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How do people perceive, understand, and anticipate responding to flash flood risks and warnings? Results from a public survey in Boulder, Colorado, USA

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SUMMARY

This study investigates flash flood forecast and warning communication, interpretation, and decision making, using data from a survey of 418 members of the public in Boulder, Colorado, USA. Respondents to the public survey varied in their perceptions and understandings of flash flood risks in Boulder, and some had misconceptions about flash flood risks, such as the safety of crossing fast-flowing water. About 6% of respondents indicated consistent reversals of US watch-warning alert terminology. However, more in-depth analysis illustrates the multi-dimensional, situationally dependent meanings of flash flood alerts, as well as the importance of evaluating interpretation and use of warning information along with alert terminology. Some public respondents estimated low likelihoods of flash flooding given a flash flood warning; these were associated with lower anticipated likelihood of taking protective action given a warning. Protective action intentions were also lower among respondents who had less trust in flash flood warnings, those who had not made prior preparations for flash flooding, and those who believed themselves to be safer from flash flooding. Additional analysis, using open-ended survey questions about responses to warnings, elucidates the complex, contextual nature of protective decision making during flash flood threats. These findings suggest that warnings can play an important role not only by notifying people that there is a threat and helping motivate people to take protective action, but also by helping people evaluate what actions to take given their situation.

1. Introduction

Over the last few decades, flash flood detection, forecasting, and warning capabilities have improved dramatically. Yet flash floods are still one of the most deadly weather-related hazards (French et al., 1983; Jonkman and Vrijling, 2008). In the US, Europe, and Australia, a large portion of flash flood deaths occur when people enter or are swept into floodwaters, either in a vehicle or on foot, in part because they are unaware of or misjudge the risks (Gruntfest et al., 1978; Jonkman and Kelman, 2005; Ruin et al., 2007; Ashley and Ashley, 2008; Haynes et al., 2009; Kellar and Schmidlin, 2012; Diakakis and Deligiannakis, 2013; Sharif et al., 2015; Becker et al., 2015). Thus, it is important not only to issue timely flash flood forecasts and warnings, but also to understand how people perceive flash flood risks and what influences their responses to warning information. This knowledge can then be used to develop evidence-based recommendations for improving communication about flash flood risks in ways that help people understand when, where, and how they are at risk and how to protect themselves when needed.

Although a number of studies have examined public risk perceptions and protective decisions for other hydrometeorological hazards, such as hurricanes and slower-onset floods (e.g., Dash and Gladwin, 2007; Lazo et al., 2015; Huang et al., in press; Bubeck et al., 2012; Kellens et al., 2013; Sherman-Morris, 2013), few studies have investigated these issues for flash floods (Gruntfest et al., 2002; Knocke and Kolivras, 2007; Wagner, 2007; Benight et al., 2007; Drobot et al., 2007; Ruin et al., 2007, 2008, 2014; Coles, 2008; League, 2009; Lazrus et al., in press). Flash floods evolve rapidly, often with significant variability and uncertainty in local conditions and impacts, and thus present distinct challenges for communicating and responding to threats. To help address these challenges, this study investigates people's perceptions,

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understandings, and interpretations of flash flood risks and alerts[1] and their anticipated responses to flash flood warnings. The analysis focuses on members of the public in the US, utilizing data from a survey of 418 residents of Boulder, Colorado, conducted in 2010.

The article examines four research questions: (1) How do members of the Boulder public perceive and understand flash flood risks? (2) How do they perceive and interpret flash flood warnings and other alerts? (3) How do they anticipate responding to flash flood alerts? (4) What influences their anticipated responses? This includes investigating people's knowledge, attitudes, and beliefs about flash flood risks and alerts and their anticipated decisions when a flash flood threatens. For time-sensitive hazards such as flash floods, people's interpretations and decision processes during a real threat are complex and difficult to measure, especially among people at high risk. By examining people's anticipated interpretations and behavior in hypothetical contexts, this study seeks to develop knowledge that can help researchers and practitioners interpret what people think and do during more complicated real-world flash flood situations.

The study area, Boulder, Colorado, is a community of approximately 100,000 people at the base of the foothills of the US Rocky Mountains, and more than 30,000 students are enrolled annually at the University of Colorado Boulder. To sample this population, members of the research team recruited survey respondents by mail, supplemented by convenience recruitment of students on the university campus. Flash flooding is a risk in the study region, and Boulder and nearby foothills and canyons experienced devastating and deadly flash flooding in September 2013. However, at the time of the survey, severe, widespread flooding had not occurred in Boulder in several decades (City of Boulder, 2012). Thus, the study examines a population with little or no direct local experience with flash flooding.

The article makes several novel contributions to the literature on public perceptions of and responses to flash flood (and other) risks. First, we examine respondents' perceptions and interpretations of flash flood risks and alerts in greater depth than previous studies and from new perspectives. For example, we build on previous work examining whether people can correctly differentiate the NWS alert terminology "watch" and "warning" by investigating people's understandings and interpretations of the alerts more broadly, using data from multiple survey questions. This includes utilizing new measures, such as perceived likelihood of flash flooding given a warning, that we anticipate may be related to how people respond to warnings. In addition, we aim to better understand how different aspects of people's flash-flood-related perceptions and interpretations influence their responses to flash flood warnings by quantitatively examining these relationships, using regression analysis. To help contextualize and interpret results from the quantitative analyses, we incorporate analysis of data from open-ended questions on flash flood warning decision making.

Another contribution of this research is that it was conducted as part of a larger, multi-method study, which included research using a mental models approach (e.g., Morgan et al., 2002) to examine how Boulder-area professionals and members of the public conceive of and make decisions about flash flood risks (Morss et al., 2015; Lazrus et al., in press). This related work found that some members of the Boulder public have misconceptions or incomplete understandings about several aspects of flash flood risks and risk reduction, which may influence their ability to avoid life-threatening situations when a flash flood threatens. The analysis presented here builds on this mental models research, first, by examining the extent to which some of these types of misconceptions are present in the larger public survey sample, and second, by using regression analysis to quantitatively examine whether such misconceptions are associated with differences in anticipated responses to flash flood warnings. Further, as part of the larger study, a similar questionnaire to that examined here was implemented with 20 Boulder-area professionals with job responsibilities related to the Boulder-area flash flood warning system, including US National Weather Service (NWS) forecasters, local emergency managers and other public officials, and television and radio broadcasters (Morss et al., 2015). This allows us to compare, for some of the survey questions, public perceptions and interpretations with those of flash flood warning professionals.

Section 2 describes the study methodology, including the survey design, implementation, and data analysis. Sections 3 and 4 discuss how respondents perceive and understand flash flood risks and flash flood forecasts and alerts (including NWS watches and warnings). Section 5 examines whether and how respondents anticipate acting given a flash flood warning and how this varies with some of the factors discussed in Sections 3 and 4. Section 6 summarizes key results and discusses potential implications for improving flash flood alerts and risk communication.

2. Methodology

2.1. Survey questionnaire development

The survey questionnaire was initially developed as part of the flash flood mental models studies discussed in Morss et al. (2015) and Lazrus et al. (in press). The 20 Boulder-area professionals and 26 Boulder residents who participated in those studies were each asked to fill out a paper version of the questionnaire towards the end of their mental models interviews. In late fall–early winter 2009, the questionnaire was revised for a larger-scale public survey based on this initial implementation as well as ideas from members of the research team and collaborators.[2] Revisions included modifications to existing questions as well as development of several new questions.

The revised version of the questionnaire was pretested in person in January 2010 with five Boulder residents, using one-on-one interviews in which the participants were asked to think aloud while reading and responding to the survey (Ericsson and Simon, 1993). The findings from the pretest were used to revise and finalize the survey questionnaire.

2.2. Survey data collection and respondents

The survey data used in this article were collected using two sampling strategies: mailings to residents of Boulder zip codes (referred to as the "mail sample") and distribution to students on the University of Colorado Boulder campus ("university sample").

For the mail sample, surveys were mailed to 1000 addresses randomly sampled from Boulder zip codes, provided by a survey sampling company. Of the 1000, 750 were sent following Dillman's (2000) recommendations, with multiple mailings, using incentives ranging from none to $5; the remaining 250 were sent in a single mailing with no incentive. All of the mail surveys were sent with a stamped and addressed return envelope. Of the

[1] In this article, we use the term "alerts" to encompass multiple types of forecast and warning communications, including (but not limited to) the flash flood "watch" and "warning" products issued by the US National Weather Service (NWS). The NWS watch and warning products are discussed further in Section 4.1.

[2] The survey data used in this article were gathered as part of a Senior Capstone project conducted by Kelsey Mulder and Curtis McDonald at the University of Oklahoma, under the mentorship of Jeffrey Lazo; Randy Peppler (Cooperative Institute for Mesoscale Meteorological Studies); and Kimberly Klockow and Gina Eosco (University of Oklahoma). Additional contributors to the survey design include the other co-authors of this article; Ann Bostrom and Rebecca Hudson (University of Washington); and Emily Laidlaw (National Center for Atmospheric Research).

Table 1
Summary of response rates and numbers of respondents for the mail, university, and full public (mail plus university) samples, and for the geolocated, student, and non-student subsamples.

