

**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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Abstract

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 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 U.S. 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 knowledge about warning 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. In addition, the analysis 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.

Keywords: Flash flooding, warnings, risk perception, communication, decision making

21 **1. Introduction**

22 Over the last few decades, flash flood detection, forecasting, and warning capabilities have
23 improved dramatically. Yet flash floods are still one of the most deadly weather-related hazards
24 (French et al. 1983, Jonkman and Vrijling 2008). In the U.S., Europe, and Australia, a large
25 portion of flash flood deaths occur when people enter or are swept into floodwaters, either in a
26 vehicle or on foot, in part because they are unaware of or misjudge the risks (Gruntfest et al.
27 1978, Jonkman and Kelman 2005, Ruin et al. 2007, Ashley and Ashley 2008, Haynes et al. 2009,
28 Kellar and Schmidlin 2012, Diakakis and Deligiannakis 2013, Sharif et al. 2015, Becker et al.
29 2015). Thus, it is important not only to issue timely flash flood forecasts and warnings, but also
30 to understand how people perceive flash flood risks and what influences their responses to
31 warning information. This knowledge can then be used to develop evidence-based
32 recommendations for improving communication about flash flood risks in ways that help people
33 understand when, where, and how they are at risk and how to protect themselves when needed.

34 Although a number of studies have examined public risk perceptions and protective
35 decisions for other hydrometeorological hazards, such as hurricanes and slower-onset floods
36 (e.g., Dash and Gladwin 2007, Lazo et al. 2015, Huang et al. 2015, Bubeck et al. 2012, Kellens
37 et al. 2013, Sherman-Morris 2013), few studies have investigated these issues for flash floods
38 (Gruntfest et al. 2002; Knocke and Kolivras 2007; Wagner 2007; Benight et al. 2007; Drobot et
39 al. 2007; Ruin et al. 2007, 2008, 2014; Coles 2008, League 2009, Lazrus et al. 2015). Flash
40 floods evolve rapidly, often with significant variability and uncertainty in local conditions and

41 impacts, and thus present distinct challenges for communicating and responding to threats. To
42 help address these challenges, this study investigates people’s perceptions, understandings, and
43 interpretations of flash flood risks and alerts¹ and their anticipated responses to flash flood
44 warnings. The analysis focuses on members of the public in the U.S., utilizing data from a survey
45 of 418 residents of Boulder, Colorado, conducted in 2010.

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

56 The study area, Boulder, Colorado, is a community of approximately 100,000 people at 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 U.S. National Weather Service (NWS). The NWS watch and warning products are discussed further in section 4.1.

57 base of the foothills of the U.S. Rocky Mountains, and more than 30,000 students are enrolled
58 annually at the University of Colorado Boulder. To sample this population, survey respondents
59 were recruited by mail, supplemented by convenience recruitment of students on the university
60 campus. Flash flooding is a risk in the study region, and Boulder and nearby foothills and
61 canyons experienced devastating and deadly flash flooding in September 2013. However, at the
62 time of the survey, severe, widespread flooding had not occurred in Boulder in several decades
63 (City of Boulder 2012). Thus, the study examines a population with little or no direct local
64 experience with flash flooding.

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

78 Another contribution of this research is that it was conducted as part of a larger, multi-
79 method study, which included research using a mental models approach (e.g., Morgan et al.

80 2002) to examine how Boulder-area professionals and members of the public conceive of and
81 make decisions about flash flood risks (Morss et al. 2015a, Lazrus et al. 2015). This related
82 work, found that some members of the Boulder public have misconceptions or incomplete
83 understandings about several aspects of flash flood risks and risk reduction, which may influence
84 their ability to avoid life-threatening situations when a flash flood threatens. The analysis
85 presented here builds on this mental models research, first, by examining the extent to which
86 some of these types of misconceptions are present in the larger public survey sample, and
87 second, by using regression analysis to quantitatively examine whether such misconceptions are
88 associated with differences in anticipated responses to flash flood warnings. Further, as part of
89 the larger study, a similar questionnaire to that examined here was implemented with 20
90 Boulder-area professionals with job responsibilities related to the Boulder-area flash flood
91 warning system, including U.S. National Weather Service (NWS) forecasters, local emergency
92 managers and other public officials, and television and radio broadcasters (Morss et al. 2015a).
93 This allows us to compare, for some of the survey questions, public perceptions and
94 interpretations with those of flash flood warning professionals.

