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"Know What to Do If You Encounter a Flash Flood": Mental Models Analysis for Improving Flash Flood Risk Communication and Public Decision Making

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Understanding how people view flash flood risks can help improve risk communication, ultimately improving outcomes. This article analyzes data from 26 mental models interviews about flash floods with members of the public in Boulder, Colorado, to understand their perspectives on flash flood risks and mitigation. The analysis includes a comparison between public and professional perspectives by referencing a companion mental models study of Boulder-area professionals. A mental models approach can help to diagnose what people already know about flash flood risks and responses, as well as any critical gaps in their knowledge that might be addressed through improved risk communication. A few public interviewees mentioned most of the key concepts discussed by professionals as important for flash flood warning decision making. However, most interviewees exhibited some incomplete understandings and misconceptions about aspects of flash flood development and exposure, effects, or mitigation that may lead to ineffective warning decisions when a flash flood threatens. These include important misunderstandings about the rapid evolution of flash floods, the speed of water in flash floods, the locations and times that pose the greatest flash flood risk in Boulder, the value of situational awareness and environmental cues, and the most appropriate responses when a flash flood threatens. The findings point to recommendations for ways to improve risk communication, over the long term and when an event threatens, to help people quickly recognize and understand threats, obtain needed information, and make informed decisions in complex, rapidly evolving extreme weather events such as flash floods.

KEY WORDS: Flash floods; mental models; risk communication; risk perception; warning

1. INTRODUCTION

Flash floods are a leading cause of weather-related deaths.[(1–3)] They pose significant threats to life and safety because they develop and evolve rapidly and contain fast-flowing water and waterborne debris.[(4–7)] Thus, it is important for people in areas at risk from flash flooding to be able to use warning information, environmental and social cues, and existing knowledge to protect themselves when necessary. One way to help people recognize, understand, and act promptly on flash flood threats is to improve flash flood risk communication. Effective communication about flash flood risks is particularly imperative as population growth drives development of areas at risk and as climate change may influence precipitation patterns.[(8,9)]

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This study aims to improve flash flood risk communication and decision making by exploring the beliefs that members of the public in Boulder, Colorado hold about flash flood risks and warnings, using a mental models approach.(10–14) Although public perceptions of flood risks have been relatively well-studied,(15–17) flash flood risks, and especially protective decisions when a flash flood threatens, have not. This article builds on mental models research in diverse contexts(10,12,14,18–23) and contributes to the growing body of research on people's perceptions of and responses to flood risks(24–28) by focusing on flash flooding and by examining warning processes as well as longer-term mitigation.

The study is based on mental models interviews conducted in 2009 with 26 residents of the City of Boulder. Boulder is located on the Front Range of the Rocky Mountains, at the base of several canyons, and is transected by multiple creeks and drainages (Fig. 1). At the time of the interviews, Boulder had not experienced a major flash flood in living memory. However, there is a history of flash flooding in neighboring Front Range communities, including the Big Thompson Canyon and Fort Collins to the north(29,30) and Manitou Springs to the south.(31) Thus, local professionals with knowledge and expertise about flash floods have long been aware of and concerned about flash flood risks in the Boulder area.(4,32) Then, in mid-September 2013, as we were compiling this article, record-breaking rainfall inundated communities along the Front Range. The resulting flooding and flash flooding caused eight fatalities and an estimated $1 billion in damage to buildings, roads and bridges, and other infrastructure.(33) This includes two fatalities and devastating damage in the City of Boulder.(34)

The study is based on data elicited in open-ended, semi-structured interviews about people's beliefs about flash flood risks and warning decisions. Using quantitative and qualitative analysis of the data, we examine how people think about flash floods and their risks, how these beliefs relate to behaviors, and whether there are important aspects of flash flood risks that people need to know, but do not, to protect themselves when a flash flood threatens. The study includes comparison with results from a companion mental models analysis of members of three groups with flash-flood warning-related professional expertise and responsibilities in the Boulder area (National Weather Service [NWS] forecasters, public officials, and media broadcasters).(4) In order to make informed decisions, members of the public do not need to understand all of the details of flash flood hydrometeorology, impacts, and warnings that professionals know. Our goal is to characterize what members of the public believe about flash flood risks in Boulder, compared to each other and to the collective knowledge of the professionals, in order to diagnose what further information could enhance their decision making and increase their safety when a flash flood threatens, ultimately leading to fewer losses.(35)

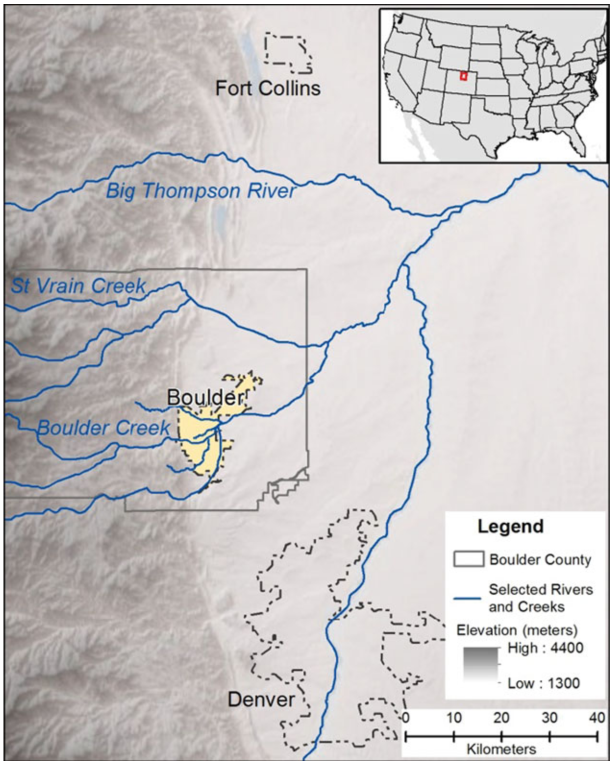

Fig. 1. City of Boulder (represented by shading) and surrounding areas in north-central Colorado, USA, including the Front Range mountains to the west of Boulder and selected rivers and creeks. The U.S. Census estimated the population of the City of Boulder to be 101,808, and the whole of Boulder County (represented by gray box) to be 305,318, in 2013. The city hosts over 32,000 students.

The aim of this study is to improve flash flood risk communication by starting with what different members of the public already know and want or need to know.(36–38) By developing an in-depth, bottom-up understanding of people's mental models of flash flood risks, we are able to offer recommendations for improving risk communication that reinforce existing actionable beliefs, or target particular areas of incomplete understanding or misunderstanding among those at risk from flash flooding. Mental models are causal beliefs about how the world works that guide decision making and behavior.[14,18,19] An individual's mental models are assembled and shaped by a variety of factors, including personal experience, media coverage, analogy, and inference,[14,23,39–43] as well as other, communications aimed at informing people about flash flood risks. Thus, risk communication can help people revise their mental models to form understandings that help improve flash flood risk management.[14] While of most relevance to the Boulder area, findings are potentially applicable elsewhere and to hazards with similar characteristics.