	Mail sample	University sample	Public sample
Distributed	1000	200	1200
Invalid address	130	Not applicable	130
Valid (= distributed – invalid)	870	200	1070
Returned completed	408	43	451
Response rate (= completed/valid)	47%	22%	42%
Reported zip code missing or not in study area	20	13	33
Sample for analysis (= completed – zip code not in study area)	388	30	418
Reported zip code in study area but does not match survey mailing address	16	Not applicable	16
Geolocated subsample (= sample for analysis – zip code does not match)	372	0	372
Student subsample	23	30	53
Non-student subsample (= sample for analysis – student subsample)	365	0	365

mailings sent to valid addresses (Table 1), 408 completed surveys were returned, a response rate of 47%.[3]

Students at the University of Colorado Boulder are potentially at risk from flash flooding, and they (and young adults in general) may perceive risks and interpret and respond to weather alerts differently than non-students (e.g., Gruntfest et al., 2002; Knocke and Kolivras, 2007; Sherman-Morris, 2010; Lovekamp and McMahon, 2011). However, because students tend to be more transient, they were expected to be underrepresented in the mail survey. Thus, the mail sample was supplemented with a convenience sample of 200 surveys personally distributed by researchers to students walking on the university campus (Table 1). Forty-three of these surveys were returned completed, a response rate of 22%.

When asked for their home zip code, a portion of respondents either did not provide a zip code or reported a zip code outside of Boulder (Table 1). Since these respondents were not confirmed residents of Boulder zip codes, they were not included in the data set used in this article. Thus, the mail sample analyzed here contains 388 respondents, the university sample contains 30 respondents, and the full "public sample" (mail plus university) contains 418 respondents (Table 1).

Addresses were not available for the university sample, so these 30 respondents could not be geolocated. Based on their reported zip code, the correct addresses for 16 respondents in the mail sample could not be confirmed, and so their locations were not used (Table 1). Residence locations for the remaining 372 respondents in the mail sample (the "geolocated subsample") were geolocated as described in Mulder (2012) and are shown in Fig. 1.

Table 2 shows sociodemographic characteristics of the full Boulder public sample compared to estimates for the City of Boulder population in 2010. The survey sample contains a higher percentage of people who are older, own their residence, have more formal education, have higher incomes, and speak English as their primary language. Many of these differences are likely associated with the under-sampling of University of Colorado Boulder students and other more transient groups that are more difficult to access with a mail survey. Although there were 23 mail sample respondents who reported being university students, the majority of the 53 students in the full survey sample came from the university convenience sample (Table 1).[4]

2.3. Data analysis

Data entry for the public survey was performed by a professional research company and quality controlled by a member of the research team. For the 372 respondents in the geolocated subsample, ArcGIS was used to determine the respondents' residence locations relative to the 100-year and 500-year designated floodplains (Fig. 1; Mulder, 2012). Results from additional geospatial analysis can be found in Mulder (2012).

For quantitative analysis of data from the closed-ended questions, we coded categorical responses onto numerical scales, if one was not provided on the survey (e.g., questions with 5 response options ranging from "Not at all likely" to "Extremely likely" were coded onto a 1-to-5 scale). Where possible, "Other" responses to closed-ended questions were recoded into one of the closed-ended responses, based on the open-ended response provided. For the open-ended questions, we analyzed the data qualitatively by developing categories inductively based on the data, then coding the responses into those categories (e.g., Miles and Huberman, 1994).

We then calculated summary statistics for the quantitative data, as well as additional statistical analyses to examine variations and associations across the data set. The quantitative analysis included multiple linear regressions[5] with stated likelihood of taking protective action given a warning as the dependent variable, and different hypothesized predictors as independent variables. For the regression analyses, missing values for the independent variables were replaced by the median response for that variable.

Unless otherwise noted, all results presented and discussed are for the Boulder public sample (mail plus university). Because some respondents did not provide responses for some of the questions, the number of respondents (N) varies by question (or question item). For some of the survey questions, we also compared data from the public sample with data from the Boulder-area professionals studied in Morss et al. (2015); due to the small number of professionals, we did not perform statistical comparisons across these samples. The wording of each survey question examined in the article is provided in the relevant table or figure or, if the data is not presented in a table or figure, in a footnote in the main text.

3. Perceptions and understandings of flash flood risks

In this section, we examine how respondents perceive and understand flash flood risks, based on data from the survey. These findings are of interest because they describe potentially important

[3] For surveys mailed using the non-Dillman method, the response rate was 27%. For those mailed using the Dillman method with no incentive, the response rate was 36%. For those mailed using the Dillman method with an incentive, the response rate varied between 53% and 66%, depending on the incentive ($1, $2, or $5). Further details on the mail survey and response rates, are available in Mulder (2012) or from the authors.

[4] Survey question H10a: "Are you a student at the University of Colorado?" [Response options: Yes, No] ($N = 363$). All 30 respondents in the university sample responded Yes. Non-respondents were coded as No.

[5] Results are shown for an ordinary least squares regression. Because the dependent variable is ordinal, we also performed the same analysis using an ordered probit regression, and the substantive results are the same as those shown.

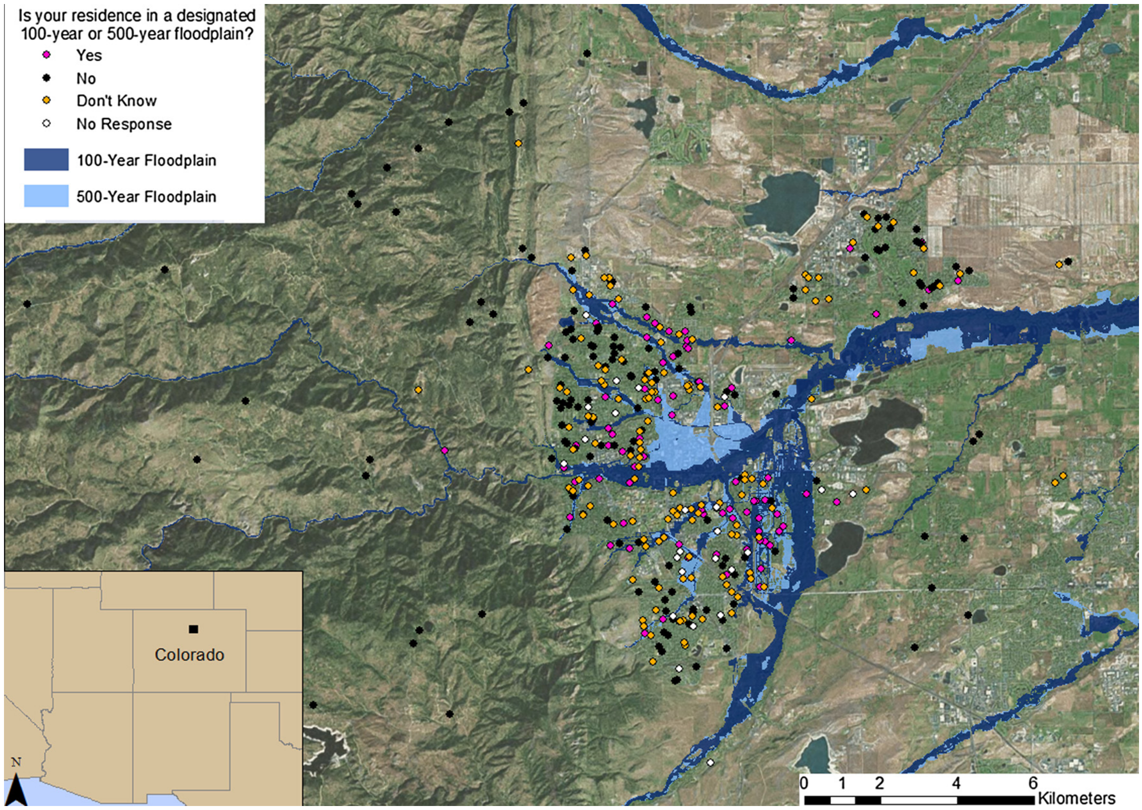

Fig. 1. Residence locations for respondents in the geolocated subsample ($N = 372$), overlaid on a map of the Boulder-area landscape and the designated Boulder County 100-year (light blue) and 500-year (dark blue) floodplains. The large floodplain that runs from west to east near the center of Boulder is along Boulder Creek (which has a drainage area of approximately 1160 km^2). In the geolocated subsample, 21 respondents (6%) lived in the 100-year floodplain, 15 (4%) lived in the 500-year floodplain, and 336 (90%) lived outside the designated 100- or 500-year floodplain. The symbol color depicts the respondents' perceived location, as indicated in the legend; summary statistics are provided in Table 4.

Table 2
Sociodemographic characteristics of the Boulder public sample (excluding missing data) and of the City of Boulder, Colorado, USA (estimated based on 2010 Census data, unless otherwise noted; US Census Bureau, 2010; Mulder, 2012).

Sociodemographic characteristic	Boulder public sample ($N = 418$)	City of Boulder (population 97,385)
Age (median)	50 years	30–34 years
Gender (% male)	53%	51%
Race (% white)	92%	88%
Residence ownership	73%	48%[a]
Length of residence in Boulder (median)	17 years	–
Education (% Bachelor's degree or higher)	81%	69%[b]
Annual pre-tax household income (median)	$60,000 to $74,999	$51,779
Primary language (% English-speaking)	97%	86%[c]
Student at University of Colorado Boulder	14%	21%[d]

[a] Percentage of housing units that are owner occupied.
[b] For those age 25 or older. In the public sample, 85% of those age 25 or older have a Bachelor's degree or higher education.
[c] Percentage of those age 5 or older who sometimes or always speak a language other than English at home.
[d] Estimated based on enrollment of 28,572 students at University of Colorado Boulder in the spring 2010 semester (University of Colorado Boulder, 2010), of whom an estimated 71% live in Boulder (on- or off-campus; Boulder Economic Council, 2011), compared to Boulder's 2010 Census population.

aspects of Boulder residents' attitudes towards and beliefs about flash flood risks, which interact with interpretations of flash flood alerts and their protective decisions.

