MAPPING WHERE RIVERS MEET PEOPLE: USABILITY AND ACCURACY OF FLOOD MAPS IN RURAL VERMONT

by

Noah Bezanson

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Golden, Colorado

Date ____________________________

Signed: ____________________________

Noah Bezanson

Signed: ____________________________

Dr. Elizabeth Reddy
Thesis Advisor

Signed: ____________________________

Dr. Paul Santi
Thesis Co-advisor

Golden, Colorado

Date ____________________________

Signed: ____________________________

Richard Krahenbuhl
Director
Humanitarian Engineering and Science Interdisciplinary Graduate Program

ABSTRACT

In July 2023, severe flooding impacted the northeastern United States. Rural Ludlow, Vermont, was hit with over six inches of rain in less than 48 hours and is still recovering. Flood hazard maps are a commonly used tool in determining the risk level faced by specific areas before floods like this one. In this context, this research has been designed to address the following research question: What challenges and opportunities exist with respect to the usability and accuracy of current flood hazard maps? To answer this question, this study uses a mixed methods approach including interviews, community mapping, and site visits. Preliminary results indicate that flood map accuracy and usability are issues of concern for research participants, including impacted residents, community organizers, and local and state officials, who highlighted ongoing erosion, infrequent map updating, and other concerns. Impacted community members, in particular, noted challenges distinguishing between the Federal Emergency Management Agency's National Flood Hazard Layer and the River Corridor maps developed by the State of Vermont. They also had difficulty effectively navigating websites and getting questions answered. As climate change causes flooding across the country to become more common and more severe [1], it is crucial to better understand how users interact with available flood prediction resources to make appropriate decisions regarding flooding issues. These decisions may have implications for the design and development of maps and additional tools. This study also shows that the accuracy of the flood maps must be improved in order for residents to trust their predictions. Flood maps do not currently reflect the experiences of community members, and are underutilized partially for this reason. The findings from this research reveal both ways to improve the current maps and criteria for the development of future flood hazard maps.

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LIST OF ABBREVIATIONS

Federal Emergency Management Agency	FEMA
International Organization for Standardization.	ISO
Geographic Information System	GIS
Participatory Geographic Information System	PGIS
National Flood Hazard Layer	NFHL
Flood Insurance Rate Map	FIRM
Letter of Map Revision	LOMR
Special Flood Hazard Area	SFHA
Base Flood Elevation	BFE
Vermont Agency of Natural Resources	ANR
United States Geological Survey	USGS
Black River Action Team	BRAT
Black River Valley Resources	BRVR
Association of Environmental & Engineering Geologists	AEG

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CHAPTER 1 INTRODUCTION

1.1 Introduction

As climate change continues to shift hydrological systems around the world, and specifically in Vermont [1], there will be more floods and more disasters. Using interdisciplinary methods, including participatory mapping [2]—a form of community based research [3]— this research project addressed identified challenges related to the usability and accuracy of flood maps; specifically, the Federal Emergency Management Agency's (FEMA) National Flood Hazard Layer and the State of Vermont's River Corridors maps. I chose to specifically focus on these maps because they were the flood hazard maps that were referenced the most across the interviews I conducted. The primary aim of this research was to understand the nature of existing flood maps and how these flood maps are currently used by different groups, including town-, county-, and state-level officials; community organizers; and impacted community members. This research also aimed to uncover how these groups access and act on the maps, and assess their accuracy and utility in relation to those uses. Finally, this research project evaluates the accuracy of each of these maps and includes a list of suggestions for improving current flood hazard maps and enhancing their value, as well as a list of criteria for any possible future maps. These recommendations are based on interviews and mapped flood data from research participants in Ludlow and Cavendish.

This section provides an overview of the study site, as well as the specific event that this research took place after. Section 3 provides a background on how I became involved in this research and completed my thesis as a part of the broader Rural Rivers/Mapping for Resilience research team. The fourth section is a literature review on flood maps, usability, and participatory mapping, while the fifth section describes the relevant flood hazard maps in detail. Section 6 presents my research questions. Sections 7 and 8 describe my research process and the methods I used to complete this project, respectively. Finally, Section 9 provides an outline of the rest of this thesis.

1.1.1 Site Description

This research project took place in Ludlow and Cavendish, two neighboring small towns in rural Vermont. The towns are situated alongside the Black River, about ten miles west of the New Hampshire border. The area is mountainous and largely forested. Dozens of brooks and streams of various sizes feed into the Black River in and around the two towns. Okemo Ski Resort is located in Ludlow and shapes the demographics and businesses in both towns. Many of the homes in Ludlow, as well as a significant number of the homes in Cavendish, are vacation homes that are empty for much of the year. Most homeowners that live in the area year-round are not wealthy, and they are impacted by a housing shortage. There are various drivers of this housing shortage, including the high number of houses owned by nonresidents or rented as short-term rentals. The year-round population of Ludlow is about 2,200, while Cavendish has approximately 1,400 people; over 90 percent of each of the towns is white [4], [5]. Both towns have many features of a stereotypical small rural town. For example, everyone seems to know everyone, and there is a single grocery store. People look out for one another when faced with disasters such as flooding. Because of the towns' sizes and the study team members' pre-existing connections with people in both communities, I was able to recruit and build productive relationships with a variety of people that I may not have been connected with otherwise.

1.1.2 Flood Event of July 2023

Devastating flooding hit the Northeastern United States in July 2023. Now referred to as the Great Vermont Flood of July 10-11, 2023, the flooding was primarily caused by a significant rainfall event over much of the region. Ludlow specifically was hit with over six inches of rain over the duration of the storm; other towns in Vermont received over nine inches of rain. The flooding caused the Black River to rise significantly - over 9 feet in some places in Ludlow and Cavendish [6]. One example of the height the water reached can be seen in Figure 1.1 below. In this example, the flooding in the Timber Inn reached the top of the first-floor windows of the building.

The most notable damage in Ludlow and Cavendish occurred close to the Black River. This is both due to the amount which the Black River rose, and also to the fact that most people and businesses live and operate in close proximity to the river. Both Ludlow and Cavendish were originally mill towns. This necessitated that their town centers be built close to the river, in order to power the mills. This initial proximity to the river has never changed.

However, inundation flooding due to the rising river was not the only cause of flooding damage in the two towns. The rain also caused erosion, landslides, seepage, and sinkholes, especially in the mountainous portions of the towns. Additionally, the network of culverts built to manage water in the area led to significant flooding damage when some became blocked or damaged. All of these different types of flood damage combined to make the storm devastating to the area.

This flood event has continued to have an impact on local residents and businesses since July 2023. Some residents were still rebuilding or repairing structures that were damaged a year later, when many of the interviews for the project were done. The Shaw's grocery store in Ludlow (which was the only chain grocery store with fresh fruit and vegetables in either Ludlow or Cavendish) was damaged significantly in the flooding, as it lies approximately 150 feet from the Black River. Shaw's was closed for 51 weeks after the flooding, only reopening during the Fourth of July weekend in 2024. A recreation area in Cavendish continues to be closed after the flooding swept away virtually all of the baseball field there, including structures such as sheds, benches, and fences (see Figure 1.2 below). These are only a few examples of the variety of ways in which the people who live and work in Ludlow and Cavendish were, and continue to be, affected by these floods.

Figure 1.1 The flood line on the Timber Inn was at the top of the windowsill. This building has been bought out and demolished, completing a process that began before the July 2023 floods, according to an interview I conducted with the owner.

Figure 1.2 This baseball field in Cavendish has become overgrown, with no immediate plans to utilize it as a baseball field again.

1.2 Background and Motivation

This thesis fulfills the requirements of the Humanitarian Engineering and Science program at the Colorado School of Mines. During their time in this program, students "learn to take a sociotechnical approach to make a difference in the world" [7]. This perspective expands the impact of engineering beyond the solely technical realm that it often inhabits. As a part of this education, students also "[conduct] leading research at the intersection of engineering and social science" [7]. This thesis is one example of research at this intersection. This research project focuses on the use and impact of flood hazard maps. As a technical tool developed by engineers and scientists using advanced software and models, typical research might focus on how well the maps predicted flooding. However, this thesis also incorporates the social aspect of flood hazard maps, by aiming to understand how people use these maps and whether people believe the maps to be accurate. Because of this broad, multidisciplinary research approach, this thesis provides a more nuanced understanding of how the maps are actually used. I was particularly excited about this research project specifically because of my interest in flooding and my connections to the New England area.

This thesis research is a small part of a broader research project. This research project, called the Rural Rivers/Mapping for Resilience project, is being completed by a multidisciplinary team at Dartmouth College and Colorado School of Mines [8]. This team is led by Dr. Charis Ford Morrison Boke and Dr. Sarah Kelly at Dartmouth College, as well as Dr. Elizabeth Reddy at Colorado School of Mines. The project's geographical focus is the Black River Valley and White River Valley in Vermont. The project is focused on researching how the impacts of flooding disasters intersect with the economic and social conditions people in the area experience. Every stage of flooding disasters is being researched, from response and recovery to mitigation of and preparation for future disasters. The Rural Rivers/Mapping for Resilience project will continue well after this thesis project and the research dissemination associated with it is completed.

1.3 Literature Review

In order to understand past work investigating flood hazard maps and people's relation with them, this thesis draws on several connected literatures. First, I investigate the literature on flood maps. This is intended to provide a background on how academics discuss flood maps. Second, I briefly discuss the literature on usability, and more specifically the usability of maps. Third, I review a few participatory mapping projects discussed in the literature. This gives an idea of how people have approached research projects similar to my thesis project. I work with these literatures together to inform my approach to this project, as well as my approach to this thesis paper specifically.

Flood hazard maps are designed and maintained by federal agencies and state governments to communicate the level of risk of a major flood event in a specific area. For example, FEMA's National Flood Hazard Layer designates 100-year floodplains, official floodways, and other relevant spaces [9]. Vermont's River Corridor maps represent erosion risks by mapping the meander belts of rivers [10]. However, the creation of these maps is not solely a technical issue; there are several social factors that must be considered to make flood hazard maps usable to end users, such as impacted community members. Map usability does not only mean that community members are able to view the flood map data. Elwood and Leitner frame this broader process as Awareness, Acquisition, and Application of Geographic Information System (GIS) maps [2]. This more comprehensive view of map usability acknowledges that community members may not have the skills or knowledge to understand and use flood maps, which are often highly technical. These challenges, as well as some ideas for overcoming them, are discussed in a case study by Auliagisni and colleagues [11]. They analyzed how a community in New Zealand used flood hazard maps, and found that the current flood hazard maps were often difficult to use by residents who could potentially be affected by flooding to find and understand. They point to the importance of creating easily readable flood maps, as well as implementing outreach groups to ensure all community members are aware of potential hazards. These actions address multiple of the levels of the map access process outlined by Elwood and Leitner [2]. My research project was designed to address the different levels of this process in a similar way.

My thesis research frames the process of using flood hazard maps as having three steps: Identification, Interpretation, and Implementation. These three steps are derived from the process described by Elwood and Leitner [2]. Taken together, the three steps outline what I refer to as the usability of flood hazard maps. A commonly cited definition of usability is one developed by the International Organization for Standardization (ISO) in ISO 9241-11: "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [12]. However, there are also a number of other definitions, many describing the various attributes of usability; these are brought together by Alonso-Ríos as knowability, operability, efficiency, robustness, safety, and subjective satisfaction [13]. Many definitions have been critiqued as being "brief and imprecise" [13], [14]. For this reason, I am using the definition of usability that follows: the degree to which a tool can be identified, interpreted, and implemented to make relevant changes. This definition is based on past literature on GIS specifically, as outlined above. Past research into the usability of GIS systems has revealed that GIS tools are often unusable in one or more of these categories [15]. This provides an opportunity for my research to investigate the specific ways in which flood hazard maps may have deficiencies in usability.

The findings from this research result in recommendations to improve the accuracy and usability of current maps, as well as a set of criteria for a future flood hazard map tool. Participatory geographic information systems, sometimes called PGIS [16], public participation mapping or participatory mapping, was a core research approach for this project and will continue to be for future work that incorporates this project's findings. This term was coined in 1996 to describe research techniques that prioritized making GIS mapping tools accessible to all stakeholders in the community being mapped [17]. PGIS originated in the field of citizen science, which has been described as how the public participates in creating and using scientific research [18]. A number of PGIS projects have taken place in the United States, many of which were conducted in urban areas [19], [20], [21]. PGIS projects have also been successful in more rural contexts, like the one in which this project takes place [22]. There are also various ways to adapt the PGIS framework to different contexts. For example, PGIS could involve creation of a three-dimensional map using different types of pins or markers [23], or it could involve drawing maps by hand on paper [21]. These case studies show that PGIS does not always require the use of advanced computer programs. This flexibility is valuable, as it enables us to find an approach that works in rural Vermont.