A few previous studies have examined mental models of floods and flash floods. Wagner[20] found that local contexts and conditions influence public flash flood knowledge in the Bavarian Alps and that people with more knowledge about flash floods rely on multiple sources of information and previous experience to build their understanding. Lave and Lave[21] conducted mental models interviews with members of the public in U.S. communities and found that people have limited knowledge of the causes of floods and how to prevent flood damage. Similarly, Wood *et al.*[22] examined mental models of flood risk management among public and risk management experts and found that despite recent events such as the 2004 Indian Ocean earthquake and subsequent tsunami and Hurricane Katrina in 2005, people remained unclear about how flood risks are produced and how they can be managed. None of these studies takes a broader perspective on flash flood forecast and warning decisions, as is done here.

The next section details our data collection and analysis methodology. Section 3 provides an overview of the Flash Flood risks and Warning system (FFW) decision model developed in the companion study, by Morss *et al.* [4] which informed some of our analyses of the interview data examined in this article. Section 4 examines public understandings of flash flood risks in Boulder, including a comparison of public and professional perspectives. Section 5 discusses the results from this analysis, Section 6 offers recommendations for improving flash flood risk communications, and Section 7 concludes.

2. METHODOLOGY

2.1. Sample and Elicitation

The mental models interviews were conducted by three interviewers with 26 members of the Boulder public at a research facility in Boulder, Colorado in September 2009. Interviewees were recruited by the facility using a screener designed to yield a sample demographic profile similar to that of City of Boulder residents. The interviews lasted an average of 53 minutes, and participants were each compensated $75 for their time. All interviews were audio recorded with participants' consent, and recordings were transcribed and checked for accuracy. Prior to conducting the interviews analyzed here, the three interviewers conducted four practice interviews with members of the public not included in the study sample. The practice interviews were used to pretest the interview protocol in order to ensure that the question wording was clear to the interviewees, to practice prompts and interview pacing with interviewees, and to align techniques among the three interviewers. The public interviews were conducted during a time period that overlapped with the professional interviews in the companion study by Morss *et al.*[4] The interview protocol was identical to that used for the professional interviews, except for minor modifications to address the different types of warning decisions made by members of the public.[4]

The interview protocol opened with two undirected questions: "Tell me about flash floods," followed by "Tell me about flash floods in Boulder." For each of these questions, the interviewer prompted the interviewee to elaborate on each major concept mentioned. Subsequent questions asked more specifically about flash flood exposure (factors affecting the occurrence of flash floods), effects (impacts from flash floods), and mitigation (actions that can or should be taken to reduce flash flood risks), following the causal structure of hazards presented in Hohenemser *et al.*[44] Interviewees were then asked a series of questions about their decisions in a previous flash flood event or warning experience, if they had one. Finally, a few closed-ended questions were asked about flash flood risk communications people may have previously received.

2.2. Data Coding and Analysis

The interview transcripts were coded in Atlas.ti, starting from the coding scheme developed in the companion study of Boulder-area flash flood professionals.[4] The coding scheme consists of

[4]Human subjects' approval was obtained prior to conducting the interviews. The full interview protocol is available from the authors on request.

hierarchical sets of codes corresponding to more general (higher-level) and more specific (lower-level) conceptual units[5] in the Flash Flood risks and Warning system (FFW) decision model (Section 3) derived in the companion analysis of professionals. As discussed further in Morss *et al.*[(4)] and Section 3, the FFW model encompasses a variety of expertise and understandings about flash flood risks; some professional interviewees had perspectives similar to members of the public. Thus, while the coding scheme was derived from the professional interviews, it included most (but not all) of the concepts mentioned by the members of the public. During the public interview coding, the coding scheme was modified to incorporate one new code important in multiple public interviews: analogies to other hazards. Other ideas not mentioned by professionals but that fit within existing categories of the coding scheme were coded with the relevant high-level code.

The final coding scheme includes 273 codes. This detail (with up to five hierarchical levels of codes) results from the variety of concepts mentioned by professionals as relevant to the flash flood forecast and warning system. Recognizing that this deviates from prior mental models studies in which the coding is based on a decision model appropriate to the decisions faced by interviewees, we nevertheless used this modified professional coding scheme to analyze the public interview data in order to enable a comparison of public perspectives with professional perspectives.[(14)] As in any such coding scheme, a single code may in some instances represent multiple understandings of a concept, among the professionals and between the professionals and public interviewees.[(10)] A conceptual unit was coded whenever a concept was mentioned, regardless of *how* it was understood by the interviewee. Hence, a given code includes variations in how the corresponding concept was discussed, and we examine those variations qualitatively below. As detailed in Section 4, the aim of this embedded comparison is to facilitate comparing how concepts were discussed and understood among the different professional and public interviewees, not to privilege a single "professional" perspective.

In order for the coding scheme to be applied consistently across the professional and public interviews, the lead author and one other coder independently coded and then compared and discussed the four practice interviews. The lead author then coded the 26 public interviews. The second coder also independently coded two of the 26 public interviews to calculate intercoder reliability. For both interviews, intercoder reliability was considered good for this type of latent concepts coding, with Cohen's kappa values of 0.75 and 0.74, indicating that the two coders applied the coding scheme consistently.[(45)]

Coded transcripts were analyzed quantitatively by determining whether each concept in the coding scheme had been mentioned by each interviewee. The percentage of public interviewees mentioning each concept was then calculated, and these were compared to the percentage of the professionals who mentioned the same concept. To understand how interviewees discussed these concepts in context, qualitative analyses examined variation in public interviewees' discussions of concepts as well as similarities and differences with the professionals.

Although the analysis of professionals' perspectives informed the public interview analysis, the primary analyst of the public interviews was not directly involved in the coding and analysis of the professional interviews. This enabled us to examine the public interviews from a bottom-up perspective for concepts that were not included in the FFW model and that were represented differently—sometimes quite differently—in the public data.

3. FLASH FLOOD RISKS AND WARNING SYSTEM MODEL APPLIED TO PUBLIC CONCEPTIONS

In the companion study, a decision-modeling session and mental models interviews with 20 Boulder-area professionals were analyzed to develop a model of the Flash Flood risks and Warning system.[(4)] The group of professionals included NWS forecasters, public officials, and media broadcasters. The professionals' individual conceptions of flash flood risks, forecasts, and warnings varied, sometimes widely, depending on their job roles, training, experience, and other factors. The FFW model is based on what these professionals *collectively* discussed as the major concepts and processes relevant to flash flood risks and risk management decisions, including professional and public decisions about creation, dissemination, and use of forecasts, warnings, and other information about flash flood threats (referred to here as "warning decisions"). As discussed in

[5]In this analysis, a "conceptual unit" or "concept" is any element identified by public interviewees or professionals as a factor influencing flash flood risks or the outcomes of the warning system.