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

101 **2. Methodology**

102 *2.1 Survey questionnaire development*

103 The survey questionnaire was initially developed as part of the flash flood mental models
104 studies discussed in Morss et al. (2015a) and Lazrus et al. (2015). The 20 Boulder-area
105 professionals and 26 Boulder residents who participated in those studies were each asked to fill
106 out a paper version of the questionnaire towards the end of their mental models interviews. In
107 late fall – early winter 2009, the questionnaire was revised for a larger-scale public survey based
108 on this initial implementation as well as ideas from members of the research team and
109 collaborators². Revisions included modifications to existing questions as well as development of
110 several new questions.

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

115 *2.2 Survey data collection and respondents*

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 Pepler (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).

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

119 For the mail sample, surveys were mailed to 1000 addresses randomly sampled from
120 Boulder zip codes, provided by a survey sampling company. Of the 1000, 750 were sent
121 following Dillman’s (2000) recommendations, with multiple mailings, using incentives ranging
122 from none to \$5; the remaining 250 were sent in a single mailing with no incentive. All of the
123 mail surveys were sent with a stamped and addressed return envelope. Of the mailings sent to
124 valid addresses (Table 1), 408 completed surveys were returned, a response rate of 47%.³

125 Students at the University of Colorado Boulder are potentially at risk from flash flooding,
126 and they (and young adults in general) may perceive risks and interpret and respond to weather
127 alerts differently than non-students (e.g., Grunfest et al. 2002, Knocke and Kolivras 2007,
128 Sherman-Morris 2010, Lovekamp and McMahon 2011). However, because students tend to be
129 more transient, they were expected to be underrepresented in the mail survey. Thus, the mail
130 sample was supplemented with a convenience sample of 200 surveys personally distributed by

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.

131 researchers to students walking on the university campus (Table 1). Forty-three of these surveys
132 were returned completed, a response rate of 22%.

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

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

144 Table 2 shows sociodemographic characteristics of the full Boulder public sample compared
145 to estimates for the City of Boulder population in 2010. The survey sample contains a higher
146 percentage of people who are older, own their residence, have more formal education, have
147 higher incomes, and speak English as their primary language. Many of these differences are
148 likely associated with the under-sampling of University of Colorado Boulder students and other
149 more transient groups that are more difficult to access with a mail survey. Although there were
150 23 mail sample respondents who reported being university students, the majority of the 53

151 students in the full survey sample came from the university convenience sample (Table 1).⁴

152 2.3 Data analysis

153 Data entry for the public survey was performed by a professional research company and
154 quality controlled by a member of the research team. For the 372 respondents in the geolocated
155 subsample, ArcGIS was used to determine the respondents' residence locations relative to the
156 100-year and 500-year designated floodplains (Figure 1; Mulder 2012). Results from additional
157 geospatial analysis can be found in Mulder (2012).

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

165 We then calculated summary statistics for the quantitative data, as well as additional
166 statistical analyses to examine variations and associations across the data set. The quantitative

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.

167 analysis included multiple linear regressions⁵ with stated likelihood of taking protective action
168 given a warning as the dependent variable, and different hypothesized predictors as independent
169 variables. For the regression analyses, missing values for the independent variables were
170 replaced by the median response for that variable.

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

179 **3. Perceptions and understandings of flash flood risks**

180 In this section, we examine how respondents perceive and understand flash flood risks,
181 based on data from the survey. These findings are of interest because they describe potentially
182 important aspects of Boulder residents' attitudes towards and beliefs about flash flood risks,
183 which interact with interpretations of flash flood alerts and their protective decisions.

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.

184 *3.1 Previous flash flood experience and preparations*

185 A number of previous studies have found that people's previous experiences with a hazard
186 (such as flooding) can influence their perceptions of the hazard as well as their protective
187 decisions (e.g., Wagner 2007, Siegrist and Gutscher 2006, Knocke and Kolivras 2007, Lin et al.
188 2008, Kellens et al. 2013, Wachinger et al. 2013, Lazrus et al. 2015, Morss et al. 2015b, Demuth
189 2015). In this sample, 57% of respondents indicated that they had no experience with flash
190 flooding⁶ (N=381)⁷. Ten percent mentioned direct personal experience with a significant flash
191 flood event as it occurred. Most of these experiences were outside the Colorado Front Range.
192 The remainder discussed issues such as being aware of flooding (e.g., from the media), seeing
193 impacts after a flood, hearing about flood experiences from family or friends, or experiencing a
194 flash flood warning or threat. This limited personal experience with flash flooding is not
195 surprising since flash flooding is rare in any one location and (at the time of the survey) major
196 flooding had not occurred in Boulder in decades.