3.1. Previous flash flood experience and preparations

A number of previous studies have found that people's previous experiences with a hazard (such as flooding) can influence their perceptions of the hazard as well as their protective decisions (e.g., Wagner, 2007; Siegrist and Gutscher, 2006; Knocke and Kolivras, 2007; Lin et al., 2008; Kellens et al., 2013; Wachinger et al., 2013; Demuth, 2015; Lazrus et al., in press; Morss et al., in press). In this sample, 57% of respondents indicated that they had no experience with flash flooding[6] ($N = 381$).[7] Ten percent mentioned direct personal experience with a significant flash flood event as it occurred (most of these experiences were outside the Colorado

[6] Survey question H1: "What previous experience, if any, do you have with flash flooding?" [Open-ended response].
[7] N indicates the number of respondents for the relevant survey question, excluding missing responses and, unless otherwise noted, "Other" and "Don't know" responses.

Table 3
Respondents' perceptions of whether their residence was located in a designated (100-year or 500-year) floodplain, comparing students and non-students in the full public sample. $N = 394$ (excluding missing responses). Percentages in the table are calculated based on the values in each row.

	Perceived location[a]			Total
	In floodplain	Not in floodplain	Don't know	
Student at university	7 (13%)	7 (13%)	38 (73%)	52 (100%)
Non-student	73 (21%)	152 (44%)	117 (34%)	342 (100%)
Total	80 (20%)	159 (40%)	155 (39%)	394 (100%)

[a] Survey question H9: "Is your residence in a designated 100-year or 500-year floodplain?" [Response options: "Yes, it is in a 100-year floodplain", "Yes, it is in a 500-year floodplain", "No, it is not in a 100-year or 500-year floodplain", "Don't know", "Other (please describe)"]. "Yes" responses were combined and "Other" responses were recoded based on the open-ended response provided.

Table 4
Respondents' perceptions of whether their residence was located in a designated (100-year or 500-year) floodplain, compared to their actual residence location, for the geolocated subsample. $N = 348$ (excluding missing responses). Percentages in the table are calculated based on the values in each row.

	Perceived location			Total
	In floodplain	Not in floodplain	Don't know	
Actual location: In floodplain	16 (48%)	6 (18%)	11 (33%)	33 (100%)
Actual location: Not in floodplain	56 (18%)	145 (46%)	114 (36%)	315 (100%)
Total	72 (21%)	151 (43%)	125 (36%)	348 (100%)

Front Range). The remainder (33%) discussed issues such as being aware of flooding (e.g., from the media), seeing impacts after a flood, hearing about flood experiences from family or friends, or experiencing a flash flood warning or threat. This limited personal experience with flash flooding is not surprising since flash flooding is rare in any one location and (at the time of the survey) major flooding had not occurred in Boulder in decades.

Taking preparatory action for a hazard can be an indication that people perceive the hazard as risky, and it can also facilitate protective action if the hazard threatens. To examine whether people had made any prior preparations for a potential flash flood, the survey asked respondents if they had engaged in five different preparatory activities.[8] Forty-one percent of respondents indicated that they had made at least one type of preparation for flash flooding ($N = 373$). The most common preparation was planning an evacuation route (23% of total), followed by making plans with household members (15%) and packing an emergency kit (14%). Fewer indicated having made changes to their home or property (10%) or making plans with non-household members (7%).

3.2. Perceptions and understandings of whether residence is located in a designated floodplain

As one measure of perceived exposure to flash flooding, the survey asked respondents whether their residence was in a designated floodplain. Table 3 shows results for perceived floodplain location for the full public sample, comparing the student and non-student subsamples. Overall, approximately 20% of respondents said they lived in a floodplain, and nearly 40% of respondents said they did not know. "Don't know" responses were especially prevalent among students (and among renters[9]). This suggests that university students in our sample tend to exhibit some differences in flood risk perceptions from non-students; this will be examined further in Section 5.2.

Table 4 and Fig. 1 compare perceived floodplain location with actual floodplain location for the geolocated respondents. Of the 33 geolocated respondents who actually lived in a designated 100-year or 500-year floodplain, only about half knew that they did. Of the 315 geolocated respondents who did not live in a floodplain, approximately one-fifth thought that they did.

As shown in Fig. 1, many of the 56 respondents who erroneously believed that they lived in a floodplain did not live near a designated floodplain or near a creek. Flooding – especially flash flooding in an urbanized area such as Boulder with multiple creeks and drainages – can and often does occur outside mapped floodplains (e.g., Highfield et al., 2013). However, most areas of Boulder had not experienced major flooding in decades (City of Boulder, 2012), and so most respondents' perceptions of floodplain locations (at the time of the survey) are not likely related to having seen flooding (or near-flooding) in these areas. Thus, it is not clear why many of these respondents thought that they lived in a designated floodplain. These perceptions could, however, influence people's responses to a flash flood threat.

3.3. Perceived likelihood of flash flooding and seriousness and controllability of flash flood impacts

As another measure of risk perception, the survey asked respondents to estimate the likelihood of flash flooding occurring in

[8] Survey question H2: "Which of the following, if any, have you done to prepare for a flash flood event? Planned an evacuation route; Packed an emergency kit; Made plans with family members who live within your residence; Made plans with family or friends who do not live in your residence; Made changes to my home or property to protect it from flash floods; Other preparations (please describe)" [Response options for each item: Yes, No, Not applicable]. The survey also asked about flood insurance, which is not included in the preparations examined in this article since insurance is not specific to flash flooding.

[9] Seventy-five percent of renters said that they did not know whether they lived in a floodplain, compared to 26% of residence owners.

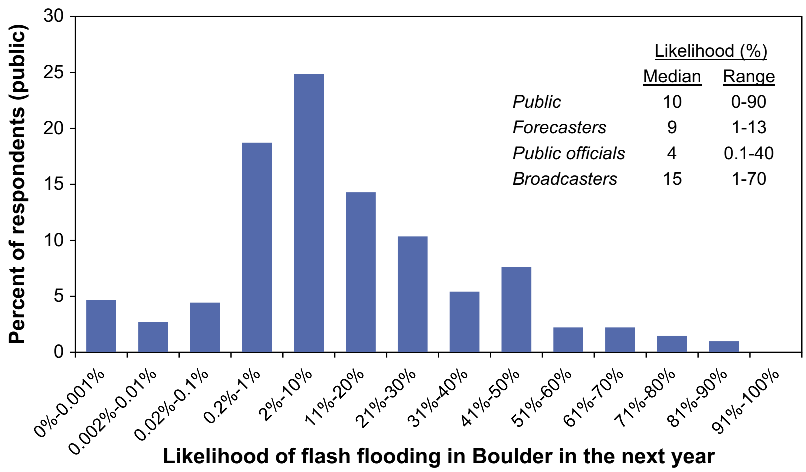

Fig. 2. Respondents' estimates of the likelihood of flash flooding in Boulder in the next year. The graph depicts results for the public sample ($N = 406$). The table in the upper right of the graph depicts the median and range of the estimates for the public sample and for the forecasters ($N = 6$), public officials ($N = 8$), and broadcasters ($N = 6$) sampled in the study of Boulder-area flash flood professionals (Morss et al., 2015). Survey question 4: "In the diagram below, please put an "X" on the line that describes your best estimate of how likely it is that flash flooding will occur in Boulder in the next year" (Respondents were given a diagram with a scale ranging from 0% to 100%, with a magnified section between 0% and 1% (Woloshin et al., 2000)).

Table 5
Perceived likelihood of different types of impacts if a flash flood occurs in Boulder,[a] for the public sample ($N = 384–406$) and for the professional sample [NWS forecasters ($N = 6$), public officials ($N = 8$), and broadcasters ($N = 6$)] from Morss et al. (2015). In the table, impacts are presented in decreasing order of likelihood for the public sample (not the order presented in the survey). "Economic losses or effects" was not included on the professional version of the questionnaire.

Type of impact	Public: mean (SD)	Forecasters: mean (SD)	Public officials: mean (SD)	Broadcasters: mean (SD)
Economic losses or effects	4.5 (0.8)	–	–	–
Disrupted transportation	4.4 (0.8)	4.0 (0.9)	5.0 (0.0)	4.8 (0.4)
Damage to buildings or other property	4.3 (0.8)	4.0 (0.6)	5.0 (0.0)	4.7 (0.5)
Ecological damage	4.2 (0.9)	4.2 (1.5)	5.0 (0.0)	4.8 (0.4)
Degraded water quality	4.0 (1.0)	3.7 (1.6)	5.0 (0.0)	4.0 (0.9)
People separated from loved ones or pets	3.8 (1.0)	3.8 (1.3)	5.0 (0.0)	3.8 (0.8)
People injured	3.7 (0.9)	3.3 (1.0)	5.0 (0.0)	3.7 (1.0)
People killed	3.0 (1.0)	2.7 (0.8)	4.6 (0.5)	2.7 (1.2)

[a] Survey question 8: "If a flash flood hit Boulder, how likely do you think each of the following impacts would be?" [Response options for each type of impact: Not at all likely, Not very likely, Somewhat likely, Very likely, Extremely likely (coded on a 1-to-5 scale), or Don't know]. The question also included an "Other impacts (please describe)" item, to which 50 respondents provided a rating or open-ended response.

Boulder during the next year. To elicit likelihood judgments (here and in Section 4.2), we used the "magnifier scale" that was developed by Woloshin et al. (2000). This scale was designed to facilitate elicitation of a wide range of numerical probabilistic estimates, including low probabilities (<1%). Woloshin et al. (2000) found that this scale has validity, reliability, and usability similar to or better than other commonly used scales, even among respondents with low numeracy. Nevertheless, it can be challenging for people to estimate probabilities associated with rare events such as flash floods, and responses can be influenced by the question framing and response format (e.g., Slovic, 2000; Fischhoff, 2012; Persoskie and Downs, 2015). Thus, we use the elicited likelihood estimates not as absolute judgments of risks, but as a way to explore differences in perceptions and interpretations among the surveyed members of the public and professionals (all of whom were asked to respond to the same question using the same scale).