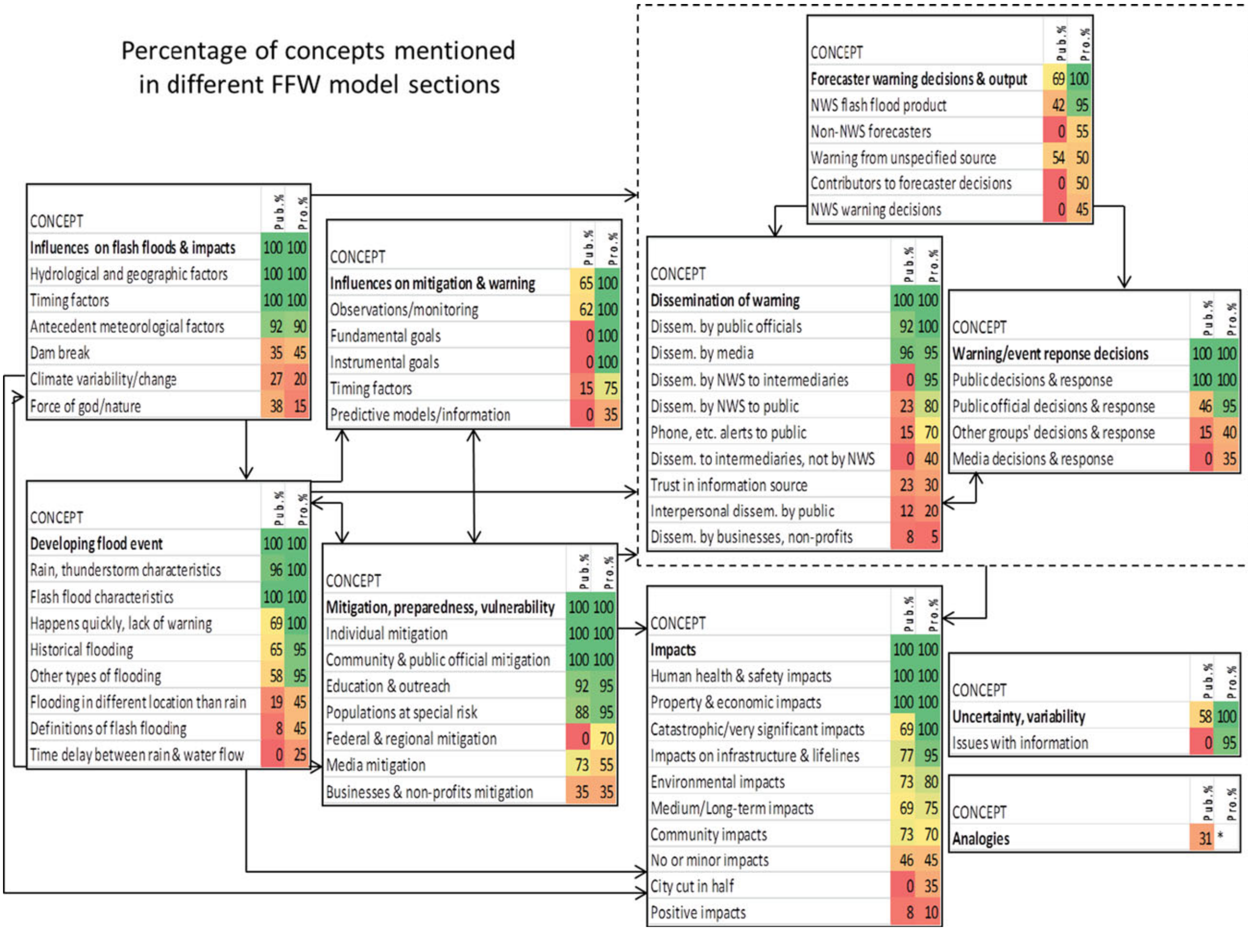

Fig. 2. Overview of the Flash Flood risks and Warning system (FFW) model (top- and second-level concepts), combining data gathered from public and flash-flood professional mental models interviews. The top-level concepts in the model (bold font) are represented by the 10 boxes with solid outlines. Second-level concepts are represented as subcategories within each box. Percentages in columns labeled Pub. % and Pro. % indicate the percentage of public interviewees and professionals, respectively, that mentioned each concept shown (with subconcept mentions aggregated into higher-level concepts); percentages are color coded from green (high) to red (low). The two left-hand boxes represent primarily "exposure" aspects of flash flood risks; the Impacts box represents primarily "effects"; and the remaining boxes represent primarily "mitigation" (except the concepts of Uncertainty and Analogies, which interact with all other concepts). The dashed box encompasses the sections of the model representing warning information and warning decisions. Analogies were not coded in the professional interviews.

Section 2.2, we use the concepts in the FFW model to provide a frame for our analysis, to help characterize different public perspectives and diagnose what additional or revised understandings could help members of the public better manage flash flood risks. Fig. 2 presents the 65 codes representing the top- and second-level concepts in the model, along with the percentages of professionals and public interviewees who mentioned each concept depicted (including subconcept mentions). Fig. 2 is organized into eight sections and two overarching concepts (uncertainty and analogies).

As expected, public interviewees vary in the depth and detail of their mental models, both overall and within different components of flash flood risks and risk management. Moreover, because of the diversity also evident among professionals, both professional and public mental models formed a continuum in different topical areas that in some cases overlapped. Data from the quantitative analysis of the coding results are used to portray this in Fig. 3, which shows the variability in number of concepts mentioned by individual interviewees overall and in different sections of the FFW model (compared to