PGIS work has long been recognized as complex. As early as 1998, Harris and Weiner [24] put forth the succinct and accurate argument that "GIS is a contradictory technology that simultaneously marginalizes and empowers people and communities" (p. 2). The authors argued that community outreach actions taken by experts are often overlooked and that PGIS is very much situated in the specific political and social context of a place. There are also barriers of cost and unequal power distribution, as outlined by Robinson and colleagues [25]. GIS software and the hardware to run it continues to be prohibitively expensive for many groups. Additionally, even the most expansive PGIS initiatives cannot directly involve every individual in the mapmaking process, and some local knowledge may be contradictory. Robbins [26] argues that this provides an opportunity for GIS to help answer questions about the formation of knowledge. These differences in local knowledge must be acknowledged. Beyond the more obvious power differential between outside researchers and community members, additional inequities exist within communities themselves. It is possible for PGIS to be used to reinforce these existing power structures by only paying lip service to community involvement and using it to support preconceived ideas [27]. McCall extensively describes the traits of successful PGIS projects, which include supporting equity and respect for rights; this could include ensuring maps' "manageability at local level by local people" (p. 8). The positive aspects of PGIS projects outlined in this paper and others will be important to emulate.

1.4 Flood Hazard Map Background

This thesis research primarily focuses on two flood hazard maps: FEMA's National Flood Hazard Layer (NFHL), and Vermont's River Corridors map. These two maps are published by different agencies, and have different purposes related to mapping flood hazards. There are additional flood hazard maps beyond these two, but these maps were the ones that were brought up repeatedly by interviewees at the local and state level. These maps can be viewed on the website of the agency that publishes it, or on several atlas-type websites. One of these websites is the Vermont Agency of Natural Resources' Natural Resource Atlas [28], referred to as the ANR Atlas. Once again, the ANR Atlas is focused on here and throughout the rest of the paper because it was used by impacted residents, community organizers, and local and state officials.

FEMA publishes the National Flood Hazard Layer to represent the current risk of inundation flooding in communities across the country. It is a combination of Flood Insurance Rate Maps (FIRMs) and Letters of Map Revision (LOMRs) [29]. As suggested by the name of the FIRMs, a primary use of the NFHL is defining flood insurance requirements [9]. There are many zones on this map, but only three appear in the study area: the Regulatory Floodway, the 1% Chance Annual Flood Hazard, and the 0.2% Chance Annual Flood Hazard. The Regulatory Floodway is defined as "the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height." [30]. The 1% Chance Annual Flood Hazard zone, also called the 100-year flood zone, represents an area that has a 1% chance of flooding in a given year [31]. This area is also called a Special Flood Hazard Area (SFHA), or a Base Flood Elevation (BFE). The 0.2% Chance Annual Flood Hazard zone, also called the 500-year flood zone, represents an area that has a 0.2% chance of flooding in a given year [31]. This area is also referred to as a moderate flood hazard area.

These flood hazard areas are calculated using United States Geological Survey (USGS) regression equations, rainfall-runoff equations, and peak discharge data gathered at USGS stream gages. These calculations provide maximum discharge estimates over a time span, such as 100 years. The peak discharges are then combined with elevation data and channel roughness values in a model such as HEC-RAS to create the actual base flood elevations [32]. During the 2023 floods, the USGS stream gage on the Black River at North Springfield, VT, recorded a maximum peak flow of 2,200 cubic feet per second, corresponding to a flood with a greater than 50 percent Annual Exceedance Probability [33]. However, this gage is located below the North Springfield Dam [34]. This results in the stream gage not accurately reflecting river conditions in Ludlow and Cavendish. While not exactly correlated with river exceedance probabilities, precipitation return intervals can also be useful. The 6 inches of rain measured over 48 hours in Ludlow [35] corresponds with a recurrence interval of approximately 25 years [36]. However, Plymouth, VT, located just ten miles of Ludlow and partially within the Black River watershed, reported rainfall of 9 inches in 48 hours [35]. This corresponds with a recurrence interval of approximately 350 years [36]. I believe the river conditions were likely somewhere between these two recurrence intervals. However, both of these numbers are under the 500-year exceedance probability. This means that the FEMA map should have been expected to accurately represent the flooding that occurred.

The State of Vermont publishes River Corridor maps to represent areas at risk of erosion due to shifts in the path of a river or stream. Unlike the National Flood Hazard Layer, River Corridor maps only have one zone. This zone is created by calculating the meander belt of the river (the area within which the river could shift, based on watershed area and geological characteristics) and adding 50 feet on each side [10]. The River Corridor maps capture smaller streams and brooks as potentially causing flooding-related damage when compared to the NFHL, as can be seen in maps later in this thesis.

1.5 Research Objectives

My research project primarily addresses three research questions. The third question builds upon the first and second ones, and combined they are designed to better understand current barriers to flood hazard map usability and accuracy. Each of the research questions were addressed in the context of the towns of Ludlow and Cavendish, and the more specific context of the July 2023 flooding. The three research questions build off of different parts of the literature, and each required different methodologies to answer.

Are current flood hazard maps usable by community members? If not, what barriers do they face?

This question was primarily answered through interviews. I recorded the experiences that interviewees belonging to different groups (impacted residents, community organizers, and response/recovery professionals) had using flood maps before, during, and after flooding in July 2023. This included detailed information on which maps were used, and what aspects of these maps were useful or proved challenging or inaccurate. I also collected data on the current technical resources that are publicly available, including information on the usability and accuracy of these tools. This question is answered in Chapter 2: Usability of Flood Hazard Maps.

Do current flood hazard maps accurately represent the impacts of flooding disasters on community members? If not, where and why do differences appear?

I used all three of the data collection methods described below to address this question: interviews, community mapping, and site visits. This question does not ask whether the inundation of the 2023 flood lined up exactly with the current flood hazard maps. Instead, this question is focused on where people living within Ludlow and Cavendish experienced flooding, and whether these experiences overlapped with the flood hazard map zones. This question is answered in Chapter 3: Accuracy of Flood Hazard Maps.

How might flood hazard maps be improved in the future, through changes to current maps, creating a new map tool, or addressing the "ecosystem" around the maps?

Answering this research question involves using the findings from the processes described above to outline a set of criteria for a new map tool. This research question is also addressed by providing recommendations for current map tools. Finally, recommendations for improving the sociotechnical ecosystem of flood hazard mapping, including how the maps are published and distributed, are also included. These recommendations go beyond the individual maps into how the systems that the maps are located within can be ameliorated. I answer this question in Chapter 4 of this thesis.

1.6 Research Process

1.6.1 Introduction

This section describes how this research project was conducted. In Section 2, the Mitigation Matters grant that I received from the Natural Hazards Center is introduced and discussed. Information on this grant is presented first because the grant requirements shaped the research process in important ways. Sections 3, 4, and 5 describe my scoping, data gathering, and dissemination trips to Vermont. Each of these trips had distinct purposes, and I interacted with community members in different ways on each trip.

1.6.2 Mitigation Matters Grant

My research was largely funded through a grant received from the Natural Hazards Center at the University of Colorado Boulder. According to the Natural Hazards Center, the Mitigation Matters supports research designed to "understand local risks and invest in long-term planning to reduce risks and enhance community well-being" [37]. My advisor and the Rural Rivers/Mapping for Resilience research team believed this project fit those goals, and assisted me in applying for the grant in November 2023. The process of applying for the grant gave me a timeline for the initial scoping of my project's methods and goals. I was notified that I had received the grant in January 2024. The grant provided $9,839 in funding, which went towards my travel to Vermont in spring 2024 (the scoping trip) and summer 2024 (the data collection trip). The grant also funded materials, such as an audio recorder, and data analysis tools, including Sonix.ai. The Mitigation Matters report due date was July 26, 2024, meaning the overall timeline for the grant was approximately six months. Because of this accelerated timeline, I began analyzing some of the data already gathered while I was still collecting new data in Vermont. The preliminary conclusions I made in the project report shaped my thinking when I analyzed the data set as a whole.

1.6.3 Scoping Trip

My first trip to Vermont took place March 14-18, 2024. I stayed in Cavendish for the duration of this trip. The purpose of this trip was twofold: to familiarize myself with the geography of the area, and to meet with state and local officials to make sure that the scope of my thesis was interesting and relevant. Over the course of the trip, I met with two state officials and a community organizer. I asked them questions about their experiences with flood hazard maps, and any other projects they were aware of that were studying flood hazard maps. I also worked with leaders of the Rural Rivers/Mapping for Resilience project to understand the area. Finally, I situated myself in Ludlow and Cavendish, exploring the towns by car and by foot, and interacting with community members while eating in restaurants or attending church. All of this work combined to provide me with an introduction to the two towns and the people living within them.

Along with developing community connections through this trip, I gained an initial understanding of how officials and community members used the flood maps. I learned that FEMA's National Flood Hazard Layer map of the area had not been updated in 15 years, during which time several major flood events had impacted the communities and changed the landscape. I learned that neither state officials nor community organizers believe the flood maps to be very helpful or very accurate. I also learned that flooding was not a new challenge for the community. The Great Vermont Flood of 1927 had been devastating, on a scale that even Hurricane Irene in 2011 and the Great Vermont Flood of 2023 had not matched. Flooding in the 1970s was also well-remembered by community members. This history of flooding demonstrated the importance of flood hazard maps, which addressed a known danger within the community. I drew on what I learned on this trip to write the interview guides that I used over the summer, as I was able to make sure that I asked about aspects of the flood hazard maps that people were likely to have strong opinions about. This was important to me because it made sure that the project was focused on specific aspects of flood map use that posed difficulties for each group of interviewees.

1.6.4 Data Collection Trip

My second trip to Vermont happened during the summer of 2024. I arrived in Vermont on May 15, and left July 26. I stayed in Perkinsville (just east of Cavendish, along Route 131) for the entire summer. This trip is when the vast majority of the data collection for this project happened. Data was primarily collected using three different methodologies: interviews, community mapping, and site visits. Each of these methods is discussed in detail below. This trip also served as a very accelerated ethnographic research approach. I am not an anthropologist, and this is not an anthropology paper. However, I lived within the community for over two months, which impacted the project in significant ways. I built relationships with members of the community, even beyond just those participating in the research project. Living within the community for these months gave me a deeper understanding of the people who lived and worked there and how they related to the land.

1.6.5 Research Dissemination Trip

A final trip to Vermont occurred from February 16-19, 2025. I stayed with one of the community members in Cavendish. The purpose of this trip was to meet with a few of the research participants and give them an overview of the findings of my research project. I gave research participants examples of how I was using any data they provided in my research. I also requested feedback on anything that the research participants thought I should focus on more. I visited a few sites that I had not seen during my summer travels. Finally, I met with members of the team at Dartmouth College to discuss additional data analysis. Each of the participants that I met with gave very positive feedback on the findings of my research. They were excited that their experiences with the flood hazard maps were being written about and disseminated more widely. This trip was an encouragement as I was wrapping up my thesis paper. It also inspired me again to disseminate the findings of this research project clearly and broadly.

1.7 Methods

1.7.1 Introduction

I used three primary data collection methods over the course of this thesis research: interviews, community mapping, and site visits. Each of these methods was conducted in collaboration with the broader Rural Rivers/Mapping for Resilience research team. In particular, the community mapping events were informed by the work of Dr. Sarah Kelly, a member of our research team, with Mapuche-Williche communities in Chile using participatory mapping [38]. After data collection was complete, a few data analysis methods were used. These were chosen based on the type of data collected. For interview data, thematic analysis was conducted. I transferred the maps created by the community into GIS format and conducted a comparative map analysis with the various flood hazard maps. Finally, I also completed an informal usability testing of the websites containing flood hazard maps. This included the ANR Atlas, as well as the primary source websites for the National Flood Hazard Layer and the River Corridor maps.

1.7.2 Interviews

I conducted semi-structured interviews conducted with two distinct groups of people. The first group was made up of professionals and community organizers who use flood maps in their official roles in some capacity. This included town managers, zoning officials, county-level regional planners, and professionals working for the State of Vermont. It also included residents who work in local community-based organizations that assist in flood response or recovery. A total of 12 people were interviewed from this group. The second group included people who were directly affected by the flooding in July 2023. This group was mostly homeowners and business owners whose property was affected by the flooding but also included residents of the area who personally assisted in response and recovery efforts. Many people in this group used flood maps either before or after the flooding, mostly to understand flood risk or how flooding might affect insurance rates. There were a total of 11 people interviewed from the second group. Because of their unique experiences with flood maps, different interview guides were used for the different groups. These interview guides can be found in Appendix A. Most of these interviews were conducted face-to-face. Some of these in-person interviews took place in the individual's offices, others were conducted in public spaces, and still others happened at people's homes. A few of the interviews were conducted over Zoom, and a very limited number took place over the phone. Members of the Rural Rivers/Mapping for Resilience research team put me in contact with potential participants from each group. In particular, Dr. Boke's experiences growing up in the area and working with local mutual aid groups in summer 2023 meant that she could connect me with a wide variety of potential interviewees. Additionally, purposive sampling was used to identify participants in the professional group through online searches, who were then contacted by email or phone. I also used snowball sampling to identify additional participants [39]. For example, participants in the impacted residents group were identified by community partners, who knew which residents may be most willing to talk about their experiences. I understood that some residents may not want to talk about their experiences, for reasons ranging from negative memories of the flood disaster to distrust of outsiders. Therefore, I focused on reaching out to residents that would likely be willing to talk, and provided them with information sheets on the Rural Rivers/Mapping for Resilience project before the interview.

