significantly lower fatalities when an earthquake occurs. Here, we have two comparable magnitude (M) 9 earthquakes and two comparable M7 earthquakes. Education and mitigation strategies dramatically reduce impacts in terms of cost and loss of life from an event (Data: USGS EQ Archive and Holzer, 1989).

It is important to note that access to information does not always imply action. Studies have shown that the methods by which information is developed and distributed affect how or if action will be taken. A series of recommendations for producing constructive communication strategies include building trust with and engaging stakeholders, (Cornell et al., 2013), using understandable language and considering social networks (Cash et al., 2003), linking relevant groups (researchers, practitioners, or public) (van Kerkhoff and Lebel, 2006), and creating people-centered information that provides actionable steps (Haer et al., 2016). The Sendai Framework (United Nations, 2015) suggests that for disaster and risk reduction practices to be successful they must, “be multihazard and multisectoral, inclusive, and accessible”. Effective implementation of this requires earth scientists, social scientists, local authorities, and the public to communicate and collaborate. To make the information inclusive and accessible it must first be non-technical (Schweizer et al., 2009; Shen, 1975; Somerville and Hassol, 2011). Second, it must incorporate location specific information (Eisenman et al., 2007; Eiser et al., 2012; Cutter et al., 2008). Third, the information should be easily discoverable, whether online, on social media, or as part of local news.

Increasingly, people are interacting and learning through online sources (Allen and Seaman, 2013). As of 2015, 68 percent of the U.S. population owned a smart phone and 73 percent a desktop or laptop computer (PEW Research Center, 2015). Communication and teaching methods for natural disaster information can leverage this trend to address specific informational priorities by creating web applications, simulations, and interactive games. Previous studies have shown these frameworks to be effective at increasing user understanding in the context of natural hazard risks (Demir and Krajewski, 2013; Mani et al., 2016; Mossoux et al., 2016).

In this paper we present HazardReady, a web application aimed at providing natural hazard data and information to the public in an accurate, granular, non-technical, and accessible way. This application incorporates the latest natural hazard data for a region, standardizes multihazard information using ArcGIS, and translates the results into location-specific non-technical language and graphics. It then pairs the hazard risk information with appropriate preparedness recommendations

1.1 Pilot Study Location ~ Missoula County, MT, U.S.A. Northern Rocky Mountains

We completed a pilot study of HazardReady in Missoula County, Montana. This is an area well suited for this application as the population is increasing rapidly, it is host to many natural hazards, several active emergency management groups exist, and experts in hazard related fields are easily accessed through the University of Montana, the Rocky Mountain Fire Research Center, and Western Montana and Central Idaho National Weather Service office. The pilot application is named MissoulaReady and was built such that the infrastructure is scalable and transferable to other communities.

Missoula County is the second most populated county in Montana and is projected to increase in population by about 50 percent in the next 50 years (REMI, 2013). The majority of the population lives within the Missoula City limits with 2,428 people per square mile compared to 7 people per square mile for the State of Montana (USCB, 2013). Missoula is host to numerous natural hazards, which include wildfire, flooding, extreme weather, earthquakes, and landslides ranked in order from highest to lowest hazard (Atkins, 2011).

Wildfires are an integral part of the mountainous landscape and local ecosystems of Missoula County (Hutto, 2008). Between 1979 and 2007 Federal and/or State disasters or emergencies were declared nine times for wildfires (Atkins, 2011). The topography of the county allows for smoke to settle in the valleys during fire season and impact air quality. Because of this, the City of Missoula was ranked 10th out of 248 U.S. cities in 2016 for 24-hour air pollution caused by smoke and particulate matter from nearby and distant wildfires (American Lung Association, 2016).

The Clark Fork, Bitterroot, and Blackfoot Rivers are the main contributors to springtime flooding with smaller creeks flooding to lesser extents in Missoula County. Similar to many areas in Montana the combination of large snowpack and sustained days of high temperatures are a typical cause of regional springtime flooding. Apart from regional floods, flash flooding has occurred as a result of thunderstorms, which are common in the summertime. These floods often develop in areas burned by wildfire where hydrophobic soils lead to overland flow rather than infiltration (Parrett et al., 2004). Minor and major flooding have occurred throughout the county’s history with the most notable in 1908. This flood was estimated to have been a 500-year event (Woelfle-Erskine et al., 2012). The prominent river type in Missoula County is meandering. As such, cut banks are prone to erosion changing future floodplain boundaries and impacting where flood hazard exists. Channel migration studies have begun for sections of the Clark Fork and Bitterroot Rivers to examine which areas may soon be at risk (Boyd, 2009). Though zoning has prevented most structures from being built in the 100-year floodplain, as of the 2008, hundreds of residential structures were considered vulnerable to a 100-year event (Atkins, 2011).

All locations within the county can experience both extreme summer and winter weather (Atkins, 2011). For summer, this entails wind, hail, thunder and lightning. For winter, this includes snowfall, wind, and blizzard conditions. Often these storms disrupt power and can initiate other destructive events like wildfire and flooding. From 1950 to 2016 there have been 11 blizzard, 56 high wind, 95 hail, and 441 heavy snow events (NOAA, 2016).

Missoula County sits in the western part of the Intermountain Seismic Belt and Lewis and Clark Zone (Stickney and Bartholomew, 1987). Earthquake recurrence intervals in the Northern Rocky Mountains have been estimated to be 40 years for M5 events and 5000 years for M7 events, but high magnitude events have been recorded in the state (Wong et al., 2005). The largest earthquake nearby was the M7.5 Hebgen Lake Earthquake in 1959, about 300 km from Missoula County. Smaller earthquakes (<M3) are common in the area (Stickney et al., 2000). Faults within the county limits are believed to have the potential to host M7+ events based on their length and the size of Quaternary scarps (Leonard, 2010).

Though mass wasting events are ranked sixth in a list of hazards for Missoula County the hilly mountainous terrain, annual wildfires, and summer thunderstorms can create ideal conditions for these events. The types of mass wasting documented in Western Montana include post-fire debris flows (Gabet and Bookter, 2008; Wondzell and King, 2003), slope failures along road cuts (Atkins, 2011), as earthquake induced landslides (Wilde et al., 2002), as well as avalanches (Karkanen, 2014). To date fatalities related to mass wasting events were from the landslide triggered by the Hebgen Lake earthquake and from the 2014 avalanche in Missoula City limits. Though these events are infrequent and localized, they pose risk to the public in Missoula County and should be considered.

The documents available to the public for understanding of local natural hazards and risks include the Pre-Disaster Mitigation (PDM) Plan for Missoula County, State of Montana Multi-Hazard Mitigation Plan and Statewide Hazard Assessment, and Missoula County Community Wildfire Protection Plan (Atkins, 2011; Tetra Tech, 2013; Wallace et al., 2005). These documents can be found on the county and state Department of Emergency Services websites, but were created for the purpose of obtaining government grant funding through the Federal Emergency Management Agency's (FEMA) PDM Grant Program.

2 HazardReady Concept

As with many other regions Missoula County has the potential for numerous natural hazards. Though consulting groups and scientists alike have begun to quantify the associated hazard risks and report them, three main issues remain. First, little communication regarding natural hazard risk information occurs among the scientific community, local governments, and the general public. In Missoula, hazard information can be gleaned from the PDM documents provided on government websites or by examining regional hazard data, but these pieces of information were not created with the intention of public use and are therefore limited for that purpose. Second, existing reports are not location-specific within Missoula County. Public outreach and education in the County is comprised of public meetings, school visits, local news reports, and public service announcements provided by local emergency managers, each presenting information about different subsets of the total regional hazard risks, as well as different mitigation and preparedness strategies. Third, recent reports and publications are updated and changed regularly making it difficult for emergency managers to provide the latest information. Missoula is not unique in these aspects. HazardReady's implementation for Missoula, MissoulaReady, is designed to address these barriers by integrating multiple hazard types, making data easily updateable, translating scientific jargon, and serving consistent preparedness information.

3 HazardReady Design: Architecture and Content

The structure of the HazardReady application was adapted from a pre-existing web application, Aftershock, developed to inform Oregon State residents of potential earthquake risks associated with a M9 earthquake scenario. The Aftershock web application is intended for one region and type of hazard. The architectural adaptations made from Aftershock to HazardReady were to expand it for multiple hazards, create a backend framework that was non-location specific, and make a product that could be easily updated as new data became available. Other modifications were made to address stakeholder feedback (Fig. 2-2).

In this section we discuss the frontend and backend of HazardReady. Frontend refers to the aspects of the application with which the user interacts and backend refers to aspects of which the user is unaware. The frontend consists of a user-friendly web application for searching local hazard risks and the backend consists of three main components: the data layers, the database that pairs with the spatial data, and the supporting software and code that connect the content with the website.

3.1 Frontend

The base frontend of the MissoulaReady implementation of HazardReady is comprised of a homepage with a clickable map overlaid with the Missoula County boundary along with information detailing the application's purpose, use, and background. Users click the map or enter an address to search for a location and are taken to a resulting content page (Fig. 2-3). Locations must be within Missoula County boundaries or no information will be provided. The second page has six clickable hazard tabs that correspond with the top natural hazards in the region ranked highest to lowest risk from left to right (Fig. 2-3b). Each tab is populated with location specific information about the "most likely" and "worst case" scenarios for that hazard at the searched location, to provide bounds on an exposure range. These scenarios are explained with short natural language descriptions of corresponding hazard intensity, and supplemented with preparedness measures and descriptions of historical events of the same type. Hazard intensity is also depicted using

HazardReady	Aftershock
Multi-hazard	Earthquake
Non-location specific	Oregon specific
Updateable data	Set data
Worst-case and likely included	Worst-case scenario
Content easily editable	Manual content input
Multi-tab scroll	One column scroll
Photos and text	Text
Historic info included	No historic information

Figure 2-2. Aftershock provides users with information specific to Oregon State and specific to the scenario of a magnitude 9 earthquake hitting off the coast. Though the idea of providing location specific information based off natural hazard data is consistent across HazardReady and Aftershock platforms, much of the backend was changed to reflect new components deemed necessary for the HazardReady platform. Aftershock can be found at: http://www.opb.org/news/widget/aftershock-find-your-cascadia-earthquake-story/

a graphical dial and color scale. The same qualitative relative hazard intensity dial is used for all of the different hazards, enabling users to easily compare different locations for the same hazard or the different hazards for the same location. For each hazard tab, information is organized into four main content sections, some encompassing subsections. The twelve subsections include various types of information from potential disaster scenarios to historic events and how to prepare (Table 2-2).

The first section in each hazard tab is an assessment of hazard potential specific to a user's search location and is generated directly from the spatial data query for all tabs except for winter and summer weather since they are not geographically predictable like the other hazards. The data themselves are not displayed to the user, but can be accessed by clicking a source link. This opens a new window that displays an overview image of the data for the region with a legend (Fig. 2-4). The second section is hazard specific preparedness information and changes depending on which hazard tab is selected. For example, safety issues for wildfire are the same throughout Missoula County so the same text will appear under safety issues for everyone who clicks on the wildfire tab. The third section is historical disaster information where available, and also varies by hazard tab. The fourth section is static information pertinent to all users and all hazards and displays on all tabs as described above. The static information includes helpful links to local resources like fire departments and weather websites. These links are interspersed throughout the content to connect the user with currently spread out, but valuable, information. Static links and generic preparedness information is provided by county and local emergency managers and represents current city and county organization and best practices.

Table 2-2. MissoulaReady section breakdown.

Section[1]	Subsection[2]	Description	Section #[3]	Input Location[4]
What to Expect	Potential	Relative to the rest of the county what is the potential scenario	1	CSV
	Worst Case Scenario	What kind of potential exists here if an extreme situation were to happen	1	CSV
	Safety Issues	Things to be aware of for each type of disaster	2	CSV
Past Events	Historic events	Severe or notable events that have happened nearby	3	CSV
	Photos of past events	Photos from those events	3	Django
How to Prepare	Get Hazard Ready	Steps that people can take to prepare	2	CSV
	Stay Tuned	Where to get local information before, during, or after and event	2	CSV
	A word from your emergency managers	What people can expect of their emergency managers in each type of event	2	CSV
Other	Supply Kit	Information about how many and what type of supplies are recommended	4	Django
	Community Leaders	Who should people look to in the event of a disaster	4	Django
	Important Links	Relevant links for people to access	4	Django

[1]All hazard tabs have main sections that provide page structure.

[2] Nested subsections contain the text that is queried and displayed to the user.

[3]Four sections describe how the information is queried and presented to the user. (1) Information is queried by lookup-value in a data layer. As a user searches new geographic locations the information will change. (2) Hazard preparedness and safety information is queried by hazard type. As user clicks different hazard tabs this information will change. (3) Historical hazard information is queried by hazard type or by lookup-value depending on what type of historical information was available. (4) Static information is general and will display the same for all pages and hazards.

[4]Each input location describes where this content is housed before the user sees it, whether it is via snugget CSV file or through the Django Admin panel.

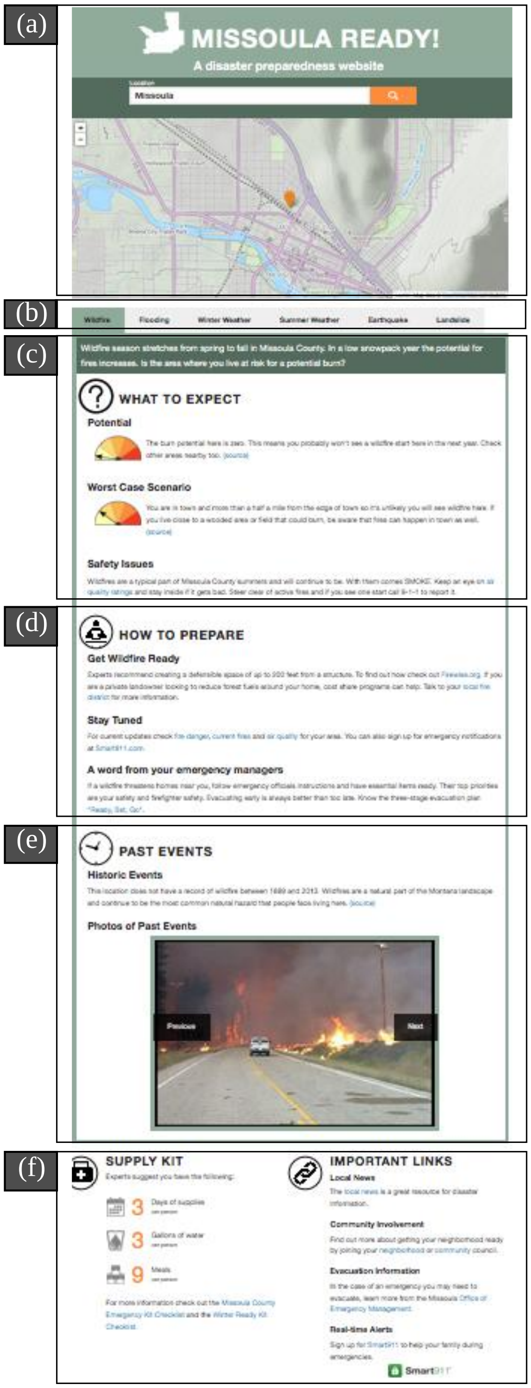

Figure 2-3. (Left) The resulting content page contains, (a) search pane and interactive map, (b) six hazards tabs. Each can be clicked for location specific information related to individual hazards, (c) the "What to Expect" section contains information on potential and worst-case scenarios and is queried using data layers. The intensity scales are provided to give user a relative intensity compared with other areas in the region, (d) the "How to Prepare" section provides basic information and links to local resources, (e) the "Past Events" section includes event information and historic photos (f) the static information below is located on all

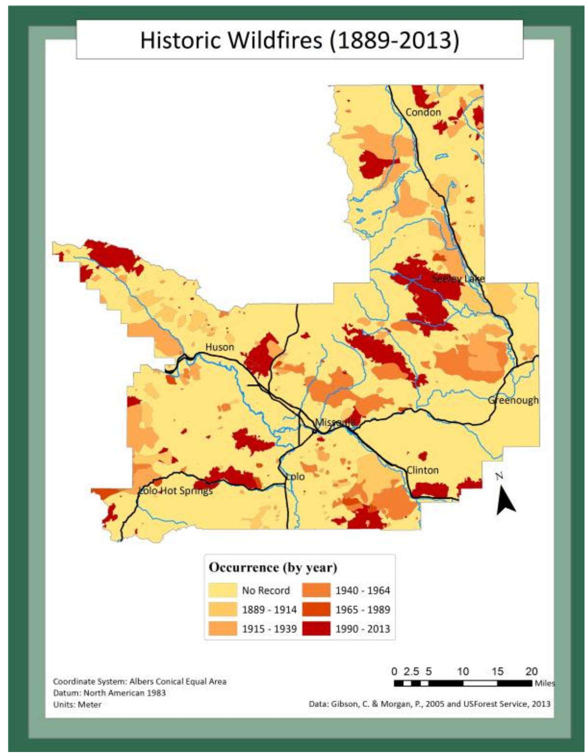

Figure 2-4. (above) Example of a data overview image provided to user. This shows historic fires within the county and contains information on data source and how the information is spread out over the county.

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3.2 Backend

The basic function of the backend is to pair descriptive text, graphical dials, and images with geospatial data layers. Each data layer is sourced from the most current publically available data, like FEMA floodplain boundaries or U.S. Geological Survey (USGS) ground shaking maps. Individual layers are then converted into spatial maps of hazard intensity, which are then matched with text and graphics that describe each intensity category. Each piece of text is called a story-nugget or “snugget” as termed by the Aftershock developers. The snuggets and other information are contained in a Comma Separated Value (CSV) file. A chain of software support stores and structures snuggets and data layers to create the dynamic content served to the frontend interface (Fig. 2-5).

3.2.1 Data Selection

The top six hazards considered highest risk for Missoula County include wildfire, flood, extreme winter and summer weather, earthquake, and landslide. These are based on frequency, potential impact, and potential number of casualties (Atkins, 2011). The data available for each hazard were acquired through both local and national resources. Local scientists and research labs were consulted to ensure data were the best available for each hazard type (Table 2-3). Date of publication and scale of data were considered. Preference was given to the most current data whose resolution was reasonable at the county level scale. These data represent likeliness, intensity, or distribution and scale of historic events. For example, data depicting probabilistic ground shaking represents the former and data depicting historic earthquakes represents the latter. For Missoula County the type, scale, and robustness of data varied significantly between hazards, which meant some data had to be modified or generated. Many U.S. cities, counties, and states have recently developed GIS products that compile and serve one or more hazard data layers of these types, such as the Seattle Hazard Explorer(http://seattlecitygis.maps.arcgis.com/) and California’s MyHazards (http://myhazards.caloes.ca.gov).

3.2.2 Data Processing and Snugget Database Creation

The three types of raw data acquired include continuous raster, vector polygon, and vector point or line data. Each was processed differently in ArcGIS, but resulted in vector polygon data, which are made up of distinct polygons, areas bounded by lines (Fig. 2-6). Continuous raster data were binned into regions based either on standard deviations from a mean or divided using logical breaks. Each binned region was converted to polygon or vector form using the ArcGIS Raster to Polygon Tool. The vector point and line data were used as inputs to ArcGIS tools. These tools helped construct polygons based on the point and line information. After all data were in vector polygon form, a column was added to the attribute table of each data layer named “lookup_val.” This column was populated with non-repeating numbers or letters that are used to query snuggets associated with each polygon. By the end of processing all data are segmented into polygons with unique lookup-values. Each data type and file was processed differently based on which hazard and data type they contained (Table 2-4).