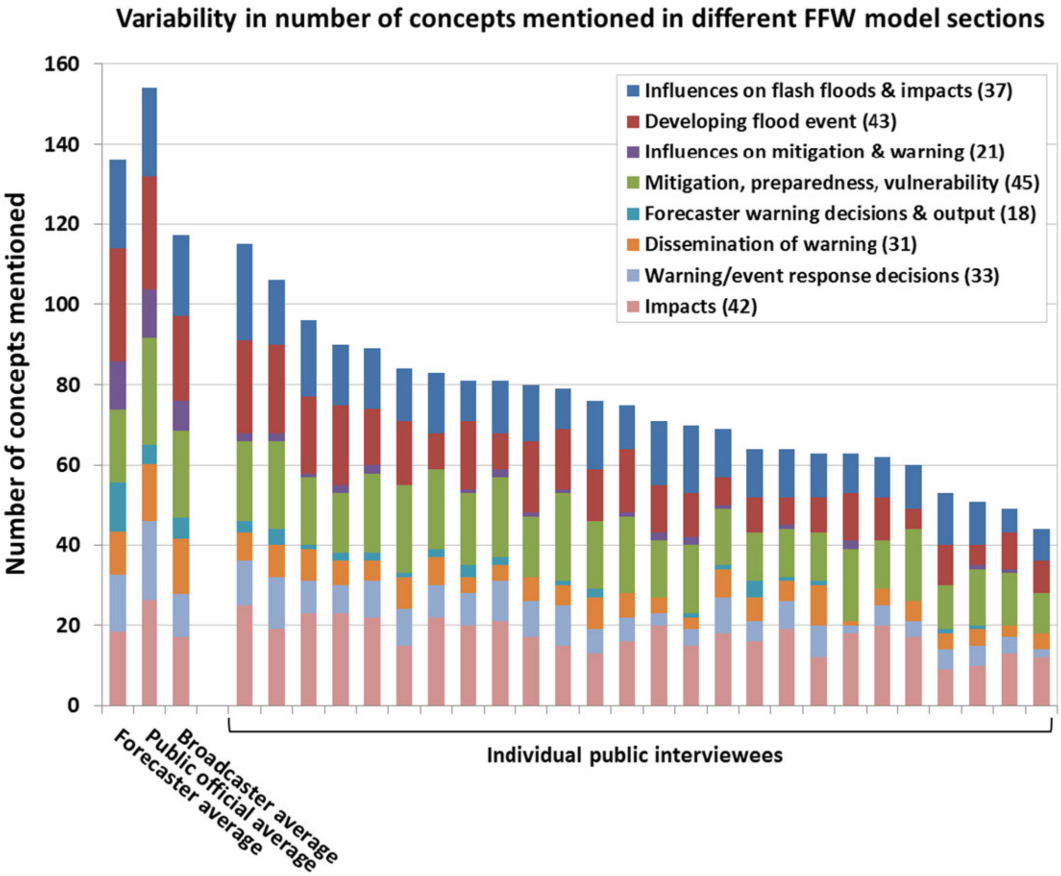

Fig. 3. Shows the number of concepts in each of the eight main sections of the FFW model (Fig. 2) that were mentioned by the three professional groups on average and the 26 individual public interviewees. Individual public interviewees are shown in decreasing order of number of concepts mentioned summed across the sections of the model. The total number of concepts in the coding scheme associated with each section of the FFW model is listed in parentheses in the legend (270 total, not counting the three concepts in the Uncertainty and Analogies categories). Because the coding aggregates over variations in how each concept was discussed (including vague and inaccurate conceptions), this is only one depiction of variability among mental models; in Section 4, qualitative analysis is used to examine variability among mental models in the context of how interviewees discussed flash flood risks.

the averages of the three professional groups). As Fig. 3 shows, a few interviewees had especially dense mental models compared to others. Nearly all of the public interviewees mentioned fewer concepts than nearly all of the professionals, but three public interviewees mentioned more concepts than three of the media professionals.[(4)] A few public interviewees had comparatively sparse mental models, although even these interviewees exhibited important knowledge about some aspects of flash flood risks.

Fig. 3 illustrates some of the diversity in how different people think about and discuss flash flood risks and responses. However, the number of concepts mentioned does not necessarily correspond to an accurate or inaccurate understanding of flash flood risks. For example, some public interviewees mentioned relatively few concepts, but demonstrated an accurate, if less detailed, understanding. Moreover, this FFW model (and thus Fig. 3) includes details about flash flood risks and warnings that members of the public cannot be expected to and do not need to know. Thus, in order to understand interviewees' mental models, it is important to examine whether and how they discussed specific concepts in greater depth. With this in mind, in the remainder of the article, we focus on discussing people's mental models in areas of the FFW model that are most relevant to the decisions they may face.

4. PUBLIC CONCEPTIONS OF FLASH FLOOD RISKS

This section conveys the primary findings from the mental models interviews with members of the public about flash flood risks in Boulder, Colorado, covering conceptions of flash flood exposure (Section 4.1), effects (Section 4.2), and risk management, including warning decisions (Section 4.3), as well as use of previous experience and analogies when discussing flash flood risks (Section 4.4). Percentage of public (*pub.)* and professional (*pro.)* interviewees that mentioned concepts and subconcepts are presented in tables or in parentheses in the text; quotations are identified by interview number (e.g., Interviewee #1).[6] Unless otherwise noted, "interviewees" refers to the sample of members of the public interviewed for this study. All references to professionals' conceptions of flash flood risks and decision making are from Morss *et al.*[4]

4.1. "Four Words; It Rains, It Floods":[7] Flash Flood Development and Exposure

As represented in the two left-hand boxes of Fig. 2, multiple interacting factors contribute to how flash floods develop and evolve.[4] All interviewees discussed rain or wet weather as a contributor to flash floods, and almost all specifically mentioned rain rate, duration, or amount *(pub. 96%, pro. 100%)*. Many interviewees mentioned thunderstorms, and most mentioned related meteorological conditions *(pub. 92%, pro. 90%)*, although they typically did so using more general terms than the professionals (e.g., "weather," "cloudy," "dark"). Some mentioned dam failure that could lead to a flash flood *(pub. 35%, pro. 45%)*.

All of the interviewees also mentioned terrain, such as mountains *(pub. 96%, pro. 100%)* or canyons *(pub. 73%, pro. 80%)*, as a factor influencing flash floods. The interviewees discussed terrain primarily as contributing to how water flows through the landscape, including collection and channeling of water *(pub. 62%, pro. 100%)* into creeks and streams *(pub. 96%, pro. 95%)*. For example, Interviewee #11 described flash flooding as "a large wall of water ... just like with a hose or something, when you put a lot of water through a small area, the velocity increases, and so you get a whole lot more erosion, a whole lot more energy involved in it. And this would be typical of creeks or ravines." Along with natural drainage, many interviewees also mentioned the influence of the built environment, especially the role of stormwater management *(pub. 54%, pro. 55%)*, for example: "streets—you hope they have enough storm drainage" (Interviewee #13). Most mentioned the concept of a floodplain *(pub. 81%, pro. 80%)*, and a few discussed that water can flow away from where rain is occurring to produce flooding in a different location *(pub. 19%, pro. 45%)*.

As the above discussion indicates, several of the factors that, according to the professionals, are most important in influencing Boulder's flash flood risks were part of many public interviewees' mental models. However, other important factors were infrequently mentioned by interviewees, or were discussed in ways that indicate misconceptions or incomplete understandings. Besides rain rate, duration, or amount, few interviewees discussed other characteristics of rain or thunderstorms, such as storm motion *(pub. 23%, pro. 90%)*, rainfall location *(pub. 38%, pro. 95%)*, or, more specifically, rain over the foothills or canyons west of Boulder *(pub. 19%, pro. 75%)*. Few mentioned land or soil properties *(pub. 35%, pro. 95%)*, including burn areas *(pub. 35%, pro. 95%)* and impervious ground such as concrete and rock *(pub. 23%, pro. 55%)*. Although people do not need to understand all of the details of flash flood exposure, these factors are important contributors to flash flood risks in Boulder. Having a better understanding of them could help people understand which of the many rainstorms in Boulder each year might lead to flash flooding and which places are at greater risk.

Interviewees also discussed how multiple factors come together to create flash floods and their impacts. Some had relatively detailed conceptions. For example, Interviewee #16 described a flash flood as occurring when "a big storm ... parks itself up on the hills and really just dumps tons of rain in a very short period of time and there's no place for the water to go other than down the creek and into town." However, many expressed fairly general understandings, for example: "Flash floods are when water coming downstream from someplace higher collects and gets out of control" (Interviewee #9). In some cases, interviewees also discussed the interaction between social and physical factors in determining flash flood outcomes, such as locations or populations that are more vulnerable to flash

[6] Quotations were edited to remove filler words such as "you know" and "like," for readability, but were otherwise not modified.

[7] Interviewee #1.

flooding and its effects *(pub. 88%, pro. 95%)*, with people in specific vulnerable locations (e.g., along creeks) and recreational or outdoor populations being most frequently mentioned. For example, Interviewee #14 noted that the impacts of a flash flood depend on "how many people are there … time of day, time of week, the size of it, where it is … how big is the volume as well as how long is it going to go on."

Some ideas about flash flood development and exposure were more prevalent among public interviewees than professionals. For example, more interviewees mentioned the 50-, 100-, or 500-year flood *(pub. 50%, pro. 40%)* and the influence of climate variability or change *(pub. 27%, pro. 20%)*. Four (15%) mentioned the influence of air pollution, which was not mentioned by any professionals. More interviewees also described flash flooding as a force of God or of nature *(pub. 38%, pro. 15%)*, including a view that flash floods are beyond human control, for example, "nature taking its course" (Interviewee #9) or "where Mother Nature comes into play" (Interviewee #12). Interviewee #15 described flash flooding as "a spiritual restoration—that if we haven't taken care of things they're kind of taken away from us." These instances illustrate how public mental models of flash flooding incorporate other environmental phenomena or discourses that most professionals do not emphasize.