1.7.3 Community Mapping

The broader Rural Rivers Project/Mapping for Resilience research team held four different community mapping exercises over the summer of 2024. These community exercises contributed to this thesis research, but were funded by another grant the Mapping for Resilience research team received through the Natural Hazards Center's Weather Ready Research Award, "Mutual Aid for Resilience: Mapping Vermont's 2023 Flood Response Networks." During these community mapping exercises, participants were asked to mark on a map where they saw flooding and/or erosion occur (see Figure 1.3 below). Paper maps were created by Rural Rivers/Mapping for Resilience researcher Aletha Spang and printed onto a three foot by four foot piece of paper. Participants marked up their map to show where roads were closed, where important hubs for recovery were set up, and what they viewed as critical infrastructure, in addition to flooding and erosion. Participants mostly used small stickers to mark these locations, with different color stickers corresponding to different themes. Participants wrote a number on each sticker, with the number corresponding to a description in an attached document of the location and how it was impacted by flooding. Some participants also wrote on the maps directly, with a pen or a highlighter. This was commonly done to signify a stretch of road that was closed. A few participants also used sticky notes or other paper markers to describe a site directly on the map. These mapping exercises revealed the physical extent of flooding damage, how people understood themselves to be impacted by the flooding, and critical decision-making information they felt that they lacked.

Figure 1.3 The main community mapping event in Ludlow, VT. Photo taken by a member of the Rural Rivers/Mapping for Resilience research team.

1.7.3.1 Main Community Participatory Mapping Event

One large community mapping event was held on June 28, 2024. Seventeen local residents and town officials attended this meeting. Participants were recruited through a variety of avenues, including flyers hung in both towns and press releases to local newspapers: the Rutland Herald, the Vermont Journal, the Eagle Times, the Reporter, the Mountain Times, the Chester Telegraph, and the Mount Holly Newsflash. The event was held in the Ludlow Community Center, and food and drink were provided. Participants at this meeting completed the mapping activity in small groups of two to five people, with groups sharing the maps they made afterwards. There were a total of five groups, with each group creating a unique map. The research team was also sitting with participants as they created the maps, taking notes on how participants were going about the mapping process and what places they were most focused on representing. Some participants were also interviewed one-on-one at this meeting. This event provided an opportunity for community members to talk with each other about their experiences with the flood, nearly a year after the flood event. This event is described and analyzed in additional detail in a forthcoming

Weather Ready grant report, authored by the Rural Rivers/Mapping for Resilience research team, titled “Using Participatory Mapping to Assess Inland Flood Events and Communicate Risks”.

1.7.3.2 Additional Community Story Mapping Events

Two other extensive mapping exercises were also hosted while I was in Vermont: at the annual Mt. Holly Energy Fair on June 16, 2024, and at the weekly farmer’s market in Ludlow on July 14, 2024. 12 people participated at the Mt. Holly Energy Fair, while 22 people participated at the Ludlow farmer’s market. The demographics of participants in the energy fair and farmer’s market activities were quite different from that of the community meeting. There was a higher level of participation from second homeowners at the weekly farmer’s market. A more scaled-back version of the exercise was additionally conducted at a community lunch in Ludlow on July 18, 2024, which was attended by dozens of people, mostly older adults. Not all attendees participated—approximately 15 people spoke with the team there. This event was almost entirely attended by permanent residents. These events provided a broader understanding of how different groups within the community were affected by flooding in distinct, yet often similar, ways.

1.7.4 Site Visits

Site visits were conducted to approximately 30 homes and businesses that flooded in July 2023. Some of the businesses and residences had applied for FEMA buyouts. Places where erosion occurred, or where roads were blocked, were also visited. Buildings in both towns that became hubs for distribution of aid during the flood recovery process were toured. These sites were all important to people’s experiences of flooding or flood recovery in some way. The site visits also provided a better understanding of the area that the flood maps display. Looking at maps in ArcGIS or Google Earth cannot indicate how people experience the land and flood events, making this project’s mixed methods approach particularly useful.

As part of site visits, residents of the area and owners or employees of local businesses were interviewed. These visits also offered opportunities for organic and unscheduled interviews that involved touring private property with the owners to observe and map where water advanced onto their property. Site visits revealed both what people expected before flooding and the actual severity of flooding damage. This information enabled me to begin addressing questions on both the usability and accuracy of the flood maps. Many site visits were completed alongside community partners who were aware of which sites within the study area flooded. These site visits with community partners were key to the research project as a whole.

1.8 Chapter Overview

This thesis contains four chapters. This section marks the end of the first chapter, which provides an introduction to the topics of the thesis and an overview of the information found in the five ensuing chapters. This first chapter also contains the methods used over the course of this research project. The second and third chapters of this thesis define and discuss the findings of this research. The third chapter describes the usability of flood hazard maps. The fourth chapter outlines how community experiences of flooding compare to the various flood hazard maps, while also recounting community members' beliefs around flood map accuracy. Through these two chapters, the two most common issues flood hazard map users encounter will both be discussed. These two chapters will each be published as individual papers in the future. The fourth and final chapter builds on the findings described in Chapters Two and Three, and suggests potential solutions to the problems encountered by flood hazard map users, while also concluding the paper. Finally, a few potential directions for future researchers to pursue are detailed before the paper is concluded.

CHAPTER 2 USABILITY OF FLOOD HAZARD MAPS

2.1 Introduction

Using any flood hazard maps (an example of which is shown in Figure 2.1 below) is a multi-step process. The maps must first be identified. This means finding the map that contains the information that is relevant to the users. Second, the maps must be interpreted. The user must analyze the map and use the legend and other information on the web page to learn what it means. Third, the maps must be implemented. This requires the user to understand what steps to take to reduce their flood risk, based on the correct interpretation of the maps. Each of these three steps presented unique barriers for users. This chapter will break down the difficulties encountered at each step by both professionals and impacted residents.

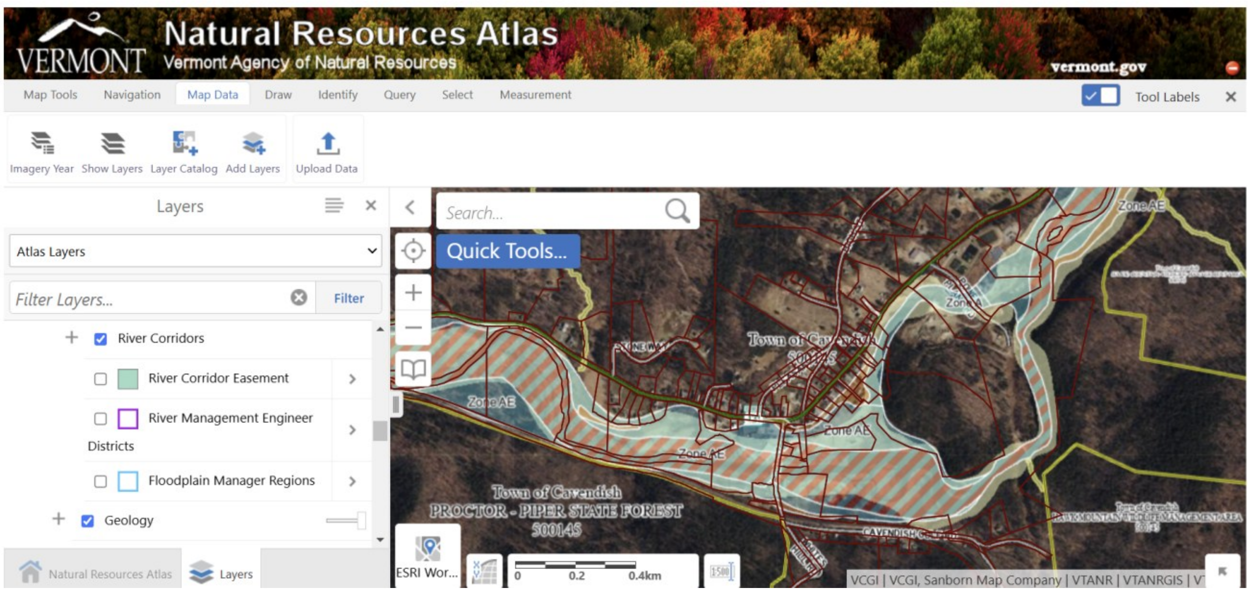


Figure 2.1 A screenshot of the Vermont Agency of Natural Resources' Natural Resource Atlas [28], showing the town of Cavendish. The FEMA National Flood Hazard Layer map, State of Vermont's River Corridor map, and the default layers are all turned on.

2.2 Identification

The first step that anyone takes when attempting to use flood hazard maps is the process of searching for maps. The vast majority of these maps, as used by both professionals and impacted residents, are found online. In rare instances, paper maps found in town offices or libraries are used, especially by town planning and zoning officials. However, even town officials primarily use online maps for any zoning needs. This first step, locating the flood hazard maps, is where users first run into difficulties. Users often begin by using Google or a similar search engine in an attempt to find the information they are looking for. However, in the words of one professional who uses flood hazard maps, "I don't necessarily think the average American is aware of the different hazard maps, in general." This was confirmed through our interviews. Users know that these maps exist, but may not know the titles of the maps or differences between the maps.

When residents in Vermont search online for flood hazard maps, they are presented with multiple options. These include FEMA's National Flood Hazard Layer and the State of Vermont's River Corridors maps, as well as the Vermont Agency of Natural Resources' (ANR) Natural Resource Atlas (commonly referred to by interviewees as the ANR Atlas), which compiles the Flood Hazard Layer and River Corridors maps alongside other layers. There are other online map services used by professionals and impacted residents, but these three were the most commonly discussed in interviews. Because impacted residents often do not know exactly the titles of the maps they are looking for, they are left to wade through the various maps that appear as a result of their search in an effort to find the information they actually need. These difficulties were summed up by one frustrated resident, who said:

> *There were many, many different maps that you could look at, and they all had different titles and none of them were matching up to what I was hearing from my insurance company or what I was hearing on the radio, or what my Google searches were finding. And I was like, I don't know what to look at and look for.*

Users of the maps rarely stated that they could not find any maps or other information on flooding. Instead, it was far more common that they were faced with too many maps and too little clarity on which maps were relevant to them.

To add to these difficulties, many of these resources include links to other maps. For example, the Vermont Flood Ready Atlas [40] includes links to a variety of websites, including the ANR Atlas and the FEMA Map Service Center. These links are presented alongside the actual ANR Atlas, which is embedded in the web page. There is also a link to the Vermont Center for Geographic Information's "Maps" page [41], which includes links to dozens of dynamic and interactive maps, some of which include information that could be relevant to flood disasters. This site also includes a link back to the Flood Ready Atlas, completing a circular flow. One interviewee expressed confusion after following these links, stating, "I'd go in and then you'd get sent to someplace else, and then you'd get sent to someplace else, and you'd get linked back to the Vermont place that I'd already been." This is not to say that including links to other relevant information on a state or federal website is bad practice. Providing users with information that they may find useful is a good idea. However, the interviews conducted revealed an opportunity to provide additional clarity alongside these links to other websites. Providing a title, and sometimes a one-sentence description, is not always enough to avoid confusion.

As might be expected, professionals and community organizers have a much easier time finding the maps that they need than impacted residents do. This is because these groups use flood hazard maps often, even daily in some cases. They may have websites bookmarked or URLs memorized. While finding the maps may initially have been of some difficulty, in many cases members of these groups had someone to show them where the maps were located in a one-on-one meeting. Being shown how to find and use the maps is an incredibly helpful resource, and one that community members said they wish they had access to. While they may not have faced this barrier, professionals and community organizers still recognize the struggles that other community members face in this step, as can be seen by the quote above. It is worth noting that these groups may also have difficulties with the flood hazard maps, albeit more rarely. Finding the correct flood hazard map is only the first step for many users.

2.3 Interpretation

2.3.1 Definitions and Terminology

Through my interviews, I learned that there are a variety of use cases for flood hazard maps. These use cases are further discussed in Section 2.4 Implementation below. After users locate the flood hazard map that they need for their specific use case, they are faced with another series of hurdles, which are often more difficult to overcome. Users must now interpret the maps in front of them to understand what each layer means, what each color or symbol under each layer represents, and where their property is located on the maps. Each flood hazard map looks slightly different, and the user interface on each is different as well. However, there are enough commonalities across the maps that they can often be discussed as a whole. For example, every map includes different zones; maps will include multiple layers, at a minimum the flood hazard map and a base map; and each map contains a legend using specific technical terminology (for example, "100-year floodplain" or "river corridor"). The first difficulty in interpreting the maps is one shared by many flood hazard maps: it is unclear what exactly what any one map specifically shows. One resident who was impacted by flooding stated:

> *I couldn't make sense of the definitions of the maps, so I didn't know what I was looking at, and I couldn't find, "Map X is showing you this, and this is the definition of that, and this is what it's used for."*

As shown in this quote, even the information surrounding the flood hazard maps, including titles and descriptions on websites, is not always clear or useful. This initial step must be understandable to users if they are to use the flood maps at all.