Data for weather, landslide, and earthquake hazard posed an issue for processing due to the quality of information available. Weather information was non-specific to geography,

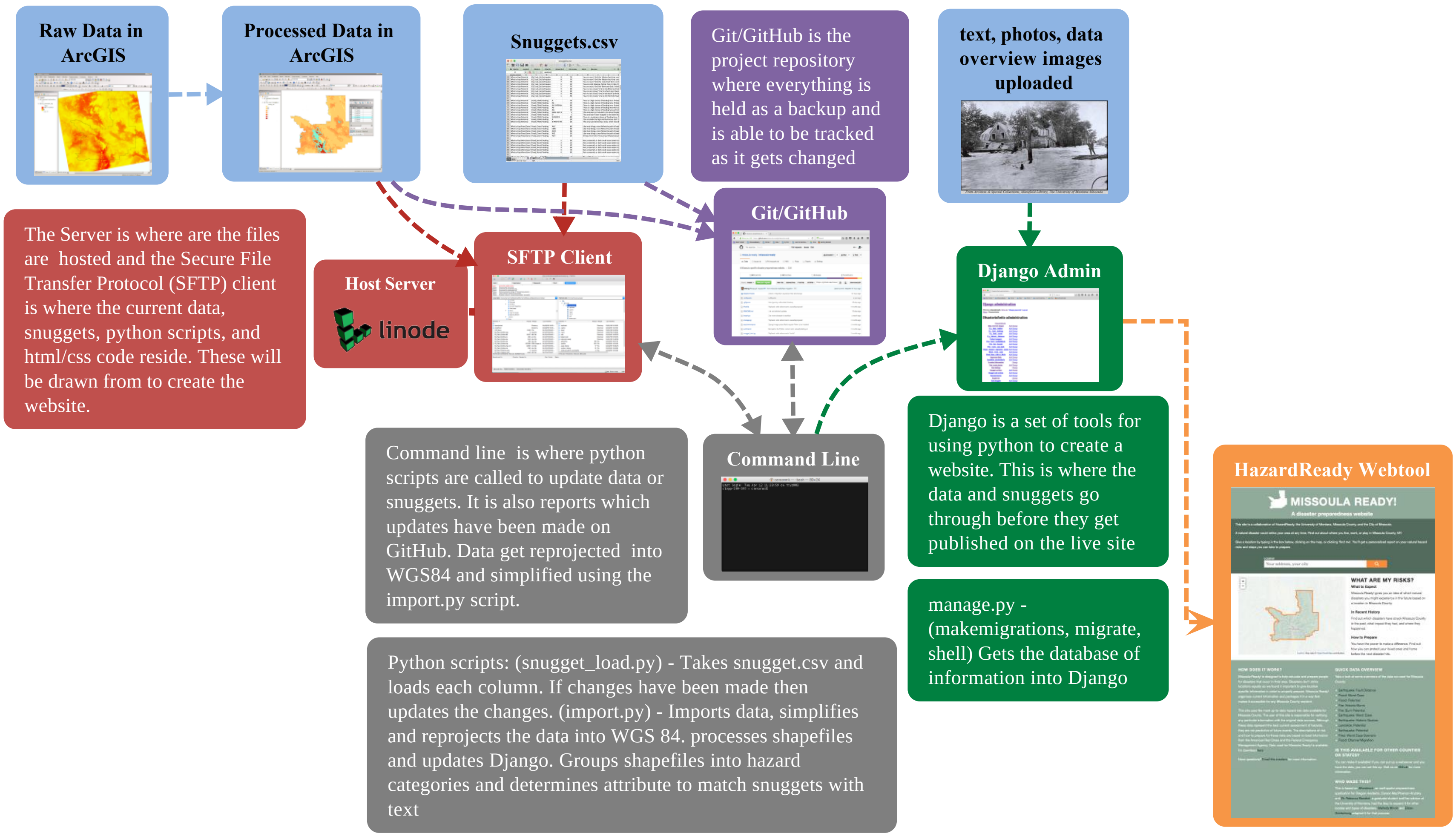
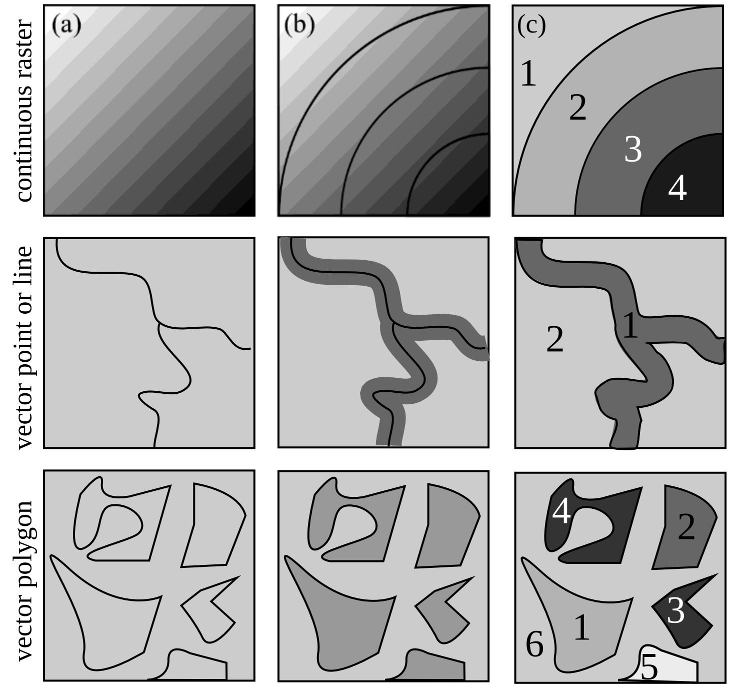


Figure 2-5. Backend flow chart. The blue boxes relate to data and information that provides the content for the website. The software between the blue boxes and the website serve as places to host the data, organize the content, and package it in a useable format.

landslide information was incomplete, and statewide ground shaking information did not adequately take into account local faults. For weather, two shapefiles were generated, one for summer and one for winter. They were comprised solely of the Missoula County boundary with a single assigned lookup-value. The information paired with the lookup-value served general weather scenarios to those who query them instead of having location-based information. Landslide hazard had no available geographic data. Landslide susceptibility was derived from available data for factors that are known to contribute to landslides like, slope, land cover, and soil (Fig. 2-7) (Dai and Lee, 2002; Iwahashi et al., 2003; Larsen and Montgomery, 2012). The probabilistic ground shaking values were used as a guide to make a best estimate for a county scale ground shake map. Buffers around active faults created distinct shaking regions (Fig. 2-8).

Table 2-3. Description of data used for each hazard in Missoula County and data source.

	Data	Description (*original data type*)	Modified, Source
Wildfire	Historic Fire Boundaries	Historic Burn areas are included from 1889-2013. Two datasets have combined to encompass longer time range (*vector polygons*)	Combined, Gibson, 2005 & USFS, 2015
	Fire Worst Case Scenario	Input 0.5 mile buffer inside towns and assumed all else could burn (*vector point, line, polygon*)	Created from town boundaries
	Burn Probability	A burn probability for each point clicked on (*continuous raster*)	Modified USFS, 2014
Flood	Flood Zones (DFIRM)	Digital flood insurance rate map with boundaries for 100/500 year floodplain (*vector polygon*)	FEMA, 2015
	Channel Migration Zones	A section of the Clark Fork River showing where the river has migrated and is likely to migrate (*vector polygon*)	Boyd, 2009
	Flood Worst Case Scenario	This layer buffers around current floodplain boundaries by 500 feet for big rivers and 250 feet for smaller ones (*vector point, line, polygon*)	Modified, FEMA, 2015
Earthquake	Distance from known active faults	1-5 mile buffer around the know active faults in Missoula County (*vector line*)	Modified, USGS
	Distance to nearest EQ >M3.0	Thiessen Polygon around magnitude 3 or greater earthquakes (*vector point*)	Modified, USGS
	Shaking Likely Scenario	Ground shaking likely for a magnitude 4-5 earthquake (*vector line*)	Influenced by Wong, et al., 2004
	Shaking Worst Case Scenario	Ground shaking likely for a magnitude 7 earthquake (*vector line*)	Influenced Wong, et al., 2004
Landslide	Landslide Susceptible Areas	Modeled using slope, soil, and land use data (*continuous raster*)	Created from USGS Nat’l Elevation Dataset, NRCS Soil type, and MT Natural Heritage Program



lookup-value	Snugget text
1	This region has low hazard risk
2	This region has moderate hazard risk
3	This region has high hazard risk
4	This region has very high hazard risk

Figure 2-6. From left to right shows how different raw data types are converted to the data powering the backend of HazardReady. The raw data starts either as continuous raster, vector polygon, or vector line or vector point. (a) The raw data in imported and displayed in ArcGIS. (b) Polygons are either created or identified (c)Lookup-values are then assigned to each polygon and (d) Snuggets for the processed continuous data in (c) are paired with values. These snuggets are the text displayed to the viewer.

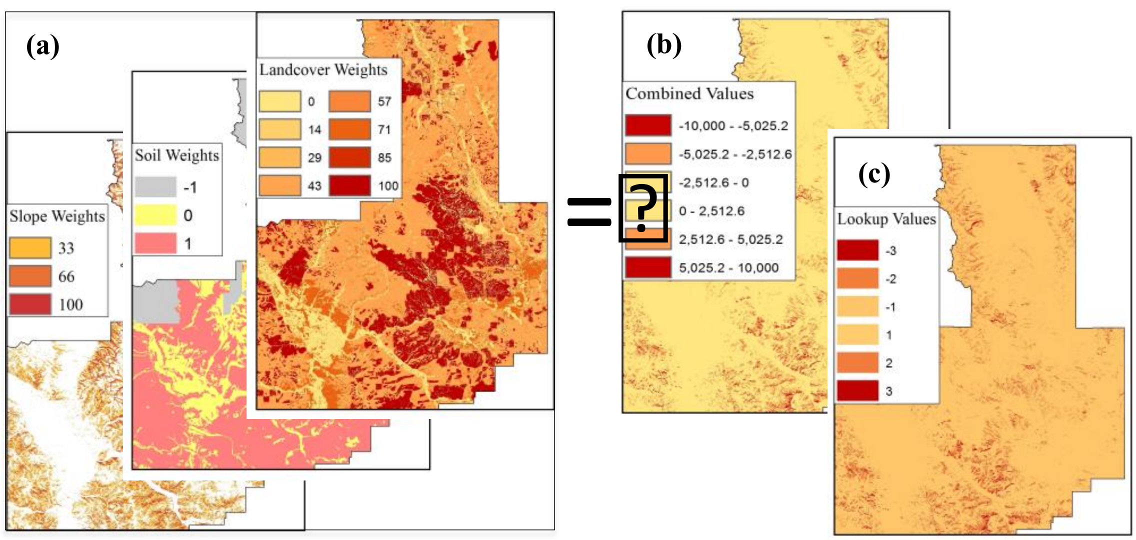


Figure 2-7. Creation of the landslide layer involved first reclassifying the slope, soil, and landcover raster datasets into values that represented contribution to landslides (0=does not contribute and 1 or 100=contributes) then (a) multiplying all rasters together. (b) The raw output was then classified by values within 2 standard deviations of zero. (c) The output raster was then reclassified and lookup-values were assigned to each location (±1=low risk, ±2=medium risk, ±3 = high risk).

Table 2-4. Data processing steps and assumptions

Hazard	Data Layer	Basic processing steps	Notes & Assumptions
Wildfire	Historic Fire Boundaries	1. Added Missoula boundary for areas where no fire had been recorded 2. Assigned lookup-values to polygons	Note: Data represent fires from 1889-2013 and therefore are not complete
	Fire Worst Case Scenario	1. Used towns boundary shapefile 2. Buffered within ½-mile to create three zones each with separate lookup-value	Note: ½-mile was chosen as the Wildland Urban Interface distance (United States Congress, 2003) Assumptions: 1. Up to edge of town could burn catastrophically 2. If location is within town more than ½-mile then unlikely to burn
	Burn Probability	1. Reclassified values into 7 zones of wildfire potential (1-none, 2-low, 2-med, 2-high) 2. Assigned lookup-values for each zone	Note: 1. Burn probability simulations were done on ground conditions for 2010 and simulation runs for 2014 2. Zones were based on fire return interval values (Haas et al., 2013)
Flood	Flood Zones (DFirm)	1. Assigned lookup-values to each polygon	Note: FEMA DFIRM was completed in 2015 and considers 100-500 year flood boundaries
	Channel Migration Zones	1. Combined two channel migration zones available for the county 2. Added Missoula Boundary for locations outside of migration zone studies 3. Assigned lookup-values for each polygon	Note: Areas without migration studies may have potential for river migration, but were not included here.
	Flood Worst Case Scenario	1. Polygons for zones A, AE, AE Floodway, AH, AO, Shaded X, X were dissolved into one shape and a 500 foot buffer added to the dissolved shape 2. 100K Streams file was added and clipped and a 250 foot buffer was added 3. Missoula Boundary was added for non-flooding zones 4. Assigned lookup-values for each polygon	Note: 100K streams file does not include all streams that could flood Assumption: 1. 250 feet for small streams and 500 feet for large rivers are reasonable buffers for a flood larger than 500-yr flood.
Earthquake	Distance from known active faults	1. Created five 1-mile buffers around quaternary active faults 2. Missoula Boundary was added for areas more than five miles from fault 3. Assigned lookup-values for each polygon	Note: Five miles was chosen to give people a general idea of proximity. Depending on region size this could be changed to include more than five miles.

	Nearest Historic EQ >M3.0	1. Historic earthquakes greater than magnitude 3.0 were selected 2. Thiessen Polygons were drawn around them to create polygons where every point within that polygon was closest to the earthquake within it 3. Assigned lookup-values for each polygon	Note: Areas where earthquakes cluster were not accounted for. In future iterations a different method should be used to express historic earthquake information such that clusters can be communicated to the user
	Shaking Likely Scenario	1. Quaternary faults nearby Missoula County were buffered at 5 mile intervals up to 25 miles 2. Missoula County boundary used for locations farther than 25 miles 3. Assigned lookup-values for intensities (I-IV) corresponding to M4 earthquake	Note: Probabilistic ground shaking map for Montana (1% exceedance in 50yrs) was used as a guide for creating this layer Assumptions: See 1. & 2. Below 3. Intensity will scale down uniformly meaning the same boundaries can be used for worst case and likely
	Shaking Worst Case Scenario	1. Quaternary faults nearby Missoula County were buffered at 5 mile intervals up to 25 miles 2. Missoula County boundary used for locations farther than 25 miles 3. Assigned lookup-values for intensities (III-V to VIII) corresponding to M7 earthquake (Magnitude-Intensity Comparison, 2016)	Note: Probabilistic ground shaking map for Montana (1% exceedance in 50yrs) was used as a guide for creating this layer Assumption: 1. Distance used as attenuation relationship for shaking intensity (Bakun, 2006; Howell, B.F. Jr., Schultz, 1975) 2. Five mile intervals represent change in Mercalli intensity value (Probabilistic map used for distance approximation)
Landslide	Landslide Susceptible Areas	1. Slope, Soil, and Landcover data layers were used to create this shapefile 2. Slope and Landcover were assigned values between 0-100 3. Soil was assigned Boolean values (-1 = no soil data, 0=no soil, 1=soil) 4. Layers were multiplied together 5. Resulting values ranged from -10,000 – 10,000 and were divided into 6 categories based zones within 2, 4, and 6 standard deviations from the zero value 6. Lookup-values assigned for each polygon	Note: 0=does not contribute to land sliding and 100=contributes to land sliding Assumptions: 1. Three contributing factors to landslide susceptibility (There are many more, but we were limited by available data) 2. Layers were of equal weight 3. Values assigned for zones accurately depicted relative contribution to landslide (Dai and Lee, 2002; Hong et al., 2016; Iwahashi et al., 2003; Larsen and Montgomery, 2012; VanWesten et al., 2003)

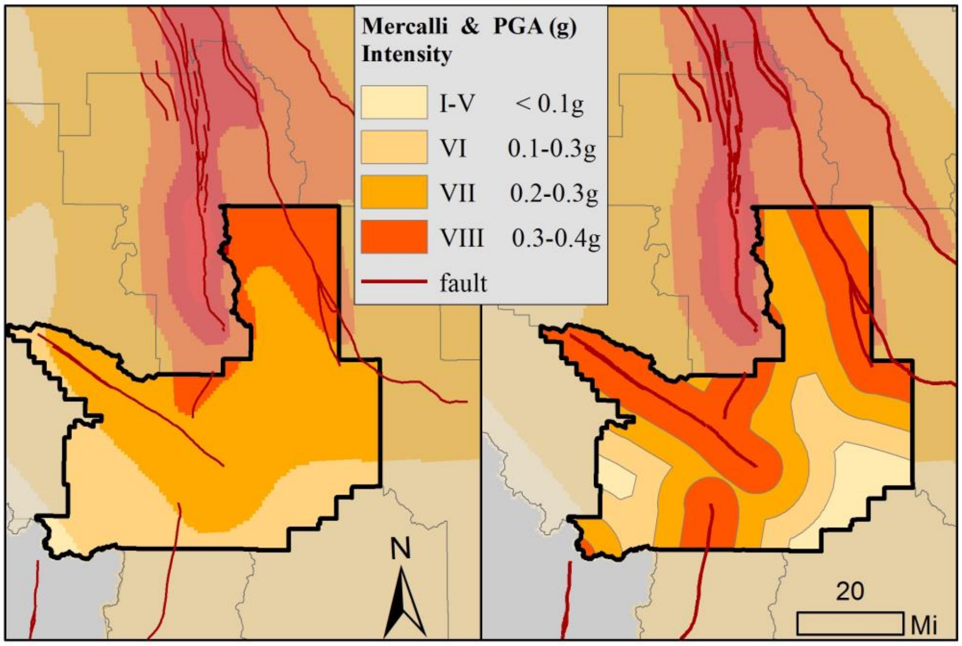


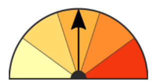
Figure 2-8. On the left is the original data from Wong et al., 2005 showing ground shaking estimates for Montana State. The image on the right is the shapefile we created to better represent ground shaking associated with local faults. Buffers were drawn around quaternary faults known to be active.

After processing data layers in ArcGIS the snugget CSV file was populated with lookup-values. In the CSV file snuggets were written for each lookup-value (Fig. 2-6d). The snugget CSV consists of eight columns that associate snuggets with individual data layers and dictate website formatting (Table 2-5). Snuggets contain the majority of the content, which is section one and two text. The remaining text and information on the website is added using the Django Framework admin website described below. After processing and content creation the data and snugget CSV file are placed on the server.

3.2.4 Supporting Software

HazardReady's backend structure is made up several groups of customized off-the-shelf components as shown in Fig. 2-5. The first group consists of a server, a Secure File Transfer Protocol (SFTP), and a GitHub Repository. All pieces serve as file storage units. SFTP was selected as opposed to FTP due to password protection capability. We used FileZilla, a free SFTP Client that allows for content viewing and simple data transfer onto the server. The server hosts not only data and snuggets, but also scripts in python used to transfer data to Django and the Cascading Style Sheet (CSS) and Hypertext Markup Language (HTML) code for templating the website. Similar to the server, GitHub is a free website that acts as a repository for all project content. The Aftershock creators used GitHub for their project, so it made it simple to "Branch" their project into a new one and continue expanding and reworking what they already created. GitHub makes sharing development process and content simple for future collaborators and can be found at: https://github.com/missoula-ready/missoula-ready.

Table 2-5. Snugget structure. In the snugget CSV file each column has information that dictates how it will get displayed to the user. This file contains tier 1 and 2 content.

Columns	Purpose
Section	The main section of the page the subsections will group under Ex: What to Expect
Subsection	The sub heading will be above text Ex: Potential
Shapefile	File name associated with the source data Ex: Fire_Burn_Potential
Heading	The type of disaster the shapefile is associated with Ex: Wildfire
Lookup_value	Values or letters that are associated with attributes/polygons in the shapefile. Ex: 1, 2, 3, 4,… or a, b, c,…
Intensity	The relative severity within region normalized between 0 and 100. Dictates arrow location on intensity scale. Ex: 50 would show as: 
Image	A static image file to use in place of intensity scale. If intensity and image are blank no image will appear. If both are blank, then no image is shown.
Text	The snugget text that will display to user Ex: The burn potential here is lower than most of the county. This means you probably won't see a wildfire start here in the next year. (source)

The second group consists of Command Line, and the Django framework and serves the purpose of database management. Django is a web framework that provides a python based programming infrastructure for web applications. It maintains code structure and is easily updateable as the web application develops, grows, and changes. All data and content must go through the Django MissoulaReady project site before it is formatted and displayed to the user. Command line is used to import the snuggets and data into Django using a series of python scripts. In running the script for importing data, import.py, the data are reprojected into ESPG: 4326 (WGS 84) and simplified using the Douglas-Peucker simplification algorithm with a tolerance of 0.00001 (Peuker, 1975). The reprojection is done so all shapefiles are uniform and queryable. The simplification reduces the number of points needed to represent the same information making queries against the polygons quicker for the user thus reducing load time. The simplification results in displacements of 0.00001 degrees of latitude or longitude which is about one meter depending on distance from the equator. For many files this halved the file size without creating a visible difference.

Django also has a project admin site where information not included in the data files and snuggets CSV can be added. This includes capabilities to upload historical and data overview images, static section four text like supply kit descriptions, and add important links as described above. After data, snuggets, images, and text are all on the Django project site the information displays on the MissoulaReady website for public viewing.

3.3 Stakeholder Input

Developing the reliable and usable content at the heart of the HazardReady tool, as well as distribution and advertising of the live website, all rely on engagement from a wide range of stakeholders. Spatial data layers must be vetted by scientists and hazard experts with direct knowledge both of the hazards and of the best sources for current hazard analyses. Emergency response and preparedness information must be provided both by experts in hazard mitigation best practices and by emergency service providers with detailed knowledge of the service area. Finally, the form of data delivery, including the spatial queries and snuggest must be assessed and refined by users and user groups as well as experts in scientific communication. All of the served information must represent the most current and accurate hazard data and the mitigation best practices in order to be useful to users and to avoid legitimate legal liability exposure. Furthermore, stakeholders involved in content development can be expected to promote site usage because they will be confident in the quality and utility of the product. Two phases of stakeholder input were conducted, predevelopment and beta testing. The first before the application was created and the second after a draft version was developed, but had not been released to a wide audience.

In phase one, a panel of regional scientists, mainly faculty at the University of Montana, representing expertise in each of the significant hazards, met to identify key characteristics of each hazard that should be communicated, to discuss the meaning and calibration of relative hazard intensity measures, and to identify the best sources of spatial hazard data available at the time of development. This panel was instrumental in identifying the critical criteria for a multihazard outreach tool as: 1) scientific accuracy, 2) spatial granularity, 3) integration of information about all relevant hazards, 4) nontechnical content, 5) appropriate preparedness activities, and 6) engagement with existing disaster response and mitigation capabilities. The development phase also included a presentation and discussion with the Local Emergency Planning Committee (LEPC) for Missoula County with the aim of obtaining feedback on the overall concept and content map. The thirty members consisted of individuals involved in law enforcement, fire management, health and human services, weather forecasting, water supply, emergency management, and other relevant positions. A ten-minute discussion and detailed one-on-one meetings with selected individuals followed the presentation over several weeks.

In phase two, two separate focus groups were held to obtain specific input from the general public and experts on the translation of technical material and ease of application use. The first focus group consisted of seven members of the general public, the intended users. The second had ten expert members, professionals in Missoula County familiar with emergency planning, communication strategies, and/or local hazards and resources. Prior to attending, none of the participants had interacted with the website. Before viewing with the website participants were asked a series of questions about current understanding of hazard resources and local preparedness (Suppl. 2-1). The subjects were given twenty minutes to explore the website and were directed to click where interested, read through the content, and note issues or aspects they liked. After that time, they were asked a set of questions about the website and how it compares with current information, features they enjoyed, and areas for improvement. All dialogue was videotaped and transcribed for review.

3.4 Website Analytics

To gauge user interaction with the web application after public release Google Analytics, a web service that monitors site usage, was used. The public release consisted of two news articles in print and online, a press release, and two broadcast news reports on local television stations. Metrics we were interested in included how many individuals were using the site (number of users), how long interactions were (session duration), locations users viewed from, and general usage trends that include bounce rate (B_r) and total sessions (TS). A session is counted when a user interacts and is engaged with the website. If a user interacts with the site on multiple occasions each instance is counted as a session. A bounce is when the user arrives at the site and leaves from the same page. A bounce rate is the percentage of single page sessions (SPS).

$$B_r = \left(\frac{SPS}{TS}\right) \tag{1}$$

The target users for the MissoulaReady product are Missoula County residents. For analysis we looked at how the non-bounced users in Missoula County interacted with the application. The metrics used were session duration and number of users over time along with number of users who signed up for email alerts. We also looked at overall metrics inside and out of the county to understand the reach of the product and gauge interest in other locations. The metrics reflect information from the first 30 days after public release.