4.1.1. *"The Whole Point of Flash Floods is the Flash Part":[8] Speed and Other Flash Flood Characteristics*

An important characteristic of flash floods is the rapid speed with which they develop, which leads to little or no warning time (as occurred in some places during the September 2013 flooding). According to formal definitions, flash flooding usually occurs on time scales from minutes up to six hours.(4,46,47) As illustrated in Table I, the short-fused nature of flash floods was mentioned by all of the professionals but only about two-thirds of public interviewees. Some interviewees had a specific understanding of how rapidly flash floods can develop and evolve. For example, Interviewee #25, recalling a flash flood experience, said: "It was so fast … from the time the rain started and you started looking up at the canyon … within 5 minutes the water was up to our, almost up to our knees," and Interviewee #9 estimated that a flash flood could occur "within the hour or two." However, some who mentioned the concept had a more vague understanding, such as: "it happens quickly with not a lot of time to prepare" (Interviewee #12). Others expressed uncertainty or confusion about the time scale of flash flooding; for example, "does it happen in 5 minutes or does it happen in 6 hours, like I just have no sense of how quickly a flood could affect someone" (Interviewee #8), or "how fast does [the water] have to rise to make it a flash flood?" (Interviewee #22). Other interviewees had misconceptions, for example, saying flash floods could develop "within a few days or a week" (Interviewee #15).

Table I. Percentage of Public Interviewees and Professionals Mentioning Selected Concepts from the "Developing Flood Event" Section of the FFW Model

Concept / Code	*Pub. %*	*Pro. %*
Happens quickly, lack of warning	69	100
Speed/force of water flow	54	85
Debris or dangerous objects in floodwater	35	85

Two other characteristics of flash floods that most of the professionals discussed as important are the speed or force of the water flow and the debris that the rapidly moving water dislodges and carries (Table I). Some interviewees mentioned these characteristics of flash floods (Table I) and recognized the risks they pose (Section 4.2). For example, Interviewee #14 said that "what makes it dangerous … [is] the sheer volume and speed of the water that can cause harm or what it has picked up along the way … it can be vegetation, trees, it could be logs, it could be pieces of fence or houses." Interviewee #21 noted that "you get crushed with all the debris that's coming down the canyon; trees and rocks and stuff like that." However, as shown in Table I, many interviewees did not mention these concepts, suggesting that they had a different conception about what flash flood waters look like. Many also did not mention flash flood waters flowing on roads *(pub. 38%, pro. 75%)*.

Many interviewees discussed one or several of these concepts but not others, indicating that they had some understanding of the nature of flash flooding but may not understand the full suite of risks that flash floods present. The interviewee who mentioned the fewest concepts overall (Fig. 3), for example, discussed heavy rain leading to fast-moving water, but did not mention the speed of flash flood development; that interviewee then said (when

[8]Interviewee #25.

Table II. Percentage of Public Interviewees and Professionals Mentioning Selected Concepts from the "Influences on Flash Floods & Impacts" Section of the FFW Model

Concept / Code	*Pub. %*	*Pro. %*
Spring (April–June)	92	70
Late summer/monsoon season (July–August)	35	95
Afternoon	58	90
Evening, night	23	80

asked toward the end of the interview about other floods): "Is there another type of flood? ... I guess I just assumed a flood's a flood ... it never occurred to me [that there is a difference]" (Interviewee #26). As we discuss further in Sections 4.2 and 4.3, these misconceptions or incomplete understandings are connected to interviewees' views of flash flood effects and mitigation, including the decisions they discussed making during a threatening situation.

4.1.2. *"The Snowmelt Has to Go Somewhere":*[9] *Causes and Timing of Flash Flood Risks*

Interviewees attributed the water that produces flash floods primarily to two factors: rain and snowmelt (Table II). Heavy rains that contribute to flooding can occur from spring through fall, but the likelihood for thunderstorms that lead to *flash* floods is highest in late summer. Peak runoff from snowmelt in Boulder is experienced in spring as temperatures rise, and although snowmelt can contribute to flooding, it typically has a longer predictive lead time than summer thunderstorms. Thus, as shown in Table II, all but one of the professionals discussed the potential for flash flooding during late summer, and the NWS forecasters and some of the other professionals discussed late summer as the time of greatest flash flood risk in Boulder.

Some interviewees recognized that snowmelt floods tend to be more predictable and less "flashy"; for example, Interviewee #1 said "spring runoff you kind of plan for. I always think of flash floods as being more unexpected, just a result of unexpected rain." However, because many connected flash flood risks with snowmelt and/or springtime rains, only one-third of interviewees mentioned late summer, and most thought that the likelihood of flash floods in Boulder is highest in spring (Table II). For example, Interviewee #26 said that "[in the] spring ... the creeks are running high already from the snowmelt, so then if you've got a big storm it would impact it greater than late summer if the creeks were already running pretty low." As this quote suggests, these misconceptions are related to the environmental cues people observe in Boulder in the spring, compared to summer when it is often dry. A few connected snowmelt with the implications of climate change for flash flooding risk. For example, Interviewee #18 said that "with global warming, we could have a warm January and something could happen."

In Boulder, thunderstorms are most likely "in the afternoons and early evenings and sometimes later evening, but usually not in the mornings" (Interviewee #10). Similarly, nearly all professionals discussed flash floods as most likely in the afternoon and evening (Table II). A few interviewees mentioned these times of day (Table II), but when asked whether there are times of day when flash flooding is more likely, many interviewees said "no" or "I don't know." Understanding times of year and day when flash flooding is a risk in Boulder is potentially important for warning decisions because people who understand the timing of flash flooding are more likely to recognize warning signs and thus respond quickly.

4.2. "It Depends How Bad it Is and it Depends Where it Is":[10] Flash Flood Effects

As Fig. 2 indicates, interviewees discussed many of the same general types of flash flood effects as the professionals. Within these general categories, however, interviewees discussed some of these effects somewhat differently. Regarding impacts on human health and safety, all of the interviewees discussed death, but compared to death by drowning, far fewer public interviewees than professionals mentioned the potential for death due to being hit by water-borne debris (Table III). Most public interviewees also discussed the potential for people to get trapped or stuck in risky locations, but fewer public interviewees than professionals mentioned people being trapped in cars or cars being swept off the road (Table III), even though this is a primary cause of flash flood deaths in the United States (including several deaths in the 2013 flood).[3,33][11] As this suggests, most interviewees understood that flash floods can pose risks

[9] Interviewee #8.

[10] Interviewee #14.

[11] The interview protocol included a prompt about what might happen to cars exposed to a flash flood. Many interviewees responded by discussing car damage from water.