The second step to interpreting the flood hazard maps is understanding the terminology each flood map uses. For some maps, such as the River Corridor maps, this is more straightforward: the maps only have one layer, and a definition of the layer can be found on the website the map is located on. However, even in this example, the definition of a river corridor as including "the width of the meander belt of a river and an additional 50' buffer to allow for a stable wooded bank when the river is at its equilibrium / least erosive slope" may not be totally straightforward for all users. For other maps, the terminology can be more complex, as maps begin to include complex legends without definitions on the same webpage. One example of this is the National Flood Hazard Layer. The legend for this layer can be seen in the figure below (Figure 2.2). Both community organizers and impacted residents expressed at least partial confusion with the terminology used in the maps. One community organizer said:

> *I see where the river is, and I see what the floodway / riverway / flood hazard way are. But the terms are not particularly helpful, and I'm not always sure what the criteria are, or the distinction between them [is].*

Additionally, another community member said, in a frustrated tone of voice, “I have been told that my house sits on a 500-year flood ... zone. I can't find that language anywhere to say, what does that mean?” Both of these quotes indicate a similar frustration, despite referring to two different maps and two different sets of terms. The language that flood hazard maps use is often indecipherable to users without someone there to explain it. Community members are capable of understanding what these terms mean; the terms are just not explained properly, and any support that is provided to help users comprehend the terminology is minimal.

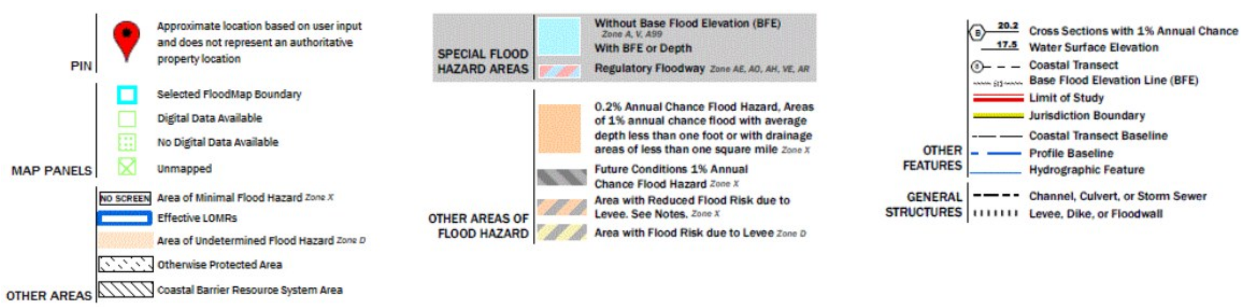


Figure 2.2 FEMA National Flood Hazard Layer Legend [42].

2.3.2 User Interfaces of Flood Hazard Maps

After the correct map is found, and the different symbols and colors on the map are understood, users of some maps need to figure out how to work with the individual layers of the maps. This does not apply to maps such as the National Flood Hazard Layer or the River Corridor maps, which only include one layer. However, maps like the ANR Atlas include dozens of layers that users can turn on or off. This feature is useful for any map of this scope – the map would be illegible if all of the layers were always activated – there are a great deal of overlapping lines, zones, numbers, and symbols. However, using the various layers of the ANR Atlas can present another challenge for users. One community organizer stated, “Some layers won't turn on. It simply doesn't work, and it just sits there on the landing page with the loading symbol going.” They went on to say, “Once I get the LIDAR elevations on the map, I know there are ways to make the colors more or less transparent, so that you can actually see the features underneath

… I'm a little less savvy with that.” The “features” mentioned here include property lines and home locations.

There could be a variety of issues causing the layers not to load, some of which could be addressed through more efficient website design, but some of which would not be. For example, internet speeds could be causing the maps to load slowly for some users, which is clearly not an issue that flood map creators can directly address.

However, changing the appearance of the layers is a website feature that already exists on the ANR Atlas, and could be more clearly highlighted and explained. Another professional said, “If you're just looking at property maps where the parcel lines are, and you bring in imagery, generally they're a little off.” This specific issue of layers failing to align with each other is not an issue of users misunderstanding the maps. However, it may still impact the ease with which ANR Atlas viewers are able to understand what the maps are attempting to communicate. People in the area are knowledgeable about the land, including where the river bends, where bridges are, and where hills and brooks are; they know when these features are not accurately represented on the maps.

Once all of the relevant steps outlined above are completed, the final step for many users is finding the specific piece of property that they are interested in viewing. This often presents an additional round of difficulties. In interviews for this project, users reported the maps to be extremely sensitive. One community organizer described what this meant for zooming in and out: “Part of the problem is that you go to blow it up … and you're trying to really keep it steady. And I … barely breathe on the thing, and it either closes or opens up into something that I don't want.” This difficulty was echoed by other community organizers and flood impacted residents who tried to use maps. The sensitivity and speed at which the maps zoom in and out are useful for professionals and other users who are constantly using online maps and need to view a specific parcel very quickly. However, for those who have less experience with online maps, the high sensitivity often impedes their ability to find their property and pan around the map. Even when the user is able to find a specific property, the delineation of the flood risk zones can be less than clear. For example, a community organizer said, “We had a real question whether or not our property was on that. And it kind of depends on how you look at it. And we're blowing them up and whatever, and we determined that [it wasn’t].” Of course, there are times when the border of a flood risk zone will go directly through a property, and it will be very hard for anyone to tell if the property is in a flood zone or not. However, there are many cases in which this confusion can be alleviated by more clearly viewable maps.

2.3.3 Finding Answers to Questions

Most of these issues, including questions around the purposes of flood maps, the terminology they use, or their features, ultimately have answers. In many instances, these answers can be found online, in tutorials or FAQs. But just because the answer is available does not mean it is easy to find. In fact, many flood hazard map users stated that the opposite was true, that answers about the flood maps were very difficult to find. A community member stated, “I couldn't find a definition. And even Googling it didn't help me get to what it actually was showing me. And that was just frustrating.”

Users of flood maps usually do not just give up when they cannot understand a map. They attempt to find answers using whatever resources are available to them. However, even additional resources beyond the flood hazard maps themselves are often lacking. Interactive tutorials are a good place to start, but even these have been reported to be unclear. Said one community organizer, “They're not always intuitive. Sometimes the tutorials assume that you know something, and then they walk you through within a certain framework. You're like, what? Wait, what is this framework? I don't understand.” Certain maps are targeted at more experienced users, which means the tutorials may be targeted at more experienced users as well.

When even the resources and tutorials explaining the maps are too complex for users to understand, their last recourse is often reaching out to experts. This final effort to find answers to their questions seems to be fruitless for many impacted residents. It is unclear who community members are supposed to contact with questions about maps, whether they are created at the state or federal level. One town official reported that his office had received what he called “spillover” after the floods of July 2023: people asking his office questions about maps that his town had no part in creating. He stated this was primarily because “people don't know where to go or who to ask” questions after the flooding. One community member whose property flooded stated that they, “Don't know one from the other”, referring to the flood risk zones, but that they knew they were in all three zones. However, they still wanted to understand the differences after they were impacted by flooding, but they were “still trying to figure it out because no one will tell me”.

Agencies from the federal level to the town level are incredibly busy after a disaster. However, community members desire answers related to how to use tools that impact their recovery. Each of the difficult aspects of interpreting maps that are described in this section are potential roadblocks to a resident affected by flooding properly using flood hazard maps. Some of these difficulties are minor and can be worked through with some effort from the end user. However, a few of these difficulties are more major, representing significant hurdles that community members without GIS experience face. When summed together, they result in a series of flood hazard maps that feel unintelligible to many users they claim to be created for. One community member relayed that she had “heard so many people just give up on the process because it took so much effort.” Interpreting flood maps should not be one of the many things that people affected by flooding disasters need to worry about.

2.4 Implementation

2.4.1 Common Uses of Flood Maps

Flood hazard maps are used for a wide range of different purposes by different groups. This is particularly true of the FEMA National Flood Hazard Layer, which is the most widely known flood map and has the most legal implications for towns and community members. The differences in how individuals use flood hazard maps are especially obvious when comparing how professionals and community organizers use flood hazard maps to how residents who may be, or have been, impacted by flooding use the same maps. One community organizer summed up the different uses of the maps into the "big three" main uses, saying they were used "for planning, for permitting and insurance." Of these three uses, town and county level officials were largely focused on using the maps for planning and permitting. Flood insurance was more of an issue for individual residents on a case-by-case basis. Across the interviews conducted, these three purposes appeared repeatedly, more than any other use cases.

Other purposes for using the flood maps were also brought up by local officials and community organizers. One professional described two examples of the types of projects that she used flood maps on, both of which are close collaborations with homeowners:

> *I work with homeowners all the time. We're looking at their flood maps, we're seeing what the flood elevation is. And we're generally saying how high they want to have their home elevated. … Or you know, just they got 2 feet of water in their basement. We look at the flood map, look what base flood is, we look at the grading of their home, and we decide if they can just raise [hot water tanks or their washer and dryer] up in the basement, or if they need to move it out of the basement and somewhere on the first floor.*

These types of collaborations are very direct mitigation efforts, using the flood hazard maps and the Base Flood Elevation maps to make homes safer. Homeowners and officials both use flood hazard maps to make tangible, effective change.

2.4.2 Moving Out Of, or Into, A Flood Risk Zone

The ultimate safety measure for residents and towns that find themselves within a flood hazard area or river corridor would be to move out of that flood area. For homeowners, this would involve selling their home and buying or building a home elsewhere. This would often mean moving out of their town entirely, because most of the homes in the town centers of Ludlow and Cavendish are under some kind of flood risk due to historic settlement patterns.

This is a drastic, life-altering measure that is impossible for many residents to even consider, for a vast number of reasons beyond the scope of this paper. Officials acknowledge that this is not even always the point of the maps, with one state official discussing the river corridor maps saying, "It's not a tool to say, oh, geez, you got to move your house. It is for somebody that comes into a town planning or zoning or design review board, [when] there's no house there." Moving is recognized as a very difficult step.

And while moving individual residents is difficult enough to consider, moving entire towns is even closer to an impossibility. One official stated it bluntly: you "can't move the town" and the "historic village center". Many interviewees mentioned the history of many Vermont towns as mill towns, being placed close to the river for industrial purposes. Now that the town center is where it is, it cannot be picked up and moved. Some small towns in Vermont have done preliminary research into moving their town center higher, away from the dangers of the river, according to multiple interviewees. However, none have actually done it, at least not yet. Both town officials and individual residents who contemplate moving higher or further from the river run into a vast number of difficulties, which often prevent them from moving.

If a homeowner does choose to move out of a flood hazard area, either because of the flood risk or for a completely unrelated reason, they usually look to sell their home. This means that someone else would be purchasing a home within a flood hazard area. The disclosure of this information by the seller to the buyer is another important case in which the flood hazard maps should be used. However, disclosure of flood risk when selling a property was not mandated by Vermont law until very recently. H.687 (or Act 181), passed on June 17, 2024 [43], updated Vermont's Act 250; one of the new requirements is that sellers must now disclose if the property they are selling is in a special or moderate flood hazard zone, as defined by FEMA.

The effects of this previous lack of legislation were brought up repeatedly by interviewees. Residents remembering when they purchased their homes told a variety of stories about their knowledge of flood risk to their property. One resident said, "when we got the property map, it had a flood plain … but that was it". Another stated, "There was no information when we bought this house that would lead us to think we needed flood insurance." Another reported not looking at floodplain maps at all when purchasing their home in a private sale. Lack of disclosure when purchasing a property was identified as an issue by multiple residents. In addition, local officials and community organizers also acknowledged this as an issue.

One official stated that he believed that this very specific use case was "really where that public accessibility becomes a problem, because they don't necessarily know when they're buying a home that it's in the flood zone." Out of all the purposes of flood hazard maps, this one was one of the most important to him, due to a sense of concern for future residents. A community organizer also stated, "If I were a realtor or somebody was asking me where to buy a house, I'd be looking at those maps." This statement points towards the requirement of the home buyer to do their own research in lieu of state laws around disclosure. Now, H.687 / Act 181 has made these maps more effective. However, it is still an important point in time for residents and town officials to take the flood hazard maps seriously.

The most common context for residents to use flood hazard maps is when they already own a property and are considering purchasing flood insurance. Flood insurance is only federally required within Special Flood Hazard Areas [9]. However, residents who live just outside of this flood hazard area also have the option to purchase flood insurance, and may use their proximity to a flood hazard area on a flood hazard map to make the decision to do so.

The flood hazard map with direct implications for flood insurance requirements is FEMA's National Flood Hazard Layer. This means that this map is often the most relevant one to homeowners. Regarding river corridor maps, one local official stated, "the river corridor … there's no nexus to flood insurance. So, you know, other than hazard vulnerability, there's less implication to a private landowner." The relevance of this map is largely based on its impact on flood insurance, which is a regulatory requirement for homeowners to act on. A state official phrased it in this way:

> *Having better and better information about flood risk by itself doesn't change anything unless people act on it. And so, what ultimately it comes down to is what people will act on. And a lot of times that comes essentially out of the NFIP requirements.*

Officials from the town level to the state level widely believe that the maps are most influential when there are regulatory requirements behind them. This is seen as the most effective way to influence people to take flood risks seriously.

2.4.3 Community Attitudes Towards Flood Hazard Maps

Two major themes affecting people's willingness to implement the changes suggested by flood hazard maps arose repeatedly across interviews with both professionals and impacted residents. These were the ideas of trust (or lack of it) in the flood hazard maps, and the idea of self-determination vs regulatory requirements. Trust in flood hazard maps is a personal belief that influences how both professionals and residents make decisions. Many people in both groups stated a belief that the flood hazard maps were not accurate enough, and therefore they did not trust them to accurately predict flooding.