4 Outcomes/Results

4.2 Stakeholder Response

The LEPC members showed interest in supporting the project whether through continued meetings or testing a future product. Concerns included if the public would use the tool and long-term plans for maintenance. Suggestions were given to incorporate information to help manage public expectations of local authorities. To do this, a section called “A word from your emergency managers” was added as section two text. After this presentation, meetings with the wildland Fire Chief and NOAA weather expert were held to inform the snuggets for wildfire and weather.

Observations from the public and expert focus group included comments on personal preparedness, web application utility and value, suggestions for improvements, and favorite aspects (Table 2-6). Overall, members in the public group expressed that the website was intuitive with simple layout and that the content was easily accessible to a public audience. Members also enjoyed interactive ability of the map and the photographs of historic disasters in the area (Table 2-7). When asked if MissoulaReady would help people to prepare, the general response from both public and experts was possibly, but that more time and testing would be needed to confirm or deny. One public attendee said that even if preparedness actions were not taken, at least people would have access to the information. Members mentioned that much of the preparedness measures people take are completed after a disaster (local or global) occurs and the pre-emptive

Table 2-6. Stakeholder input and feedback

Topic	Public	Both	Expert
1. Perceived current level of personal and county preparedness	•Ranged from not at all to very prepared in group depending on past experiences		•Services fairly good except for when extreme events happen •Public not adequately prepared for specific disasters
2. Compared to currently available information MissoulaReady is…		•More comprehensive. It aggregates information	
3. Web tool clarity & ease of use	•Intuitive/user-friendly •Liked layout and map	•Spoke common language	•Too much information •Tabs could be made clearer
4. Intended user		•Public •New residents •Neighborhood councils	•Tool for local gov't to engage with public
5. Did available resources and natural hazards awareness increase?	•Yes, with earthquake hazard, general understanding of relevant hazards gained •Visited websites they hadn't been to before	•Historic events	•Most experts are involved in Local Emergency Planning Committee so fairly aware
6. Think it will help public be more prepared?	•Even if doesn't prepare at least people are aware	•Perhaps will help some people take preparedness steps •Don't know	
7. Favorite Aspects		•Historic events/ photos •Interactive ability of map	
8. Missing information /improvements	•Add links to local newspaper, Department of Transportation •Add personal stories or video clips and link to social media	•Add helpful sidebar with links •Incorporate real-time information	•Add printable basic fact sheet •Connect with schools/curriculum

Table 2-7. Selected focus group quotes

Topic	Focus Group Quotes
Layout and Content	"One of the things it (the application) did well was spoke a common language. It wasn't tied up with jargon." "It's accessible language. I don't have to look at complicated maps of radar."
Interactive Map	"I think it is super cool that I can put in my address." "I like the interactive map where you can click around and see different places"
Historic Information	"I really liked the historical part. I like to know what has happened in the past. It definitely gets people intrigued more talking about the past."

nature of this application may not lend itself to how individuals and communities have historically prepared.

Attendee recommendations for improving the MissoulaReady included making it accessible to blind and other disabled persons, adding links to resources that were not previously incorporated, and making a sidebar that consolidated the links. A number of people expressed that social media would be a good outlet to connect people with the site and to incorporate real-time information. Select expert group members suggested reducing the amount of text and adding more visuals to the site. These suggestions were incorporated in part by adding links, rephrasing text, modifying images, and developing an email sign up list to provide users with natural hazard alerts going forward. Some of the recommendations were not feasible within scope and scale of the project and were not applied.

4.3 Google analytics

Within the first thirty days of release there were page visits from 34 different U.S. states. Montana, Utah, and Washington had the three highest numbers of visitors. During this time there were a total of 809 users and 1,035 sessions. The average session time was 2 minutes and 16 seconds with an average bounce rate of 43.4 percent. When concentrating on user interactions specific to Missoula County, the metrics improve. Roughly 60 percent of users in the first month were individuals in Missoula County. Of this group, 65 percent engaged actively with the website and did not bounce (Fig. 2-9). The non-bounced users represent 0.3 percent of the Missoula County population (U.S. Census Bureau, 2014). For users who did not bounce, 54 percent interacted with the site for more than 1 minute, 29 percent for more than 3 minutes, and 9 percent for more than 10 minutes (Fig. 2-10). The average time for non-bounced Missoula users was 3 minutes and 37 seconds. That is 1 min and 21 seconds longer than the average for all users. The number of sessions fluctuated over the course of thirty days from release date with three spikes in session activity (Fig. 2-11). The largest spike occurred after the initial media coverage. The second occurred a few days later when a link o the website was added to the University of Montana Geoscience

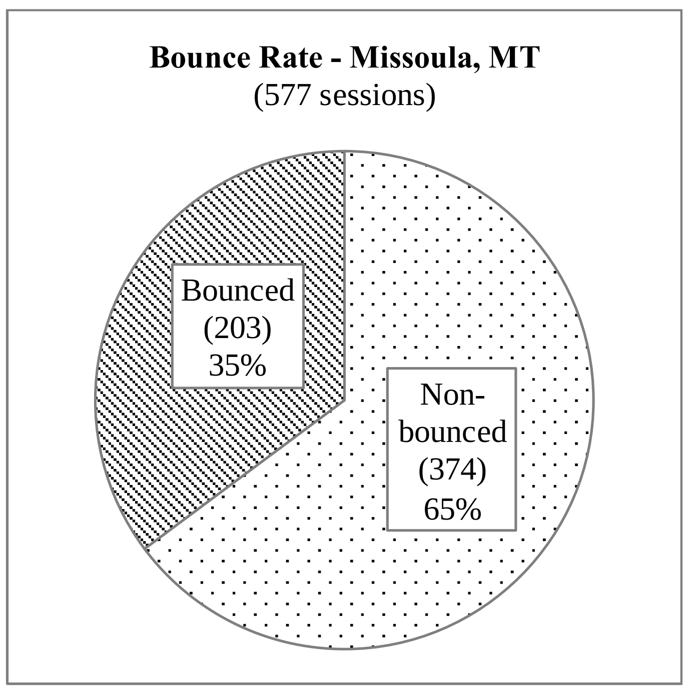
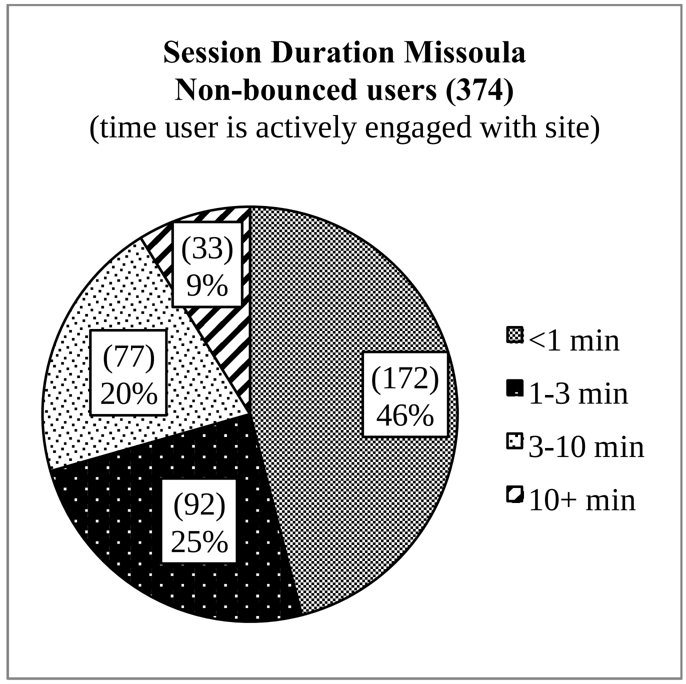


Figure 2-9. Google Analytics reports show that in the first month after the official launch of the website the total number of sessions on the MissoulaReady application from the Missoula region was a total of 577. Of that total 65% stayed on the site and interacted with it. A user who doesn't go past the homepage is considered to have bounced and not interacted with the site.

Figure 2-10. Users of MissoulaReady engaged with the site to varying degrees in terms of time spent viewing the site. Over a quarter of the users spent more than three minutes using the site. It is unlikely that those that spent less than a minute on the site were able to glean much information about their hazard risks. The group that spent over 3 minutes on the site were likely able to navigate through the tabs and interact with the site.



page. The third is the smallest and occurred after a talk was given to students about MissoulaReady and its' features. The general trend is a decrease in use over time. The subscription rate for email alerts started off high for the first week and leveled off over the course of the month. During the first week the number or registered users increased by rate of 20 percent each day. The second week dropped to a daily increase of 1.05 percent, with registration in the third and fourth week increasing by 0.17 percent each day (Fig. 2-12).

5 Discussion

The HazardReady application was developed to provide easily accessible natural hazard information to the general public while maintaining scientific accuracy. The four issues this application sought to address were, 1) natural hazard information is spread out, 2) it is often physically or technically inaccessible, 3) risk is rarely paired with preparedness information, and 4) it is difficult to obtain location specific hazard information. MissoulaReady, the resulting product created for Missoula County, addressed all of these items to varying degrees. This application serves as an aggregator for Missoula County natural hazard information that is currently dispersed and held by different agencies. It translates the information into easily understood language and includes information specific to a searched location.

5.1 Stakeholder Insights

The primary outcome from the focus groups was that the HazardReady platform made technical hazard information accessible for public audiences. It was clear that people enjoyed being able to search their specific location. This could prove a beneficial way of communicating natural hazard information. The suggestion of adding real-time information was popular in both focus groups and could be a technique to maintain user engagement with the HazardReady application. Conversations from the focus groups provide ample material to generate a second version of HazardReady that incorporates real-time information, reduces text, increases graphics, and includes more location

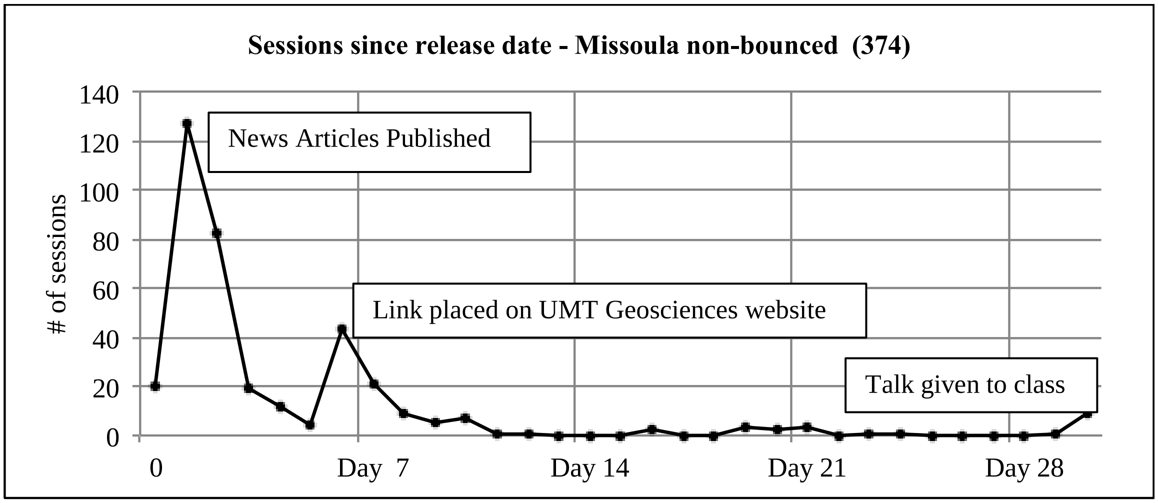


Figure 2-11. The number of sessions spiked in the first few days as media picked up the launch of the website, when a link was placed on the geosciences homepage as well as when a talk was given about the project. We anticipate that future spikes will occur when disasters happen globally or locally as that is when concern about these topics increases.

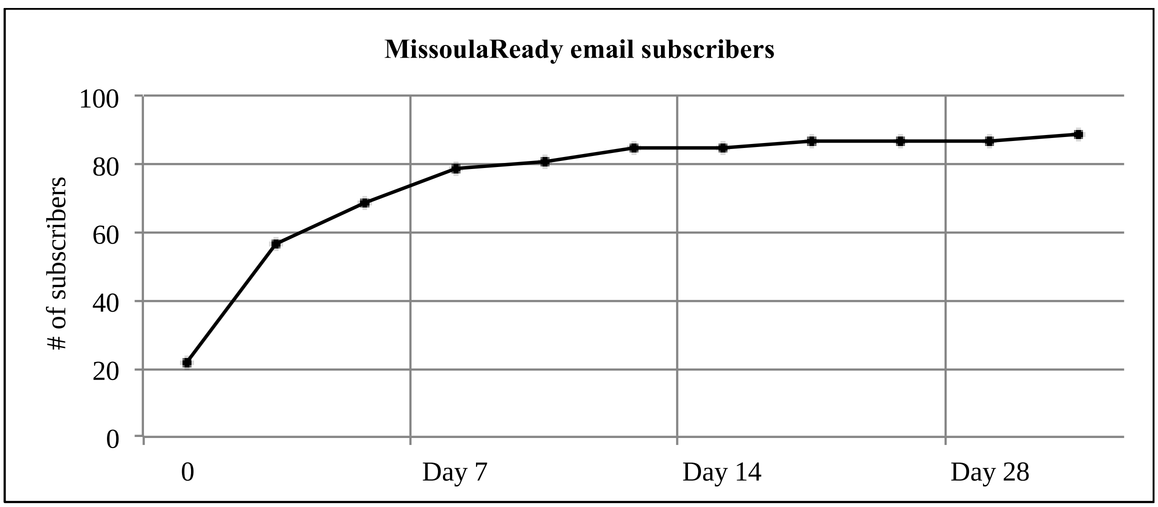


Figure 2-12. The number of people who subscribed for email alerts shows a positive trend that is leveling off.

specific information. Time is needed to investigate how individuals use this application, especially if it is promoted in conjunction with emergency mitigation outreach currently being done by Missoula County OEM. We anticipate that local events will drive traffic to the site episodically.

5.2 What do the analytics mean?

It was surprising that users of the MissoulaReady website spanned 34 states since content is Missoula County specific. This is promising in that it suggests interest in the HazardReady tool elsewhere. The overall bounce rate of 43.9 percent for all users is reasonable for content-based websites with average bounce rates for such sites of about 50 percent (conversionvoodoo.com, 2013; kissmetrics.com, 2010; techwyse.com, 2016).

The bounce rate for Missoula County residents at 35 percent is low and suggests that visitors to the MissoulaReady website are interested and intending to explore and engage with the information.

Session duration for non-bounced Missoula users shows that about half of the people interacted long enough to glean information from the site. We assume that the 46 percent of non-bounced users who spent less than a minute on the site gained little, if any, information. Conversely, the 54 percent who spent more than a minute may have absorbed some of the natural hazard and preparedness information. User surveys are needed to address the specifics on how people interacted with the site and to understand what extent of knowledge was gleaned. The analytics over the first month imply that for a location-based web application such as this, initial interest exists that brings users to the website, but with time popularity falls. This is not unexpected. Without real-time information, there is little “hook” for people to return to the site. This is not necessarily a negative outcome. If people access the relevant information during one session they need not return, especially if they sign up for email alerts. The spikes in usage that correspond with publicity indicate that repeated announcements and sustained outreach will be required to maintain or increase the number of site visitors. We anticipate future spikes in usage, as floods, fire, earthquakes and other disasters occur to bring natural hazard risks into public consciousness.

5.3 Outcomes

5.3.1 Limitations and challenges

A key limitation of the HazardReady product is that information supplied to the user is only as good as the available data. For Missoula County the available data varied in quality depending on hazard. Flood hazard was well documented with recent floodplain maps and channel migration studies for local rivers, whereas earthquake shaking potential had poor resolution for the research area and lacked substantial data to improve it. In these cases scientific expertise helped determine how to incorporate data in a manner that represented the best understanding of hazards for the region. The issue of data quality will be a recurring challenge for developing HazardReady in new regions whether it is in data-rich or data-poor settings.

A second aspect of HazardReady that may pose challenging is how to keep the information up-to-date. The release of publically available data is irregular and mitigation measures may change over time. Continued funding will need to be acquired to ensure that updates to data and content can happen at regular intervals going forward, especially if multiple HazardReady sites are developed.

This study would be strengthened by pre-use and post-use tests for those using MissoulaReady to better understand who is using the site, how they are interacting with site features, and what knowledge they gain. A second aspect that would strengthen MissoulaReady is to make it fully accessible for disabled persons. This was not done due to time and monetary constraints, but should be considered for future HazardReady iterations.

5.3.2 Benefits

The first benefit of the development of the MissoulaReady tool is the comprehensive assessment of local hazard information. For Missoula, this analysis was valuable for understanding where the major gaps in information exist and highlighting areas where future study and research are needed. The same would prove true of any area where a HazardReady tool was developed.

The second benefit is the adaptable nature of the HazardReady framework. The ability to input any type of geographically based data and translate them for the public makes the possible uses of this tool wide-ranging. Whether it is communicating natural hazard risks, future sea levels, or spread extents of viruses, the translation of technical datasets into a simple format can prove valuable.

The third benefit is the stakeholder connections. The development of MissoulaReady requires collaboration between researchers, practitioners, and the public making the potential for its' use much greater than if we had developed it solely using university resources. The connection with the Missoula OEM resulted in them recently including our link on their website. We anticipate that linking it to a higher traffic website like the OEM will increase usage and the number of people signed up for email alerts. Development of the HazardReady tool for other regions will require more connections to be made and only serves to strengthen hazard mitigation efforts.

This study highlights the need for natural hazard scientists to work alongside communications experts, psychologists, educators, and the public to address the existing gap between the scientific knowledge of hazard risks, public understanding, and mitigation practices. This challenging cross-disciplinary work will become necessary in the coming years as population and number of disasters increase. HazardReady creates a platform for this work to begin.

6 References

Allen, I. E. and Seaman, J.: Changing course: ten years of tracking online education in the United States., 2013.

American Lung Association: Most Polluted Cities: By Short-Term Particle Count: http://www.lung.org/our-initiatives/healthy-air/sota/city-rankings/most-polluted-cities.html, last access: 31 May 2016.

Atkins: Pre-Disaster Mitigation Plan 2011 Update, Missoula County and City of Missoula, 2011.

Bakun, W. H.: MMI attenuation and historical earthquakes in the basin and range province of western North America, Bull. Seismol. Soc. Am., 96(6), 2206–2220, doi:10.1785/0120060045, 2006.

Boyd, K.: Clark Fork River Channel Migration Pilot, Applied Geomorphology and DTM Consulting Inc., Missoula County, MT, 21 pp., 2009.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J. and Mitchell, R. B.: Knowledge systems for sustainable development., Proc. Natl. Acad. Sci. U. S. A., 100, 8086–8091, doi:10.1073/pnas.1231332100, 2003.

Conversion Voodoo, How does your bounce rate match up to others in your industry?,

http://www.conversionvoodoo.com/blog/2013/04/how-does-your-bounce-rate-match-up-to-others-in-your-industry/, last access: May 2016, 2013.
Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J. D., Jäger, J., Chabay, I., de Wit, B., Langlais, R., Mills, D., Moll, P., Otto, I. M., Petersen, A., Pohl, C. and van Kerkhoff, L.: Opening up knowledge systems for better responses to global environmental change, Environ. Sci. Policy, 28, 60–70, doi:10.1016/j.envsci.2012.11.008, 2013.
Dai, F. C. and Lee, C. F.: Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong, Geomorphology, 42(3-4), 213–228, doi:10.1016/S0169-555X(01)00087-3, 2002.
Demir, I. and Krajewski, W. F.: Towards an integrated Flood Information System : Centralized data access , analysis , and visualization, Environ. Model. Softw., 50, 77–84, doi:10.1016/j.envsoft.2013.08.009, 2013.
Eisenman, D. P., Cordasco, K. M., Asch, S., Golden, J. F. and Glik, D.: Disaster planning and risk communication with vulnerable communities: lessons from Hurricane Katrina., Am. J. Public Health, 97(Supp 1), doi:10.2105/AJPH.2005.084335, 2007.
FEMA: Hazard Mitigation Assistance Guidance, Washington, DC. [online] Available from: http://www.fema.gov/media-library-data/20130726-1737-25045-4275/final_june_1_2010_hma_unified_guidance_09252012a_508.pdf, 2015.
Gabet, E. J. and Bookter, A.: A morphometric analysis of gullies scoured by post-fire progressively bulked debris flows in southwest Montana, USA, Geomorphology, 96, 298–309, doi:10.1016/j.geomorph.2007.03.016, 2008.
Haas, J. R., Calkin, D. E. and Thompson, M. P.: A national approach for integrating wildfire simulation modeling into Wildland Urban Interface risk assessments within the United States, Landsc. Urban Plan., 119, 44–53, doi:10.1016/j.landurbplan.2013.06.011, 2013.
Haer, T., Botzen, W. J. W. and Aerts, J. C. J. H.: The effectiveness of flood risk communication strategies and the influence of social networks—Insights from an agent-based model, Environ. Sci. Policy, 60, 44–52, doi:10.1016/j.envsci.2016.03.006, 2016.
Hassol, S. J.: Improving how scientists communicate about climate change, Eos (Washington. DC)., 89(11), 106–107, doi:10.1029/2008EO110002, 2008.
Haynes, K., Barclay, J. and Pidgeon, N.: Volcanic hazard communication using maps: An evaluation of their effectiveness, Bull. Volcanol., 70, 123–138, doi:10.1007/s00445-007-0124-7, 2007.
Hong, Y., Adler, R. and Huffman, G.: Use of Satellite Remote Sensing Data in the Mapping of Global Landslide Susceptibility, Nat. Hazards Spec. Issue, Use of Sat, 2016.
Howell, B.F. Jr., Schultz, T. R.: Attenuation of modified mercalli intensity with distance from the epicenter, , 65(3), 651–665, 1975.
Hutto, R. L.: The Ecological Importance of Severe Wildfires: Some like It Hot, Ecol. Appl., 18(8), 1827–1834 [online] Available from: http://www.jstor.org/stable/27645904, 2008.
Iwahashi, J., Watanabe, S. and Furuya, T.: Mean slope-angle frequency distribution and size frequency distribution of landslide masses in Higashikubiki area, Japan,

Geomorphology, 50(4), 349–364, doi:10.1016/S0169-555X(02)00222-2, 2003.