Table III. Percentage of Public Interviewees and Professionals Mentioning Selected Concepts from the "Impacts" Section of the FFW Model (Subconcepts Indented)

Concept / Code	*Pub.* %	*Pro.* %
Death	100	100
-Drowning	73	75
-Hit by debris	38	65
Trapped in risky location	88	90
-Trapped in car, car swept off road	62	90
-People in water, swept off feet, washed away	65	75

to life, but some did not understand key mechanisms of how and why people die in flash floods. These misunderstandings are related to some interviewees' incomplete understandings of the danger associated with rapidly flowing, debris-filled flash flood waters, including water on roads, discussed in Section 4.1.1.

Many interviewees also brought up the potential for flash flooding to impact the environment *(pub. 73%, pro. 80%)*. Reflecting the environmental and outdoor-oriented mindsets prevalent in Boulder, discussions of environmental impacts focused primarily on landscape changes, erosion or loss of land, or loss of plants, animals, or habitat. For example, Interviewee #10 discussed the personal value of a certain tree near the interviewee's home and then explained: "losing landscaping ... that's a huge part about the quality of life here in Boulder." Few or no interviewees mentioned other types of environmental impacts discussed by some professionals, such as hazardous materials *(pub. 4%, pro. 40%)* or changes in creek or river channels *(pub. 0%, pro. 30%)*. These types of impacts were important in the 2013 flood when, for example, changes in creek and river channels destroyed homes and roads and hampered rebuilding.

Two other types of effects discussed by most or all professionals were mentioned by fewer public interviewees: impacts on infrastructure and lifelines *(pub. 77%, pro. 95%)* and the potential for catastrophic or very significant effects *(pub. 69%, pro. 100%)*. Regarding infrastructure, some interviewees did not mention the potential for transportation impacts *(pub. 65%, pro. 90%)*, including road or bridge damage or closures *(pub. 38%, pro. 75%)*, even though this is often a major impact of flash flooding. Few mentioned impacts on gas and power services *(pub. 19%, pro. 35%)*, communication systems *(pub. 8%, pro. 30%)*, or emergency or medical services *(pub. 8%, pro. 40%)*. Regarding catastrophic impacts, some interviewees mentioned the potential for a "major disaster" (Interviewee #14), but overall and in contrast to the professionals, few expressed concern about a devastating flash flood in Boulder.

The majority of interviewees mentioned community impacts *(pub. 73%, pro. 70%)* and medium- and longer-term impacts *(pub. 69%, pro. 75%)*, indicating that they recognized the potential for flash floods to have broader-scale and indirect effects. For example, Interviewee #16 said: "[I]n the long term ... probably being without power, without clean water, possibly diseases getting into the water because the water system got overrun ... there's more than just that kind of immediate risk, it definitely is going to cause some serious trouble to the City." However, the fact that many did not mention specific infrastructure, lifeline, or second-order impacts suggests that they did not fully recognize the potential complexity of a during- and post-flash flood situation and the recovery process.

A few types of effects were discussed by a slightly higher number of public interviewees than professionals. These include personal financial losses *(pub. 42%, pro. 35%P)*, agricultural or crop losses *(pub. 38%, pro. 25%)*, and psychological impacts *(pub. 54%, pro. 45%)*. Given that these aspects of flash flood risks appear salient to some people, they may be important for professionals to consider in risk management and when communicating about flash flood risks with the public.

4.3. "How Do You Affect the Result, the Damage and the Notifications?":[12] Flash Flood Mitigation and Warning Decisions

Flash flood risks can be mitigated through longer-term risk management activities, as well as warning communication and response when an event threatens (Fig. 2). Most interviewees mentioned longer-term flood risk mitigation by local government *(pub. 92%, pro. 100%)*, such as floodplain management, floodwater engineering, and flood risk mapping. Many also mentioned longer-term household-level mitigation of flood risk, especially selection of home location *(pub. 54%, pro. 55%)*, for example, "don't live in a floodplain" (Interviewee #9). In addition, many mentioned the concept of a warning system, which is a form of longer-term mitigation that helps enable warning decisions when an event threatens.

[12] Interviewee# 18.

Regarding warning decisions, all interviewees mentioned the concept of a warning or alert for flash flooding, and most mentioned having access to or receiving warning-related information *(pub. 92%, pro. 90%)*. Most commonly mentioned were alerts obtained from sirens *(pub. 77%, pro. 65%)*, television *(pub. 85%, pro. 90%)*, radio *(pub. 58%, pro. 80%)*, and through the Internet *(pub. 54%, pro. 80%)*, though these discussions were often nonspecific, for example "turn on the TV" (Interviewee #9). Although the NWS originates most flash flood warnings in the United States, only about half of interviewees mentioned the NWS as a source or disseminator of warnings *(pub. 58%, pro. 100%)*. Few interviewees mentioned information from public officials, such as evacuation orders *(pub. 15%, pro. 60%)*. Thus, most interviewees had only general conceptions of what warning-related information is available from whom and how it is disseminated. These sparse understandings may limit people's abilities to quickly obtain information or decide which information to trust in a flash flood threat, especially if their usual source or channel is unavailable or does not have the requisite information.

All interviewees mentioned the concept of individual protective decisions in response to a warning or other indication of a flash flood threat, and almost all discussed the importance of knowing what to do when a flash flood threatens *(pub. 92%, pro. 95%)*. Most mentioned people moving to a safer location *(pub. 81%, pro. 95%)*, although fewer mentioned the more specific response "go to higher ground" (*pub. 69%, pro. 95%*). Fewer public interviewees than professionals also mentioned avoiding driving into risky areas *(pub. 19%, pro. 45%)*. Some had incorrect conceptions of the most effective protective decisions during a flash flood. For example, Interviewee #17 said that "it might be prudent to have a boat, a canoe" to evacuate high water and discussed the importance of knowing "how to swim, swimming skills are good."

Because flash floods are spatially localized and complex, a person's best specific course of action may depend on the circumstances. A few interviewees discussed the potential complexity of protective decision making in a rapidly evolving, life-threatening situation, for example: "you think you'll just climb to higher ground, but not if sheets of water are coming down at you, and slippery mud and topsoil … it's good to know what to do beforehand because some people will brain lock" (Interviewee #25). Others had more general understandings of protective actions, for example, wondering "if there's a map of a good place to go … some sort of place for people to find safety" (Interviewee #6) or admitted "I wouldn't know what to do if there was a flash flood" (Interviewee #7). Thus, although all of the interviewees were aware that people might be alerted about a threat and need to take action to protect themselves, many did not discuss these concepts in much detail, and a few had misconceptions or gaps in understanding. Such vague, uncertain, or inaccurate understandings further reflect a lack of understanding about the rapid onset and evolution of flash flood threats and the immediate risks they can pose to human safety.

Due to the fast onset and complexity of flash floods, people may not receive a warning or aid from public officials, and they may need to evaluate the details of their situation to decide what to do.[(48)] For these reasons, the professionals discussed situational awareness and personal observations as important to support warning decision making. These concepts were also mentioned by many public interviewees, but often in general terms; for example, Interviewee #21 discussed "pay[ing] attention to the weather … being aware of your surroundings." However, some discussed situational awareness and personal observations in more detail. For example, discussing different stages of a flash flood threat, Interviewee #11 said: "awareness [of] … the potential for heavy rains in the mountains … that should say, maybe you don't want to go by the streams today. … [If] you missed the awareness issue and you suddenly see things rising or the change in the stream or whatever, then that would be the next thing to flag you to get out if you can."