197 Taking preparatory action for a hazard can be an indication that people perceive the hazard
198 as risky, and it can also facilitate protective action if the hazard threatens. To examine whether
199 people had made any prior preparations for a potential flash flood, the survey asked respondents

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.

200 if they had engaged in five different preparatory activities⁸. Forty-one percent of respondents
201 indicated that they had made at least one type of preparation for flash flooding (N=373). The
202 most common preparation was planning an evacuation route (23% of total), followed by making
203 plans with household members (15%) and packing an emergency kit (14%). Fewer indicated
204 having made changes to their home or property (10%) or making plans with non-household
205 members (7%).

206 *3.2 Perceptions and understandings of whether residence is located in a designated floodplain*

207 As one measure of perceived exposure to flash flooding, the survey asked respondents
208 whether their residence was in a designated floodplain. Table 3 shows results for perceived
209 floodplain location for the full public sample, comparing the student and non-student
210 subsamples. Overall, approximately 20% of respondents said they lived in a floodplain, and
211 nearly 40% of respondents said they did not know. “Don’t know” responses were especially

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.

212 prevalent among students (and among renters⁹). This suggests that university students in our
213 sample tend to exhibit some differences in flash flood risk perceptions from non-students; this
214 will be examined further in section 5.2.

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

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

229 *3.3 Perceived likelihood of flash flooding and seriousness and controllability of flash flood*

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

230 *impacts*

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

244 As shown in Figure 2, public respondents indicated a wide range of likelihoods of flash
245 flooding in Boulder. The median values for the public’s and professionals’ estimates are similar.
246 However, some members of the public indicated very low probabilities, in the 0-0.1% range —
247 lower than all of the professionals. This suggests that some members of the public perceive
248 Boulder as less susceptible to flash flooding than local flash flood professionals (see also Morss
249 et al. 2015a, Lazrus et al. 2015).

250 Psychometric studies of risk have found that characteristics other than risk likelihood, such
251 as controllability and seriousness of consequences, are important attributes of laypeople’s
252 judgments of risks (e.g., Fischhoff et al. 1978, Brun 1992, Teigen et al. 1999, Kellens et al.

253 2013). Following this previous work, the survey asked respondents to rate these two aspects of
254 risk perceptions for flash flooding (along with six other types of risks).¹⁰ For seriousness of
255 consequences, public respondents' mean rating was 4.4 (SD¹¹=1.5), near the midpoint (between
256 minor injuries and mostly deaths). For controllability of impacts, their mean rating was 3.1
257 (SD=1.8), suggesting that respondents felt on average that they had some, but not substantial,
258 personal control over the impacts of flash flooding.

259 *3.4 Perceptions and understandings of the risks posed by flash flooding*

260 To investigate perceptions of the risks posed by flash flooding in Boulder in greater detail,
261 the survey asked respondents about the likelihood of eight types of potential impacts if a flash
262 flood were to occur in Boulder. As shown in Table 5, on average public respondents rated

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 Figure S1.

¹¹ SD = standard deviation

263 economic losses, disrupted transportation, and building and property damage as the most likely
264 impacts of flash flooding in Boulder. They rated people killed, on average, as the least likely of
265 the eight impacts but still as somewhat likely (the scale mid-point). The public respondents'
266 average ratings of likelihood of the impacts were similar to those of the forecaster and media
267 professionals, but less than those of the public official professionals (who rated each of the eight
268 types of impacts as very to extremely likely).

269 The most prominent drainage in Boulder is Boulder Creek, which travels down Boulder
270 Canyon and then through downtown Boulder (Figure 1), where a large number of people and
271 buildings are located in the floodplain. Thus, Boulder Creek is often considered as the place of
272 highest flood risk in Boulder due to the potential for significant loss of life and catastrophic
273 impacts (Gruntfest et al. 2002, Stewart 2006, City of Boulder 2012, Morss et al. 2015a).
274 However, as demonstrated in the 2013 flood, multiple creeks and areas in Boulder are at risk for
275 flash flooding (NWS 2014b, Gochis et al. 2015, Morss et al. 2015a). To explore perceptions of
276 which locations in Boulder are at risk, the survey asked respondents how much they agreed that
277 *only* areas in Boulder near Boulder Creek are at risk from flash flooding¹² (N=414). Although
278 75% disagreed, 19% said that they strongly or somewhat agreed. This suggests that (at the time

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].