For example, one town official said, "I take some of those maps with a grain of salt, not because I don't trust the people that do them. I just think that it's difficult to keep accurate." This quote demonstrates the idea that the river changes with every flood event, but the flood hazard maps are not necessarily updated in a timely manner, due to the extensive resources needed.

Going beyond a recognition of the difficulties in keeping the flood hazard maps accurate and up to date, some interviewees stated a lack of trust in the process of creating the flood hazard maps itself. One impacted resident stated, "it's hard to think about FEMA as separate from insurance companies" and reported looking for the flood hazard maps after the July 2023 flood because they "wanted to see what the map looked like before somebody changed it, because I was worried that somebody was changing it". They went on to state:

I remember feeling very frustrated and distrustful. I felt distrustful of everything because it just was like, why? When things are really hard to navigate and access, it's like, did somebody do this on purpose to keep me from this information? Or is it just a scientist did this and they weren't thinking about people, lay people?

This feeling of a lack of trust in the companies providing flood insurance, and sometimes FEMA itself by proxy, is a hindrance to some people taking the flood hazard maps seriously. Whether or not this feeling is common among residents of the area, the sentiment certainly exists among at least a few interviewees.

While trust or distrust of the flood hazard maps is a very personal opinion, the policies that towns and states create and enforce through regulations impact entire communities. As discussed in the context of flood insurance, policy is one of the most powerful ways to influence homeowners and other residents to take flood risks seriously. However, these policies and regulations are not always popular, especially in Vermont, where many residents prioritize individual freedoms. Both residents and town officials brought up the personal responsibility of homeowners and business owners. One homeowner stated that when flood maps were initially being created, there was a feeling of “If I lose it, that’s on me”. And one official reported having a feeling of, “if you want to build it there and you want to take that gamble, and you could lose your house because it floods, it's not my money”, while also recognizing the obvious need for regulations, “if it jeopardizes life safety, very drastically jeopardizes town infrastructure, something that's just egregious.”

This tension between policy changes and personal freedom is a much broader topic than just flood maps, but it certainly impacts the implementation of the flood maps. Additionally, one state official stated that some towns in Vermont can be hesitant to implement policies that already exist. A community organizer gave one explanation for this hesitancy, in the context of FEMA buyouts of properties in floodplains: “Town managers don't really want to do buyouts because it impacts their tax base.” With every property that is bought out by FEMA, one less homeowner or business is paying taxes to the town.

Finally, residents repeatedly stated that the lack of clarity on what the policies around floodplains actually meant prevented them from following the policies. One resident said that in the wake of the July 2023 floods, they “did what we could and found out what we did wrong later”. Even when reaching out to government officials or agencies to try to gain clarity on the policies after the floods, answers were difficult to find. The value of self-determination, placed against the requirement of towns to make and enforce reasonable policies and regulations, creates significant barriers to the usefulness of flood hazard maps to professionals. A lack of trust in the maps creates barriers to residents of these communities using the maps at all.

2.5 Conclusion

Flood hazard maps exist primarily as a tool for the creation and enforcement of policies and regulations designed to protect property and lives. They are used to dictate flood insurance requirements, assess risk to properties, and make physical changes to homes and towns to mitigate flood risk. However, these flood hazard maps are not easy for all residents to identify, interpret, and implement. These difficulties act as roadblocks for people trying to find information on the level of danger that they, and their property, are in. In order to make it easier for residents and professionals to prepare for future flooding, these maps should be improved in a variety of ways. Recommended steps to take to make these maps more user friendly are discussed in Chapter 4.

CHAPTER 3 ACCURACY OF FLOOD HAZARD MAPS

3.1 Introduction

The various flood hazard maps serve as predictions of various types of flooding. These predictions shape, or are expected to shape, how residents and professionals approach flood insurance, zoning, permitting, emergency planning, and flood resilience upgrades to buildings. Because of the wide range of important uses for these flood hazard maps, it is imperative that the maps represent where flooding actually occurs as accurately as possible. This accuracy can be tested in a few different ways. One would be to create an inundation map of a flood event and overlay that map on the various flood hazard maps. USGS creates inundation maps after many significant flood events. Unfortunately, the creation of these maps commonly takes three to four years, and no such maps yet exist for the July 2023 flooding. Another way to measure this accuracy is to learn where community members saw flooding, and see if these various locations are represented on the flood hazard maps. This chapter follows the latter approach. By using community-created maps alongside site visit data and interview results, the accuracy of the flood maps in the Ludlow and Cavendish area is discussed. To conclude this chapter, there is a discussion of how significant the accuracy of the flood maps actually is to community members.

3.2 Community Experiences of Floods vs Flood Hazard Maps

The FEMA National Flood Hazard Layer and the State of Vermont's River Corridors map are the two primary maps used by impacted residents and professionals in the communities of Ludlow and Cavendish. The State of Vermont's ANR Atlas is also used, but it is a compilation of the data from the two other maps, as well as other sources; for this reason, the National Flood Hazard Layer and the River Corridor maps will be focused on in this section.

These maps are designed to represent very specific consequences of flooding. FEMA's maps represent inundation flooding. The Regulatory Floodway zone includes the channel of the river and the adjacent land that is lower than the Base Flood Elevation (BFE). The 1% Annual Chance Flood Hazard zone is the area that has a 1% chance of flooding in any given year (also called a 100 year risk zone). The 0.2% Annual Chance Flood Hazard zone is the area that has a 0.2% chance of flooding in any given year (also called a 500 year risk zone). The River Corridor maps display potential erosion risk, and only include one zone. This zone represents the meander belt of the river, plus a 50 foot buffer zone. Taken together, they are used to give a picture of flooding risk as a whole. However, these flood hazard maps do not always capture the places where people say they are most affected by flooding. In this section, parts of the maps produced during the main community mapping event are presented. They are compared to the FEMA and State of Vermont maps, and the number of points which fall in each flood zone are presented. These maps and tables provide quantitative data to support the more specific stories and beliefs presented later in this chapter.

3.2.1 Reported Flooding vs FEMA Flood Map

The first analysis of these maps is a comparison of the points of flooding recorded by community members and the FEMA National Flood Hazard Layer (Figure 3.1, Table 3.1). This is intended to measure the accuracy of the FEMA map in predicting the actual experienced flooding. The majority of the points (54 of 98, or 55%) that were mapped by community members as places where flooding happened fall within one of the FEMA flood hazard zones. The other 45% of points were entirely outside the FEMA flood hazard zones. However, 18% of these points fell within the regulatory floodway. This means that only 36% of the points indicating flooding fell within the 1% annual chance flood hazard area or the 0.2% annual chance flood hazard area. The FEMA National Flood Hazard layer was much more accurate along the Black River itself. It failed to capture many of the points further away from the river, where smaller brooks or streams flooded.

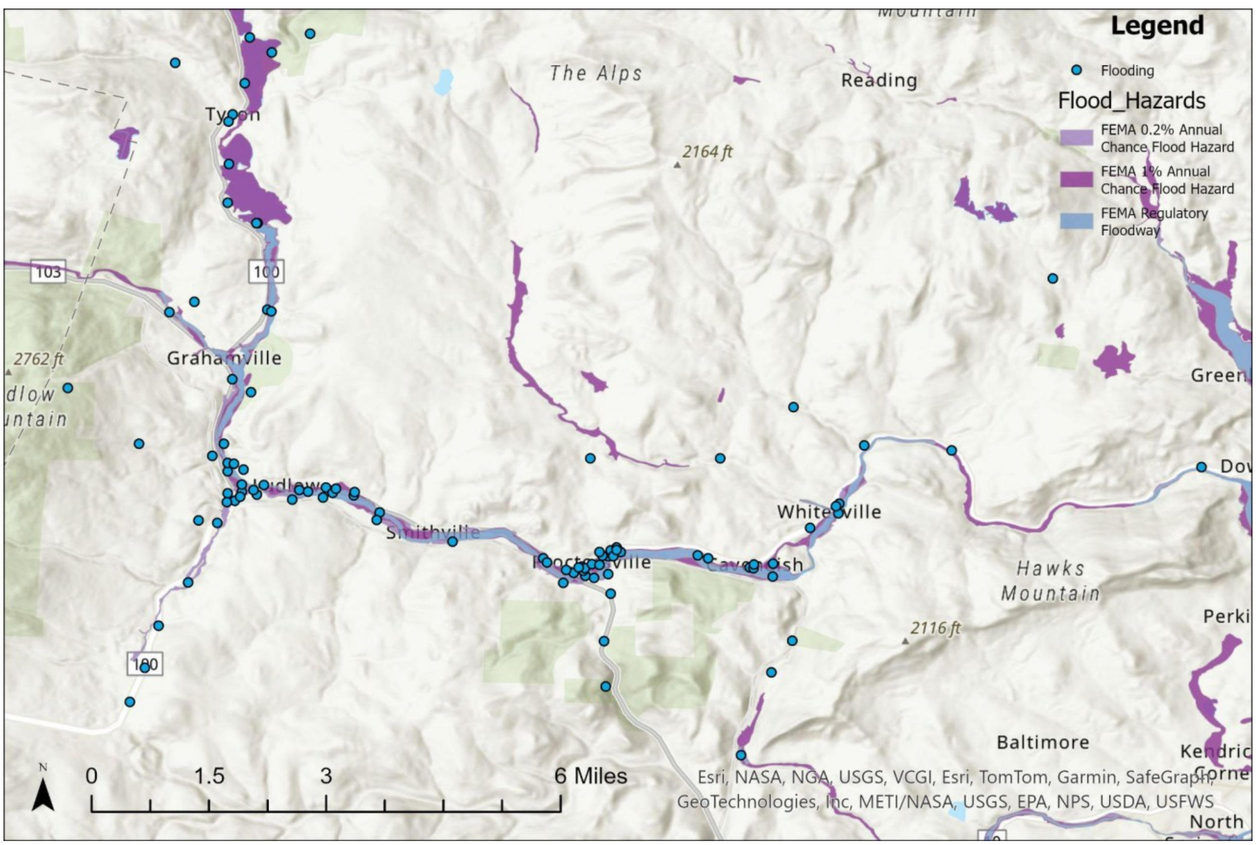


Figure 3.1 Points of Flooding Mapped by Community overlaid on FEMA National Flood Hazard Layer.

Table 3.1 Results of Mapping Activity: Reported Flooding vs FEMA Flood Map. Percentages in the bottom row do not add up to 100 due to rounding.

Location	Total	Overlaps with FEMA Floodway	Overlaps with FEMA 1%	Overlaps with FEMA 0.2%	Do Not Overlap with FEMA Zone
Grahamville	15	0	6	1	8
West Ludlow	25	2	2	6	15
East Ludlow	12	4	5	1	2
Proctorsville	25	7	4	4	10
Cavendish	10	2	4	2	2
Whiteville	11	3	1	0	7
Total (#)	98	18	22	14	44
Total (%)	100	18	22	14	45

3.2.2 Reported Erosion vs River Corridor Maps

The second analysis of the maps is a comparison of the points of erosion recorded by community members and the River Corridor map (Figure 3.2, Table 3.2). This is intended to measure the accuracy of the River Corridor in predicting the actual experienced erosion (its intended use). There is an almost exactly even split between points of erosion that fall within the River Corridor boundaries, and the points that are outside the boundaries. 47% of the mapped erosion points are within the River Corridor, while 53% fall outside of the River Corridor. Four of the 19 mapped points (21%) are a significant distance away from the nearest River Corridor or body of water. It should be noted that some points of erosion were mapped by community members as flood damage. However, because not every team making maps described each of the points they were mapping, it was not possible to differentiate these points in a consistent way.