As shown in Fig. 2, public respondents indicated a wide range of likelihoods of flash flooding in Boulder. The median values for the public's and professionals' estimates are similar. However, some members of the public indicated very low probabilities, in the 0–0.1% range – lower than all of the professionals. This suggests that some members of the public perceive Boulder as less susceptible to flash flooding than local flash flood professionals (see also Morss et al., 2015; Lazrus et al., in press).

Psychometric studies of risk have found that characteristics other than risk likelihood, such as controllability and seriousness of consequences, are important attributes of laypeople's judgments of risks (e.g., Fischhoff et al., 1978; Brun, 1992; Teigen et al., 1999; Kellens et al., 2013). Following this previous work, the survey asked respondents to rate these two aspects of risk perceptions for flash flooding (along with six other types of risks).[10] For seriousness of consequences, public respondents' mean rating was 4.4 (SD[11] = 1.5), near the midpoint (between minor injuries and mostly deaths). For controllability of impacts, their mean rating was 3.1 (SD = 1.8), suggesting that respondents felt on average that they had some, but not substantial, personal control over the impacts of flash flooding.

[10] Survey question 1: "For some hazards, the impact is minor (for example, minor injuries or illnesses). For other hazards, the most serious consequences are those that result in deaths. For each of the following hazards, if they occurred in the United States how serious are the consequences?" [Response options: Minor injuries/illnesses (1) to Mostly deaths (7), for each of the 7 hazards shown], and survey question 2: "How much personal control do people in the United States have over the impacts on themselves from each of the following hazards?" [Response options: Little personal control (1) to Much personal control (7), for each of the 7 hazards]. Results for flash flooding compared to the six other hazards, and for the public sample compared to the professionals, are shown in Fig. S1.

[11] SD = standard deviation.

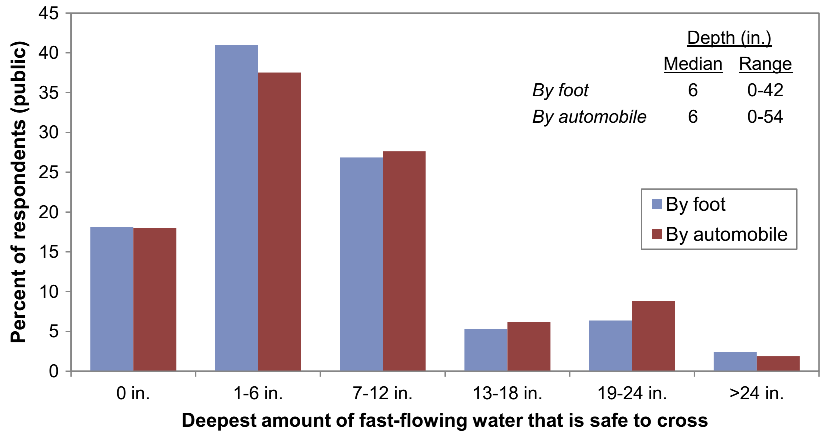

Fig. 3. Public respondents' perceptions of the depth of fast-flowing water that is safe to cross by foot or by car. Survey question 17: "The deepest amount of fast-flowing water that is safe to cross by foot is ______" ($N = 376$) and survey question 18: "The deepest amount of fast-flowing water that is safe to cross by automobile is ______" ($N = 373$) [Open-ended responses]. These questions were not asked on the professional version of the questionnaire.

3.4. Perceptions and understandings of the risks posed by flash flooding

To investigate perceptions of the risks posed by flash flooding in Boulder in greater detail, the survey asked respondents about the likelihood of eight types of potential impacts if a flash flood were to occur in Boulder. As shown in Table 5, on average public respondents rated economic losses, disrupted transportation, and building and property damage as the most likely impacts of flash flooding in Boulder. They rated people killed, on average, as the least likely of the eight impacts but still as somewhat likely (the scale mid-point). The public respondents' average ratings of likelihood of the impacts were similar to those of the forecaster and media professionals, but less than those of the public official professionals (who rated each of the eight types of impacts as very to extremely likely).

The most prominent drainage in Boulder is Boulder Creek, which travels down Boulder Canyon and then through downtown Boulder (Fig. 1), where a large number of people and buildings are located in the floodplain. Thus, Boulder Creek is often considered as the place of highest flood risk in Boulder due to the potential for significant loss of life and catastrophic impacts (Gruntfest et al., 2002; Stewart, 2006; City of Boulder, 2012; Morss et al., 2015). However, as demonstrated in the 2013 flood, multiple creeks and areas in Boulder are at risk for flash flooding (NWS, 2014b; Gochis et al., 2015; Morss et al., 2015). To explore perceptions of which locations in Boulder are at risk, the survey asked respondents how much they agreed that *only* areas in Boulder near Boulder Creek are at risk from flash flooding[12] ($N = 414$). Although 75% disagreed, 19% said that they strongly or somewhat agreed. This suggests that (at the time of the survey) some members of the Boulder public did not understand that areas further from Boulder Creek, including but not limited to areas along other creeks and drainages, are at also risk.

In the US, the majority of flash flood deaths in recent decades have occurred when people become trapped in or enter floodwaters, usually in a vehicle or on foot (Drobot et al., 2007; Ashley and Ashley, 2008). Previous research suggests that this may be because some people misunderstand the risks posed by flash-flood waters (Knocke and Kolivras, 2007; Drobot et al., 2007; Becker et al., 2015; Lazrus et al., in press). To investigate people's understandings of these risks, the survey asked respondents what depth of fast-flowing water was safe to cross by foot and by automobile, in separate questions (Fig. 3). Although estimates of what is "safe" vary, most US guidelines indicate that 6 in. (15 cm) or less of moving water is unsafe on foot; 24 in. (60 cm) of water can carry away most vehicles, and lesser depths (6–18 in.; 15–46 cm) can cause many vehicles to stall and float and thus are unsafe (NWS, 2015a; FEMA, 2015; City of Boulder, 2015). Approximately one-third of respondents provided conservative estimates, saying that little or no water (0–3 in.; 0–8 cm) was safe to cross by foot or car. However, 41% indicated that more than 6 inches (15 cm) of fast-flowing water was safe to cross on foot, and 17% indicated that more than 12 in. (30 cm) was safe to cross in a car. This suggests that, similar to previous findings in Boulder and other US communities (Gruntfest et al., 2002; Knocke and Kolivras, 2007; Drobot et al., 2007), a significant portion of the Boulder population misunderstands the risks of entering flash-flood waters on foot or in a car.

The above discussion examines respondents' perceptions of the risks posed by flash flooding to a person or in Boulder in general. Previous research indicates that people take protective action for a hazard when they feel that they or their family are personally at risk, or not safe (e.g., Mileti, 1995; Mileti and Sorensen, 1990; Riad et al., 1999; Whitehead et al., 2000; Dow and Cutter, 1998; Dash and Gladwin, 2007; Burnside et al., 2007; Morss and Hayden, 2010; Lindell and Perry, 2012; Brotzge and Donner, 2013; Lazo et al., 2015). As a more personalized measure of risk perception, the survey asked respondents' about their perceived personal safety from flash flooding[13] ($N = 403$). Only 18% of respondents selected "Neither agree nor disagree"; most either strongly or somewhat agreed (43%) or disagreed (39%) that they were safe from flash flooding.

3.5. Perceptions of factors contributing to flash flooding

As discussed in the introduction, Lazrus et al. (in press) found that some members of the Boulder public have misconceptions

[12] Survey question 12: "How much do you agree or disagree with the following statement? 'Only those on or near Boulder Creek are at risk from flash flooding in Boulder.' " [Response options: Strongly agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Strongly disagree (coded on a 1-to-5 scale), or Don't know].

[13] Survey question 19: "The following are statements some people tell us about not personally taking action in response to a flash flood warning. Please indicate the extent to which you agree or disagree with these statements. Check the box indicating your level of agreement for each statement. ... I believe I am safe from flash flooding." [Response options: Strongly disagree, Somewhat disagree, Neither agree nor disagree, Somewhat agree, Strongly agree (coded on a 1-to-5 scale), or Don't know].

Table 6
Perceived importance of different factors in contributing to flash flooding,[a] for the Boulder public sample (N = 394–404) and for the NWS forecasters (N = 6), public officials (N = 8), and broadcasters (N = 6). In the table, contributing factors are presented in decreasing order of importance for the public sample (not the order presented in the survey).

Contributing factor	Public: mean (SD)	Forecasters: mean (SD)	Public officials: mean (SD)	Broadcasters: mean (SD)
Elevation compared to stream or street level	4.5 (0.7)	4.5 (0.8)	4.4 (0.7)	4.5 (0.6)
Nearness to a creek, stream, or drainage ditch	4.5 (0.7)	4.2 (0.8)	4.9 (0.4)	4.7 (0.5)
Amount of rainfall during the last 24 h	4.5 (0.7)	3.7 (0.8)	3.9 (0.6)	4.5 (0.6)
Amount of rainfall during last hour	4.4 (0.8)	4.7 (0.5)	4.6 (0.5)	4.8 (0.4)
Nearness to a canyon	4.3 (0.8)	4.2 (1.0)	4.9 (0.4)	4.3 (1.2)
Burned land from past wildfires in area	3.9 (1.0)	4.2 (0.8)	4.3 (0.7)	4.7 (0.5)
Nearness to a dam	3.8 (1.1)	3.2 (1.0)	3.3 (0.9)	3.7 (1.0)
Nearness to a lake, pond, or detention basin	3.5 (1.0)	2.7 (0.5)	3.0 (0.5)	3.8 (1.2)

[a] Survey question 11: "The likelihood of flash flooding at a given location depends on several factors. How important do you think each of the following factors is in determining the likelihood of flash flooding at a given location?" [Response options for each factor: Not at all important, Not very important, Somewhat important, Very important, Extremely important (coded on a 1-to-5 scale), or Don't know]. The question also included an "Other factors (please describe)" item, to which 20 respondents provided a rating or open-ended response.