279 of the survey) some members of the Boulder public did not understand that areas further from
280 Boulder Creek, including but not limited to areas along other creeks and drainages, are at also
281 risk.

282 In the U.S., the majority of flash flood deaths in recent decades have occurred when people
283 become trapped in or enter floodwaters, usually in a vehicle or on foot (Drobot et al. 2007,
284 Ashley and Ashley 2008). Previous research suggests that this may be because some people
285 misunderstand the risks posed by flash-flood waters (Knocke and Kolivras 2007; Drobot 2007;
286 Lazrus et al. 2015, Becker et al. 2015). To investigate people’s understandings of these risks, the
287 survey asked respondents what depth of fast-flowing water was safe to cross by foot and by
288 automobile, in separate questions (Figure 3). Although estimates of what is “safe” vary, most
289 U.S. guidelines indicate that six inches (15 cm) or less of moving water is unsafe on foot; 24
290 inches (60 cm) of water can carry away most vehicles, and lesser depths (6-18 inches; 15-46 cm)
291 can cause many vehicles to stall and float and thus are unsafe (NWS 2015a, FEMA 2015, City of
292 Boulder 2015). Approximately one-third of respondents provided conservative estimates, saying
293 that little or no water (0-3 inches; 0-8 cm) was safe to cross by foot or car. However, 41%
294 indicated that more than 6 inches (15 cm) of fast-flowing water was safe to cross on foot, and
295 17% indicated that more than 12 inches (30 cm) was safe to cross in a car. This suggests that,
296 similar to previous findings in Boulder and other U.S. communities (Gruntfest et al. 2002,
297 Knocke and Kolivras 2007, Drobot et al. 2007), a significant portion of the Boulder population
298 misunderstands the risks of entering flash-flood waters on foot or in a car.

299 The above discussion examines respondents’ perceptions of the risks posed by flash
300 flooding to a person or in Boulder in general. Previous research indicates that people take
301 protective action for a hazard when they feel that they or their family are personally at risk, or

302 not safe (e.g., Mileti 1995, Mileti and Sorensen 1990, Riad et al. 1999, Whitehead et al. 2000,
303 Dow and Cutter 1998, Dash and Gladwin 2007, Burnside et al. 2007, Morss and Hayden 2010,
304 Lindell and Perry 2012, Brotzge and Donner 2013, Lazo et al. 2015). As a more personalized
305 measure of risk perception, the survey asked respondents' about their perceived personal safety
306 from flash flooding¹³ (N=403). Only 18% of respondents selected "Neither agree nor disagree";
307 most either strongly or somewhat agreed (43%) or disagreed (39%) that they were safe from
308 flash flooding.

309 *3.5 Perceptions of factors contributing to flash flooding*

310 As discussed in the introduction, Lazrus et al. (2015) found that some members of the
311 Boulder public have misconceptions or incomplete understandings of the factors contributing to
312 flash flood risks. This was examined in the survey by asking respondents to rate the importance
313 of eight different factors in determining the occurrence of flash flooding at a location. As shown
314 in Table 6, on average public respondents rated elevation, nearness to a creek or canyon, and
315 amount of rain in the last hour or 24 hours as the most important contributing factors. These

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].

316 results are similar to those from the mental models interviews with members of the Boulder
317 public discussed in Lazrus et al. (2015), in which elevation or terrain, creeks or streams, and rain
318 were mentioned by all or nearly all interviewees.

319 For most of the contributing factors, the public’s average ratings of importance were similar
320 to the professionals’ ratings. One potentially important difference is that the professionals
321 (especially the forecasters and public officials) rated rainfall in the last 24 hours as less important
322 than rain in the last hour, whereas the public on average did not. All of the professionals rated 1-
323 hour rainfall as Very or Extremely Important in determining flash flooding, compared with 86%
324 of the public respondents. This corroborates results from Lazrus et al. (2015) that (compared to
325 professionals) some members of the Boulder public underestimate the rapid-onset nature of flash
326 flooding and the importance of thunderstorm rains in contributing to flash flood risks, relative to
327 the risks of snowmelt and rain from other types of storms (see also Knocke and Kolivras 2007,
328 Wagner 2007).