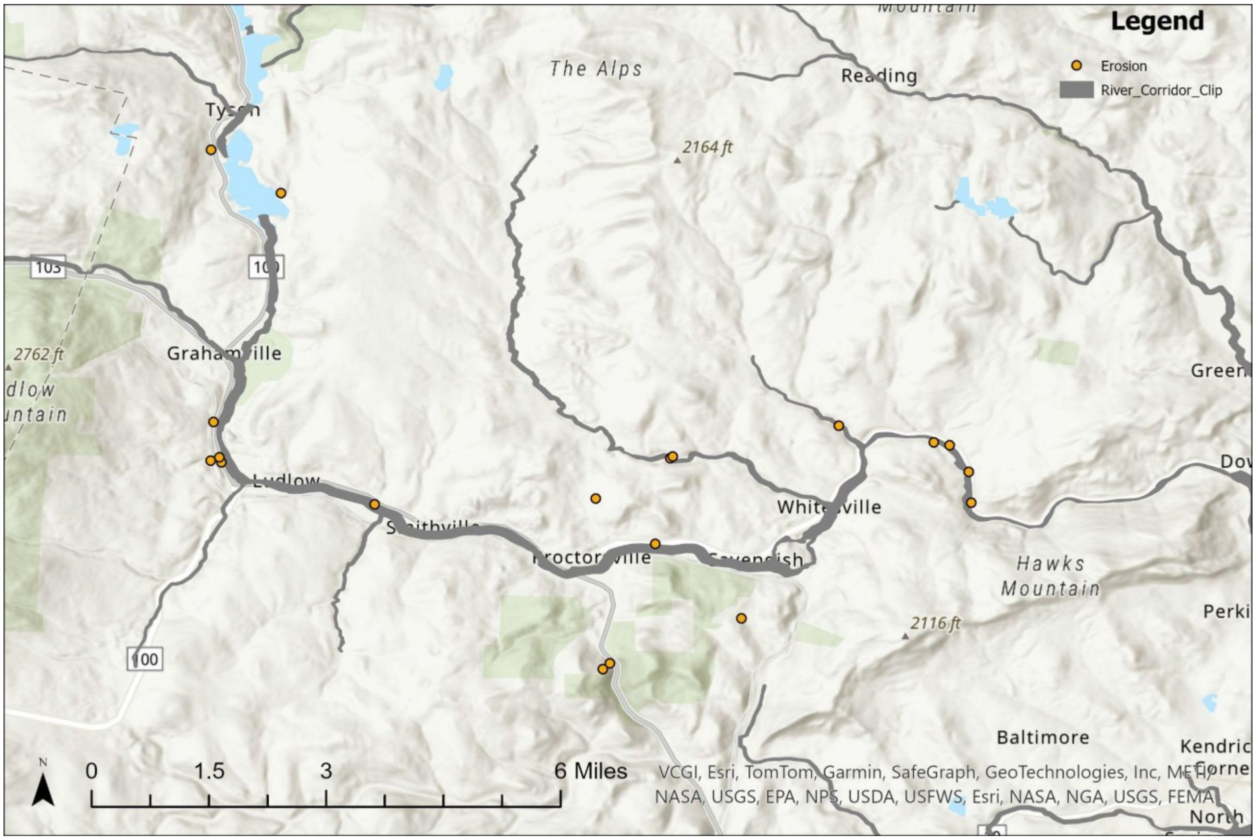


Figure 3.2 Points of Erosion Mapped by Community overlaid on River Corridor Map.

Table 3.2 Results of Mapping Activity: Reported Erosion vs River Corridor Map.

Location	Total	Overlap with River Corridor	Do Not Overlap with River Corridor
Study Area (#)	19	9	10
Study Area (%)	100	47	53

3.2.3 Reported Flooding vs River Corridor Maps

The third and final analysis of the maps is a comparison of the points of flooding recorded by community members and the River Corridor map (Figure 3.3, Table 3.3). The River Corridor maps are not designed to map flood inundation. Because of this, it is no surprise that there are fewer mapped points of flooding within the River Corridor boundaries than the FEMA flood hazard zones. Only 41% of the flooding points are within the River Corridor. However, there are some surprising differences between the two maps. The River Corridor is significantly narrower along much of the Black River itself than is the FEMA map. This is where the FEMA Flood Hazard Layer performs significantly better than the River Corridor maps. However, the River Corridor maps do capture flooding that the FEMA maps miss farther away from the Black River. The River Corridor maps brooks and streams where flooding occurred that the FEMA maps do not capture at all. This is a significant gap in the FEMA maps that the River Corridor maps prove could be remedied. While residents near the Black River should first consult the FEMA National Flood Hazard Layer, as a better predictor of flooding near the main river, residents further away from the river living along brooks and streams may find the River Corridor map to be the more useful tool. The examples in the following section emphasize this point.

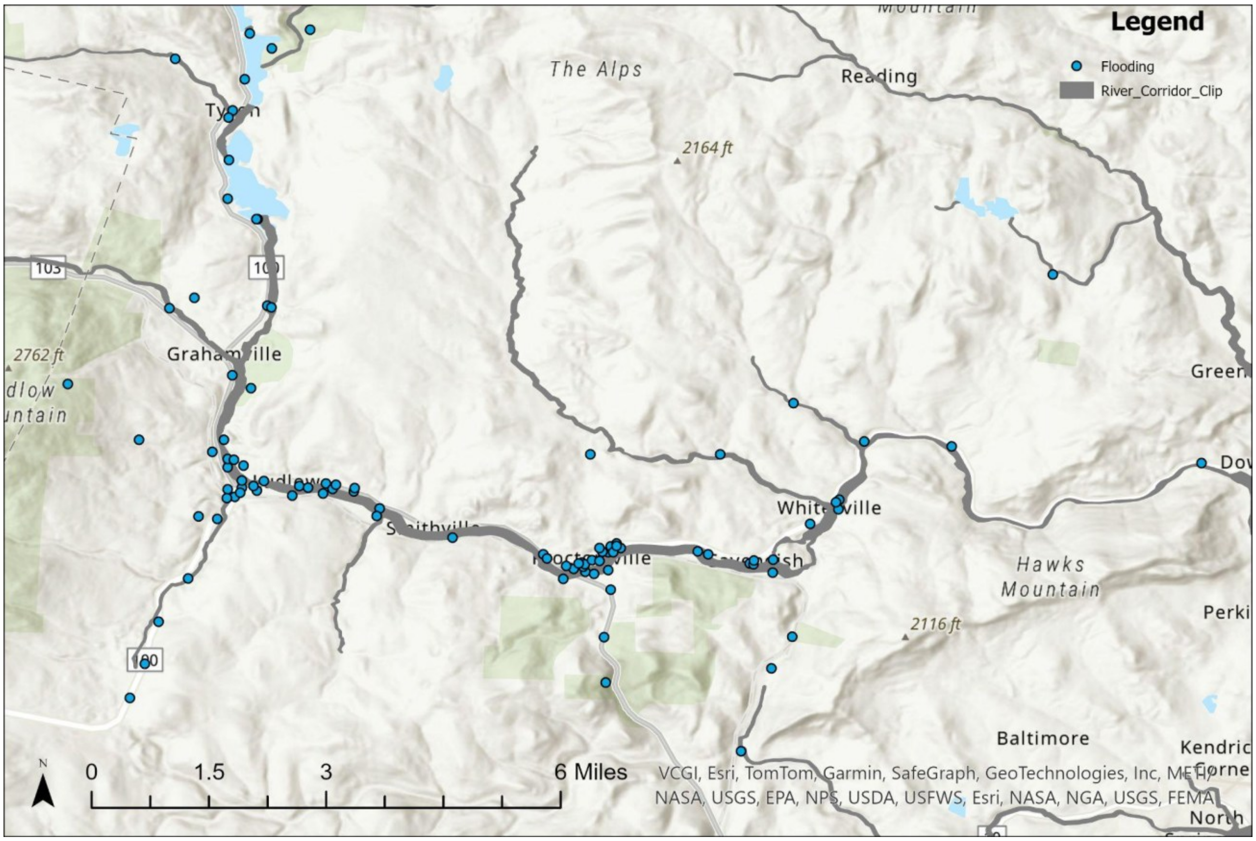


Figure 3.3 Points of Flooding Mapped by Community overlaid on River Corridor Map.

Table 3.3 Results of Mapping Activity: Reported Flooding vs River Corridor Map.

Location	Total	Overlap with River Corridor	Do Not Overlap with River Corridor
Grahamville	15	5	10
West Ludlow	25	8	17
East Ludlow	12	7	5
Proctorsville	25	8	17
Cavendish	10	6	4
Whiteville	11	6	5
Total (#)	98	40	58
Total (%)	100	41	59

3.2.4 Limitations of Activity

It should be clarified that the methodology of community mapping, as implemented over the course of this research project, has multiple potential limitations. First, these community mapping meetings all took place approximately one year after the July 2023 flood event. This means that community members may have forgotten certain details of how the flooding happened. However, this confusion was likely minimal. Participants would remember whose basements they were working in, and which roads were impassable. Additionally, many community members have seen multiple flood events hit their towns in very similar ways. Broadly speaking, they know where flooding happens in their towns. Second, the process of the actual community mapping exercise could be somewhat inaccurate. Placing a sticker on a map of two entire towns is not the most precise map creation process. Additionally, while some mapping participants were able to find locations easily, others struggled to connect the top-down image of the map with their own mental perception of spaces and relied on the help of their phone maps or input from people at their table. This introduced locational error in the collected data points, along with the digitization into a point-based computer data model, which implies a level of precision in the findings that was absent in the paper maps. However, the descriptions of the sites provided by participants aligned very closely with the exact spot they marked on their maps. Any community based research activity will necessarily have room for inaccuracies. However, analysis of the maps created through these exercises revealed that participants were able to clearly and specifically communicate their knowledge of the places where different impacts of the flood event occurred.

3.3 Specific Sites

Each of the points on the maps presented in the last section have specific stories associated with them. These stories are valuable because they illuminate how different flooding hazards directly affect community members. Telling each of the dozens of stories is outside of the scope of this thesis, but a few particularly interesting ones are presented below. I selected these cases in specific because they are representative of areas where either one or both of the flood hazard maps I am analyzing failed to accurately represent flood risk.

3.3.1 Knapp Pond Road

One place severely impacted by flooding that is not within a half mile of a flood hazard area of any kind is located on Knapp Pond Road. This road runs along Knapp Pond Brook, from Knapp Brook Pond Number 1 until it intersects with the North Branch of the Black River on the other side of VT 106 (see location map on Figure 3.4a). Both Knapp Brook Pond Number 1 and the North Branch of the Black River are designated 1% annual flood hazard risk areas on the FEMA National Flood Hazard Layer, but Knapp Brook has no flood hazard designation along it. A residential home built along Knapp Pond Road was cut off from all emergency services after water levels in the Brook rose above two bridges on Knapp Pond Road. The home was built between these two bridges and was inaccessible during flooding. No other road provided an alternative way to access the home. The homeowners were trapped in their house for over 24 hours, until the water receded, and the bridges were deemed safe to travel. If residents of this home had relied on the FEMA flood National Flood Hazard Layer before the July 2023 flooding, they may have been given a false sense of security. The brook that the home lies along is not deemed to be a flood hazard. As can be seen in Figure 3.4c, the brook does not appear to be a risk under normal conditions, but one purpose of flood hazard maps is to identify less frequent, but potential, dangers. Displaying a 500 year flood hazard zone implies that areas outside of this zone are not expected to pose a risk, even in a 500 year storm. While most of these areas never pose a risk, the ones that do can be particularly dangerous, because of the potential perception of safety. Additionally, this site is identified on the River Corridor map as a site of potential erosion. This proves that it is possible to predict that this site and others like it will be at risk of flood damage.

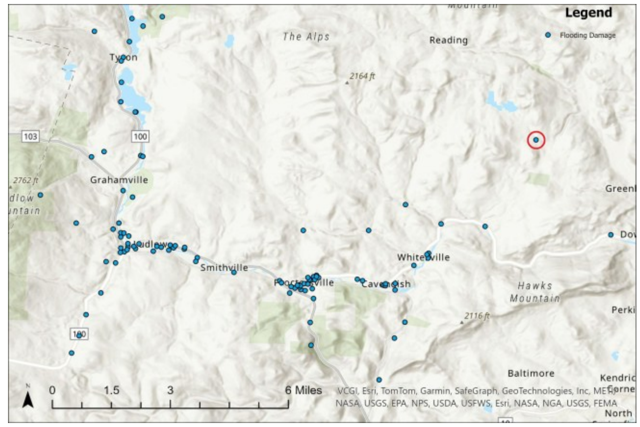
(a)

(b)

Figure 3.4 Images from Knapp Pond Road. (a) Water ran down the road shown, making it impassable. (b) A crack in the bridge. (c) Knapp Pond Brook under normal conditions. (d) The location of the site is circled in red.