Table 7
Summary of respondents' descriptions of the difference between a flash flood watch and a flash flood warning (the two major types of flash flood alerts provided by the US NWS).[a] The left-hand column shows the major categories of responses, based on the qualitative analysis. For each category, the middle column shows the percent of public respondents coded into that category, and the right-hand column shows an example public response. Many of the responses were coded into more than one category, as illustrated by the examples. Description categories in italic text were mentioned by at least one of the 20 Boulder-area professionals in their responses to the same survey question. N = 386.

Category of description of watch/warning difference	% of public respondents	Example public response
Likelihood	56%	"Watch – flooding possible; warning – flooding likely"
Imminence	30%	"Warning is immediately, watch is the potential"
Occurrence	20%	"Warning: flash flooding already occurring upstream, watch: conditions favorable to flash flooding, but not occurring yet"
Environmental conditions	18%	"Warning-flash flood likely. Watch-conditions for flash flood present"
Actions required	13%	"Flood watch puts us on alert/standby, warning triggers flood action plan"
Seriousness	10%	"Warning means likely enough for great danger; watch is much less serious, but reason to keep tuned for potential warning"
Certainty	5%	"Watch = may be building but no confirmation. Warning = it's coming, and we are pretty certain"
Timing (including temporal coverage and lead time)	4%	"The warning precedes the watch? Or is it the other way? . . ."
Location (including spatial coverage and proximity)	2%	"A warning is specific as to time and locality – fairly high probability. A watch is general – next few hours, large area, moderate probability"
Accuracy	0.5%	"A warning is more accurate than a watch. A watch is less certain"
Other	2%	"I have never heard of a flash flood watch"

[a] Survey question 25: "What differences, if any, are there between a flash flood warning and a flash flood watch?" [Open-ended response].

or incomplete understandings of the factors contributing to flash flood risks. This was examined in the survey by asking respondents to rate the importance of eight different factors in determining the occurrence of flash flooding at a location. As shown in Table 6, on average public respondents rated elevation, nearness to a creek or canyon, and amount of rain in the last hour or 24 h as the most important contributing factors. These results are similar to those from the mental models interviews with members of the Boulder public discussed in Lazrus et al. (in press), in which elevation or terrain, creeks or streams, and rain were mentioned by all or nearly all interviewees.

For most of the contributing factors, the public's average ratings of importance were similar to the professionals' ratings. One potentially important difference is that the professionals (especially the forecasters and public officials) rated rainfall in the last 24 h as less important than rain in the last hour, whereas the public on average did not. All of the professionals rated 1-h rainfall as Very or Extremely Important in determining flash flooding, compared with 86% of the public respondents. This corroborates results from Lazrus et al. (in press) that (compared to professionals) some members of the Boulder public underestimate the rapid-onset nature of flash flooding and the importance of thunderstorm rains in contributing to flash flood risks, relative to the risks of snowmelt and rain from other types of storms (see also Knocke and Kolivras, 2007; Wagner, 2007).

4. Perceptions and interpretations of flash flood forecasts, warnings, and other alerts

In this section, we examine how respondents perceive and interpret flash flood forecasts and alerts. This includes respondents' understandings of NWS watch and warning alert terminology and their interpretations of what flash flood warnings mean, analyzed using data from several survey questions. It also includes respondents' trust in flash flood forecasts and warnings, their opinions about flash flood forecast and warning accuracy, and the relationship between them.

4.1. Interpretations of US National Weather Service "watch" and "warning" alerts

The US NWS currently issues two primary types of alerts for potential flash flooding (and other hazards): a *watch*, which indicates that there is an increased risk of a hazardous event in the

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THE NATIONAL WEATHER SERVICE IN DENVER HAS ISSUED A

* FLASH FLOOD WARNING FOR...
  CENTRAL AND EAST BOULDER COUNTY IN NORTHEAST COLORADO

* UNTIL 1145 PM MDT

* AT 927 PM MDT...NATIONAL WEATHER SERVICE DOPPLER RADAR INDICATED VERY HEAVY
RAIN FROM A THUNDERSTORM IN THE WESTERN PART OF BOULDER. THIS STORM WAS
MOVING EAST AT 5 MPH.

* LOCATIONS IN THE WARNING INCLUDE BUT ARE NOT LIMITED TO BOULDER.

THIS INCLUDES THE FOLLOWING STREAMS AND DRAINAGES... BOULDER CREEK, SKUNK
CREEK, BEAR CREEK, GOOSE CREEK, AND FOURMILE CANYON CREEK.

DOPPLER RADAR ESTIMATES THAT RAIN FROM THE STORM IS FALLING AT THE RATE OF 2
TO 3 INCHES IN 45 MINUTES.  ANOTHER 1 TO 2 INCHES OF RAIN CAN BE EXPECTED
BEFORE DIMINISHING.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

A FLASH FLOOD WARNING MEANS THAT FLOODING IS IMMINENT OR OCCURRING. IF YOU
ARE IN THE WARNING AREA MOVE TO HIGHER GROUND IMMEDIATELY. RESIDENTS LIVING
ALONG STREAMS AND CREEKS SHOULD TAKE IMMEDIATE PRECAUTIONS TO PROTECT LIFE
AND PROPERTY. DO NOT ATTEMPT TO CROSS SWIFTLY FLOWING WATERS OR WATERS OF
UNKNOWN DEPTH BY FOOT OR BY AUTOMOBILE. TURN AROUND...DO NOT DROWN.
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Fig. 4. Flash flood warning message provided in questionnaire, for survey question 27. The message was adapted from previously issued NWS warning products for the Boulder area.

area, and a *warning*, which indicates that a hazardous event is occurring, imminent, or highly probable in the area.[14] Previous studies have found that many or most, but not all, members of the US public understand these two terms (although specific results vary depending on the hazard, location, and question format; see, e.g., Legates and Biddle, 1999; Balluz et al., 2000; Gruntfest et al., 2002; Mitchem, 2003; Powell and O'Hair, 2008; Schultz et al., 2010; Sherman-Morris, 2010; Ripberger et al., 2015). The fact that some people confuse or otherwise misunderstand these two terms has raised concerns about watch/warning terminology in the US and helped motivate discussion in the US meteorological community about modifying NWS hazard messaging (e.g., Jacks et al., 2013; Horvitz et al., 2014; NWS, 2015c).

When asked to describe the difference (if any) between a flash flood watch and warning, 74% of respondents in this survey indicated a correct understanding of the difference between the two types of alerts (see Table 7 for question wording). Twelve percent reversed the definitions of the two terms.[15] A few respondents (1%) indicated that the two terms were the same, and 5% said that they did not know. The remainder (8%) of the responses could not be categorized (e.g., "One is less serious than the other"). Thus, when viewed from this perspective, our results are similar to those from past studies: most, but not all, respondents can correctly differentiate between a "watch" and a "warning".

To help build deeper understanding of people's interpretations of flash flood watches and warnings, we examined this issue from several additional perspectives. First, we examined the ways that respondents described the difference between the two types of alerts, shown in Table 7. This analysis indicates the multiple, overlapping ways that people can interpret watches and warnings. For example, some discussed the terms as conveying the likelihood of event occurrence, imminence of the event, or seriousness of the threat. Others discussed the terms with respect to the temporal or spatial aspects of the alerts or actions to take in response. Moreover, within these conceptualizations, public respondents discussed the meanings of "watch" and "warning" differently (for example, warning likelihood as "possible," "likely," "very likely," "extremely likely," "almost certain," or "happening"). Thus, even when people can correctly distinguish the two terms, they can have different interpretations, which may or may not correspond to the intended information content.

As shown in Table 7, each of these conceptualizations of the difference between "watch" and "warning" – except for certainty and accuracy – was also mentioned by one or more of the professionals. In other words, these different interpretations are also evident among the professionals who create and convey the alerts. This suggests that the alerts have multi-dimensional, situationally dependent meanings, among professionals as well as members of the public. Because these more complex underlying meanings are difficult to convey with a single word, additional information is often needed to interpret what a watch or warning means in a given situation.

To investigate respondents' relative understandings of a watch and warning in two additional ways, we compared: (1) each respondent's estimates of the likelihood of a flash flood occurring if a flash flood (a) watch or (b) warning is issued (discussed further in Section 4.2) and (2) each respondent's stated likelihood of taking protective action after receiving a flash flood (a) watch or (b) warning for their location (discussed further in Section 5.1). About half of the 12% of respondents who reversed the terms in the open-ended question also reversed them in both of these two comparisons, suggesting a consistent reversal in their understandings of the two terms. However, many of those who reversed the terms still indicated high likelihood of flash flooding and high likelihood of taking protective action given a warning. Together with Table 7,

[14] According to the US NWS glossary (NWS, 2015b): "A watch is used when the risk of a hazardous weather or hydrologic event has increased significantly, but its occurrence, location, and/or timing is still uncertain. It is intended to provide enough lead time so that those who need to set their plans in motion can do so." "A warning is issued when a hazardous weather or hydrologic event is occurring, is imminent, or has a very high probability of occurring. A warning is used for conditions posing a threat to life or property."