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

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

335 *4.1 Interpretations of U.S. National Weather Service “watch” and “warning” alerts*

336 The U.S. NWS currently issues two primary types of alerts for potential flash flooding (and
337 other hazards): a *watch*, which indicates that the risk of a hazardous event has increased
338 significantly in the area, and a *warning*, which indicates that a hazardous event is occurring,

339 imminent, or highly probable in the area.¹⁴ Previous studies have found that many or most, but
340 not all, members of the U.S. public understand these two terms (although specific results vary
341 depending on the hazard, location, and question format; see, e.g., Legates and Biddle 1999,
342 Balluz et al. 2000, Grunfest et al. 2002, Mitchem 2003, Powell and O’Hair 2008, Schultz et al.
343 2010, Sherman-Morris 2010, Ripberger et al. 2015). The fact that some people confuse or
344 otherwise misunderstand these two terms has raised concerns about watch/warning terminology
345 in the U.S. and helped motivate discussion in the U.S. meteorological community about
346 modifying NWS hazard messaging (e.g., Jacks et al. 2013, Horvitz et al. 2014, NWS 2015c).

347 When asked to describe the difference (if any) between a flash flood watch and warning,
348 74% of respondents in this survey indicated a correct understanding of the difference between
349 the two types of alerts (see Table 7 for question wording). Twelve percent reversed the
350 definitions of the two terms.¹⁵ A few respondents (1%) indicated that the two terms were the

¹⁴ According to the U.S. 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

351 same, and 5% said that they did not know. The remainder (8%) of the responses could not be
352 categorized (e.g., “One is less serious than the other”). Thus, when viewed from this perspective,
353 our results are similar to those from past studies: most, but not all, respondents can correctly
354 differentiate between a “watch” and a “warning”.

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

367 As shown in Table 7, each of these conceptualizations of the difference between “watch”

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.

368 and “warning” — except for certainty and accuracy — was also mentioned by one or more of the
369 professionals. In other words, these different interpretations are also evident among the
370 professionals who create and convey the alerts. This suggests that the alerts have multi-
371 dimensional, situationally dependent meanings, among professionals as well as members of the
372 public. Because these more complex underlying meanings are difficult to convey with a single
373 word, additional information is often needed to interpret what a watch or warning means in a
374 given situation.

375 To investigate respondents’ relative understandings of a watch and warning in two
376 additional ways, we compared: 1) each respondent’s estimates of the likelihood of a flash flood
377 occurring if a flash flood a) watch or b) warning is issued (discussed further in section 4.2); and
378 2) each respondent’s stated likelihood of taking protective action after receiving a flash flood a)
379 watch or b) warning for their location (discussed further in section 5.1). About half of the 12% of
380 respondents who reversed the terms in the open-ended question also reversed them in both of
381 these two comparisons, suggesting a consistent reversal in their understandings of the two terms.
382 However, many of those who reversed the terms still indicated high likelihood of flash flooding
383 and high likelihood of taking protective action given a warning. Together with Table 7, these
384 results illustrate the importance of investigating people’s interpretations of watches and warnings
385 in context as well as their definitions of the terminology.

386 When people receive alerts for real flash flood threats, the term watch or warning is usually
387 accompanied by information that helps people evaluate the level of threat and appropriate action.

388 To investigate how people understand and interpret warning *information* (rather than warning
389 *terminology*), the survey included a question that asked respondents what they would do if they
390 received the hypothetical NWS flash flood warning message shown in Figure 4.¹⁶ As discussed
391 further in section 5.1, when given a warning along with this informational context, nearly all
392 respondents discussed either taking an action or evaluating the risk given their situation. This
393 suggests that even if people misunderstand or are unclear about the meaning of the NWS term
394 “warning” compared to “watch”, most can still adjust their understandings when given warning
395 information in context. In other words, while the phrase “flash flood warning” may be useful in
396 triggering actions for professional users such as public officials, a warning is often most
397 meaningful and useful to members of the public within its informational context. This is not
398 surprising, since the term “warning” is used for purposes other than alerting people about
399 imminent life-threatening weather-related events, and thus can have different meanings in
400 different situations.