Kargel, J. S., Leonard, G. J., Shugar, D. H., Haritashya, U. K., Bevington, A., Fielding, E. J., Fujita, K., Geertsema, M., Miles, E. S., Steiner, J., Anderson, E., Bajracharya, S., Bawden, G. W., Breashears, D. F., Byers, A., Collins, B., Dhital, M. R., Donnellan, A., Evans, T. L., Geai, M. L., Glasscoe, M. T., Green, D., Gurung, D. R., Heijenk, R., Hilborn, A., Hudnut, K., Huyck, C., Immerzeel, W. W., Jiang Liming, Jibson, R., Kääb, A., Khanal, N. R., Kirschbaum, D., Kraaijenbrink, P. D. A., Lamsal, D., Liu Shiyin, Lv Mingyang, McKinney, D., Nahirnick, N. K., Nan Zhuotong, Ojha, S., Olsenholler, J., Painter, T. H., Pleasants, M., Kc, P., Yuan, Q. I., Raup, B. H., Regmi, D., Rounce, D. R., Sakai, A., Shangguan Donghui, Shea, J. M., Shrestha, A. B., Shukla, A., Stumm, D., van der Kooij, M., Voss, K., Wang Xin, Weihs, B., Wolfe, D., Wu Lizong, Yao Xiaojun, Yoder, M. R. and Young, N.: Geomorphic and geologic controls of geohazards induced by Nepal's 2015 Gorkha earthquake., Science (80-.)., 351(6269), 141–151, doi:10.1126/science.aac8353, 2016.

Karkanen, S.: Mount Jumbo Avalanche Accident, Missoula, MT., 2014.

Keaton, J. R., Wartman, J., Anderson, S., Benoit, J., DeLaChapelle, J., Gilbert, R., Committee, S. and Montgomery, D. R.: The 22 March 2014 Oso Landslide, available from: http://snohomishcountywa.gov/DocumentCenter/View/18180, 2014.

Kissmetrics.com, Bounce Rate Demystified, https://blog.kissmetrics.com/bounce-rate/, last access: May 2016, 2010.

LaHusen, S. R., Duvall, A. R., Booth, A. M. and Montgomery, D. R.: Surface Roughness Dating of Long-Runout Landslides near Oso, Washington (USA), Reveals Persistent Postglacial Hillslope Instability, Geology, (m), 1–4, doi:10.1130/G37267.1, 2015.

Larsen, I. J. and Montgomery, D. R.: Landslide erosion coupled to tectonics and river incision, Nat. Geosci., 5(7), 468–473, doi:10.1038/ngeo1479, 2012.

Leonard, M.: Earthquake fault scaling: Self-consistent relating of rupture length, width, average displacement, and moment release, Bull. Seismol. Soc. Am., 100(5 A), 1971–1988, doi:10.1785/0120090189, 2010.

Lombardo, K., Boggs, J., Bodreau, H. J., Chilles, P., Erickson, J., Gerstel, W., Montgomery, D., Shipman, L., Radcliff-Sinclair, R., Strachan, C. S., Trimm, B. and Sugimura, D.: The SR 530 Landslide Commission. Available from: http://www.governor.wa.gov/sites/default/files/documents/SR530LC_Final_Report.pdf, 2014.

Mani, L., Cole, P. D. and Stewart, I.: Using video games for volcanic hazard education and communication, NHESS Discuss., doi:10.5194/nhess-2016-23, 2016.

Miller, D. J. and Sias, J.: Deciphering large landslides: linking hydrological, groundwater and slope stability models through GIS, Hydrol. Process., 12, 923–941, doi:10.1002/(SICI)1099-1085(199805)12:6<923::AID-HYP663>3.0.CO;2-3, 1998.

Mossoux, S., Delcamp, A., Poppe, S., Michellier, C., Canters, F. and Kervyn, M.: Hazagora : will you survive the next disaster ? – A serious game to raise awareness about geohazards and disaster risk reduction, , 16, 135–147, doi:10.5194/nhess-16-135-2016, 2016.

National Oceanic and Atmospheric Association (NOAA): Storm Events Database-Results for Missoula County, Montana 1/1/50-2/28/2016, National Centers for Environmental Information (NCEI): http://www.ncdc.noaa.gov/stormevents/, last access: 31 May 2016.
Ozener, H., Zerbini, S., Bastos, L., Becker, M., Meghraoui, M. and Reilinger, R.: WEGENER: World earthquake GEodesy network for environmental hazard research, J. Geodyn., 67, 2–12, doi:10.1016/j.jog.2012.12.005, 2013.
Parrett, C., Cannon, S. and Pierce, K.: Wildfire-Related Floods and Debris Flows in Montana in 2000 and 2001, , 1–22, 2004.
PEW Research Center; Technology Device Ownership: 2015, http://www.pewinternet.org/2015/10/29/technology-device-ownership-2015/, last access: March 2016, 2015.
Regional Economic Models Inc. (REMI): Montana County Population Projections-County Comparisons, 1990-2060, http://ceic.mt.gov/Population/PopProjections_StateTotalsPage.aspx, last access March 2016, 2013.
Richard Eiser, J., Bostrom, A., Burton, I., Johnston, D. M., McClure, J., Paton, D., van der Pligt, J. and White, M. P.: Risk interpretation and action: A conceptual framework for responses to natural hazards, Int. J. Disaster Risk Reduct., 1, 5–16, doi:10.1016/j.ijdrr.2012.05.002, 2012.
Schweizer, S., Thompson, J. L., Teel, T. and Bruyere, B.: Strategies for Communicating About Climate Change Impacts on Public Lands, Sci. Commun., 31, 266–274, doi:10.1177/1075547009352971, 2009.
Shannon and Associates: Report on Slide on North Fork Stillaguamish River Near Hazel, WA, Department of Game and Fisheries, Seattle, WA., 1952.
Shen, B. S. P.: Science Literacy Views Public understanding of science is becoming vitally needed in developing and industrialized countries alike, Am. Sci., 63(3), 265–268, 1975.
Somerville, R. C. J. and Hassol, S. J.: Communicating the science of climate change, Phys. Today, 64(10), 48–53, doi:10.1063/PT.3.1296, 2011.
Stickney, M. C. and Bartholomew, M. J.: Seismicity and Late Quaternary Faulting of the Northern Basin and Range Province, Montana and Idaho, Bull. Seismol. Soc. Am., 77(5), 1602–1625, 1987.
Stickney, M. C., Haller, K. M. and Machette, M. N.: Special Publication No. 114: Quaternary Faults and Seismicity in Western Montana Map, 2000.
Susan L Cutter, Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E. and Webb, J.: A place-based model for understanding community resilience to natural disasters, Glob. Environ. Chang., 18, 598–606, doi:10.1016/j.gloenvcha.2008.07.013, 2008.
Techwyse.com, What is a good analytics bounce rate?, https://www.techwyse.com/blog/website-analytics/improving-website-bounce-rates/, last access: May 2016, 2010.
Tetra Tech: 2013 Update State of Montana Multi Hazard Mitigation Plan and Statewide Assessment, Montana Department of Military Affairs Disaster and Emergency Services, Helena, MT, 2013.
Thompson, M. P., Haas, J. R., Gilbertson-Day, J. W., Scott, J. H., Langowski, P., Bowne, E. and Calkin, D. E.: Development and application of a geospatial wildfire

exposure and risk calculation tool, Environ. Model. Softw., 63, 61–72, doi:10.1016/j.envsoft.2014.09.018, 2015.
Thorsen, G. W.: Memorandum: Landslide of January 1967 which diverted the North Forl of the Stillguamish River near Hazel, Olympia, WA., 1969.
United Nations: Sendai Framework for Disaster Risk Reduction 2015-2030, Geneva, Switzerland, 2015.
United States Census Bureau (USCB): State and County QuickFacts- Missoula city & Missoula County, quickfacts.census.gov/qfd/states, last access: December 2014, 2013.
United States Congress: Healthy Forests Restoration Act. [online] Available from: http://www.fs.fed.us/emc/applit/includes/hfr2003.pdf, 2003.
United States Geological Survey (USGS), USGS Significant Earthquake Archive: Haiti Region (2010), Near E. Coast of Honshu, Japan (2010), Off West Coast of N. Sumatra (2004) http://earthquake.usgs.gov/earthquakes/eqinthenews, last access: October 2014.
Van Kerkhoff, L. and Lebel, L.: Linking Knowledge and Action for Sustainable Development, Annu. Rev. Environ. Resour., 31, 445–477, doi:10.1146/annurev.energy.31.102405.170850, 2006.
VanWesten, C. J., Rengers, N. and Soeters, R.: Use of geomorphological information in indirect landslide susceptibility assessment RID A-4043-2010, Nat. Hazards, 30(3), 399–419, doi:10.1023/B:NHAZ.0000007097.42735.9e, 2003.
Wallace, G., Reeves, S., Ellis, J.: Missoula County Community Wildfire Protection Plan, Missoula County Office of Emergency Services, Missoula, MT, 2005.
Wilde, E. M., Sandau, K. L., Kennelly, P. J. and Lopez, D. A.: Compilation of Landslide Location Maps and Index for Identification of Slide-Prone Areas : A Pilot Study for the Butte District., 2002.
Woelfle-Erskine, C., Wilcox, A. C. and Moore, J. N.: Combining historical and process perspectives to infer ranges of geomorphic variability and inform river restoration in a wandering gravel-bed river, Earth Surf. Process. Landforms, 37(12), 1302–1312, doi:10.1002/esp.3276, 2012.
Wondzell, S. M. and King, J. G.: Postfire erosional processes in the Pacific Northwest and Rocky Mountain regions, For. Ecol. Manage., 178(1-2), 75–87, doi:10.1016/S0378-1127(03)00054-9, 2003.
Wong, I., Olig, S., Dober, M., Wright, D., Nomser, E., Lageson, D., Silva, W., Stickney, M., Lemiux, M., Anderson, L.: Probabilistic Earthquake Hazard Maps for the State of Montana, Special Publication 117, Montana Bureau of Mines and Geology, 2005.

Supplement 2-1. MissoulaReady- Focus Group Questions

Expert Users (county and city officials and staff)
8-10 people, ~2 hours
iPads, notepads, pens, and baked goods provided

Introduction: "Hello and thank you for coming to this focus group looking at MissoulaReady, a disaster preparedness website for Missoula County Residents. My name is Carson and I am a graduate student at the University of Montana interested in how scientists can communicate their science to the public in a more useful way. We got you all together today to get feedback on this website my advisor, myself and two web developers created in order to make it as useful as possible and understand how it couple be improved. Before we start, I want to briefly explain the product to give you an idea of what it is and what it does. This website is meant for Missoula Residents to gain location specific information about the top 6 natural hazards they may be at risk for. To create this website we have sourced publically available county data, like flood maps and earthquake fault locations that create the backend/behind the scenes information that powers this site. Text is then paired with the data and displayed to the user. Today that will be you all.

The aim of this tool is to help educate people about their risks and provide county specific information on steps they can take to prepare. With this group we want to get specific feedback on what this tool does well, what could be improved or expanded, and understand if we've left anything out from a government or emergency officials stand point. Since this group has experience with how Missoula County runs and operates, we felt that you were a necessary group to get feedback from. Thank you for your participation. We encourage you to give honest and practical feedback as that is the only way we can adapt MissoulaReady to make it is best and most useful tool so don't hold back!

The way this focus group will works is I will ask you to navigate to something on the website and we will have some questions to answer before and after looking at the website. Before we get started I want to remind you that your responses will never be connected with your names and identifying information will be removed for presentations and publications. We have some informed consent forms for you to sign so you know how the focus group information will be used and your rights as a member of the focus group. After you fill these out we will go over some questions before we look at the website. Then I will guide you around the website and we will get feedback as we go. Thank you again for being here. Does anyone have any questions before we start?"

Pre activity questions (asked to entire group):

1. Where do you currently find information on natural hazards in Missoula County?
2. Is the information you need readily available?
3. For you, as a county or city employee, what are the two most important things that you've learned about natural hazards in Missoula?
4. What are the two most important things that you'd like members of the public to know about natural hazards in Missoula?

5. When you think about natural hazards in Missoula, how prepared do you think the city or county is?
6. When you think about natural hazards in Missoula, how prepared do you think you are as an individual?
7. Do you have an emergency supply kit at your home with non-perishable food, water, and other items? Why or why not?

Activity

"Here are IPads which you will be using to view this site. I am also handing out some pens and notepads. Please use these notepads to jot down thoughts or ideas as you go."

Instructions:

Please spend 10-15 minutes exploring the website. Please take notes on what you like and don't like, what could be improved, what is missing, how the information is presented – really any feedback you have. Feel free to talk with your neighbors while you are exploring the site.

1. *Everyone go to Hazardready.org and read the home page information.*
2. *Use mouse on map to double click a location or type in an address to navigate to a location in Missoula County you are interested in (Ex: home, where you work, where you go hiking, etc.)*
3. *Click a few locations (ex. close to a river, up on a hill, in a neighborhood) and see how the text and hazard scales change.*
4. *Check out what the various tabs have to say.*
5. *Go to the bottom of the page and click on some of the data layers.*

Post-Activity Questions

1. What are your initial impressions about the site?
2. How does this site compare to your current sources of information on natural hazards in the county?
3. What did you learn about natural hazards in Missoula that you didn't already know?
4. What groups of people do you think would find this site useful?
5. Do you think this site will help the city and county be more prepared for natural hazards?
6. Do you think it will help members of the public be more prepared?
7. Was there anything confusing or anything that didn't make sense?
8. Was there any information that was missing?
9. Do you have any other suggestions for the site?

Public Group
8-10 people, ~2 hours
iPads, notepads, pens, and baked goods provided

Introduction: "Hello and thank you for coming to this focus group looking at MissoulaReady, a disaster preparedness website for Missoula County Residents. My name is Carson and I am a graduate student at the University of Montana interested in how scientists can communicate their science to the public in a more useful way. We got you all together today to get feedback on this website my advisor, myself, and two web developers created in order to make it as useful as possible and understand how it couple be improved. Before we start, I want to briefly explain the product to give you an idea of what it is and what it does. This website is meant for Missoula Residents to gain location specific information about the top 6 natural hazards they may be at risk for. To create this website we have sourced publically available county data, like flood maps and earthquake fault locations that create the backend/behind the scenes information that powers this site. Text is then paired with the data and displayed to the user. Today that will be you all.

The aim of this tool is to help educate people about their risks and provide county specific information on steps you can take to prepare. With this group we want to get specific feedback on how easy to use the website is, if anything is confusing, if it is interesting and has helpful information, and how likely you would be to take preparedness steps after using it. Since this would be similar to those who are actually using this site we felt that you were a necessary group to get feedback from. Thank you for your participation. We encourage you to give honest and practical feedback as that is the only way we can adapt MissoulaReady to make it is best and most useful tool so don't hold back!

The way this focus group will works is I will ask you to navigate to something on the website and we will have some questions to answer before and after looking at the website. Before we get started I want to remind you that your responses will never be connected with your names and identifying information will be removed for presentations and publications. We have some informed consent forms for you to sign so you know how the focus group information will be used and your rights as a member of the focus group. After you fill these out we will go over some questions before we look at the website. Then I will guide you around the website and we will get feedback as we go. Thank you again for being here. Does anyone have any questions before we start?

Pre activity questions (asked to entire group):

1. Where do you currently find information on natural hazards in Missoula County?
2. Is the information you need readily available?
3. What are the two most important things that you, as a member of the public, need to know about natural hazards in Missoula?
4. When you think about natural hazards in Missoula, how prepared do you think you are as an individual?
5. Do you have an emergency supply kit at your home with non-perishable food, water, and other items? Why or why not?

Activity

"Here are iPads which you will be using to view this site. I am also handing out some notepads. Feel free to jot down thoughts or ideas as you go."

Instructions:

Please spend 10-15 minutes exploring the website. Please take notes on what you like and don't like, what could be improved, what is missing, how the information is presented – really any feedback you have. Feel free to talk with your neighbors while you are exploring the site.

1. *Everyone go to Hazardready.org and read the home page information.*
2. *Use mouse on map to double click a location or type in an address to navigate to a location in Missoula County you are interested in (Ex: home, where you work, where you go hiking, etc.)*
3. *Click a few locations (ex. close to a river, up on a hill, in a neighborhood) and see how the text and hazard scales change.*
4. *Check out what the various tabs have to say.*
5. *Go to the bottom of the page and click on some of the data layers.*

Post-Activity Questions

1. What are your initial impressions about the site?
2. What did you learn about natural hazards in Missoula County that you didn't already know?
3. Did you find this site useful?
4. Do you think this site will help members of the public be more prepared for natural hazards?
5. Was there anything confusing or anything that didn't make sense?
6. Was there any information that was missing?
7. Do you have any other suggestions for the site?

Chapter 3: Data selection, assessment, and modification

1 Data quality assessment and process

The data that power the HazardReady application must be appropriate for the location of interest and represent the best science available to ensure the disseminated information is accurate. It is imperative that the data selection process includes assessment of significant hazards and relevance, quality, density/sparseness, and resolution of data. Incorporating substandard or non-representative data negates the purpose of the HazardReady tool, which is to impart the best available information to the public. In some regions poor quality data may be the only information available. In this case, expertise is needed to determine if acquired data can be modified to denote risk, or if a specific hazard should be removed due to lack of quality information.

The five sections below outline steps established to select high-quality data for use in the MissoulaReady application as well as actions to take when data are absent or quality is poor (Fig. 3-1). These steps can be followed for developing the HazardReady application for any Area of Interest (AOI) and are as follows, (1) to define relevant hazards for the AOI, (2) to acquire data that represent hazard risk or historical occurrence, (3) to collect data from reliable sources, (4) to assess quality of data with respect to the AOI, and (5) to determine what level of modification or file generation is appropriate. This process results in a set of data layers that represent the best available natural hazard information and are tailored to a specific region.

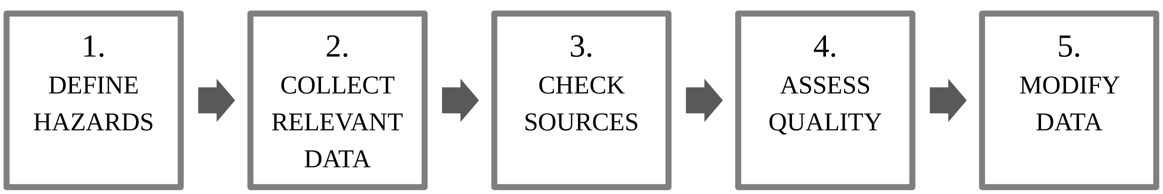


Figure 3-1. Flow chart of criteria used to select and quality check the data used to power the MissoulaReady application.

1.2 Step 1: Define Hazards

The first step in selecting data is to determine which hazards are relevant to the region of interest. For MissoulaReady this was done using the local hazard assessment for the Missoula County which outlined and ranked local hazards (Atkins, 2011). The method for ranking hazards was assessed to ensure relevant factors were incorporated and that data used in this document were adequate to represent risk. The Pre-Disaster Mitigation Plan measures overall risk (R) as the combination of frequency of events (F), potential impact (I), and potential for casualties (C),

$$F(I + C) = R \quad (1)$$

High values signify greater risk. This method for measuring risk is consistent with previous studies (Roberts et al., 2009; United Nations Department of Humanitarian Affairs, 1992; Villagran De Leon, 2006). For a region lacking a hazard risk assessment, accepted methods for quantifying natural hazard risk will need to be performed prior to data selection. Regional characteristics will dictate the numbers of hazards to incorporate into the tool, for Missoula County, the six leading hazards were selected. The process of data selection begins only after the relevant hazards are determined.

1.3 Step 2: Relevant data

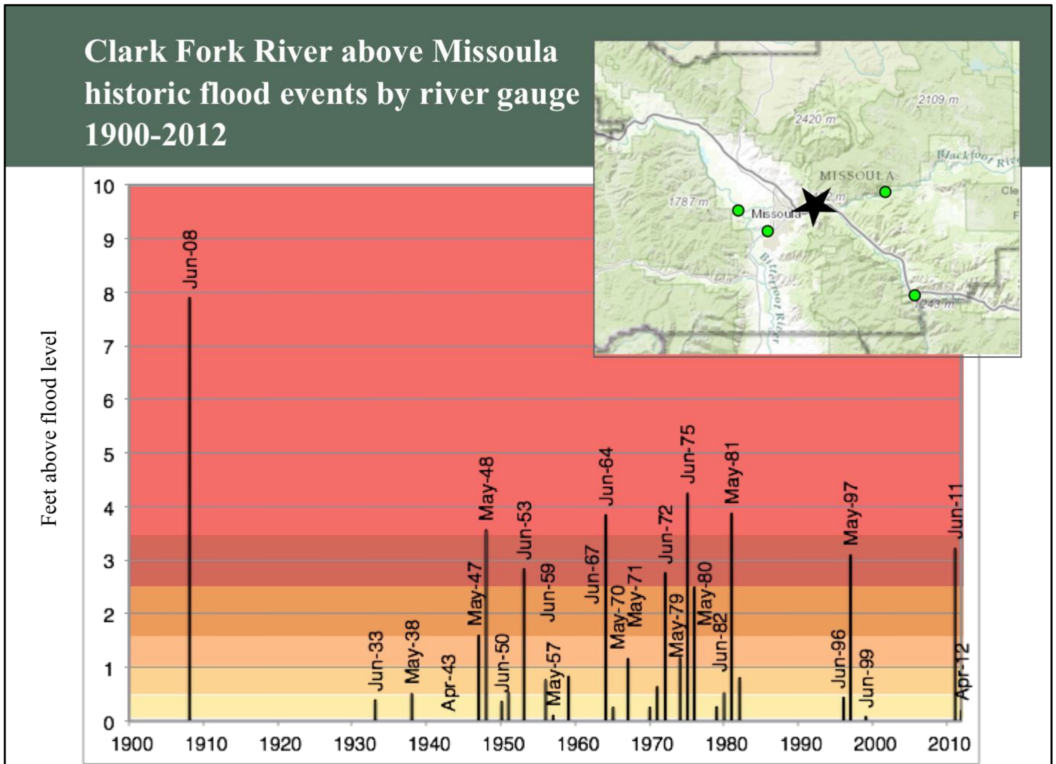
The primary data types acquired for HazardReady are those representing either spatial hazard risk (during a 30-year timeframe, e.g., lifetime of a mortgage) or historical distribution of natural disasters. The former typically includes probabilistic estimates derived from models that depict ground shaking (Petersen et al., 2014; Wong et al., 2004), floodplain boundaries (FEMA, 2015), or burn prone zones (FPA & USFS, 2014). The latter can be point or extent locations of events such as earthquake epicenters, flood inundation zones, or burn areas. To address uncertainty associated with hazard risk estimates, data that could be adapted to show worst-case scenarios were also acquired. These serve as upper bounds for potential disasters while the typical (30-year timeframe) data serve as lower bounds. See section on data modification below for more details.