[15] Unlike Powell and O'Hair (2008), we did not find that many respondents were confused by thinking that the term "watch" meant visual confirmation of the hazard. Five respondents who reversed the definitions said (incorrectly) that a watch means a flood has been observed or spotted, but 14 of the respondents who correctly differentiated the terms said that a warning means a flood has been observed or spotted.

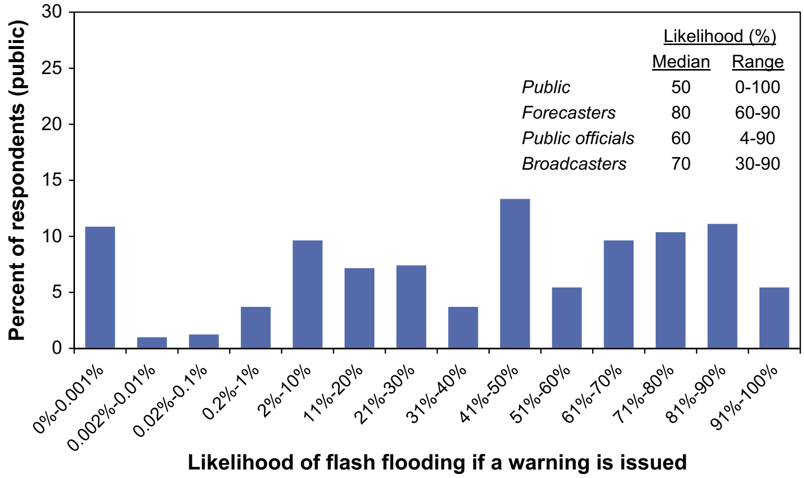

Fig. 5. Respondents' estimates of the likelihood of flash flooding in Boulder if a warning is issued for Boulder ($N = 405$). The graph depicts results for the public sample, and the table in the upper right depicts the median and range of the estimates for the public and professional samples, as in Fig. 2. Survey question 6: "If a flash flood warning is issued for Boulder, please put an "X" on the line that describes your best estimate of how likely it is that flash flooding will occur in Boulder in the next 24 h." [Respondents were given a diagram with a scale ranging from 0% to 100%, with a magnified section between 0% and 1%.]

these results illustrate the importance of investigating people's interpretations of watches and warnings in context as well as their definitions of the terminology.

When people receive alerts for real flash flood threats, the term watch or warning is usually accompanied by information that helps people evaluate the level of threat and appropriate action. To investigate how people understand and interpret warning *information* (rather than warning *terminology*), the survey included a question that asked respondents what they would do if they received the hypothetical NWS flash flood warning message shown in Fig. 4.[16] As discussed further in Section 5.1, when given a warning along with this informational context, nearly all respondents discussed either taking an action or evaluating the risk given their situation. This suggests that even if people misunderstand or are unclear about the meaning of the NWS term "warning" compared to "watch", most can still adjust their understandings when given warning information in context. In other words, while the phrase "flash flood warning" may be useful in triggering actions for professional users such as public officials, a warning is often most meaningful and useful to members of the public within its informational context. This is not surprising, since the term "warning" is used for purposes other than alerting people about imminent life-threatening weather-related events, and thus can have different meanings in different situations.

4.2. Perceptions of flash flood likelihood given a warning

Using the same magnifier scale discussed in Section 3.3, the survey asked respondents to estimate the likelihood of a flash flood occurring in Boulder in the next 24 h if a flash flood warning were issued in Boulder.[17] Results are shown in Fig. 5. NWS guidelines for the Boulder region indicate that forecasters are to issue a flash flood warning if there is "an 80% or greater chance of flooding that is expected to reach warning criteria" (NWS, 2014a, p. 3). Corresponding to this, NWS forecasters provided estimates within a small range around 80%. On average, public respondents' estimates of the likelihood of flash flooding given a warning were lower than the forecasters' (and other professionals') estimates. Moreover, a significant portion of public respondents indicated low likelihoods of flash flooding given a warning, suggesting that they have a different interpretation of the threat indicated by a flash flood warning than the forecasters and other professionals.

One might expect that these low estimates of flash flood likelihood in Boulder given a warning for Boulder are primarily associated with reversals of the watch-warning terminology. However, they are not: the mean estimate was 45% for public respondents who correctly differentiated the two terms in their open-ended responses in Section 4.1, compared with 49% for those who reversed the terms. This suggests that, whether they confuse watches with warnings or not, a significant portion of public respondents underestimated the level of risk that forecasters intend to convey when they issue a flash flood warning. Such interpretations may influence people's behavioral responses to warnings.

4.3. Trust in and perceived accuracy of flash flood forecasts and warnings

Previous research has shown that trust in information and information sources can be an important component of people's interpretations and use of information about risks, including floods and other weather-related hazards (e.g., Mileti, 1995; Mileti and Sorensen, 1990; Sherman-Morris, 2005; McComas, 2006; Parker et al., 2009; Morss, 2010; Lazrus et al., 2012; Lindell and Perry, 2012; Wachinger et al., 2013; Ripberger et al., 2015). When asked about their trust in flash flood forecasts and warnings,[18] respondents on average said that they trust the information somewhat or very much (mean = 3.6, SD = 0.7; $N = 404$, excluding missing responses but including "Don't Know" responses). No respondents selected "I don't trust them at all", and only 5% selected "Don't know".

As discussed in Ripberger et al. (2015), it seems likely that perceived trust in forecasts and warnings would be related to

[16] Survey question 27: "Say it was 9:30 PM, you were in Boulder, and you received the following message:" [See Fig. 4 for message] "Again, if it was 9:30PM and you were in Boulder, what would you do?" [Open-ended response] ($N = 392$). Flash flooding is most likely to occur in Boulder in the evening or night, and the 9:30 PM time was selected to reduce variation in what people would typically be doing when they received the warning (i.e., most would not be at work, commuting, or asleep).

[17] Respondents were also asked the same question for a flash flood watch; results are shown in Fig. S2.

[18] Survey question 23: "How much do you, or would you, trust flash flood forecasts and warnings?" [Response options: I don't trust them at all, I do not trust them very much, I trust them somewhat, I trust them very much, I trust them completely (coded on a 1-to-5 scale), or Don't know].

perceived accuracy. When asked about perceived accuracy of flash flood forecasts and warnings,[19] respondents on average said "somewhat accurate" (mean = 3.2, SD = 0.7; $N = 403$, excluding missing responses but including "Don't Know" responses). Only one respondent selected "Not at all accurate." However, 37% selected "Don't know", many more than in the trust question. This is likely because flash floods are sufficiently rare that many respondents felt that that they could not evaluate flash flood forecast and warning accuracy. For example, at the time of our study, the NWS had issued only 4 flash flood warnings and 12 flash flood watches for Boulder County in the previous 10 years.[20]

For those who responded to both questions, trust and perceived accuracy were significantly and positively correlated (Pearson's $r = 0.66$, $p < 0.001$). However, overall, those who said they did not know how accurate forecasts and warnings are had similar levels of trust (mean = 3.7, SD = 0.7) to those who did provide an estimate of accuracy (mean = 3.6, SD = 0.7). This suggests that although trust in forecasts and warnings can be related to perceptions of accuracy, they are different constructs, at least for some individuals (see also Demuth et al., 2011; Lazo et al., 2015). Further, these results indicate that members of the public can trust forecasts and warnings even if they have limited direct experience with them and do not know how accurate they are.

5. Protective decision making in response to flash flood warnings

Finally, we examine respondents' anticipated likelihood of taking protective action given a flash flood warning, followed by an analysis of which perceptions, understandings, and interpretations influence anticipated warning responses. We then use data from open-ended questions on the survey to explore how respondents discussed their choices of protective action and their decision processes, and what this means for protective decision making when a flash flood threatens.

5.1. Anticipated likelihood of taking action given a flash flood warning

The survey included several questions to examine anticipated responses to flash flood alerts, in closed-ended and open-ended formats. One of the closed-ended questions asked respondents how likely they were to take protective action if they received a flash flood warning for their location.[21] As shown in Fig. 6, nearly three quarters (72%) of respondents said that they were very or extremely likely to take action if they received a warning.[22]

Another survey question provided a hypothetical NWS flash flood warning message for Boulder, which would be disseminated to the public (often verbatim) via NOAA Weather Radio, television, radio, and internet when a warning was issued. Respondents were then asked (in an open-ended format) what they would do if they received this message (see Fig. 4 and Section 4.1). In their response, 87% of respondents discussed engaging in some sort of protective activity, such as moving to a higher or different location, avoiding risky areas, seeking more information, assessing the situation or staying alert, making preparations, or notifying others. Most of the remaining respondents (13%) said they would stay home or do nothing, usually because they did not believe their home was at risk and/or they were trying to avoid risky areas. Only a few said that they did not know what they would do or suggested that the warning would not change their activities at all. Thus, if they received flash flood warning information, most respondents anticipated, at minimum, assessing their risk and deciding what (if anything) to do.

5.2. Factors explaining anticipated likelihood of taking action given a flash flood warning

To explore how individuals' flash flood warning responses relate to their perceptions, understandings, and interpretations, next we investigate the variations in Fig. 6 in greater depth using regression analysis. The dependent variable is individuals' anticipated likelihood of taking some kind of protective action if they received a flash flood warning (also referred to as protective action intentions). Independent variables used in the regression included sociodemographic characteristics and a subset of the variables discussed in Sections 3 and 4 that we anticipated might influence responses to warnings, based on the results in Sections 3 and 4, previous work on protective decision making for flash flooding and other hazards, and the findings in Lazrus et al. (in press). Regression results are shown in Table 8. The adjusted R-squared of 0.35 suggests a strong fit for a model of human behavior.