One way that people develop knowledge about flash flood risks is through education and outreach, a form of longer-term impact mitigation and preparedness discussed by most interviewees *(pub. 85%, pro. 95%)*. For example, Interviewee #22 discussed the importance of "education to teach people … how to recognize flash flood conditions and what to do in those situations, what not to do." The most common form of education mentioned by interviewees was media coverage of flooding and flood risks *(pub. 73%, pro.45%)*, including newspaper articles, videos of flash floods seen on television, and documentaries about historical or potential floods that convey "how serious this issue could be in Boulder" (Interviewee #16). More public interviewees than professionals mentioned signs in at-risk areas, including signs advising people to "climb to safety in case of flash flood" placed in canyons along the Colorado Front Range[(49)] *(pub. 65%, pro. 25%)*.

Describing the value of this form of education, Interviewee #10 said that "most people read [the signs] and go, oh okay, but I think it does tend to stick in the back of their mind. If all of the sudden water in that area starts rising pretty quickly they probably go, 'Oh, that's what that sign meant.'" Interviewees also mentioned learning about flash flood risks through information enclosed in utility bill mailings or a sculpture marker near Boulder Creek that shows "what the flood levels would be in different cases of a flood" (Interviewee #16). Although most interviewees focused primarily on education by others, a few discussed the importance of people taking personal responsibility by "educat[ing] themselves" (Interviewee #5).

4.4. "We All Saw Pictures of Katrina":[13] Flash Flood Experience and Use of Analogies

At the time of our interviews, none of the interviewees had experienced major flooding in Boulder. Some mentioned historical flood events *(pub. 65%, pro. 95%)*, including the Big Thompson flash flood of July 1976 *(pub. 31%, pro. 90%)* and the Fort Collins flash flood of July 1997 *(pub. 8%, pro. 50%P)* (Fig. 1). Others mentioned experiences of family or friends or, as described in Section 4.3, learning about flash flooding from media coverage or documentaries. However, only a few had directly experienced flash flooding, which has been shown in other research to influence people's perceptions.[15] Those few interviewees with direct experience tended to have more descriptive and nuanced ways of discussing some characteristics of the risk—such as the rapid onset of flash floods and the speed of water—consistent with previous research on the influence of direct hazard experience.[20,50] For example, Interviewee #12 recalled "how quickly it all happened, how unexpected it was and there really was no time to prepare, and when it was happening there wasn't a lot we could do"; Interviewee #25 remembered "rocks hurled against our legs that were being pushed by this water that was moving so fast."

When discussing flash floods, one-third of interviewees drew on analogies to other natural hazards—including other types of flooding, tornadoes, fires, and hurricanes. Analogies can help people make sense of risks they have not personally experienced or do not understand well.[43,51,52] Visschers *et al.*[43] describe how people associate unknown risks to risks that are more familiar based on personal experience, media coverage, and general knowledge. People rely on risk associations to estimate severity and consequences, assess tolerance, and suggest benefits and resolutions of unknown risks. However, as discussed by Bostrom,[51] associations or analogies can also be misleading and contribute to misconceptions or misunderstandings of risk exposure, effects, and mitigation. An interesting analogy to flash flooding that was made by four interviewees was the flooding associated with Hurricane Katrina, which devastated New Orleans and nearby areas in 2005, and received extensive media coverage. For example, Interviewee #7 said that people could reduce their own flash flood risks in Boulder by "keep[ing] a supply of sandbags around … I just know that from watching TV, obviously there was the Katrina incident, and so people were sandbagging everything to try to keep the water out as best they could." Given the rapid evolution and speed and force of water in a flash flood, this was not discussed by the professionals as a way to reduce flash flood risks, especially the risks to life.

Overall, we found that interviewees who described having some experience with flash flooding may have a better sense of some aspects of flash flood risks than those without any stated experience, a finding that is consistent with previous research.[15] Some interviewees who had seen flash flood media coverage or been exposed to information about flash flood risks through their workplace mentioned more of the concepts discussed by professionals or discussed some aspects of flash flood risks in greater depth. In the absence of experience with flash flooding and other exposure to directly relevant knowledge, people may try to fill gaps in their understanding by drawing on analogies to other hazards, which can in some cases lead to inaccurate understandings.

5. DISCUSSION

Interviewees varied significantly in the extent and depth of their knowledge about flash flood risks overall (Fig. 3) and within sections of the FFW model (Fig. 2). As expected, most public interviewees understood flash flood risks in a more general way than most professionals, who tended to have more detailed mental models and to use more specialized language and concepts in their areas of expertise. Across the components of the FFW model that are most relevant for public decision making (that is, how, when,

[13] Interviewee #8.

and where flash floods can occur, the associated risks, and what protective actions can increase safety), a few interviewees had fairly complete mental models. These interviewees mentioned most of the key concepts identified by professionals in Morss *et al.*[4] and some of the more specific concepts. Most of the public interviewees, however, mentioned some key concepts but not others, and also exhibited imprecise or unclear understandings for some of the concepts they discussed. Some of these gaps—such as being unaware of the risk of flash floods in late summer—likely reduce people's capacity to effectively manage flash flood risks. Members of the public surveyed in southwest Virginia in a previous study did not typically have enough understanding of flash flood risks to make protective decisions.[15] The findings reported in this article are consistent, yet provide more nuanced insights into flash flood mental models.

Inaccurate or incomplete causal models of flash flooding can contribute to inaccurate or vague understandings of flash flood risks (Section 4.1). All interviewees recognized that rain and terrain contribute to flash flood development and exposure in Boulder, but many thought that spring snowmelt runoff was also more important than it usually is. Although antecedent moisture can play a role in flash flooding, many interviewees discussed it as necessary and thus did not recognize the significant risks of flash flooding associated with late summer thunderstorms. People do not need to understand the full set of concepts and interactions in the FFW model in detail in order to take effective protective action.[53] However, if people do not understand, for example, that heavy rain from a summer thunderstorm in the foothills can be channeled and accelerate down canyons into the town of Boulder below, even when creeks are dry and there is no rain in Boulder itself, then they may be less inclined to attend to weather forecast information and environmental cues when important, and slower to recognize and respond to such a threat.

In the United States and some other countries, the majority of people who die in flash floods or experience life-threatening situations are caught in flash flood waters on foot or in a vehicle, often because they enter the water or engage in other risky behaviors.[3,6,7,16,54] Thus, it is important for people to understand that the rapidly rising, fast-flowing, debris-filled nature of flash flood waters poses immediate risks to people and cars in and near the water (including on roads). Otherwise, people may believe that they can outrun, outswim, or outdrive the floodwaters; they may not know to avoid risky areas when flash flooding is a threat and to find safer ground immediately if directly endangered. For example, Interviewee #17, who discussed boating or swimming out of a flash flood (Section 4.3), did not mention (and appears not to have understood), the speed or force of flash flood waters or water-borne debris. Importantly, of the 31% of interviewees that did not mention how quickly flash floods happen (Section 4.1.1), none mentioned the concept of people responding quickly.