Figure 3.4 continued

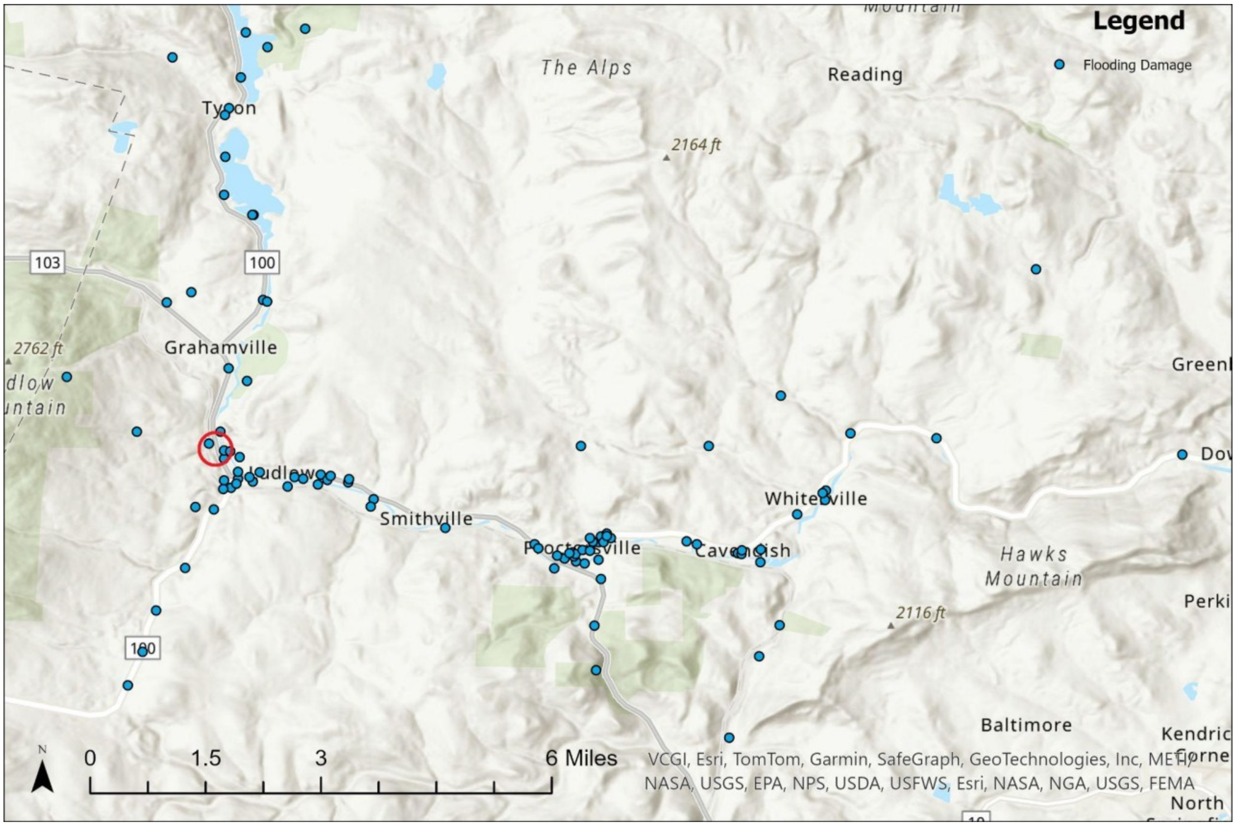
(c)



(d)

3.3.2 Okemo Railway Culvert

The Okemo Marketplace is a shopping mall located between the Black River and the Okemo ski resort in Ludlow, shown in Figure 3.5. During the July 2023 flood event, it flooded from both directions: from rising river levels as well as from runoff from the mountainside. The flooding from the Black River was predictable, and represented on both the FEMA National Flood Hazard Layer and the River Corridor map. The mall is low-lying, and located directly adjacent to the river. However, the flooding off of the mountain was more unexpected. There is a large culvert across Route 103 from the mall that is designed to direct the water from the mountain under a set of railway tracks. However, the culvert did not have enough capacity to carry the amount of water running off the mountainside. Instead of flowing through the culvert, a significant amount of water overflowed the culvert and submerged the railway tracks. This water ultimately ended up flowing into the mall. This flooding is not predicted on either the FEMA maps or River Corridor maps. Dangers from culverts are particularly difficult to predict via traditional flood mapping methodologies.



(a)

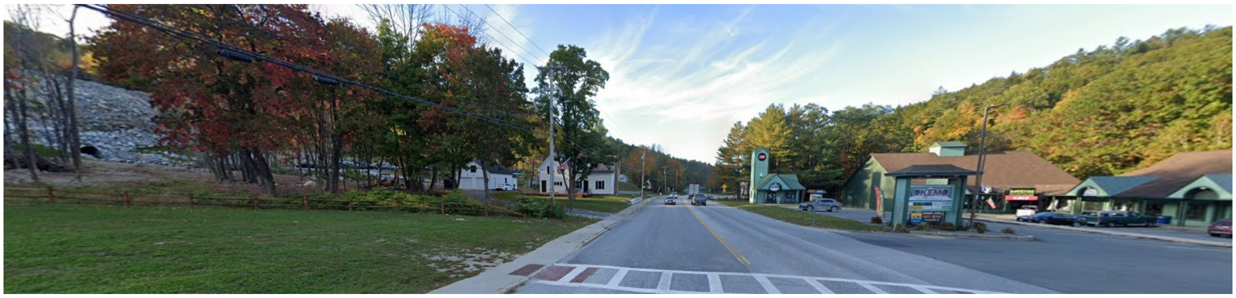
Figure 3.5 Images from Okemo Railway Culvert. (a) the location of the site is circled in red. (b) Culvert shown. (c) Okemo Marketplace. (d) Location of culvert relative to the Okemo Marketplace. (b), (c), and (d) from Google Earth [44].

Figure 3.5 continued

(b)

(c)

Figure 3.5 continued



(d)

3.4 Community Beliefs About Map Accuracy

Whether these flood hazard maps accurately represent where flooding happens is important to research. It is also important to understand whether or not flood hazard map users *believe* the flood hazard maps accurately represent flooding. This belief dictates how professionals, community organizers, and concerned residents approach the flood hazard maps. This section will show that there is a pervasive lack of trust in the accuracy of the maps by all three of these groups. Members of each of these groups pointed to a number of reasons why they believed the flood hazard maps might be inaccurate, but the most common one by far was that the maps are simply outdated. Community residents responded to this belief by rarely using the maps, often reporting that they were unnecessary because they already knew where flooding would occur, having seen their town experience flooding repeatedly over their lifetimes.

3.4.1 Maps Are Inaccurate

There is a prevalent belief among people who live and work in Ludlow and Cavendish that flood hazard maps are inaccurate. This belief is also shared by many state officials who work with the flood hazard maps. This belief was shared early and often when the topic of flood maps was brought up in interviews. One local business owner put it simply, stating that the maps are "not accurate enough." Examples of this were commonplace. One state official reported that, “We have structures that are literally being washed away. And they're not in a special flood hazard area, because the river was so incised due to historic channelization.” This official pointed to a specific issue that the FEMA National Flood Hazard Layer overlooks - erosion. While the FEMA maps are not designed to represent erosion, it is a major effect of flooding in mountainous areas, and has significant ramifications for homeowners.

This is one example of a feature that the FEMA maps do not always represent accurately. Additionally, the maps also have issues with areas that appear within the floodplain. Occasionally, areas that are within the floodplain end up not being affected by flooding at all. As one town official said, “It's more common to see those that aren't in the floodplain that do get whacked as opposed to the other way around. But we do see both, fairly regularly.” Of course, homes that aren’t in the floodplain getting “whacked” are the more dangerous issue. But homes that do not flood that are within the floodplain may be obligated to purchase flood insurance that they do not truly need. So while one situation is obviously more life-threatening, both false positives and false negatives are potential issues. Residents and professionals report having both of these accuracy issues with the flood hazard maps.

3.4.2 Maps Are Outdated

Community members also have strong beliefs about why the maps are inaccurate. More specifically, there is one sentiment that was expressed repeatedly by impacted residents, community organizers, town and county officials, and state officials. This was the belief that the flood maps were outdated. One state official said, “Floodplain maps in Vermont are primarily very old”, before elaborating by saying, “most of those digital maps … were only brought into the computer world really recently, and don't really have updated hydrologic data.” In fact, these maps were last updated in 2007 [42]. These updates were minimal, and the last major map updates happened in the 1970s [45].

The fact that the maps are out of date is widely acknowledged. For example, one community organizer said, “The most recent stream geomorphic assessment was done before Irene [in 2012], so I'm sure those maps have changed.” And a resident impacted by the flooding confirmed during an interview, “You do know that all the floodplain maps are out of date?” An awareness of the age of the maps is not limited to state or local professionals - this knowledge has spread throughout the entire community. Another community organizer stated, “These maps are really outdated, and it's not reflecting how the river has moved.” Community members know that the maps are old. They also know that the age of the maps is likely to make them inaccurate. Their belief that the maps are not accurate is backed up by logical and evidence-based reasoning.

3.4.3 Maps Are Unnecessary

While community members believe the maps are inaccurate, primarily because they have not been updated in decades, those who were interviewed for this project largely do not feel that this is an issue that requires an urgent solution. This is primarily because many community members do not see the maps as necessary at all. Most residents who live in the community have seen the area be affected by flooding multiple times in the past fifteen years, and many town and county officials have worked on recovering from those floods. As one local official who also lives in the area said, “I think we all generally know what floods and where it floods, because the group I work with, we have a lot of the emergency management teams on that group.” A community organizer phrased it like this: “Where it has flooded is sort of the map that I have in my head, or the stories that I have of what has flooded and what needs to be done, more so than the actual flood maps.”

If everyone already believes they know where the dangerous areas are, there is little reason for residents to use the flood hazard maps, especially if they are inaccurate. Of course, professionals must still use the maps to fulfill planning and zoning requirements. This group would grow frustrated with the maps for a different reason, if they must continue to use them while they do not accurately represent what they have experienced in the past. So while the maps are used by professionals, they are largely seen as superfluous by residents of the community who are interested in knowing where the next flood may hit.

3.5 Discussion

The widely held belief that maps are inaccurate can be nuanced with an analysis of the maps made by the community during community mapping events. These maps revealed that the FEMA National Flood Hazard Layer actually performed relatively well along the Black River. The map was not perfect, but encompassed the vast majority of community-mapped points of flooding. However, this relative accuracy decreased significantly farther away from the Black River, along smaller brooks and streams, which were often not represented as being at risk of flooding at all on the FEMA map. This nuance is valuable because it shows where the flood maps can be trusted to a degree (along the Black River), as well as where they should be questioned much more (along small brooks and streams). This knowledge will make sure that residents living along the smaller brooks and streams do not have a false sense of security by believing that the FEMA maps do not indicate flood risk at their homes.

Ultimately, the accuracy of these flood hazard maps only truly matters if people use them. The flood maps will always have professional users due to zoning laws, which might very between local, regional, state, and federal levels. Updating the flood maps is important for town planners and managers to be able to make decisions that are not only legally required, but that also keep people and property safe. However, accurate flood maps currently matter less to residents, who do not trust the maps. If these maps are not trusted, they will not be used to the fullest extent possible, and the inaccuracy of the maps will have a relatively limited negative impact. Obviously, this is not the ideal situation. When the maps are updated to reflect the current conditions of the Black River, rebuilding resident's trust in the maps will take time. It will need to be clearly communicated that the updates have made the maps more accurate. Once this trust is regained, consistently updating the maps will be even more important.

3.6 Conclusion

The beliefs that community members hold about the accuracy, or inaccuracy, of flood hazard maps are based on their experience of the maps repeatedly failing to accurately represent flooding in some of the areas where it matters the most to them. These beliefs are well-founded, and are supported by a comparison of their experiences of flooding to the various flood hazard maps. Both the National Flood Hazard Layer and the River Corridor maps have specific accuracy issues. The National Flood Hazard

Layer does not capture the flood risk further away from the Black River. The River Corridor maps are often not as wide closer to the Black River when compared to the FEMA map. Knowing these differences and specific weaknesses provides an opportunity to improve both of the maps.

Residents also know specific stories of their neighbors' experiences with flooding. With the knowledge of where their towns are actually impacted by flooding, the flood maps have little use to residents. This causes the accuracy of the maps to matter even less to residents, who often do not even bother using them. The maps should be updated and made more accurate for two major reasons: to make sure that professionals are using accurate tools to follow planning and zoning laws, and to rebuild trust in the flood hazard maps among residents. While professionals are required to use flood hazard maps even if they question the accuracy, their communities will be safer if they are accurate. Improving the accuracy of flood hazard maps will make the maps much more effective and beneficial to professionals and residents alike.

CHAPTER 4 CONCLUSION

4.1 Main Findings

Both professionals and community members impacted by flooding have difficulties using flood hazard maps and concerns about the accuracy of these maps. Issues with the usability of the maps are encountered at three different stages: while finding, interpreting, and implementing the maps. Each of these steps includes a unique set of difficulties, and improving the maps will require understanding how people use the maps at each step. The maps also have accuracy issues. These issues are different depending on the maps. These differences provide an opportunity to combine the strengths of each of the maps and provide more nuanced risk assessments depending on the geographic location of an area. Both the usability and accuracy issues impact community trust in the maps and the confidence that professionals have while using them.

4.2 Recommendations for Next Steps

This study has focused on a few of the difficulties encountered by residents and professionals who use various flood hazard maps. This chapter will build off of these findings and recommend a few ways in which these difficulties could potentially be reduced. First, technical improvements to the current maps will be suggested. These include ideas on how to make the flood maps more accurate, as well as specific improvements that could make the user interface easier to navigate. Second, I present a list of criteria for what features a new flood hazard map should represent, as well as what it should look like technically. Third, a number of suggestions for improving the experience of using the flood hazard maps are discussed. These ideas do not depend on the flood hazard maps themselves, so they could be applied to any new or existing maps. A table appears at the end of this third section (Table 4.1), summarizing the recommendations given across all three sections and clarifying what level of government the recommendation will be the most relevant to.

4.2.1 Recommended Technical Improvements to Current Maps

The most obvious improvement to make to the flood hazard maps is also the most necessary one. The maps must be updated more often. The flood hazard maps do not accurately reflect risk after the occurrence of multiple flood hazards in the area. After multiple decades without significant updates, the maps are simply no longer valuable and accurate tools.

There are a few ways that consistent updates to flood hazard maps could be implemented. For example, a process could be developed which uses new LIDAR data as it becomes available to newly map the flood hazard areas. Current LIDAR data will reveal changes in the rivers and brooks in the area since the maps were last updated. Incorporating this data into the flood hazard maps could be done without requiring an entirely new hydrologic study of the area. Another update could be to look at updating the flood hazard maps soon after a devastating flood event. This need not occur immediately after a disaster; however, it could happen alongside other long-term efforts. The list of which flood maps should be most urgently updated should reflect how great the changes to the area are estimated to be. This would result in the prioritization of areas that have experienced one or multiple weather events that would be reasonably expected to change the area's hydrologic behavior.