Of the sociodemographic characteristics, only age was a significant predictor in the regression: younger respondents had significantly lower protective action intentions for a flash flood warning. As anticipated in Section 2.2, respondents who were university students exhibited lower perceptions and understandings of flash flood risks in several ways. For example, as discussed in Section 3.2, students were significantly more likely than non-students to say they did not know whether they lived in a floodplain. Students also rated flash flood impacts as significantly less serious and controllable, thought that people were significantly less likely to be killed if a flash flood occurred, and thought that deeper fast-flowing water was safe to cross on foot (additional analyses not shown). However, there was not a strong association between being a student and protective action intentions, controlling for the other variables included in the regression.

Protective action intentions for flash flooding were significantly higher among respondents who said they had developed an evacuation plan or made other preparations for the hazard. This is consistent with previous research investigating factors associated with public responses to tornado and hurricane threats (e.g., Balluz et al., 2000; Nagele and Trainor, 2012; Lazo et al., 2015). Past direct experience with a significant flash flood, on the other hand, was not a significant predictor in the regression.

Several flash flood risk perception and understanding variables from Sections 3.2–3.5 were included in the regression, but only two were significant predictors. First, protective action intentions were higher for respondents who perceived a greater likelihood of people being killed if a flash flood hit Boulder. This is likely because respondents who think that people are more likely to be killed in a flash flood perceive a greater threat to their own lives in a flash flood warning situation. Second, protective action intentions were higher for respondents who perceived that they were less safe from flash flooding, consistent with the previous literature discussed in Section 3.4. The flash flood likelihood, seriousness, and controllability measures tested were not significant predictors of anticipated warning response (see also Lazo et al., 2015).

The analysis in Section 3 found that some respondents have incorrect or incomplete understandings of their residence location relative to floodplains, the areas in Boulder at risk from flash

[19] Survey question 21: "In your opinion, how accurate are flash flood forecasts and warnings in general at this time?" [Response options: Not at all accurate, Not very accurate, Somewhat accurate, Very accurate, Extremely accurate (coded on a 1-to-5 scale), or Don't know].

[20] Data obtained from http://mesonet.agron.iastate.edu/vtec. Note, however, that respondents' experience with flash flood alerts for other areas and with other types of weather forecasts and warnings likely influenced their perceptions of flash flood forecast and warning accuracy.

[21] Because the question did not specify what type of protective action, different respondents may have had different actions in mind when answering these questions.

[22] Respondents were also asked the same question for a flash flood watch; results are shown in Fig. S3.

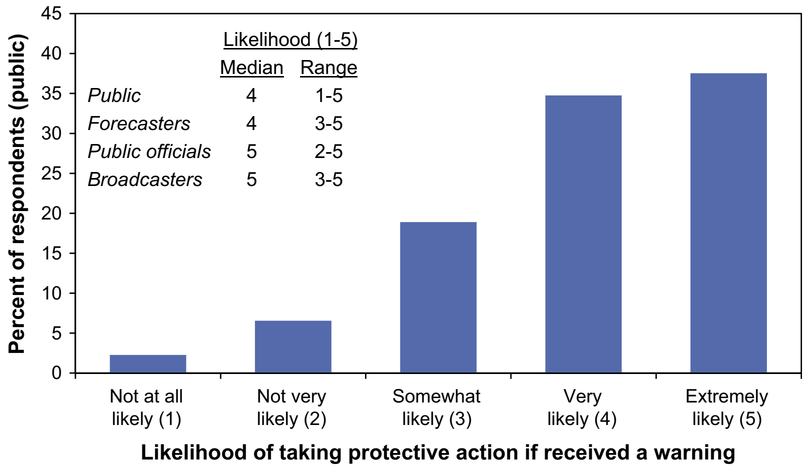

Fig. 6. Respondents' anticipated likelihood of taking protective action if they received a flash flood warning ($N = 393$). The graph depicts results for the public sample, and the table in the upper left depicts the median and range of the estimates for the public and professional samples, as in Fig. 2. Survey question 24: "How likely is it that you would take protective action if you were to receive the following flash flood notifications for your location? Flash flood warning, ..." [Response options: Not at all likely, Not very likely, Somewhat likely, Very likely, Extremely likely (coded on a 1-to-5 scale), or Don't know].

flooding, the depth of fast-flowing water that is safe to cross, and the importance of 1-h and 24-h rainfall in contributing to flash flooding. Similar misconceptions of flash flood risks have also been found in other studies, and these have potential to influence warning decisions (Gruntfest et al., 2002; Drobot et al., 2007; Knocke and Kolivras, 2007; Wagner, 2007; Ruin et al., 2007; Lazrus et al., in press). However, in our analyses, none of these variables was a significant predictor of protective action intention, controlling for the other variables included in the regression.

Three measures of flash flood warning perceptions and interpretations from Section 4 were included in the regression, and all were highly significant predictors. Respondents who correctly differentiated a flash flood watch from a warning, when asked to describe the difference, had higher protective action intentions. This suggests that although understanding of watch/warning terminology is not a comprehensive measure of whether people understand and can use warning information, people who understand the terminology may be more likely to take action when they hear that there is a flash flood warning with little or no accompanying information. Protective action intentions were also higher for respondents who thought that flash flooding was more likely given a warning and for those who had greater trust in flash flood forecasts and warnings. This corroborates the discussion in Section 4.1, that what people think a warning means (as measured here, in terms of likelihood of threat) and how much they trust it are also important for warning decision making.

5.3. What protective action? Complexity of decision making when a flash flood threatens

Sections 5.1 and 5.2 focused primarily on whether respondents anticipated taking some type of action given a flash flood warning. To explore whether people know what protective actions to take, the survey asked respondents what they should do if they heard a flash flood warning while driving, while in a building on the ground floor or below, or while outdoors (in different questions). Analysis of responses in the outdoors scenario is presented in Table 9; results from the other two questions are similar, except as noted.

Two frequently advocated safety rules for flash flood threats in the US are to seek higher ground ("climb to safety"; e.g., Gruntfest et al., 2002) and to not try to drive or go through flooded areas ("turn around, don't drown"; NWS, 2015a). As shown in Table 9, most respondents mentioned moving to a higher location or avoiding risky areas, suggesting that at least in theory, they know how to protect themselves when a flash flood threatens (see also Gruntfest et al., 2002). A closer examination of the responses, however, illustrates how even if one knows these safety rules, deciding what specific actions to take can be complex. A person can seek higher ground, for example, by climbing or running on foot outside, driving to a higher location, entering a building and moving up, or even climbing a tree. Sometimes it may be best to move to a different location or seek shelter inside. Which course of action is best depends on the specific circumstances, which are often difficult to evaluate in the midst of a spatially variable, highly uncertain, rapidly evolving flash flood threat (Ruin et al., 2014; Morss et al., 2015). Thus, as some respondents noted, it may also be important to assess the situation, be alert, or seek more information.

In the driving scenario, responses were similar to those in Table 9, except that many respondents mentioned that they would seek safety in the car (27%), out of the car (20%), or by either staying in or leaving the car depending on the situation (13%).[23] Many of those who said they would try to drive to safety discussed avoiding low-lying areas or driving through water, suggesting that they recognized the potential hazards of trying to drive in a flash flood situation. However, as indicated by the number of deaths and rescues of people caught in flash flooding in vehicles, it is not always apparent what is hazardous and what is not until it is too late.

The complex, contextual nature of protective decision making for flash flooding is also evident in people's responses to the hypothetical warning message in Fig. 4 (Section 5.1). For example, some respondents discussed situational factors (such as family members or their routine activities at that time) that would influence their actions. Many indicated the importance of their location, compared to at-risk locations mentioned in the warning message or in general. As one respondent said: "Note the areas affected and get out of there if in them or do not go in the areas if out of them"; another simply said that "It depends on where in Boulder I am." Such assessments are useful; however, given the rapidly changing, localized, and often extreme nature of flash flooding, it is often difficult to know which locations are at risk, which are safe, and where one is relative to those locations in a specific flash flood threat, and how those will change as the threat evolves. Thus, as some respondents noted, environmental and social cues (e.g.,

[23] Only four responses to the outdoor scenario (and none in the building scenario) mentioned getting in a car or driving, suggesting that most who were not in car when they received the warning would not try to move to a safer location by car.

Table 8
Results from multiple linear regression with respondents' likelihood of protective action if they received a warning as the dependent variable ($N = 397$). Independent variables significant at $p < 0.1$ are indicated in bold text.