When asked how individuals can reduce risks of flash flooding, some interviewees who had misunderstandings about these aspects of flash flooding focused on longer-term or property mitigation activities, with little discussion of flash flood warnings or short-term activities to protect human safety. This suggests that people who have critical gaps in knowledge about flash flood risks may have difficulty evaluating specific flash flood threats and taking appropriate actions, especially in the limited time they may have available. Although most interviewees discussed the importance of knowing what to do when a flash flood occurs, many had only a general conception of what one actually should do, and some held misconceptions (Sections 4.3, 4.4). In addition, few exhibited an understanding of the spatially localized, uncertain nature of flash flood risks and the associated importance of evaluating the situational context in order to make safe decisions. Further, most interviewees had only a basic understanding of who provides warning-related information and how it can be accessed. These incomplete understandings may limit people's abilities to obtain and interpret information and make appropriate protective decisions quickly when a flash flood threatens.

Some concepts relating to flash flood development and exposure were mentioned more frequently or discussed in different ways by the public interviewees than by the professionals. For example, interviewees' discussions of climate change and pollution (Section 4.1) indicate that some members of the public may make or emphasize conceptual connections between environmental phenomena that differ from those made by professionals.[12,55] Such differences in causal beliefs about hazards can correspond to important differences in perceptions of risks and the effectiveness of responses to them.[56,57]

6. RECOMMENDATIONS

The findings lead to several recommendations for improved communication about flash flood risks that target what people need to know to make protective decisions and that convey information in ways that respect what people already know about a risk[41,58] as well as at an appropriate level of detail.[15] Because people engage in location- and time-specific activities, their willingness and ability to adjust their behavior depends on event timing and location, as well as other contextual factors.[48] This underscores the importance of flash flood communications that relate to people's existing mental models and their situational contexts in order to motivate appropriate behavioral responses when needed.

In Boulder, our analysis indicates that it is important to communicate that: (1) flash floods are rapid-onset and require quick response, so that people know immediately what a *flash* flood warning means; (2) rapidly moving and debris-laden water can sweep away people and cars; (3) areas along creeks and streams, especially at the base of canyons, are particularly risky; and (4) summer thunderstorms can produce flash flooding, even when creeks and soils are dry and the storms are not directly overhead. In addition, it is important to improve people's understanding of what to do in a flash flood situation given the characteristics listed above. This includes providing "rules of thumb" such as advice to climb to safety, avoid driving into risky areas, and take action immediately. It also involves conveying the value of knowledge, planning, and situational awareness—including how to recognize environmental cues and obtain warning-related information—to aid decision making in a complex, rapidly evolving flash flood event. While these recommendations are based on our study of Boulder, other studies suggest that they are also relevant for flash flooding in other regions.[15–17,20,48]

To address key gaps in public understandings about flash flood risks and protective responses, both long- and short-term communication, utilizing multiple mechanisms, is needed. Previous research in other contexts corroborates that people may monitor flood situations but be unaware of how to find more information about warnings, the risks posed by an event, and actions to take depending on the situation.[15,17] Long-term strategies such as awareness campaigns on television and in utilities bills can explain the components of flash flood risks that our study reveals are often misunderstood in order to help people have sufficiently accurate, complete mental models to draw from when a flash flood threatens. Carefully developed forecast and warning content that includes information about situational awareness and protective actions (such as noted in the previous paragraph) can try to address any remaining misconceptions through the warning communication process, and also serve a longer-term educational role for those who hear the warning but are not directly threatened. The fact that many interviewees mentioned signs in at-risk areas and media coverage suggests that these have already successfully served as important sources of knowledge about flash flood risks and warning decisions.

The insights and recommendations above were developed based on data gathered about flash flood risk communication in Boulder. However, they are derived from findings that are relevant to other hazards and contexts. First, people who have little experience with a hazard may not understand the specific hazard characteristics that carry the potential to cause harm (such as rapid development and fast-flowing water in the case of flash flood risks). Second, while people may understand that it is important to know what to do when the hazard threatens, the best protective decisions may be less clear, especially if the risks are not well understood. Third, people may not know how to access information to learn more about a hazard in general or when an event is unfolding. Not only does this lack of awareness increase their risk, but it may also put the agencies and organizations producing the information at risk if voters and taxpayers do not realize the source of these services.

At the time of our data collection, many interviewees did not have experience with flash floods. The September 2013 flooding has likely contributed to revised understandings about flood and flash flood risks for many in the Boulder area. The 2013 event is not representative of the full range of flash flood risks in Boulder, however, and many did not directly experience the flash flood characteristics of the larger flooding event. Given that our analysis shows the importance of experience, analogies, and media coverage for informing people's understandings of flash flood risks (Sections 4.3, 4.4), a further recommendation is to address incomplete and inaccurate understandings by using images and stories of the September 2013 event to illustrate flash flooding characteristics, impacts, and decision making.[50,59,60] A recommendation for future research with members of the Boulder public is to examine the influence of the September 2013 flooding on people's mental models, for example, to diagnose how individuals' different experiences of the event affect patterns of knowledge, including any remaining gaps or misconceptions about flash flood risks.

The recommendations offered in the preceding paragraphs all reflect our findings about what people need to know, but may not know, in order to be aware of, recognize, and respond to flash flood (and other) risks. In this way, we hope to promote more collaborative forms of risk communication and education by taking into account what people already understand and believe. By starting from how people already conceive of risks, we can begin to make suggestions for communication and education practices that are more responsive to, and respectful of, existing knowledge and promote joint responsibility for safety. In addition, some members of the public emphasized conceptual connections and perspectives that were rarely mentioned or not present in the professionals' interviews. A few concepts were mentioned more often by public interviewees than by the professionals or discussed in different ways. Thus, we also recommend that complementary understandings of the causal structure of hazards are important for professionals to consider when forecasting, communicating, and managing hazard risks.

7. CONCLUSION

Flash floods, like other extreme weather events, threaten communities around the world. An important component of flash flood risk management is warning communication and response. To help improve outcomes when flash flooding occurs, this article uses a mental models approach to examine how members of the public in Boulder, Colorado conceive of flash flood risks and risk management, with a focus on warning decisions. The analysis includes comparison with the in-depth analysis of warning system professionals' perspectives presented in Morss *et al.*[4] Although mental models approaches for risk communication have most commonly been used to examine longer-term risk management decisions,[19] this study demonstrates how a mental models methodology can also be used to examine warning decision making for rapid-onset hazards.

Based on the analysis, we recommend improvements to flash flood risk communication—over the longer term and when an event threatens—that both address important gaps in people's knowledge and are likely to be useful to people given their existing mental models. Conducted prior to the September 2013 flooding, the interviews provide insights that will be helpful for reducing future vulnerability to flash floods and provide a baseline for future assessments of flash flood risk perceptions and knowledge in Boulder. Some themes of our results are consistent with studies of flash flood risk communication, perception, and decision making in other regions,[15–17, 20, 48] indicating the relevance of our findings beyond the community that we studied.

Advances in scientific observation, prediction, and warning system technology continue to improve our ability to forecast and prepare for weather-related events. However, as people living in and around Boulder, Colorado experienced firsthand in September 2013, flash flood development, impacts, and protective decision making are highly complex and uncertain.[4,33] Thus, for extreme weather events such as flash floods, it is also important for people to be able to understand forecast and warning information, recognize extreme weather risks when they arise, and make informed response decisions. Educational efforts and warning content that build on what people already know to address important misconceptions or incomplete understandings about extreme weather risks can equip people with the ability to interpret incoming information, monitor the situation, and make the best protective decisions possible when needed.

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