It must be clarified that FEMA is currently working on updating the National Flood Hazard Layer in Vermont. These updates are in different stages depending on the specific area. The towns of Ludlow and Cavendish have not yet received preliminary maps for review, as of the summer of 2024. The update project as a whole is expected to take five years and to be completed in 2027, according to interviewees. This update project is a positive development and a necessary solution for the area. However, it is unclear whether there is a plan in place to more consistently update the flood hazard maps in the future.

Beyond updating the maps more consistently, there are a few more straightforward ways that the current maps could be improved. These focus on the actual user interface of the flood hazard maps and how people are able to view and read the flood hazard maps. First, the layers of the flood hazard maps should be easier to find within different websites. This is particularly true of the State of Vermont's Agency of Natural Resources Atlas (the ANR Atlas). This product enables users to view multiple maps at once, such as the River Corridor map and the FEMA National Flood Hazard Layer. However, these layers are organized in a confusing way, and are often difficult to find. Particular attention should be paid to the needs of users without a background in GIS. Second, these layers and any other legends on the maps should be more clearly defined. The titles of the layers often fail to concisely communicate the information that the layers contain. This update could involve focus group testing with users who are not professionals, in order to confirm which titles make sense to this group. Third, the map should be made easier to navigate by making zooming and scrolling speeds less sensitive. The sensitive inputs work well for professionals who are used to using the tool and looking at the map. However, they are much less helpful for inexperienced users who may have trouble identifying exactly where their property is, and who may scroll or zoom too quickly and end up looking at an entirely different place on the map. If these features are made less sensitive by default, an option can be provided to increase the sensitivity, which will be straightforward for experienced users to figure out. None of these improvements to the flood hazard maps would require mapping new features, and should be able to be done quickly and easily.

4.2.2 Criteria for a New Flood Hazard Map

While there are a number of improvements that can be made to the current maps, flood hazard mapping could go beyond the currently accepted frameworks. There are a few geographic features that could feasibly be mapped and would be useful for impacted residents as they prepare for and experience a flood event. Adding these to flood hazard maps would require rethinking the way flood hazard mapping is done. One of the most notable features is road blockages. Roads that are predicted to be shut down during a flood event could be highlighted. This would include roads within flood inundation hazard areas, and roads within river corridors. However, as seen in Chapter 3, simply mapping these roads may not be enough. It will also be important to map the predicted type of damage to the road - for example, is the road predicted to be damaged by erosion, or will there be water flowing across the road? Knowledge of roads that could be made impassable in a storm would enable residents to make alternative plans, such as using different roads or stocking up on supplies.

Another infrastructure feature that could be included in future maps is culverts. Culverts are a serious danger during flooding in mountainous areas, as they often become clogged, backing up water behind them. This often happens when culverts are undersized or damaged. Keeping an updated map of culvert size and condition would facilitate the prediction of which culverts may become an issue during flooding. This could be done by town or state officials, or it could be crowdsourced by asking residents to look at the culverts on and near their property and compare their conditions to a provided guide on what a culvert should look like. After this map is made, residents living near the potentially problematic culverts would be made aware of the issue, and town managers could prioritize upgrading or fixing the culvert while also planning for flooding caused by the culvert. The Rural Rivers/Mapping for Resilience research team and other Dartmouth students are currently collaborating with community organizations, including the Black River Action Team (BRAT) and Black River Valley Resources (BRVR), on a project called Culvert Crawlers, in which they are mapping culverts in the Ludlow and Cavendish area. For more information, please see the Weather Ready grant report titled "Using Participatory Mapping to Assess Inland Flood Events and Communicate Risks".

One new process for mapping roads and culverts that may become a risk during flooding is incorporating historical flooding data into the maps the predict future flooding. As shown in Chapter 3, past events have affected Ludlow and Cavendish in very similar ways. It stands to reason that future flooding will also happen in a similar way to these past floods. This past data should include both areas of flood inundation or erosion, as well as roads that were closed. While many residents know dangerous areas and unreliable roads from past experiences, it would be useful to all residents to have a map of these areas. Additionally, this mapped data would be helpful for county- and state-level officials who may be less familiar with the area. This is especially true for emergency response teams who would greatly benefit from knowing which roads will be impassable. If historical maps are used to predict the possible impacts of future flooding, this should be made clear on the map.

A new flood hazard tool targeted primarily at residents fills a need displayed throughout the interviews conducted. For example, it should be very straightforward to search for an address and see information relevant to your property. This would include the flood map on and around the property, maps of historical flooding events impacting the property, information on whether the flood maps of the property have been updated recently, and information on actions to take based on the flood risk to the property. While flood hazard maps targeted at professionals should also be updated and improved, residents of these communities will greatly benefit from new features making the maps easier to use and more reflective of potential experiences of flooding.

4.2.3 Assorted Points of Improvement for the Flood Map Ecosystem

Updating new flood maps in a variety of ways is necessary to make them accurate and usable by all members of the community. Creating a new flood map tool would further advance these accuracy and usability goals. In addition to updated maps or entirely new maps, there are a few changes that could be made to the ecosystem around flood maps to make them easier and more helpful to use. These improvements would not directly involve changing the maps themselves, but would change how the maps are presented and supported.

First, the original intended uses of different flood hazard maps must be made clear as soon as a user enters a website. As discussed above, this is not the case with many current flood hazard maps, most notably the National Flood Hazard Layer. This map is primarily intended for insurance purposes. It is also used by towns and counties for permitting and zoning purposes, which is closely related to the insurance uses. However, impacted residents looking for a flood hazard map will likely first find this map. It may not be immediately clear to users that this is *not* what the map is originally created for. While it is certainly useful for this purpose, it should not be the single authority for residents. This will lead to less confusion among people who are not professionals when they attempt to discern their flood risk.

Second, community liaisons should be established between agencies that publish flood hazard maps and community members across the country. Many residents seek out authority figures with questions when they run into issues using the flood hazard maps. As reported above, they often turn to town or state officials with these questions. But town and state officials did not create the maps; while they may use them, they should not be expected to have all the answers. They also should not need to spend their time working on these maps with residents, especially in the immediate aftermath of a flood. However, residents do not know who else to turn to, because the various government bodies that publish the maps have not made it easy to get in contact with anyone who may have answers. Community liaisons should be appointed, and their contact information should be easily available on the flood hazard map websites. This would take a burden off of local and state officials while also greatly helping community members.

Improving the accuracy of the maps is the most important step to restoring this trust. This obviously means making sure the maps accurately reflect where flood inundation happens, but it also goes beyond this. It also means representing other consequences of flooding that acutely affect community members, such as road closures. Along with improvements to the accuracy of the maps, the usability of the maps must also be improved. Once these steps are taken, restoring the trust of the community will still take time. However, these steps are essential to beginning the journey towards restoring that trust.

Table 4.1 Summary of Recommendations and Relevant Stakeholders.

Recommendation	Type of Recommendation	Relevant Stakeholders
Update flood hazard maps more often	Technical Improvement	State or federal officials, depending on the map
Make layers more straightforward	Technical Improvement	State officials
Define layers and zones on maps more clearly	Technical Improvement	State or federal officials, depending on the map
Make map navigation less sensitive by default	Technical Improvement	State or federal officials, depending on the map
Map road blockages	Criteria for New Map	Local and state officials, community organizations
Map culverts that present potential issues	Criteria for New Map	Local officials, community organizations
Add historic flooding data	Criteria for New Map	Local and state officials
Improved search features	Criteria for New Map	State and federal officials
Clarify use of flood hazard maps	Flood Map Ecosystem	State and federal officials
Hire community liaisons	Flood Map Ecosystem	State and federal officials

4.3 Study Limitations

This research project had a few limitations that should be clarified. One of them is that this research project took place in one study area, with a specific geography and culture. This impacts the findings of the research project in two important ways. First, the risks from flooding in mountainous, inland areas are much different than the risks in flat or coastal regions. Erosion and landslides have a much larger impact in rural New England than they would in much of the rest of the country. Flood hazard maps of other areas may need to focus on more relevant dangers to their specific geographical contexts. The culture of these communities also played a role in the findings. The mistrust of government-created tools may not exist to the same degree in other parts of the country. Similarly, other communities may be more welcoming of government policies around potential safety risks.

A final limitation is that this research project focused on only one flooding event. For a true quantitative analysis of the ways in which flood hazard maps are inaccurate, multiple events would be required. Not every flood event in Ludlow and Cavendish will happen the exact same way as this one (although many interviewees reported historical flood events were very similar). This is true for events in the area, let alone events elsewhere. The impact of flooding disasters on communities, and related topics, almost always must be studied individually due to the nature of these disasters.

4.4 Dissemination of Research

The completion of this thesis paper does not mean that work on this project is finished. The research findings outlined in this paper will continue to be disseminated over the upcoming months. This will be done through both presentations at conferences and publications in peer-reviewed journals. This research project will be presented at the Natural Hazard Center's 2025 Researcher's Meeting, which will follow their 2025 Workshop. This conference in July 2025 will provide the opportunity to present my research to other researchers in the field. I am also planning to give a talk on this work at the 68th Annual Meeting of the Association of Environmental & Engineering Geologists (AEG) in September 2025. Additionally, a poster representing this research was presented at Colorado School of Mines' GRADS conference in April 2025. These presentations will all both be to academic audiences, as this work has already been presented to community partners. There will also be a paper published in a peer-reviewed journal as a result of this work. I am currently planning on submitting an abridged version of this thesis paper to the Journal of Disaster Studies. This journal is a new journal that is open to work on disasters from across disciplines, making my approach throughout this paper a good fit.

The broader Mapping for Resilience research team will continue to work on projects related to flooding in Black River and White River watersheds. Data gathered over the course of the project will continue to be analyzed by the team. While this thesis was focused specifically on flood hazard maps, the research team is working on flood resilience more broadly. To assist in advancing this research, the interviews conducted for this project also included broader questions around people's experiences with flooding. The community mapping exercises will also be further analyzed. The maps created by participants included much more data than presented in this thesis, such as data on important hubs for recovery after the flooding. This information is informing continued work on the project and will be published in the future. The nature of my research involvement with this team means I will remain connected after the completion of my degree in order to co-author publications and consult with this team.

4.5 Future Research Directions

This research focused on a single rural area in the United States, and one specific flood event. These limitations were necessary because of the methods and the timeline of this research project. This means there is a significant opportunity for future research projects along similar lines as this one. Future research could delve into how impacted residents and professionals in other rural areas across the United States use FEMA's National Flood Hazard Layer maps, as well as any state-specific flood hazard maps.

This could reveal regional differences in uses of the maps, or reinforce the findings of this paper. Additional research in other areas, or even in the New England region, would also involve different flood events. This would be valuable because of the unique characteristics of each flood event, even in similar areas. A future research project investigating similar research questions in a different context could be very valuable.

Future research could also look further into the different use cases of flood hazard maps by people impacted by flooding. While there are many different scenarios discussed in this thesis research, it does not come close to covering all of the ways in which people use flood hazard maps. Gaining a more thorough understanding of how and why people use different flood maps would enable the designers of the flood maps to present the flood maps in a more usable way, making them a helpful tool for as many users as possible. Continued research into different professional use cases would be valuable as well. This would also undoubtedly reveal differences across geographic contexts. Understanding a broader range of uses of the flood hazards maps would enable them to be designed and disseminated in even more effective ways.

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APPENDIX A INTERVIEW GUIDES

A.1 Formal (Professional / Community Organizer) Role

- What does your formal role entail?
- How was your work in this role impacted by the flooding?
- Were you personally impacted by the floods?
- Do you use flood maps of the area? If so, which ones?
- Do you use different maps for different scenarios or purposes?
- Did you use flood maps during or immediately after the floods last July?
- Have you had issues with the usability of any flood maps?
- Have you noticed specific accuracy issues with maps of the area? False positives or false negatives?
- Overall, are certain maps more accurate or useful than others?
- Do you use flood maps while working with other people?
- Have you used flood maps to make specific recommendations or changes?
- Did you use other maps at all during/after the flood? If so, which ones? Why and how did you use them?
- What other tools did you use during and after the flood? Why and how did you use them?
- What is your perspective on the relationship between Town, State, and Federal roles in response to last year's flood? and/or to flooding in general?
- What's going on in terms of recovery and mitigation? Are there particular challenges and barriers you see? How about innovations and insights?
- Would you be willing to share photos or videos from your flood experience, either in your official role or in your personal experience? If so, what's your email so we can send you a link to upload them?
- Anything else you'd like to share?

A.2 Impacted Resident

- What's your connection to this town?
- How about your connection to the river? Generally.
- Would you mind telling us about your flood experience?
- What did you do during and after the floods? Were you with particular people?
- Where did you access information about the flooding? Where did you access information about flood recovery?
- How did you get where you were going? (e.g., on foot, by car, how did you navigate)
- What helped? What felt challenging?
- Are there things that happened because of the floods that you didn't expect?
- Do you know about any town, state, or federal government policies or programs that deal with flooding? If yes, what have you heard about them?
- What do you think should happen next?
- Would you be willing to share photos or videos from your flood experience? If so, what's your email so we can send you a link to upload them.
- Anything else you'd like to share?