Independent variable	Parameter estimate (standard error)	Significance
Sociodemographic characteristics		
Age (years)	**0.010 (0.004)**	$\boldsymbol{p = 0.007}$
Gender (female = 1; male = 0)	0.09 (0.09)	$p = 0.35$
Education (years)	−0.02 (0.04)	$p = 0.65$
Student at university (yes = 1; no = 0)	0.24 (0.16)	$p = 0.15$
Length of residency in Boulder (years)	−0.006 (0.004)	$p = 0.15$
Residence ownership (rent = 1; own = 0)	0.05 (0.13)	$p = 0.69$
Flash flood experience and preparations		
Prior experience (direct major = 1; other = 0)	−0.07 (0.15)	$p = 0.66$
Reported prior preparations (yes = 1; no = 0)	**0.22 (0.09)**	$\boldsymbol{p = 0.01}$
Perceptions and understandings of flash flood risks		
Perceived residence in floodplain? (yes = 1; don't know, no = 0)[a]	0.13 (0.12)	$p = 0.27$
Perceived residence in floodplain? (don't know = 1; yes, no = 0)	−0.05 (0.11)	$p = 0.66$
Likelihood of Boulder flash flooding in next year (%)	0.0002 (0.002)	$p = 0.92$
Seriousness of consequences (1–7 scale)	0.02 (0.03)	$p = 0.56$
Personal control over impacts (1–7 scale)	−0.04 (0.02)	$p = 0.13$
Likelihood of people killed (1–5 scale)	**0.10 (0.05)**	$\boldsymbol{p = 0.04}$
Personal safety from flash flooding (1–5 scale)	**−0.13 (0.04)**	$\boldsymbol{p = 0.001}$
Only Boulder Creek at risk (1–5 scale)	−0.03 (0.04)	$p = 0.43$
Depth of water safe to cross on foot (feet)	−0.003 (0.006)	$p = 0.60$
Importance of 24-h rain (1–5 scale)	0.02 (0.07)	$p = 0.65$
Importance of 1-h rain (1–5 scale)	0.02 (0.06)	$p = 0.68$
Perceptions and interpretations of warnings		
Watch/warning difference (correct = 1; other = 0)	**0.40 (0.09)**	$\boldsymbol{p < 0.0001}$
Likelihood of flash flood if warning (%)	**0.004 (0.001)**	$\boldsymbol{p = 0.007}$
Trust in forecasts and warnings (1–5 scale)	**0.49 (0.06)**	$\boldsymbol{p < 0.0001}$
Adjusted R^2	0.35	
F	10.69	$p < 0.0001$

[a] The three categories for the perceived residence location variable (Yes, in floodplain; No, not in floodplain; Don't know) are represented in the regressions as two dummy variables, with No as the reference category.

Table 9
Summary of respondents' descriptions of actions that a person should take in response to a flash flood warning.[a] The left-hand column shows the major categories of responses, based on the qualitative analysis. For each category, the middle column shows the percent of respondents coded into that category, and the right-hand column shows one or more example responses. Many of the responses were coded into more than one category, as illustrated by the examples. $N = 405$.

Action	% of respondents	Example public response(s)
Move to higher location	84%	"Climb to safety" "Run to higher ground" "Get to higher ground and hold on" "Climb a tree..." "Get to a multilevel building and get to the top" "Drive uphill, get out of car and continue uphill on foot" "Get as high as possible"
Move to different location	18%	"Drive to flatland, away from Boulder Creek away from mountains and to higher land" "Run like nuts" "Get to nearest safety shelter, hospital, firehouse"
Avoid risky areas	12%	"Stay away from creeks + rivers" "Move away from creek areas" "Find higher ground away from electric lines"
Go inside	10%	"Get inside a strong building" "Go in a commercial building or knock on a door"
Assess situation	4%	"Think! Assess vulnerability of location and act accordingly..." "Determine if the flood will be in your area and take appropriate action" "Have high ground picked out nearby and go to it if you see the water and debris coming"
Be alert	3%	"Raise alert level and make plan for possible action" "Be aware of nearby floodways/drainages"
Seek more information	1%	"Try to obtain more info about where to go for safety"
Depends	7%	"Go to higher place or leave area if there is time" "It depends on where you are?"
Don't know	1%	"Honestly, I have no idea"
Other	8%	"Check to hear if it is a practice warning or a real one - then call loved ones and go to a safe location" "Call for help and look for high ground"

[a] Survey question 16: "Please complete each statement in your own words: ... If you hear a flash flood warning and you are outdoors walking, biking, recreating, or working, you should ________".

"Look out the window. Check the Internet for more information. Call friends to get their experiences. ...") are often important in conjunction with warnings, to help assess the risk that the threat poses to oneself (Lindell and Perry, 2012; Ruin et al., 2014; Morss et al., 2015).

As these results indicate, even when people are aware of and decide to respond to a flash flood threat, deciding what specific actions to take can be complex. Thus, flash flood warnings are important not only for notifying people about a threat and motivating them to take protective action; warning communication can also play an important role in helping people assess what the threat means given their situation and decide which actions to take, as the situation evolves.

6. Summary and discussion

Warning systems are a key component of effective flash flood risk management. However, the rapid, complex evolution of flash flood events and the associated uncertainty create major challenges for timely warning and protective decision making. This study aims to improve flash flood warning communication and responses by investigating how members of the US public perceive and understand flash flood risks, how they interpret and anticipate responding to flash flood alerts, and what factors influence their warning responses. The findings are based on quantitative and qualitative analysis of data from a survey of 418 members of the public in Boulder, Colorado, including a random mail sample and a convenience sample of university students. A similar questionnaire was implemented with 20 Boulder-area flash flood warning professionals, allowing a comparison of public and professional perspectives.

Public respondents' estimates of the likelihood of flash flooding in Boulder varied widely, as did their perceptions of the seriousness and controllability of flash flood impacts. Some public respondents incorrectly believed that only areas of Boulder near Boulder Creek were at risk from flash flooding, and many (especially students and renters) could not accurately identify whether their residence was in a designated floodplain. Some also overestimated the depth of fast-flowing water that is safe to cross by foot or automobile. In the regression analysis, however, these measures of general flash flood risk perceptions and understandings were not significant predictors of anticipated likelihood of taking protective action given a warning. Protective action intentions in response to a warning were, however, higher for respondents who said they had made preparations for flash flooding, such as planning an evacuation route or creating a household plan. Protective action intentions were also higher for respondents who perceived a greater likelihood of people being killed if a flash flood hit Boulder and those who believed they were less safe from flash flooding. These latter results are consistent with other research showing that more concrete and personalized perceptions of risks are stronger motivators for protective behaviors (e.g., Mileti and Sorensen, 1990; Lindell and Perry, 2012; Bubeck et al., 2012; Zwickle and Wilson, 2014).

To contribute to discussions about improving weather alert messaging, we explored respondents' understandings and interpretations of the two primary types of flash flood alerts issued by the US NWS (watches and warnings), using data from several survey questions. The analysis indicates that a small segment of respondents did confuse a flash flood watch with a warning. According to the regression analysis, respondents who correctly described the difference between the two terms indicated higher likelihoods of taking protective action given a warning (presented without additional information). However, when asked how they would respond to a hypothetical US warning message, nearly all respondents (even most of those who reversed the terminology) mentioned engaging in some type of protection-related activity. The analysis also indicates that flash flood watches and warnings have multi-dimensional, situationally dependent meanings, for both members of the public and professionals, that are difficult to convey with a single word or other piece of information. Thus, it is unlikely that any simple alert classification scheme (e.g., terminology, color, symbol) will, on its own, be sufficient to convey what people need to know to interpret the alert's meaning in a given situation. Together, these results suggest that the term "warning" (or "watch") itself is not as important as the overall information content, since recipients will interpret the meaning of the words in the context of other available information.

Respondents provided a wide range of estimates of the likelihood of flash flooding given a watch or a warning, indicating significant variation in how they interpret the alerts. Respondents who perceived a lower likelihood of flash flooding given a warning reported lower likelihoods of taking protective action in response to a warning. Protective action intentions were also lower for those who indicated less trust in flash flood forecasts and warnings. This suggests that in order to enhance forecast and warning response, it is important to understand how people interpret risks given forecast and warning information, how much they trust the information, and why. Additional measures of how people interpret forecast and warning information would be valuable to test in future work.

Analysis of data from open-ended survey questions asking what people should or would do given a warning illustrate the complex, context-dependent nature of protective decision making for a flash flood threat. General safety rules, such as those in the last paragraph of the warning message in Fig. 4, are valuable. However, the best way to implement those safety rules depends on one's specific location and other circumstances relative to the details of the flash flood event, as it evolves. Moreover, it can be difficult to evaluate what to do (e.g., where and how to seek higher ground, which roads and other areas to avoid) during a rapidly evolving, highly uncertain flash flood situation. The challenge is, as one person responded to the hypothetical warning message: "Get to higher ground – but I really wouldn't know quite where to go!"

These results, together with related work, identify several important areas for future research. First, more in-depth investigation of how different people perceive, interpret, and respond to hydrometeorological alerts is needed, in realistic informational, social, and decision contexts. More specifically, our findings suggest that it is important to understand what influences people's trust in flash flood warnings, what underlies their beliefs about whether they are safe from flash flooding or not, and how these interact with their warning interpretations and decisions. In addition, the study reported here focused on investigating cognitive risk perceptions (e.g., perceived likelihood of threat, severity of impacts, and controllability). As other research suggests, it is also important to investigate people's affective responses (such as fear and worry) to flash flood threats and their perceived efficacy (or coping appraisal), since these can have important influences on decisions (e.g., Witte, 1992; Loewenstein et al., 2001; Slovic et al., 2004; Grothmann and Reusswig, 2006; McComas, 2006; Terpstra, 2011; Keller et al., 2011; Bubeck et al., 2012).

The findings also suggest that in order to improve flash flood warning communication and response, it is important to go beyond investigating whether people understand what a warning is, whether people will take protective action if they receive a warning, and whether people know in general what they should do to protect themselves. It is also critical to understand how people integrate and use different types of information (including warnings and environmental and social cues) to make decisions for flash floods and other rapidly evolving threats (Mileti, 1995; Ruin et al., 2014). This knowledge can then be used to improve alerts with the goal of helping people evaluate their risk and decide what to do as quickly and effectively as possible, given the dynamic, uncertain, location-dependent nature of such threats (Morss et al., 2015). This will be especially valuable as flash flood detection, forecasting, and warning capabilities continue to improve, providing more detailed information about approaching and evolving threats.

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Appendix. A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jhydrol.2015.11.047.

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