401 *4.2 Perceptions of flash flood likelihood given a warning*

¹⁶ Survey question 27: “Say it was 9:30PM, you were in Boulder, and you received the following message:” [See Figure 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 9:30PM 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).

402 Using the same magnifier scale discussed in section 3.3, the survey asked respondents to
403 estimate the likelihood of a flash flood occurring in Boulder in the next 24 hours if a flash flood
404 warning were issued in Boulder.¹⁷ Results are shown in Figure 5. NWS guidelines for the
405 Boulder region indicate that forecasters are to issue a flash flood warning if there is “an 80% or
406 greater chance of flooding that is expected to reach warning criteria” (NWS 2014a, p. 3).
407 Corresponding to this, NWS forecasters provided estimates within a small range around 80%. On
408 average, public respondents’ estimates of the likelihood of flash flooding given a warning were
409 lower than the forecasters’ (and other professionals’) estimates. Moreover, a significant portion
410 of public respondents indicated low likelihoods of flash flooding given a warning, suggesting
411 that they have a different interpretation of the threat indicated by a flash flood warning than the
412 forecasters and other professionals.

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

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

420 influence people's behavioral responses to warnings.

421 *4.3 Trust in and perceived accuracy of flash flood forecasts and warnings*

422 Previous research has shown that trust in information and information sources can be an
423 important component of people's interpretations and use of information about risks, including
424 floods and other weather-related hazards (e.g., Mileti 1995, Mileti and Sorensen 2000, Sherman-
425 Morris 2005, McComas 2006, Parker et al. 2009, Morss 2010, Lazrus et al. 2012, Lindell and
426 Perry 2012, Wachinger et al. 2013, Ripberger et al. 2015). When asked about their trust in flash
427 flood forecasts and warnings¹⁸, respondents on average said that they trust the information
428 somewhat or very much (mean=3.6, SD=0.7; N=404, excluding missing responses). No
429 respondents selected "I don't trust them at all", and only 5% selected "Don't know".

430 As discussed in Ripberger et al. (2015), it seems likely that perceived trust in forecasts and
431 warnings would be related to perceived accuracy. When asked about perceived accuracy of flash
432 flood forecasts and warnings¹⁹, respondents on average said "somewhat accurate" (mean=3.2,

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].

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].

433 SD=0.7; N=403, excluding missing responses). Only one respondent selected “Not at all
434 accurate.” However, 37% selected “Don’t know”, many more than in the trust question. This is
435 likely because flash floods are sufficiently rare that many respondents (at the time of the study)
436 felt that that they could not evaluate flash flood forecast and warning accuracy. For example, at
437 the time of our study, the NWS had issued only 4 flash flood warnings and 12 flash flood
438 watches for Boulder County in the previous 10 years.²⁰

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

447 **5. Protective decision making in response to flash flood warnings**

448 Finally, we examine respondents’ anticipated likelihood of taking protective action given a
449 flash flood warning, followed by an analysis of which perceptions, understandings, and

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.

450 interpretations influence anticipated warning responses. We then use data from open-ended
451 questions on the survey to explore how respondents discussed their choices of protective action
452 and their decision processes, and what this means for protective decision making when a flash
453 flood threatens.

454 *5.1 Anticipated likelihood of taking action given a flash flood watch or warning*

455 The survey included several questions to examine anticipated responses to flash flood alerts,
456 in closed-ended and open-ended formats. The closed-ended questions asked respondents how
457 likely they were to take protective action if they received a flash flood watch or a warning for
458 their location (in separate questions).²¹ As shown in Figure 6, nearly three quarters (72%) of
459 respondents said that they were very or extremely likely to take action if they received a
460 warning.²²

461 Another survey question provided a hypothetical NWS flash flood warning message for
462 Boulder, which would be disseminated to the public (often verbatim) via NOAA Weather Radio,
463 television, radio, and internet when a warning was issued. Respondents were then asked (in an
464 open-ended format) what they would do if they received this message (see Figure 4 and section
465 4.1). In their response, 87% of respondents discussed engaging in some sort of protective

²¹ Because the questions 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 Figure S3.

466 activity, such as moving to a higher or different location, avoiding risky areas, seeking more
467 information, assessing the situation or staying alert, making preparations, or notifying others.
468 Most of the remaining respondents (13%) said they would stay home or do nothing, usually
469 because they did not believe their home was at risk and/or they were trying to avoid risky areas.
470 Only a few said that they did not know what they would do or suggested that the warning would
471 not change their activities at all. Thus, if they received flash flood warning information, most
472 respondents anticipated, at minimum, assessing their risk and deciding what (if anything) to do.