If spatial historical data were missing, but numerical data existed, they were used to provide information to the public. In Missoula County the only available historical flood information was gauge data showing crest heights, date, and flood stage for the Clark Fork, Bitterroot, and Blackfoot Rivers (NWS, 2016). These data were used to generate files with graphs showing gauge levels with respect to measurement date (Fig. 3-2). Details of risk at each gauge level were written in plain language based on NOAA descriptions. These files can be accessed through links in the Past Events section of the flood hazard tab. The MissoulaReady user is able to select which historical river information is of interest to them.

Some of the available data for local hazards did not explicitly indicate risk, but were valuable for informing the public and were modified to do so. For example, local active fault traces do not depict earthquake risk, but when paired with the studied relationship between shaking and fault distance (Bakun, 2006; Howell, B.F. Jr., Schultz, 1975; Pasolini et al., 2008) a better understanding of earthquake hazard can be gleaned. Modified Mercalli Intensity is greater proximal to a fault and decreases with distance. With this understanding the fault data (USGS & NMBMMR, 2006) were buffered by one-mile intervals up to five miles. When this shapefile is queried it provides users with information on how close, active, and well studied the nearest fault is. The examples above highlight that non-spatial or imperfect data types can still provide useful information for the HazardReady application and should not be overlooked. Expertise is needed to resolve which data types have significance and which are irrelevant.

1.4 Step 3: Data source

The data were obtained from credible sources to ensure high quality information was used. Sources include national databases, government agencies, or data published in peer-reviewed journals. If the source of data was missing, the dataset was not used. Metadata for each dataset was used to assess if methods for data collection or model generation



Height above action stage	Description
>3.5ft	**Major Flood Stage:** Wide spread flooding from east missoula to the Bitterroot River is possible. Flood prone areas include U.S. Highway 10 east of Missoula, low lying homes along Rattlesnake Creek, East Front Street and homes in the lower south Third Street area. Extensive flooding in the Orchard Homes area continues.
>2.5ft	**Moderate Flood Stage:** Flood waters are now flooding numerous streets and homes in the Orchard Homes area. The following streets are being flooded, Kahrwald Drive, Channel Drive, Tower Street, Nancy Lou Drive, Keck Street and Stone Street.
>1.5ft	**Moderate Flood Stage:** Flooding is possbile along the clark fork river from reserve street through the orchard homes residential area toward the confluence with the Bitterroot River near Kelly Island. Flood waters are now flooding Tower street, Kahrwald Drive and Channel Drive with 10 to 15 homes being flooded.
>1ft	**Flood Stage:** Flood waters surround home owners property on Kahrwald Drive with water flowing down the streets.
>0.5ft	**Flood Stage:** Flooding of low lying areas adjacent to the river is possible. Flood waters begin to flood streets in the Orchard Homes area, specifically the north end of tower street including Kahrwaldt drive.
>0ft	**Action Stage**: The stage which represents the level where the NWS needs to take some type of mitigation action in preparation for possible significant hydrologic activity. The type of action taken varies for each gage location.

Data and information
"Advanced Hydrologic Prediction Service-Clark Fork above Missoula, MT," National Weather Service Missoula Forecast Office, NOAA,,August 2015, accessed Feb 2016.

Figure 3-2. Example historic flood graph. This shows the historic flood occurrence for the Clark Fork River running through Missoula County. The graph provides a visual of flood occurrence over time while the key and text below provides information about what areas would be impacted and the results of each flood stage.

aligned with best practices. This was based on literature review completed for each hazard type. Apart from where data were sourced, priority was also given to data from recent studies. If the only obtainable data was old, but signified risk according to present day best practices, they were used. This was true for the burn probability data (FPA & USFS, 2014), which was based off of 2010 ground conditions and 2014 weather information. The model used to create this dataset is still in use, but until a run with updated ground conditions is completed, this is the best available data for Missoula County. It is important to note that the use of older data can introduce inaccuracy. Burn probability values for areas that have burned since 2010 will not contain values representative of current wildfire hazard potential, while areas with static ground conditions since 2010 will likely maintain similar risk values. This is a challenging issue to address but can be remedied by updating shapefiles as new data are published, including a disclaimer on the website, and making metadata accessible for users.

1.5 Step 4: Data quality

The quality of data was an important consideration for data selection. The term quality is used here to mean the ability of collected data to represent accurate natural hazard information for Missoula County. Quality was assessed by analyzing original datasets for scale, resolution, density, and sparseness of data. Original datasets were developed for variety of extents including the United States, Montana State, and Missoula County. Data with more detailed source scales (e.g., 1:24,000 scale) were given priority over data with less detailed source scales (e.g., 1:1,000,000 scale). Hence, data layers generated for Missoula County were given preference. These were acquired for most hazards, but when unavailable, state and then national datasets were considered for use. For example, the only data representing wildfire risk had a scale of 1:250,000. Although this is not ideal, fire modeling for the U.S. has become sophisticated in recent years (Sullivan, 2009) and experts in Missoula County confirmed that this was the best dataset for our purposes. Alternatively, the existing earthquake shaking potential data were developed for Montana State and the United States with varying scales closer to 1:1,000,000. The underlying assumptions made and data used for developing these ground motion predictions were limited in Montana by lack of data and fault slip rates. Both outputs underestimated potential shaking on faults in Missoula County assigning highest hazard to the only nearby fault that has had paleoseismic studies done to constrain slip, the Mission Fault. See the earthquake section in Chapter 3 for more details on why these conclusions were made and how new shaking layers were developed for Missoula County. Where possible the hazard layers used were based on good data with fine resolution. If these were unavailable, the next best data were selected or modified to represent best estimates of hazard potential.

1.6 Step 5: Data modification and layer creation

An important aspect of data assessment includes determining the level of modification needed for the collected data (Table 3-1). If available data were high quality then minimal modifications were required. If multiple datasets existed for a region and quality was good, moderate modification was needed to merge layers and update attributes. If data did not represent best available information for a region (e.g. earthquake potential shaking) or did not exist for a specific hazard or data type (e.g. landslide, worst-case scenarios), then new layers were generated. This determination was made using expertise provided by scientists in hazard-related fields. Their expertise dictated if and how new layers were generated to ensure methods aligned with best practices and that scientific accuracy was maintained throughout this process. See specific details of layer development for data layers in the high modification category in the sections below.

Table 3-1. Modification levels and descriptions

Level	Adjustments	Data Layers
1. Minimal	Attributes edited, converted to vector polygon, lookup-values assigned	• Burn probability • FEMA flood zones
2. Moderate	Multiple layers combined, attributes edited, converted to vector polygon, look-up values assigned	• Historical fire boundaries • Channel migration zones
3. High	Related data used as inputs to ArcGIS tools to generate new shapefiles, attributes assigned, converted to vector polygon, lookup-values assigned	• Worst-case scenarios for flood, wildfire, and earthquake • Fault distance • Historical earthquake • Likely earthquake shaking • Landslide potential

2 Section Overview

ArcGIS 10.3 software was used to process and translate of collected geographic hazard layers to be input into the MissoulaReady web application. Eleven hazard shapefiles were generated from existing data and information. The variety of data and natural hazard types resulted in unique processing steps that are described below in order of highest to lowest hazard risk for Missoula County. Scientific principles were applied to ensure accurate modifications were made. As mentioned in chapter two three types of data were acquired: continuous raster, vector point and line, and vector polygon, and transformed into vector polygon and each polygon assigned lookup-values (Fig. 2-6.) Data layers were selected for each natural hazard representing relative potential, worst-case scenarios, and historic events. This section reviews why the original data were selected, which modifications and assumptions were made, and how technical information was translated to a user-friendly format. Each shapefile description is followed by example snugget text that pairs with the data.

3 Wildfire

Wildfire poses the greatest threat to Missoula County residents and is the most common natural hazard in the state (Atkins, 2011; Montana DES, 2013). Wildfire is not typically considered in geological investigations unless in conjunction with geomorphological events such as landslides or debris flows (Gabet and Bookter, 2008) so expertise and guidance regarding this information came from fire hazard modeling and risk specialists with the US Forest Service. The data layers for wildfire include burn probability, wildfire worst-case scenario, and historic fire boundaries.

3.1 Hazard Potential Layers

3.1.1 Burn probability

The burn probability (BP) raster dataset was the most recent dataset regarding wildfire risk for the region. Probabilistic output values made for simple translation into risk potential. The BP raster dataset has a 250m-grid resolution and represents the annual probability for a given pixel to burn. Though a smaller scale dataset would be preferable, one is not currently available. It was modeled using LANDFIRE refresh 2010 fuel and terrain data, historical fire occurrence data, surface weather records, and fire danger rating information (Metadata, 2014). Within the Missoula County boundary, burn probabilities ranged between 0 to 3.4 percent (Fig. 3-3a). Polygons were generated from the continuous raster data by reclassifying the raster into new categories. A study by Haas et al. (2013) separated burn probabilities into high, medium, and low levels based on fire

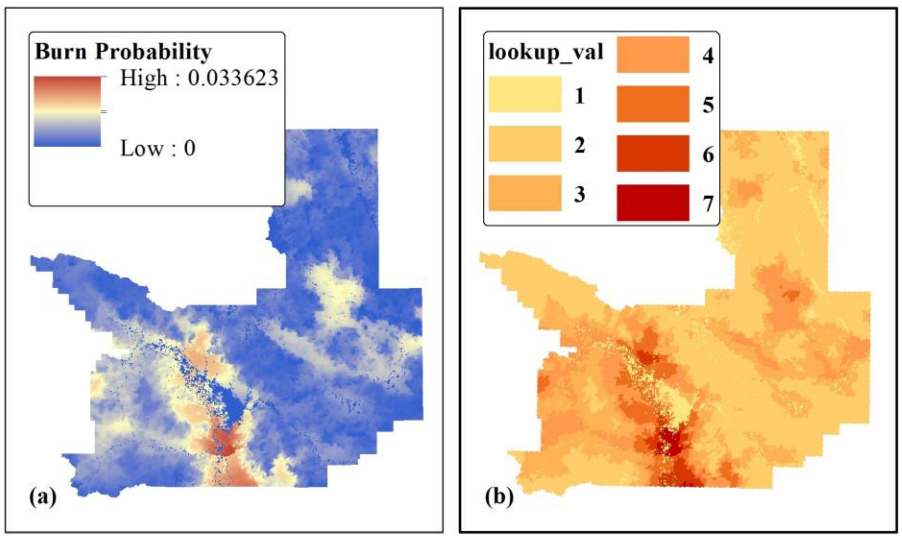


Figure 3-3. Burn Probability. (a) The unprocessed data were continuous and in raster format with a range of probabilities from 0 to 0.034 in Missoula County. (b) After processing the continuous data were binned into seven categories from 1 to 7 with 1 representing a no risk zone and 7 representing a high-risk zone.

recurrence intervals seen in table 3-2.These categories were further subdivided to give finer detail to the Missoula County user (Table 3-3). The subdivision resulted in the low category becoming low and very low, and high becoming high and very high. Once reclassified, the raster dataset was converted to polygons using the "raster to polygon" tool in ArcGIS and lookup-values were assigned one through seven. One corresponded to the lowest burn probability and seven to the highest (Fig. 3-3b). The main issues with using the burn probability dataset are that the resolution is nationwide, the simulations were run from 2010 ground cover data, and are the simulations were run in 2014. As finer scale burn probability information is created and new simulations are run this file will need to be updated.

Table 3-2. Burn probabilities divided into low, medium and high categories based on corresponding fire recurrence interval times (Haas et al., 2013).

Lower Probability		Category		Upper Probability	Fire recurrence interval (years)
0.0005	≤	BP_{low}	≤	0.01	1 in 2000-100
0.01	<	BP_{medium}	≤	0.02	1 in 100-50
0.02	<	BP_{high}			1 in 50 or less

Table 3-3. The divisions made by Haas et al. were further subdivided to give express the burn probability in finer detail (e.g., instead of low we now have low and very low) (2013). Low, medium, and high rankings still follow the categories that were previously defined.

Lower Probability		Category		Upper Probability	Fire recurrence interval (years)	Lookup-value
0	=	None	=	0	None	1
0	<	$BP_{verylow}$	≤	0.005	1 in 200+	2
0.005	<	BP_{low}	≤	0.01	1 in 200-100	3
0.01	<	BP_{medium}	≤	0.015	1 in 100-65	4
0.015	<	BP_{medium}	≤	0.02	1 in 65-50	5
0.02	<	BP_{high}	≤	0.025	1 in 50-40	6
0.025	<	$BP_{veryhigh}$	≤	0.034	1 in 40-30	7

Lookup_val	Intensity (0-100)	Burn probability snugget example
1	5	The wildfire burn potential here is extremely low. This means you probably won't see a wildfire start here in the next year. Check other areas nearby too.
7	90	The wildfire burn potential here is the highest in the county. This means you could see a wildfire start here in the next year if the conditions are right. Take steps to prevent fire near your home.

3.1.2 Worst-case fire scenario

The worst-case fire scenario shapefile was generated using the existing town boundaries file and the Missoula County Boundary file (Fig. 3-4a). Most of the wildfire hazard comes from the intersection of homes and property with the forest. This areas is called The Wildland Urban Interface (WUI) and is, "the area where human development meets natural vegetation and the chance for catastrophic wildfire increases" (Ellis et al., 2005). WUI can be defined as various distances from human development, but for this shapefile we used the designation given by the U.S. Congress of 0.5 miles from the edge of a city (2003).

The Buffer tool in ArcGIS was used to define the WUI boundary within 0.5 miles of town boundaries. This zone was merged with the County boundary file and resulted in three areas (Fig. 3-4b); (1) the area within the city boundary by more than half a mile, which is unlikely to burn, (2) the WUI zone which could experience a catastrophic wildfire and, (3) the forested area outside of town, which could burn catastrophically. In

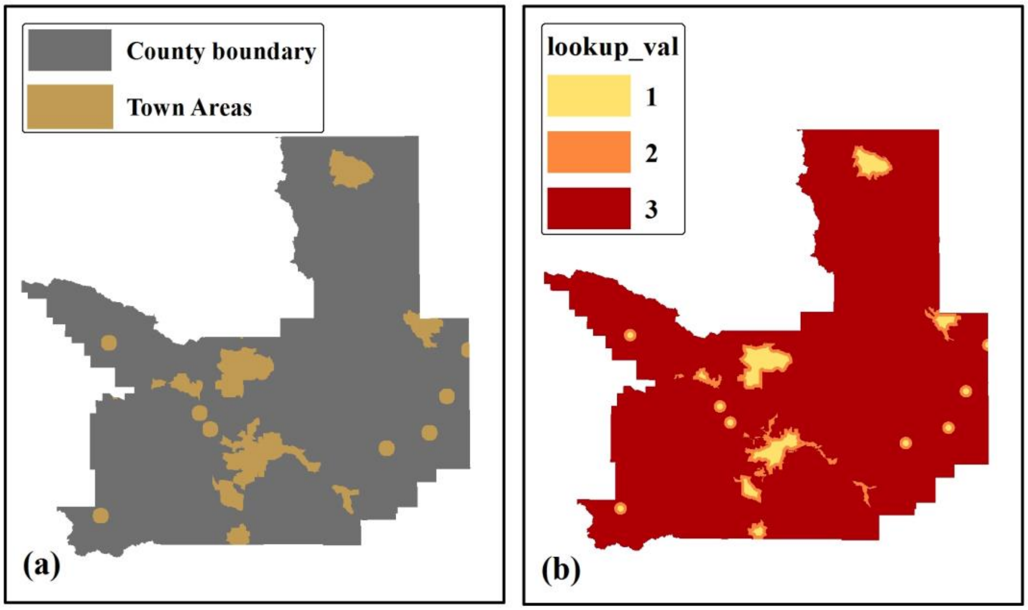


Figure 3-4. Fire Worst Case Scenario, (a) Two existing files were used to develop this layer, the town area file and the Missoula County Boundary file. (b) The resulting layer had three zones, 1-low catastrophic fire potential, 2-at edge of town with potential for catastrophic fire, and 3- high catastrophic fire potential.

this case, a catastrophic wildfire indicates a crown fire with high heats and strong winds creating the potential for fast spread rate and poor containment. Two key assumptions were made for generating this file. The first, that any location within half a mile of the edge of town could experience a catastrophic wildfire. With the majority of Missoula County being forested land, the edge of town is typically where forests meet structures. The second, that locations within town more than half a mile will not burn catastrophically due to roads and lack of fuel limiting spread possibility. We recognize that these assumptions leave out other factors that should be considered. Future iterations of this shapefile should be revised to exclude water bodies and include ground conditions or fuel types. It should be noted that for the smaller towns, the town boundary was simply a 1-mile buffer around the center of town point. This is not representative of where people live and perhaps a different file should be used like parcel locations. The type of information supplied by this shapefile would benefit from including egress potential for local homes and neighborhoods to warn people about the difficulties of evacuating if a catastrophic wildfire were to occur.

Lookup_ val	Intensity (0-100)	Worst case snugget example
1	20	You are in town and more than a half a mile from the edge of town so it's unlikely you will see wildfire here. If you live close to a wooded area or field that could burn, be aware that fires can happen in town as well.
	50	You are within half a mile of the edge of town. If a wildfire approaches city limits you could be at risk of a fire reaching your home. There will be limited evacuation time so be prepared.

3.2 Historical layers: fire boundaries

Historically, wildfires have occupied much of the Missoula County landscape, and are a natural part of the mountain landscape (Atkins, 2011). The decision to include historical data was made to provide concrete hazard information. Probabilistic predictions can be intangible to the public, but historic occurrences provide concrete examples of what has happened. This file was generated by merging two historic burn datasets, one spanning from 1889 to 2003 and the other from 1985-2013, and the county boundary file (Fig. 3-5a). The original files consisted of polygons of historic fire burn areas and contained date and burn size information. These files were merged. Since the datasets overlapped for 28 years there were redundancies that were deleted from the attribute table of the merged dataset by hand Attributes containing year and acreage of wildfire were retained after the merge, but other attribute information was deleted. A lookup-value was assigned for each of the 326 wildfires in the County. It should be noted that though these datasets represent reported historic fire boundaries, they are not comprehensive. Earlier years include fewer fires since fire boundary mapping and reporting was not as precise or pervasive a hundred years ago. This dataset ends in 2013 and fires like the Lolo complex fire have occurred since then that should be incorporated in future shapefiles, but were not due to time constraints.

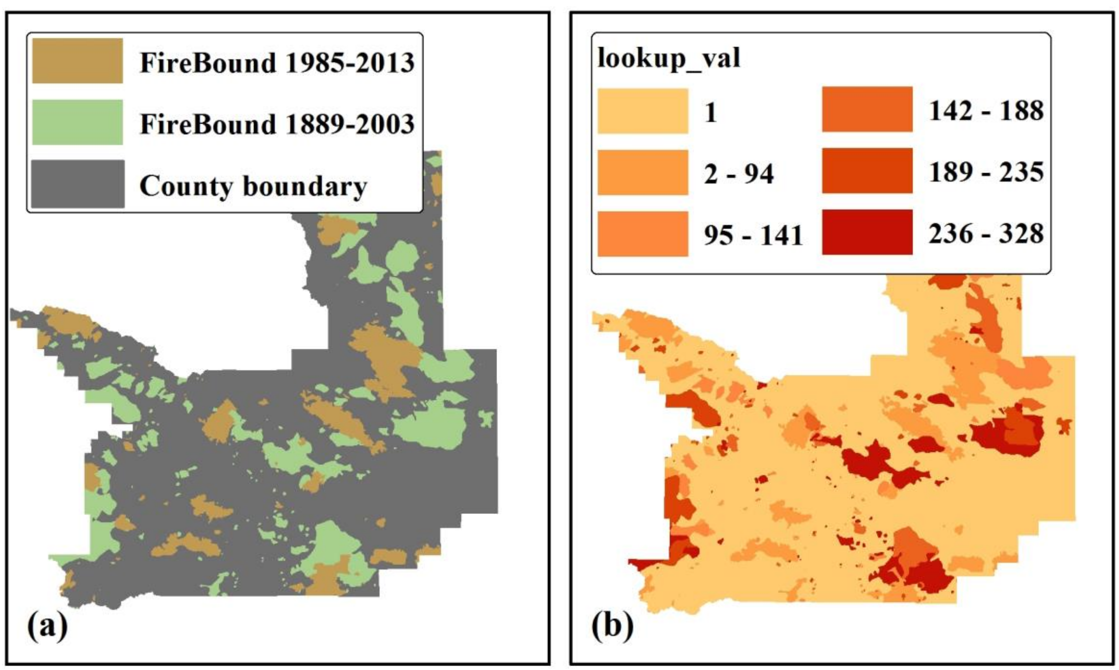


Figure 3-5. Historic Fire Boundaries. (a) Two datasets were combined along with the Missoula county boundary file as they each covered different fire boundaries. (b) There were over 300 individual fires and each was given a lookup-value. Corresponding snuggets were written for each one.

Lookup_val	Intensity (0-100)	Historic fire snugget example
1	n/a	This location does not have a record of wildfire between 1889 and 2013. Wildfires are a natural part of the Montana landscape and continue to be the most common natural hazard that people face living here.
83	n/a	In 2000, 16682 acres burned in this location. Wildfires are a natural part of the Montana landscape and continue to be the most common natural hazard that people face living here.

4 Flooding

Missoula County is host to numerous rivers, streams, and creeks that have been subject to springtime flooding. In recent history flooding tends to be minor, but has impacted specific neighborhoods that are prone to floodwaters especially the Orchard Homes neighborhood and those on Tower Street. In 1908 a massive flood took out bridges and swept away homes in the county. For MissoulaReady three data layers were acquired or created for the County. They include, the Digital Insurance Rate Map (DFIRM), channel migration zones (CMZ), and flooding worst-case scenario. Unfortunately no historic flood inundation maps exist for the region.

4.1 Hazard Potential Layers

4.1.1 FEMA Digital Flood Insurance Rate Map (DFIRM)

The Federal Emergency Management Agency (FEMA) is responsible for developing and updating Missoula County's floodplain boundary map. The most recent update was in 2015. The DFIRM for Missoula County indicates 100/500-year floodplain boundaries of the main rivers. Missoula County GIS group provides a floodplain query tool to the public at: http://gis.missoulacounty.us/caps/floodplain/. The legend indicates FEMA zone assignments, but provides no information for public understanding. These zones have specific meanings for flood inundation and risk potential as defined by FEMA (Table 3-4). Minimal processing for the shapefile was needed as the DFIRM shapefile was in vector polygon format. A "lookup_val" column was added to the attribute table and populated with zone names (Fig. 3-6). Snuggets were written for each lookup-value to explain the zones in practical terminology.

The 100-year flood terminology was avoided when translating the technical zone descriptions into a non-technical language as it is easily misinterpreted (Holmes and Dinicola, 2010). Instead we converted probability of 1% annual occurrence to the chance in a ten-year time span. This amounts to the probability of one or more 100-year floods occurring in the next ten years. Floods are assumed to be independent events and can be modeled using the Poisson distribution (Hall and Howell, 1963). The probability of exactly r occurrences of a flood can be given as

$$P(r) = \frac{e^{-\lambda}\lambda^r}{r!} \qquad (1)$$

where λ is the mean number of occurrences of the event per time interval and can be calculated using the given time interval (Δt) and the return period (T),

$$\lambda = \frac{\Delta t}{T} \qquad (2)$$

The probability (P) of one or more flood occurrences would be

$$P\ (1, 2, \dots \infty) = \sum_{r=1}^{\infty} P(r) = e^{-\lambda}\left(\frac{\lambda}{1!} + \frac{\lambda}{1!} + \cdots \infty\right)$$
$$= 1 - e^{-\lambda}$$
$$= 1 - e^{-\frac{\Delta t}{T}} \qquad (3)$$

It follows that the probability of one or more 100-year floods occurring during a 10-year time interval is 9.5%. Since individuals are more able to process natural frequencies rather than percentages the flood snuggets for this section was written as a 1 in 10 chance instead of a probability of 9.5% (Gigerenzer et al., 1995; Hoffrage and Gigerenzer, 1998).

Table 3-4. Floodplain zone designation is used for all FEMA FIRM maps and indicates what type of flooding may occur in the event of a 100-year flood. (FEMA, 2016)

Flood Zones	**FEMA definitions**
A	Areas subject to inundation by the 1-percent-annual-chance flood event generally determined using approximate methodologies. Because detailed hydraulic analyses have not been performed, no Base Flood Elevations (BFEs) or flood depths are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply.
AE	Areas subject to inundation by the 1-percent-annual-chance flood event determined by detailed methods. Base Flood Elevations (BFEs) are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply.
AE Floodway	The floodplain area designated on the official floodplain maps that must be reserved in order to discharge a base flood without cumulatively increasing the water surface elevation more than one half (1/2) foot
AH	Areas subject to inundation by 1-percent-annual-chance shallow flooding (usually areas of ponding) where average depths are between one and three feet. Base Flood Elevations (BFEs) derived from detailed hydraulic analyses are shown in this zone. Mandatory flood insurance purchase requirements and floodplain management standards apply.
AO	Areas subject to inundation by 1-percent-annual-chance shallow flooding (usually sheet flow on sloping terrain) where average depths are between one and three feet. Average flood depths derived from detailed hydraulic analyses are shown in this zone. Mandatory flood insurance purchase requirements and floodplain management standards apply.
Shaded X	Area of moderate flood hazard. This flood risk is reduced, but not removed. Flood insurance is not required in this zone, but is available and local floodplain development codes may apply.
X	X (unshaded) – These properties are outside the high-risk zones. Flood risk is reduced, but not removed. FI is not required in this zone, but is available and local floodplain development codes may apply.
X protected by levee	Levee Protected Zone
Area not included	Area not included
D	The Zone D designation is used for areas where there are possible but undetermined flood hazards. In areas designated as Zone D, no analysis of flood hazards has been conducted.

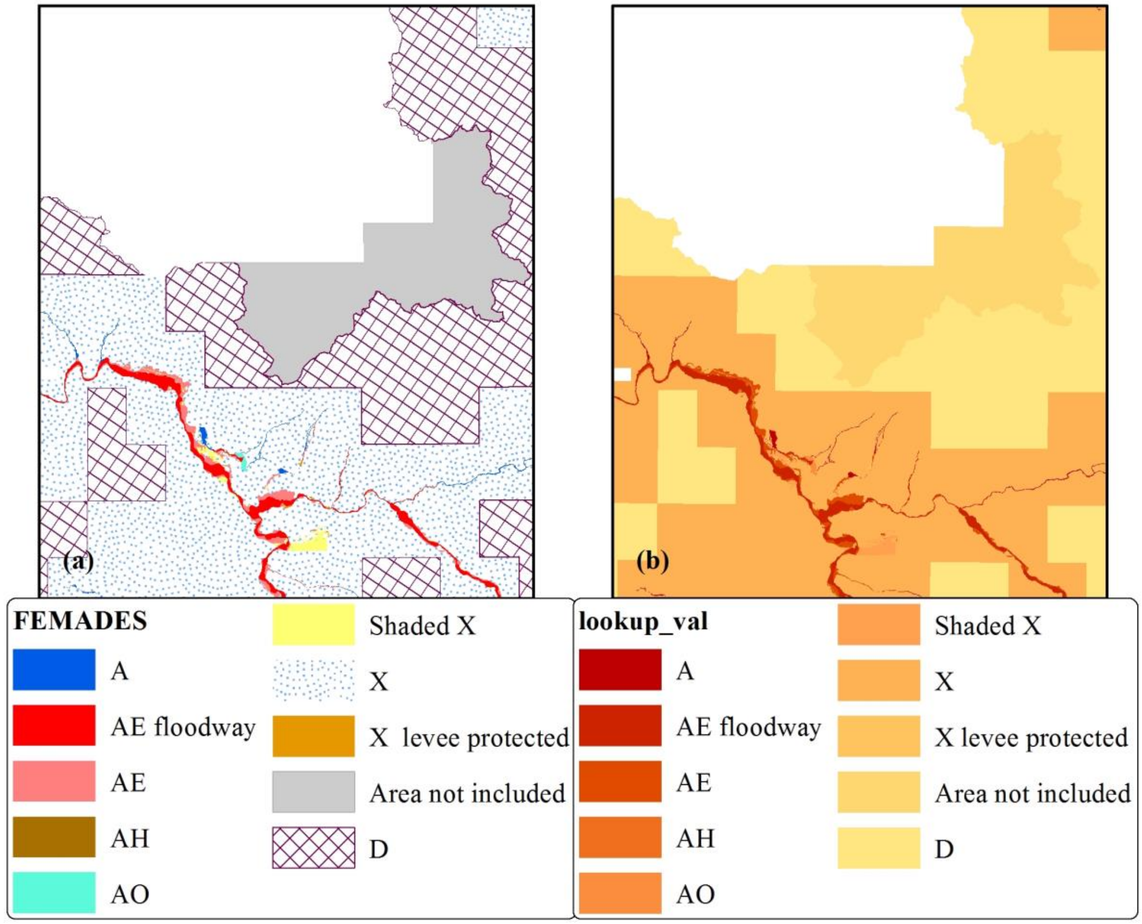


Figure 3-6. FEMA DFIRM Flood Map. Very little processing was done here. The lookup-values were assigned the same names as found in the FEMADES column of the original shapefile attribute table.

Lookup_ val	Intensity (0-100)	Flood snugget example
A	70	There is a high chance of flooding here. Probably once in the next ten years. To check flood stage on the Clark Fork, Bitterroot, and Blackfoot Rivers go to the NWS Page: http://water.weather.gov/ahps2/index.php?wfo=mso
D	5	This area hasn't been mapped in the latest floodplain map so no flood information is available. If you have questions, get in touch with your county or city floodplain administrators, Todd Klietz (tklietz@co.missoula.mt.us) or Wade Humphries (whumphries@ci.missoula.mt.us)

4.1.2 Channel migration zone (CMZ)

In the western U.S. channel migrations zone studies are becoming a popular tool for cities and counties to plan for future river incision and erosion zones (Boyd, 2009; Butler, 2015; WA Dept. of Ecology, 2011). Missoula County has two such studies done on the Clark Fork and Bitterroot Rivers. This type of dataset is valuable for the public as it informs individuals of future areas for concern.

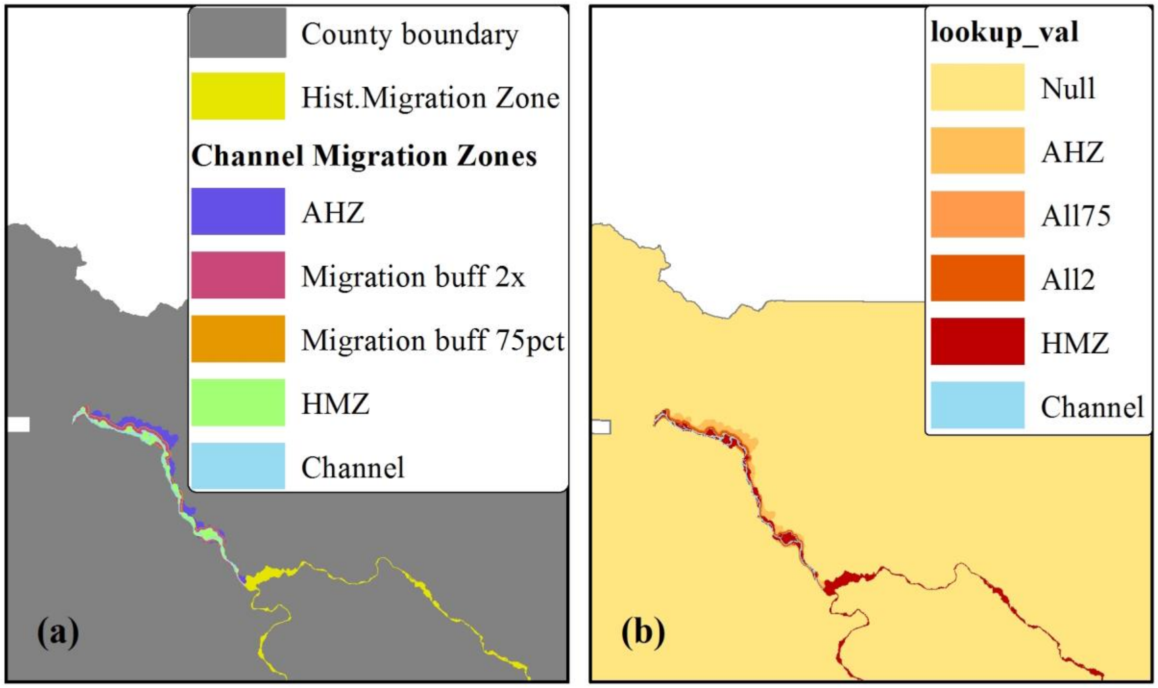


Figure 3-7. Channel Migration Zones. (a) Three files were used, the county boundary (grey), the historic migration zone (yellow) and the channel migration zones (purple, pink, orange, green, and blue). The pink migration buffer represents twice the mean 50-year migration rate giving an approximation for the next 100 years and the orange migration buffer reflects twice the 75th percentile value measured between 1955 and 2005 as migration can be non-constant and may be more than average. (b) After processing the two HMZs were merged and all zones were given unique lookup-values.

The two shapefiles include a hazard migration zone (HMZ) shapefile for the Clark Fork east of the City of Missoula from the Clark Fork-Bitterroot confluence south representing channel locations from 1955 to 2011 and a more detailed CMZ shapefile for a region west of the Bitterroot-Clark Fork confluence that extends to Huson, MT from 1955 to 2005 (Boyd, 2009). The CMZ study was completed for a 100-year timeframe. Apart from historic migration zones the composite CMZ shapefile also includes other relevant zones such as the active channel, erosion buffers, and the avulsion hazard zone (AHZ) (Fig. 3-7). The two erosion buffers are calculated based on over a hundred measurements of migration rates along the river. The AHZ is where local geology and geography could allow for channel relocation during flood events. The HMZ is also included and represents where the channel has historically migrated.

Similar to the FEMA DFIRM lookup-values were renamed for each zone with snuggets written to describe them. Anywhere outside of the study areas was given a null value and text was written accordingly. Unfortunately these studies have only been done for selected sections of the rivers in the County and to varying extents. There are likely other unmapped avulsion prone areas. The level of CMZ data availability varies throughout the region and favors areas with current data.

Lookup_ val	Intensity (0-100)	CMZ snugget example
HMZ	90	Like most things, rivers follow the path of least resistance, changing course over time. The river flowed here historically and could again, especially if a big flood happens.
Null	20	Did you know that rivers across Missoula County are constantly readjusting and changing? They tend to change most during and after floods. If you live near a river be aware.

4.1.3 Worst-case flooding scenario

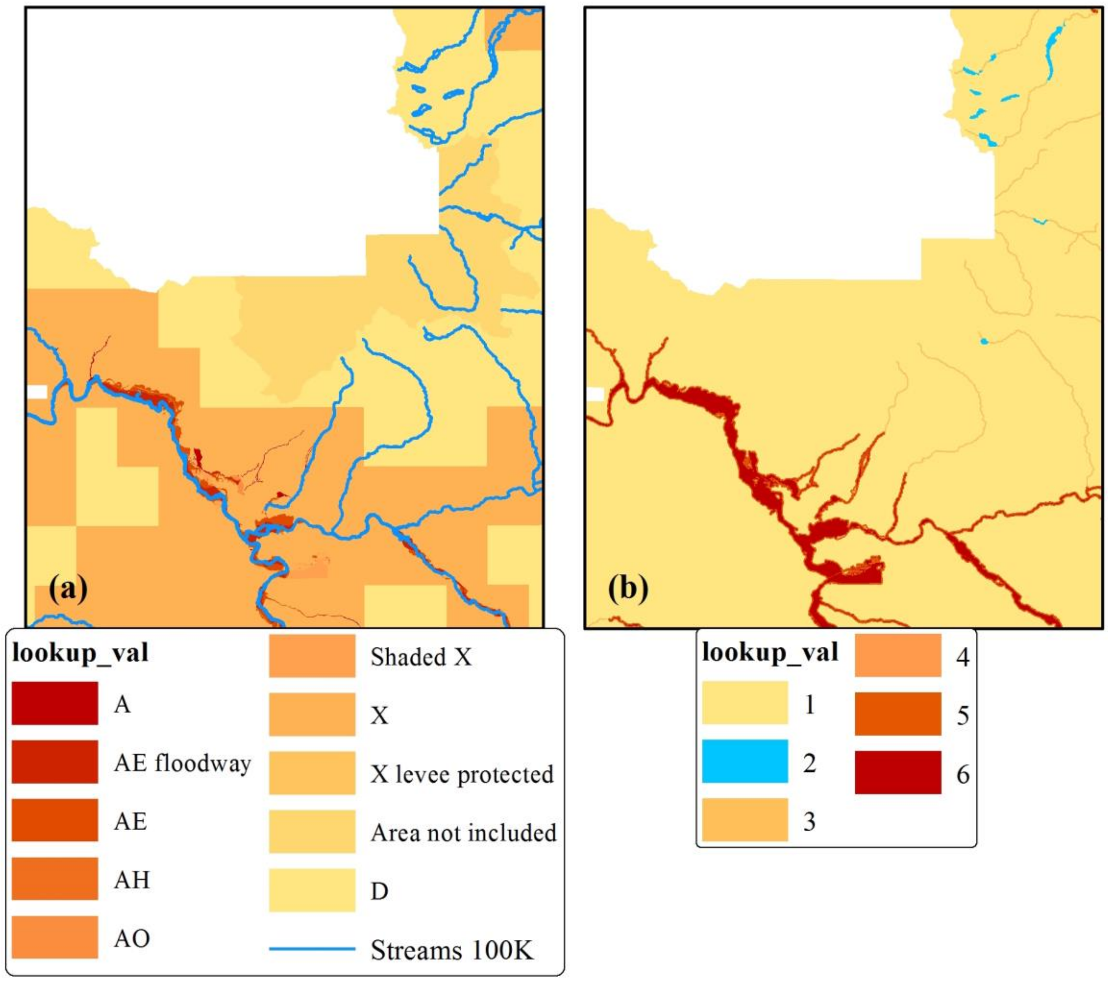


Figure 3-8. Worst-case scenario flooding (a) The FEMA DFIRM boundaries and the major streams file for the county were used in the creation of the worst-case shapefile (b) All interiors were dissolved and a 500 foot buffer was added to the DFIRM boundaries and a 250 foot buffer added to the streams. Lake boundaries were kept as-is. The six values represent the following, 1) null or no flood potential, 2) lakes, 3) 250-foot buffer around streams, 4) Areas previously protected by levees, 5) 500 foot buffer around current floodplain, 6) The area within current floodplain

The FEMA flood boundary maps do not identify 500-year floodplains directly, but floods of this size have occurred in the Missoula Valley (Atkins, 2011). For determining a worst-case scenario shapefile, reports of past flood events were used to guide file creation. In 1908, what was estimated to be a 500-year flood hit the valley (Woelfle-Erskine et al., 2012). This flood decimated local bridges and many homes in Missoula

County. No inundation boundaries exist for historical floods so potential flood boundaries were estimated as described below.

For developing this layer the current floodplain boundary file was used as well as a 1:100,000 scale streams file that included lesser streams not present in the floodplain map (Fig. 3-8a). Since the border of larger floods would extend past currently delimited floodplain boundaries the FEMA layer inner zones were dissolved into one and a 500-foot buffer was added on the floodplain edges. A 250-foot buffer was added surrounding local streams. These regions were then merged. The resulting shapefile has six lookup-values ranked from lowest to highest hazard, (Fig. 3-8b). The buffer distances were chosen as reasonable estimates, but do not reflect local topography so can only be used as a rough approximation of where inundation may occur. That said, those living within 250 to 500 feet of local rivers should be aware of potential flood risks. Snuggets were written to inform people what might cause a large flood and what they might experience in the event of a worst-case scenario flood. More works needs to be done with river discharge, topography, and surveying in order to make a more accurate 500+ year floodplain estimate.

Lookup_ val	Intensity (0-100)	Worst-case flood snugget example
1	10	Rain, snowmelt, or both could cause waters to rise rapidly overtopping riverbanks, flooding roadways, and impacting neighborhoods. This area is outside of the main areas impacted, but you could see water on roadways and road closures. Bridges may be unusable. This could last days to weeks.
6	90	Rain, snowmelt, or both could cause waters to rise rapidly overtopping riverbanks, flooding roadways, and impacting neighborhoods. Debris-filled floodwaters could rush into this area. Get sandbags to protect your home and evacuate. Do not try to drive through submerged areas. This could last days to weeks.

4.2 Historical flood layers

Historic flood inundation boundaries would be useful to inform people of the local extent of historic floods, but these data layers do not exist currently. There are, however, four river gauges in Missoula County, one on the Blackfoot River, two on the Clark Fork River, and one on the Bitterroot River that have been recording river stage, a measure of water level, for the past 50 to 100+ years. For each gauge, NOAA has correlated stage levels with four flood categories that include action, flood, moderate flood, and major flood stage. Since developing a geographic map was unfeasible for this type of data graphs were developed for each river showing how high the river has been historically (Fig. 3-2). For the Clark Fork, the gauge above Missoula was used. The graphs include water level in feet above flood level, flood categories, and descriptions that match flood categories with specific information about flood prone areas in Missoula County. One snugget was written for this section and will display the same to everyone, but contains links to the historic information for each river.

Lookup_ val	Intensity (0-100)	Historic flood snugget example
n/a	n/a	In 1908, a massive flood swept away the Higgins Bridge in the City of Missoula and destroyed many homes. In 2011, homes on Tower Street and Kehrwald Drive flooded. Check out graphs of historic floods on the Clark Fork, Bitterroot, and Blackfoot Rivers.

5 Weather

5.1 Summer and winter weather

For weather the entire region was treated uniformly, but separate descriptions were given for typical scenarios, worst-case, and historic events. Local weather experts were consulted for creating the content to make sure the correct points were stressed. Extreme summer weather means thunderstorms, lightning, hail, potential for wind and flooding. Extreme winter weather means low temperatures, snowfall, power outages, and windstorm potential.

Subsection	Intensity (0-100)	Winter weather snugget example
Potential	50	Across Missoula County winters come with below freezing temps, icy road conditions, and the potential for major storms. The valleys often get inversions causing poor air quality. Stock up on hot cocoa and get your winter supply kit ready.
Worst-case	90	There could be a blizzard in Missoula County. This means sustained winds or frequent gusts of 35 mph or more. Temperatures will be in the negatives and with wind chill even lower. Walking will be difficult and whole trees will sway. It will be hard to see due to falling or blowing snow.
Historic	n/a	In February of 2014 several feet of snow fell in the Missoula Valley with high winds loading nearby peaks. A blizzard warning was issued and on March 2nd an avalanche charged down Mount Jumbo into the Rattlesnake Neighborhood in the City of Missoula. It caused damage to multiple homes, injuries, and one death.

Subsection	Intensity (0-100)	Summer weather snugget example
Potential	50	Across Missoula County summers are hot. Along with people floating the rivers, taking hikes, and herding cattle you might also see thunderstorms, windstorms, and heat waves hit the county.
Worst-case	90	Severe thunderstorms can happen here. This means high winds, thunder, and lighting. They can lead to flash flooding (super fast floods) and include hail greater than an inch in diameter. You could see 60-80mph winds that cause trees to topple and damage to homes and power lines.
Historic	n/a	In August of 2015 a major windstorm hit the Missoula Valley with winds gusting up to 70 miles per hour. Dozens of trees were uprooted, power lines knocked down, and small fires started. 18,000 were without power at some time. It took days to remove debris from roads and restore power. Emergency crews were overwhelmed with phone calls of reported incidents.

6 Earthquake

Montana is divided into a mountainous western region known for historical seismicity and normal faulting and an flat eastern region which is seismically quiet (Wong et al., 2004). Missoula County sits on the westernmost edge of the state with the Lewis and Clark Fault Zone (LCFZ) running through its' center. This zone trends NW-SE and has been suggested to represent the northern boundary of the Basin and Range Province (Stickney and Bartholomew, 1987). The LCFZ is host to many small earthquakes less than magnitude 4 and marks a change in seismicity from other active regions nearby such as the Centennial Tectonic Belt and the Intermountain Seismic Belt. Four active faults in the Missoula County include the Bitterroot, Jocko, Ninemile, and Swan Faults. The Mission Fault, though outside the County, could induce shaking within it and was therefore included in this discussion. These are considered normal faults with approximate slip rates of 0.2-1 mm/year based on historic fault traces and geomorphic evidence (Haller et al., 2000). Paleoseismological studies have not been done on these faults except for the Mission fault which has had trenching on numerous locations along its' length (Haller et al., 2000). Holocene surface rupture on this fault was reported and a recurrence interval of less than 7.3 – 11.3 k.y. was estimated (Haller et al., 2000). All other fault recurrence intervals are unknown.

Lack of data and a short earthquake catalog are key limiting factors in the understanding of earthquakes and potential hazard in this region (Hofmann et al., 2006; Wong et al., 2004). Data collection through paleoseismic and Global Positioning System (GPS) studies are needed to accurately assess earthquake hazard in and around Missoula County. Since limited data exist the layers included in this section contain as much general information as possible and include distance from faults, likely and worst-case scenarios, and historic earthquakes.

6.1 Hazard Potential Layers

6.1.1 Distance from faults

Fault trace data seen in Fig. 3-9a were in vector line format and sourced from the quaternary faults database (USGS and NMBMMR, 2006). These fault locations were used to develop a shapefile that denotes proximity to active faults within Missoula County. One-mile buffers were created using the fault traces as inputs to the Buffer Tool

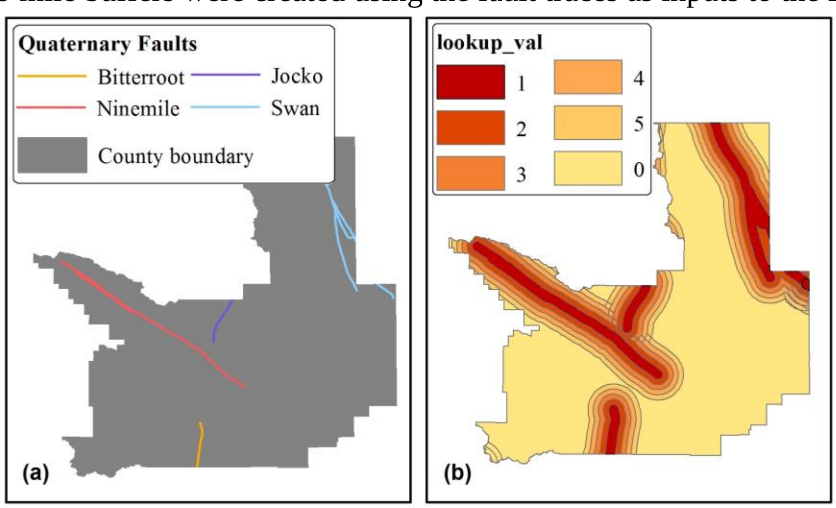


Figure 3-9. Faults in Missoula County and distance buffers.

in ArcGIS. The buffers extended five miles from the Bitterroot, Jocko, Mission, Ninemile, and Swan Faults (Fig. 3-9b). Areas farther than five miles, but still in Missoula County were assigned a null value. Overlapping regions were maintained and assigned multiple lookup-values. We chose not to extend the buffers past five miles since buffers began to overlap significantly past this distance cluttering the shapefile and inundating the amount on information provided to the user. Snuggets written for this shapefile describe locations of faults using familiar landmarks and include relative distance from faults. Future versions of this shapefile should include local geology, which could give residents an indication of amplification due to shaking if a larger earthquake did occur.

Lookup_ val	Intensity (0-100)	Fault distance snugget example
55	90	You are very close (~1mi) to the Jocko fault that runs from Big Knife creek to Finley Creek. Scientists haven't seen many earthquakes here, but since the record is short, you could feel one in the future.
6	20	You are a fair distance, farther than 5 miles, from the nearest active fault. This means that if an earthquake happens you will feel less shaking than those closer to the fault.

6.1.2 Likely & Worst Case Shaking potential

The most current probabilistic ground motion estimates for the United States and Montana were developed by the USGS and by Wong et al. (Fig. 3-10 & 3-11) (Petersen et al., 2014; Wong et al., 2004). Peterson et al. explain that in their model slip rates spanning recent seismic cycles were given more consideration and that paleoseismic data were used to develop the fault-source model they implemented (2014). In the northern Rocky Mountains recurrence times for earthquakes (M6+) range between 400-5,000 years (Wong et al., 2004) and slip rates are poorly constrained by historical seismicity. The Mission Fault sits northwest of Missoula County and runs parallel to the Swan Fault. It is the only nearby fault where trenching has lead to reliable slip rate estimates. No paleoseismic studies have been completed for faults in Missoula County (Haller et al., 2000). As a result, both Peterson et al.'s and Wong et al.'s ground motion predictions show the Mission Fault as having significantly higher shaking potential than the Swan, Bitterroot, an Ninemile faults in Missoula County. Though hardly studied, recent LiDAR and GPS results suggest that these faults are likely to have comparable slip rates (Shmeelk, 2016) and their scarp lengths indicate the potential for them to host large earthquakes (Fig. 3-12). For this reason we developed two shapefiles representing shaking potential for most-likely and worst-case earthquake scenarios based on distance from faults.

For the most-likely scenario a M 4.0 earthquake was considered. This selection was based on historical occurrence and potential to be felt by residents. In recorded history there have been 13 earthquakes between M 3.5-4.4 inside or within 20 miles of Missoula County (USGS, 2015). Above magnitude 3 or Modified Mercalli Intensity (MMI) 2 some can feel shaking. Above a M4.0 or MMI 4, many can feel shaking (USGS, 2013). For the M 4 earthquake scenario, MMIs between 1-4 were considered for Missoula County (Fig. 3-13a).

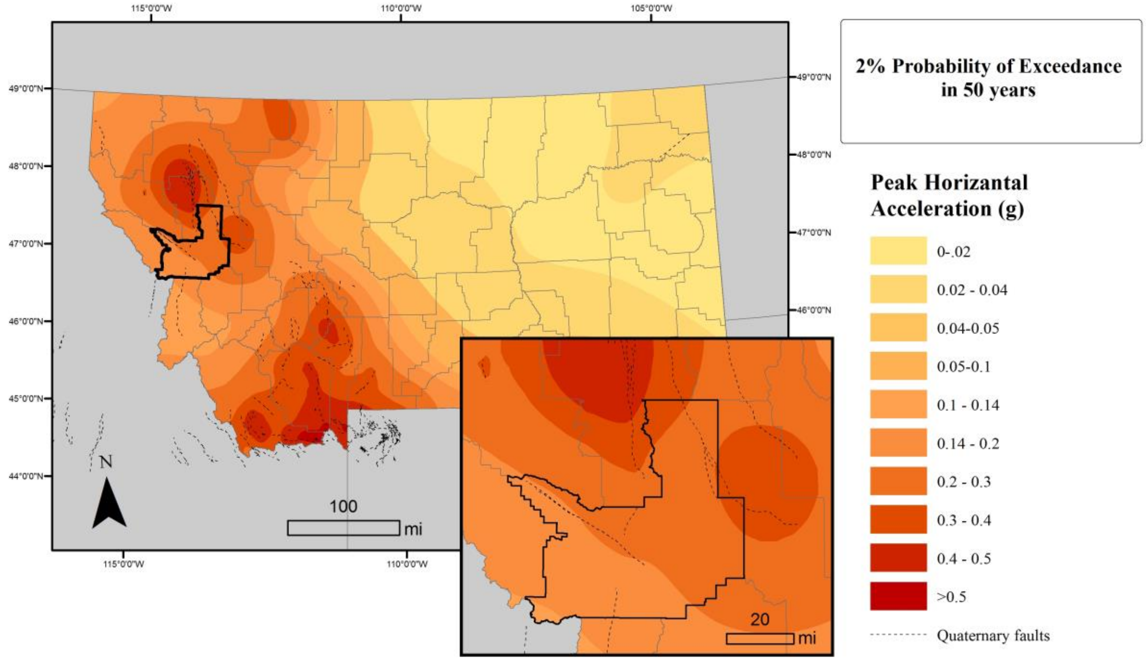


Figure 3-10. USGS ground shaking map for Montana (modified Petersen et al., 2014). PHA values range between 0.12-0.3g in Missoula County.

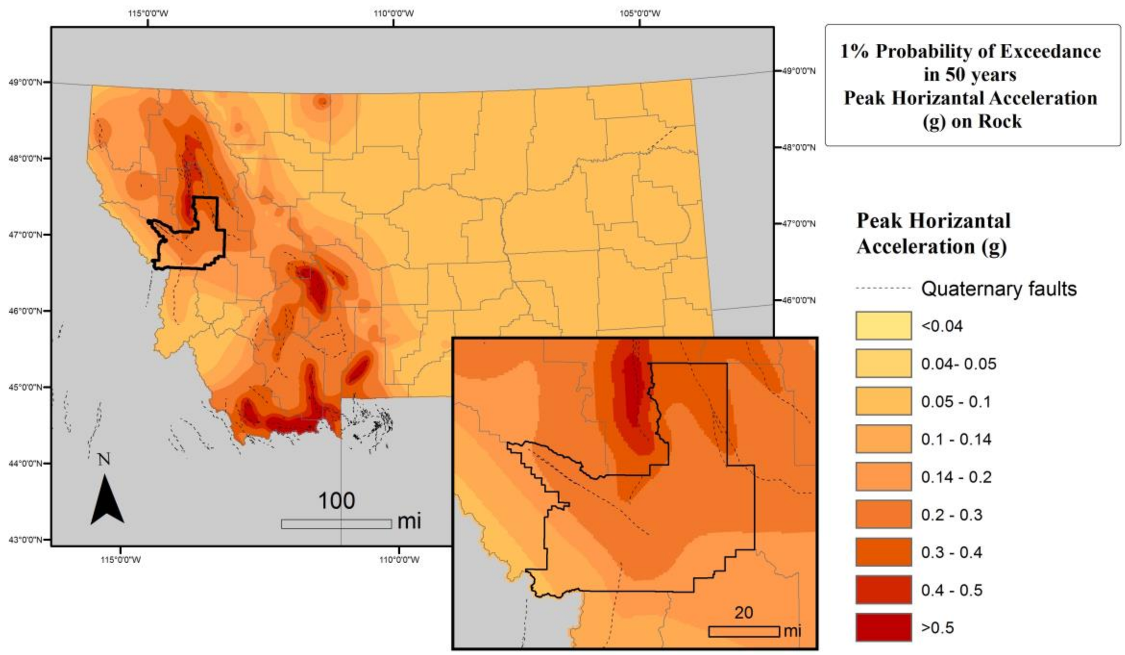


Figure 3-11. Ground shaking map for Montana (modified Wong et al., 2004). PHA values range between 0.09-0.43g in Missoula County.

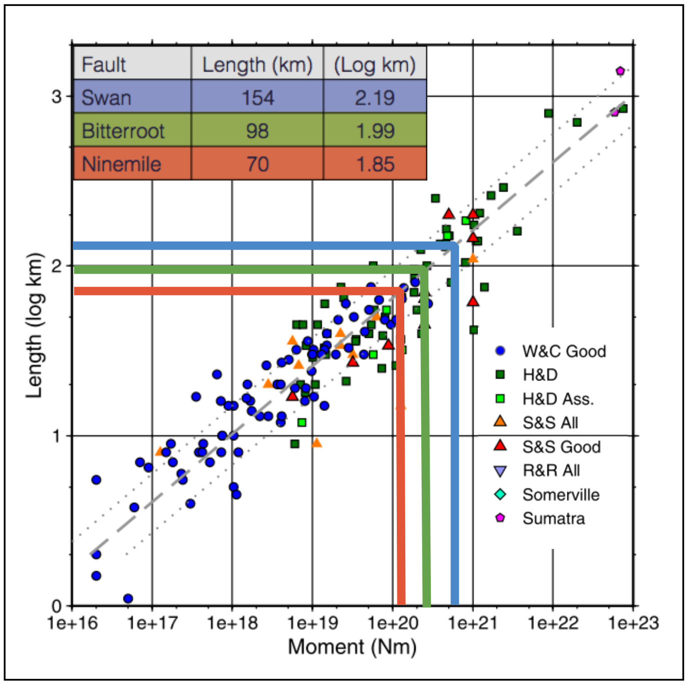


Figure 3-12. The moment (M_0) versus fault length data is shown here for dip-slip earthquakes. The dashed line is the best-fit line to all data. Based on lengths of active faults in Missoula County the potential M_0 values correspond to magnitudes (M_w) between 7.3-7.9. The sources for data are W&C for Wells and Coppersmith (1994), H&D for Henry and Das (2001), S&S for the Shaw and Scholz (2001) catalog published in Manighetti et al. (2007), R&R for Romanowicz and Ruff (2002), and Somerville is Somerville et al. (1999). (Modified: Leonard, 2010)

For the worst-case scenario a M 7.0 earthquake was considered. The earthquake ground-shaking potential maps for the state of Montana developed by the USGS and Wong et al. show earthquake shaking for recurrence intervals of 2500 and 5000 years, respectively (2014; 2004). These maps approximate peak ground accelerations (PGA) matching that of a M 7.0 earthquake with MMI 8. For the M 7.0 earthquake scenario, MMIs between 3-5 and 8 were considered (Fig. 3-13b).

MMI, ground acceleration, and magnitude relationships were used to estimate shaking levels for M 7.0 and M 4.0 earthquakes (Table 3-5). Distance from fault was used to develop the shaking regions. For each fault, four 5-mile buffers were created extending from the faults outwards twenty miles. The 5-mile distance was chosen as it reflects the size of shaking regions around faults in the Montana ground shaking maps (Wong et al., 2004). These buffers were dissolved to create four zones. Each zone represents a different MMI level and was scaled up to create the worst-case shapefile from the most-likely shapefile.

This method for file creation assumes that as distance from active faults increases the shaking intensity decreases. This is generally true, but local geology should be considered since Montana is host to numerous sedimentary basins that can amplify shaking away from the faults (Wong et al., 2004). This method also assumes that 5-mile distances represent a change in MMI value. This may not be a realistic assumption, but more information is needed to better constrain true Mercalli zones at a county level scale. Snuggets were written to inform public of what type of shaking they might experience in each scenario and translates PGA values into relatable terms.

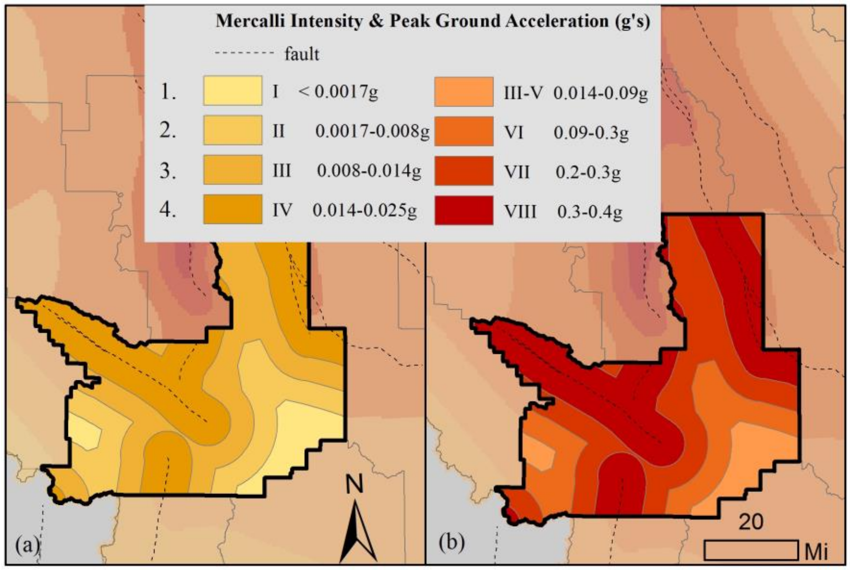


Figure 3-13. (a) Shaking zones for most-likely earthquake scenario include MMI from 1 to 4. (b) Shaking zones for worst-case earthquake scenario include MMI from 3 to 8. Numbers 1-4 on the left represent lookup-values assigned for each region to the right.

Table 3-5. Comparison used for developing shaking zones. Modified Mercalli Intensity–Peak Acceleration comparison and magnitude-Mercalli Intensity comparisons were used to approximate ground shaking regions (USGS, 2016; Wald et al., 1999)

Modified Mercalli Intensity	I	II-III	IV-V	VI-VII	VII-IX	≥VIII
Description	Not Felt	Weak	Light-Moderate	Strong-V. Strong	V. Strong-Extreme	Severe-Extreme
Magnitude (M)	1.0-3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	≥7.0
Peak Acceleration (%g)	<0.17	0.17-1.4	1.4-9.2	9.2-34	34-65	≥65
Peak Acceleration (g's)	<0.0017	0.0017-0.014	0.014-0.092	0.092-0.34	0.34-0.65	≥0.65

Lookup_val	Intensity (0-100)	Likely (M 4.0 earthquake) snugget example
1	10	If a small earthquake hits somewhere in Missoula County, you will experience intensity 1 shaking. You probably won't feel a thing. If you do, it will be slight and won't cause any damage.
4	50	If a small earthquake hits near here, you will experience intensity 4 shaking. Many people will feel the shaking and some people sleeping will wake up. Windows, dishes, and doors will shift. It will feel similar to a truck hitting a building.

Lookup_val	Intensity (0-100)	Worst-case (M 7.0 earthquake) Snugget example
1	50	If a magnitude 7 earthquake happens near here, you will experience intensity 3-5 shaking. The shaking will wake people up and cause dishes and windows to break. It will feel similar to a truck hitting a building.
4	90	If a magnitude 7 earthquake happens near here, you will experience intensity 8. The major shaking will be scary and everyone will run outside. It will cause chimneys, walls, and factory stacks to crack and fall. Wood-frame houses will move if they're not bolted down.

6.2 Historical Layers: Nearest historic earthquake

Historic earthquake location and magnitude information was acquired from the USGS earthquake archive (USGS, 2015). Earthquakes with magnitudes less than 3 are common occurrence in Missoula County, but are not typically felt by people (Atkins, 2011). For this reason only historic earthquakes equal to or greater than M 3.0 were included. This consisted of 16 earthquakes with a maximum M of 4.3 (Fig. 3-14a). These data were in vector point format.

To transform the data into vector polygon data the Thiessen Polygon tool in ArcGIS was used. This tool divides the specified region with point features into Thiessen zones. Within a Thiessen zone all locations are closer to a specific point than to any other point in the region (ESRI, 2016). Inputting the historic earthquake point data into the Thiessen Polygon tool generated an output with polygons corresponding to individual historic earthquakes (Fig. 3-14b). When a location within Missoula County is searched information about the nearest historic earthquake will be queried. Each polygon was assigned a lookup-value and snugget text was written describing the year, size, and possible shaking that was felt for each earthquake. One drawback to this method is that since polygons are generated for individual earthquakes a swarm of earthquakes in a small area will not be captured. In future, another layer should be made to inform people if multiple earthquakes have occurred nearby.

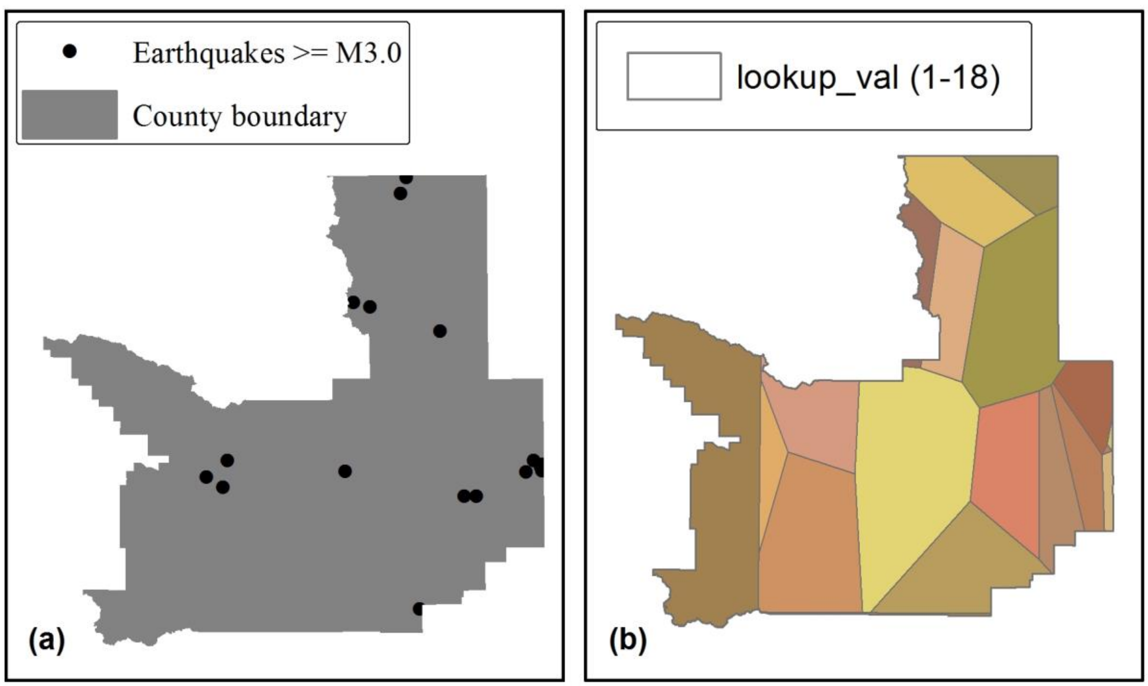


Figure 3-14. (a) Historic earthquakes greater than M3 in Missoula County. (b) Thiessen polygon regions that correspond with individual earthquakes.

Lookup_val	Intensity (0-100)	Snugget example
1		In 2004, a magnitude 3.0 earthquake likely caused some shaking nearby, but people may not have realized it was an earthquake. It would have felt similar to the vibrations of a passing truck.
14		In 2004, a magnitude 3.0 earthquake likely caused some shaking nearby, but people may not have realized it was an earthquake. It would have felt similar to the vibrations of a passing truck.

7 Landslide

Landslides rank sixth on the hazards list for Missoula County (Atkins, 2011). Very little geographic information exists about landslides in Missoula County other than written reports of incidences with general locations and a U.S. wide susceptibility study. The statewide hazard assessment for Montana uses the USGS landslide susceptibility report for the lower 48 (Radbruch-Hall et al., 1982). The state-wide assessment suggests that with population growth and percent of buildings exposed, Missoula County ranks third of all Montana counties at risk for landslide exposure, but also recognizes that the poor scale and scarcity of landslide information makes the report unsuitable for use in planning (Montana DES, 2013). The Pre-Disaster Mitigation plan for Missoula County recognizes that risk exists and that landside susceptibility can be increased after a burn, with heavy rainfall, or due to an earthquake and that slopes in the county are steep enough to host landslides (Atkins, 2011). Though no susceptibility maps exist for Missoula County other data exist that can be used to predict susceptible areas. ArcGIS has become a popular tool for integrating multiple data sets that represent land-sliding factors like slope, land-cover, precipitation, aspect as well as others. Studies have developed intricate ways of weighting landslide factors to best approximate areas of high, medium, and low landslide susceptibility (Dai and Lee, 2002; Hong et al., 2016; Shahabi and Hashim, 2015). There is significant variability in methods and factors used to constrain susceptibility, but the general model involves weighting data layers, standardizing values, and adding or multiplying their values to obtain resulting values that qualitatively represent low to high landslide susceptibility. This study creates a landslide susceptibility shapefile using available datasets for Missoula County.

7.1 Hazard Potential Layer: landslide susceptibility

A difficulty in producing landslide susceptibility maps is defining which factors to use. This issue stems, in part, from localities having different topography, weather, geology, etc. that can influence landslide susceptibility. For example, forest fires in Montana create favorable conditions for landslides if followed by rainstorms and should therefore be considered, but may be unnecessary in places without wildfire (Gabet and Bookter, 2008). Previous landslide susceptibility studies helped guide which landslide factors were used in this study. Slope was consistently the main factor associated with landslide incidence (Dai and Lee, 2002; Fernández et al., 2008; Iwahashi et al., 2003; Jiménez-Perálvarez et al., 2009). Other factors varied depending on region and thoroughness of the study, but often included datasets like lithology, soil depth/type, land-use or vegetation, and precipitation amongst others. Datasets available for Missoula County included soil, land cover, normalized difference index (NDVI), annual precipitation, and geologic units. This analysis was limited by ability to reasonable standardize the data and data resolution so three of the five datasets were chosen. They included slope, soil, and land-use type. Future iterations of this analysis should include more variables as factors and their weights are better understood.

The four steps for analysis include, 1) dataset acquisition, 2) dataset standardization, 3) multiplication of datasets, and 4) output categorization. For step one, the slope file was derived from a 1/3 Arc Second Digital Elevation Model (DEM) using ArcGIS "Slope" tool. The Soil data were acquired from the Soil Survey Geographical (SSURGO) Database. Detailed soil information existed for the most of Missoula County except for the Flathead Indian Reservation and some parts along the Ninemile Region, which had no soil information. The land cover data were sourced from The Natural Resource Information System (NRIS) and included information on land types and uses (Table 3-6).

Step two involved converting files into raster format and assigning standard values across datasets so they could be multiplied using the Raster Calculator function in ArcGIS. The attributes of each data layer were used to assign values to each representing how significantly they contribute to landslide (Table 3-7). Slope and landcover were ranked on a scale from zero to one hundred. After slope was categorized the areas with slopes less than 20 degrees, assigned a zero, value were clipped out of the data so only integer assigned regions and potential for landslides in slopes less that 20 degrees are low. The landcover data were divided using rankings from previous studies and to some degree adjusted depending attribute descriptions. The soil data had little information to help rank this file into many categories. This resulted in a binary classification for soil; a value of one was assigned to areas with soil and a zero value for areas classified as a cliff, outcrop, or water. Since parts of Missoula County were missing soil data those were classified as negative one. This was done to track zones without soil data as data layers were multiplied together. Once all layers were standardized they were multiplied together to complete step three (Fig. 2-7),

$$Ouput\ Values = slope \begin{bmatrix} 33 \\ 66 \\ 100 \end{bmatrix} \times\ soil \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix} \times\ landcover \begin{bmatrix} 0 \\ 14 \\ 29 \\ 43 \\ 57 \\ 71 \\ 85 \\ 100 \end{bmatrix} \qquad (4)$$

This resulted in an output values ranging from 0 to ±10,000. The negative values represented areas where no soil data existed and are based solely on slope and landcover.

Step four included dividing the output values into six groups. Two standard deviations were used to separate the first and second groups and qualitative descriptions of low medium and high landslide risk were assigned as well as lookup-values (Table 3-8). Snuggets were written such that individuals would know which factors were used in estimating landslide susceptibility in their region.

The main issue with this method is that it does not highlight the low-lying areas at the base of the slope where a landslide travels. Instead it highlights areas on the slopes that are prone to landslide initiation. In its current state a user who lives at the base of a slope has to check the areas upslope of where they live to understand risk. A future iteration should include areas downslope of high-risk landslide zones. Future iterations could also include other relevant data layers as a better understanding of their interactions in this region emerges.

Table 3-6. Landcover dataset has the following attribute values with descriptions that allowed for a basic assessment of which items would contribute to landslide potential or improve slope stability (Data: MT Natural Heritage Program, 2013).

Attribute Value	Definition of Attribute Value
Open Water/Wetland and Riparian Systems	Natural systems located in areas where the soil or substrate is periodically saturated with or covered with water.
Human Land Use	Developed areas in rural or urban settings (including roads), strip mines and gravel pits, and agricultural lands.
Alpine Systems	Barren substrate or herbaceous and low shrubby vegetation above mountain timberline.
Forest and Woodland Systems	All natural forest and woodland systems, with the exclusion of riparian systems.
Shrubland, Steppe and Savanna Systems	All natural shrub/scrub systems, with the exclusion of alpine and riparian systems. Shrubland: Shrubs generally greater than 0.5m tall with individuals or clumps overlapping to not touching (generally forming more than 25% cover, trees generally less than 25% cover). Shrub cover may be less than 25% where it exceeds tree, dwarf-shrub, herb, and nonvascular cover, respectively. Vegetation dominated by woody vines is generally treated in this class. Dwarf shrubland: Low-growing shrubs usually under 0.5 m tall. Individuals or clumps overlapping to not touching (generally forming more than 25% cover, trees and tall shrubs generally less than 25% cover).
Grassland Systems	All natural herbaceous systems, with the exclusion of alpine and riparian systems. Herbaceous: Herbs (graminoids, forbs, and ferns) dominant (generally forming at least 25% cover; trees, shrubs, and dwarf-shrubs generally with less than 25% cover). Herb cover may be less than 25% where it exceeds tree, shrub, dwarf-shrub, and nonvascular cover, respectively.
Sparse and Barren Systems	Badlands, dunes, and cliffs and canyons, that are characterized by sparse vegetation or are unvegetated. Abiotic substrate features dominant. Vegetation is scattered to nearly absent and generally restricted to areas of concentrated resources (total vegetation cover is typically less than 25% and greater than 0%).
Recently Disturbed or Modified	Recently burned or harvested vegetation, and introduced upland and riparian vegetation.

Table 3-7. Classification used for each data layer. Ranking is set on a scale from zero, for little to no contribution to landslide, to 100 or 1, for greater contribution to landslide.

Data	Attribute Description	Ranking (0-100 or 0-1 scale)	Sources used for classification
Slope	0-20°	0	Dai and Lee, 2002,
	20-30°	33	Iwahashi et al., 2003,
	30-40°	100	Larsen and Montgomery,
	>40°	66	2012
Landcover	Open Water and Riparian Vegetation	0	Dai and Lee, 2002, Hong et al., 2016,
	Human Land Use	0, 14 (if other roads, quarries/gravel pits)	VanWesten et al., 2003
	Alpine Systems	29, 0 (if barren)	
	Forest and Woodland Systems	43	
	Shrubland, steppe and savannah systems	57	
	Grassland Systems	71	
	Sparse or Barren Systems	85, 0 (if talus)	
	Recently Disturbed or Modified	100 , 85 (if introduced vegetation)	
Soil	Yes	1	Jay Brooker, Missoula Area
	No (cliff, rocky, outcrop, water)	0	Resource Soil Scientist,
	No data	-1	NRCS (Phone Contact, February 2016)

Table 3-8. The values resulting from multiplying standardized slope, soil, and landcover were divided into six lookup-values, but three qualitative ranks of low, medium, and high.

Output Value	Standard Deviation #	Qualitative Rank[*]	Lookup-value
2512.2-0	2	Low	1
5025.6-2512.2	4	Medium	2
10,000-5025.6	>4	High	3
-2512.6-0	2	Low[*]	4
-5025.2--2516.2	4	Medium[*]	5
-10,000--5025.2	>4	High[*]	6

[*]Rank and values are based on slope and landcover only. Soil information was not included for these values

Lookup_val	Intensity (0-100)	Snugget example
1	33	There is lower chance for a landslide here given the slope, land type, and soil. If you live beneath a slope or drainage (where water concentrates) check points uphill to see if they have a higher chance for sliding.
6	100	There is higher chance for a landslide here given the slope and type. If you live beneath a slope or drainage (where water concentrates) you could be at risk.

8 Discussion

The data layers discussed above provide the backend of the MissoulaReady product. Once loaded into the Django framework, as mentioned in chapter 2, they are available for use on the website. When a location in Missoula County is searched, each data layer described above is queried. The lookup-value for that location is associated with the snuggets CSV file and text is formatted and displayed to the user. This happens in a matter of seconds and provides a customized report of hazard risks and preparedness steps for each location. The above data layers were selected to generate content for the “What to Expect” and “Historic Events” sections for each hazard tab on the MissoulaReady website. The assigned intensity values shown in the snugget examples above are displayed via graphical dial with colors ranging from yellow (low risk) to red (high risk). These values are estimated based on relative risk within Missoula County. Providing the dial simplifies the process of comparing risks across hazards. A user can click through the various hazard tabs, compare intensity dials, and read brief descriptions of risk and hazard potential. This makes for uncomplicated qualitative comparisons across hazards allowing people to determine which hazards they are at higher risk for within the county.

As new data become available it will become important to update the files powering the MissoulaReady website. A main aim of developing this tool was to make incorporating new data rather seamless. To replace an existing data layer with a new one similar steps as those required to process the original data must be taken. They include using ArcGIS to polygonize data, adding lookup-values, and writing new snugget text. The old shapefile must then be replaced with the new one and added to the server along with the revised snuggets CSV file using SFTP. The snugget_load.py and import.py scripts must then be run using command line. The data update process would likely take one to two days per data layer depending on how complex the new data are.

This approach to simplifying technical data into a user-friendly format has a number of strengths and a few weaknesses. One strength is that only basic ArcGIS expertise is needed to process data layers. Now that processing techniques have been defined a trained undergraduate student could complete data layer updates with supervision. A second strength is the ability to incorporate many kinds of geographic data. Much of the hazard data put out are in varied formats, but this method provides a way to standardize them. This ability also allows for scaling the product up or down in size and developing it for other locations depending on available data. A third strength is that after data collection and processing all relevant natural hazard data for a region are easily accessible in one location.

A weakness includes that it hard for users to tell if they are on the edge of a polygon. This is because we chose not to include interactive data overlay images so as not to overwhelm the viewer with too much information. To mitigate this issue a pdf image of the data is provided through clickable link in the snugget text (Fig. 2-4). A second weakness is that certain aspects of the data are hard to capture with this method. As described above, the clustering of past earthquakes was not addressed since each polygon and lookup-value described only one earthquake. Further investigation into ArcGIS tools may provide useful ways to tackle this problem. The third and perhaps most important issue is that this tool is only as good as the data available. A recurring issue with hazards in Montana is the lack of available data to constrain potential hazards and a variability of data quality. This tool provides the latest information, but does not express the uncertainty or lack of data for some of the hazards. Much of the resources used to develop hazard assessments and tools such as these rely on outdated data or data with resolutions too low to apply to the study area. Until more research is done, hazard assessments and educational tools will be based on limited information. This work highlights the immense need for future research and studies that assess and quantify natural hazard factors and risks for not only Missoula County, but Montana State as well. The potential for many types of disaster is non-trivial in Montana and as population influxes continue it will become important to adequately assess the potential for catastrophes and communicate it to relevant stakeholders.

9 References

Atkins: Pre-Disaster Mitigation Plan 2011 Update, Missoula County and City of Missoula, 2011.

Bakun, W. H.: MMI attenuation and historical earthquakes in the basin and range province of western North America, Bull. Seismol. Soc. Am., 96(6), 2206–2220, doi:10.1785/0120060045, 2006.

Boyd, K.: Clark Fork River Channel Migration Pilot, Applied Geomorphology and DTM Consulting Inc., Missoula County, MT, 21 pp., 2009.

Butler, T. and Lott, Fred: Cedar River Channel Migration Study, King County Department of Natural Resources and Parks, Water and Land Resources Divison, Seattle, WA, 2015.

Dai, F. C. and Lee, C. F.: Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong, Geomorphology, 42(3-4), 213–228, doi:10.1016/S0169-555X(01)00087-3, 2002.

Ellis, J., Wallace, G. and Reeves, S.: Missoula County Community Wildfire Protection Plan, 2005.

Federal Emergency Management Agency (FEMA): Digital Insurance Rate Map (DFIRM), ftp://www.co.missoula.mt.us/GISPublicFTP/Data/Shapefile, Last access: 2 Feb. 2016, 2015.

Fernández, T., Irigaray, C., El Hamdouni, R. and Chacón, J.: Correlation between natural slope angle and rock mass strength rating in the Betic Cordillera, Granada, Spain, Bull. Eng. Geol. Environ., 67(2), 153–164, doi:10.1007/s10064-007-0118-x, 2008.

Fire Program Analysis (FPA) System and US Forest Service (USFS) Missoula Fire Sciences Laboratory: Burn Probabilities for the Conterminous US (270-m GRID) from Calibrated FSim Runs for the 2014 FPA Submissions [bp_20140307], National Interagency Fire Center, Boise, ID, 2014.

Gabet, E. J. and Bookter, A.: A morphometric analysis of gullies scoured by post-fire progressively bulked debris flows in southwest Montana, USA, Geomorphology, 96, 298–309, doi:10.1016/j.geomorph.2007.03.016, 2008.

Gigerenzer, G., Hoffrage, U., Mellers, B. A. and McGraw, A. P.: How to Improve Bayesian Reasoning Without Instruction: Frequency Formats, Psychol. Rev., 102(4), 684–704, doi:10.1037/0033-295X.102.4.684, 1995.

Haas, J. R., Calkin, D. E. and Thompson, M. P.: A national approach for integrating wildfire simulation modeling into Wildland Urban Interface risk assessments within the United States, Landsc. Urban Plan., 119, 44–53, doi:10.1016/j.landurbplan.2013.06.011, 2013.

Hall, W. A. and Howell, D. T.: Estimating Flood Probabilities Within, J. Hydrol., 1, 265–271, 1963.

Haller, K. M., Dart, R. L., Machette, M. N. and Stickney, M. C.: Data for Quaternary faults in western Montana Open-File Report 2000-411., 2000.

Henry, C., and S. Das; Aftershock zones of large shallow earthquakes: Fault dimensions, aftershock area expansion and scaling relations, Geophys. J. Int. 147, 272–293, 2001.

Hoffrage, U. and Gigerenzer, G.: Using Natural Frequencies to Improve Diagnostic Inferences, Acad. Med., 73(5), 538–540, 1998.

Hofmann, M. H., Hendrix, M. S., Sperazza, M. and Moore, J. N.: Neotectonic evolution and fault geometry change along a major extensional fault system in the Mission and Flathead Valleys, NW-Montana, J. Struct. Geol., 28, 1244–1260, doi:10.1016/j.jsg.2006.03.030, 2006.

Holmes, R. and Dinicola, K.: 100-Year Flood – It's All About Chance: Haven't we already had one this century?, USGS General Infromation Product, Reston, VA, 1–3, 2010.

Hong, Y., Adler, R. and Huffman, G.: Use of Satellite Remote Sensing Data in the Mapping of Global Landslide Susceptibility, Nat. Hazards Spec. Issue, Use of Sat, 2016.

Howell, B.F. Jr., Schultz, T. R.: Attenuation of modified mercalli intensity with distance from the epicenter, , 65(3), 651–665, 1975.

Iwahashi, J., Watanabe, S. and Furuya, T.: Mean slope-angle frequency distribution and size frequency distribution of landslide masses in Higashikubiki area, Japan, Geomorphology, 50(4), 349–364, doi:10.1016/S0169-555X(02)00222-2, 2003.

Jiménez-Perálvarez, J. D., Irigaray, C., El Hamdouni, R. and Chacón, J.: Building models for automatic landslide-susceptibility analysis, mapping and validation in ArcGIS, Nat. Hazards, 50(3), 571–590, doi:10.1007/s11069-008-9305-8, 2009.

Larsen, I. J. and Montgomery, D. R.: Landslide erosion coupled to tectonics and river incision, Nat. Geosci., 5(7), 468–473, doi:10.1038/ngeo1479, 2012.

Manighetti, I., M. Campillo, S. Bouley, and F. Cotton; Earthquake scaling, fault segmentation, and structural maturity, Earth Planet. Sci. Lett. 253, no. 3–4, 429–438, 2007.

Montana DES: 2013 Update to the State of Montana Multi-Hazard Mitigation Plan and Statewide Hazard Assessment-Landslide Section., 2013.

National Weather Service (NWS) Missoula Forecast Office, Advanced Hydrologic Prediction Service for the Clark Fork above Missoula, MT, Blackfoot near Bonner, and Bitterroot Below Missoula, NOAA, http://water.weather.gov/ahps2/index.php?wfo=mso, Last access: Feb 2016.

Pasolini, C., Albarello, D., Gasperini, P., D'Amico, V. and Lolli, B.: The Attenuation of Seismic Intensity in Italy, Part II: Modeling and Validation, Bull. Seismol. Soc. Am., 98(2), 692–708, doi:10.1785/0120070021, 2008.

Petersen, M. D., Moschetti, M. P., Powers, P. M., Mueller, C. S., Haller, K. M., Frankel, A. D., Zeng, Y., Rezaeian, S., Harmsen, S. C., Boyd, O. S., Field, N., Chen, R., Rukstales, K. S., Luco, N., Wheeler, R. L., Williams, R. A. and Olsen, A. H.: Documentation for the 2014 Update of the United States National Seismic Hazard Maps., 2014.

Roberts, N. J., Nadim, F. and Kalsnes, B.: Quantification of vulnerability to natural hazards, Georisk Assess. Manag. Risk Eng. Syst. Geohazards, 3(3), 164–173, doi:10.1080/17499510902788850, 2009.

Romanowicz, B., and L. J. Ruff; On moment-length scaling of large strike slip earthquakes and the strength of faults, Geophys. Res. Lett. 29, 12, 2002.

Shahabi, H. and Hashim, M.: Landslide susceptibility mapping using GIS-based statistical models and Remote sensing data in tropical environment, Sci. Rep., 5, 9899, doi:10.1038/srep09899, 2015.

Shaw, B. E., and C. H. Scholz; Slip-length scaling in large earthquakes: Observations and theory and implications for earthquake physics, Geophys. Res. Lett. 28, no. 15, 2995–2998, 2001.

Somerville, P., K. Irikura, R. Graves, S. Sawada, D.Wald, N. Abrahamson, Y. Iwasaki, T. Kagawa, N. Smith, and A. Kowada; Character- izing crustal earthquake slip models for the prediction of strong ground motion, Seism. Res. Lett. 70, 59–80, 1999.

Stickney, M. C. and Bartholomew, M. J.: Seismicity and Late Quaternary Faulting of the Northern Basin and Range Province, Montana and Idaho, Bull. Seismol. Soc. Am., 77(5), 1602–1625, 1987.

Sullivan, A. L.: Wildland surface fire spread modelling, 1990–2007. 3: Simulation and mathematical analogue models. International Journal of Wildland Fire, 18, 387–403, doi: 10.1071/WF06144, 2009.

United Nations Department of Humanitarian Affairs: Internationally agreed glossary of basic terms related to Disaster Management., 1992.

United States Congress: Healthy Forests Restoration Act. [online] Available from: http://www.fs.fed.us/emc/applit/includes/hfr2003.pdf, 2003.

USGS and New Mexico Bureau of Mines and Mineral Resources (NMBMMR): Quaternary fault and fold database for the United States, http//earthquake.usgs.gov/hazards/qfaults/, last access: 10 Dec 2016, 2006.

VanWesten, C. J., Rengers, N. and Soeters, R.: Use of geomorphological information in indirect landslide susceptibility assessment RID A-4043-2010, Nat. Hazards, 30(3), 399–419, doi:10.1023/B:NHAZ.0000007097.42735.9e, 2003.

Villagran De Leon, J. C.: Vulnerability: a conceptual and methodological review, United Nations University-Institute for Environment and Human Security (UNU-EHS), Bonn, Germany, 2006.

WA Dept. of Ecology: Channel Migration Assessment Mason County, Washington, 2011.

Wald, David J., Quitoriano, Vincent, Heaton, Thomas H., Kanamoori, H.: Relationships between Peak Ground Acceleration, Peak Ground Velocity, and Modified Mercalli Intensity in California, Earthq. Spectra, 15(3), 557–564, 1999.

Wells, D. L., and K. J. Coppersmith; New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, Bull. Seismol. Soc. Am. 84, no. 4, 974–1002, 1994.

Woelfle-Erskine, C., Wilcox, A. C. and Moore, J. N.: Combining historical and process perspectives to infer ranges of geomorphic variability and inform river restoration in a wandering gravel-bed river, Earth Surf. Process. Landforms, 37(12), 1302–1312, doi:10.1002/esp.3276, 2012.

Wong, I., Olig, S., Dober, M., Wright, D., Nemser, E., Lageson, D., Silva, W., Stickney, M., Lemieux, M. and Anderson, L.: Earthquake Ground Shaking Hazard Maps for the state of Montana, 13th World Conf. Earthq. Eng., (1013), 2004.