473 *5.2 Factors explaining likelihood of taking action in response to a flash flood warning*

474 To explore how individuals' flash flood warning responses relate to their perceptions,
475 understandings, and interpretations, next we investigate the variations in Figure 6 in greater
476 depth using regression analysis. The dependent variable is individuals' anticipated likelihood of
477 taking some kind of protective action (also referred to as protective action intentions) if they
478 received a flash flood warning. Independent variables used in the regression included
479 sociodemographic characteristics and a subset of the variables discussed in sections 3–4 that we
480 anticipated might influence responses to warnings, based on the results in sections 3–4, previous
481 work on protective decision making for flash flooding and other hazards, and the findings in
482 Lazrus et al. (2015). Regression results are shown in Table 8. The adjusted R-squared of 0.35
483 suggests a strong fit for a model of human behavior.

484 Of the sociodemographic characteristics, only age was a significant predictor in the
485 regressions: younger respondents had significantly lower protective action intentions for a flash
486 flood warning. As anticipated in section 2.2., respondents who were university students exhibited
487 lower perceptions and understandings of flash flood risks in several ways. For example, as
488 discussed in section 3.2, students were significantly more likely than non-students to say they did

489 not know whether they lived in a floodplain. Students also rated flash flood impacts as
490 significantly less serious and controllable, thought that people were significantly less likely to be
491 killed if a flash flood occurred, and thought that deeper fast-flowing water was safe to cross on
492 foot (additional analyses not shown). However, there was not a strong association between being
493 a student and protective action intentions, controlling for the other variables included in the
494 regression.

495 Protective action intentions for flash flooding were significantly higher among respondents
496 who said they had developed an evacuation plan or made other preparations for the hazard. This
497 is consistent with previous research investigating factors associated with public responses to
498 tornado and hurricane threats (e.g., Balluz et al. 2000, Nagele and Trainor 2012, Lazo et al.
499 2015). Past direct experience with a significant flash flood, on the other hand, was not a
500 significant predictor in the regression.

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

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

512 from flash flooding, the depth of fast-flowing water that is safe to cross, and the importance of 1-
513 hour and 24-hour rainfall in contributing to flash flooding. Similar misconceptions of flash flood
514 risks have also been found in other studies, and these have potential to influence warning
515 decisions (Gruntfest et al. 2002, Drobot et al. 2007, Knocke and Kolivras 2007, Wagner 2007,
516 Ruin et al. 2007, Lazrus et al. 2015). However, in our analyses, none of these variables was a
517 significant predictor of protective action intention, controlling for the other variables included in
518 the regression.

519 Three measures of flash flood warning perceptions and interpretations from section 4 were
520 included in the regression, and all were highly significant predictors. Respondents who correctly
521 differentiated a flash flood watch from a warning, when asked to describe the difference, had
522 higher protective action intentions. This suggests that although understanding of watch/warning
523 terminology is not a comprehensive measure of whether people understand and can use warning
524 information, people who understand the terminology may be more likely to take action when
525 they hear that there is a flash flood warning with little or no accompanying information.

526 Protective action intentions were also higher for respondents who thought that flash flooding was
527 more likely given a warning and for those who had greater trust in flash flood forecasts and
528 warnings. This corroborates the discussion in section 4.1, that what people think a warning
529 means (as measured here, in terms of likelihood of threat) and how much they trust it are also
530 important for warning decision making.

531 *5.3 What protective action? Complexity of decision making when a flash flood threatens*

532 Sections 5.1 and 5.2 focused primarily on whether respondents anticipated taking some type
533 of action given a flash flood warning. To explore whether people know what protective actions
534 to take, the survey asked respondents what they should do if they heard a flash flood warning

535 while driving, while in a building (on the ground floor or below), or while outdoors (in different
536 questions). Analysis of responses in the outdoors scenario are presented in Table 9; results from
537 the other two questions are similar (except as noted).

538 Two frequently advocated safety rules for flash flood threats in the U.S. are to seek higher
539 ground (“climb to safety”; e.g., Grunfest et al. 2002) and to not try to drive or go through
540 flooded areas (“turn around, don’t drown”; NWS 2015a). As shown in Table 9, most respondents
541 mentioned moving to a higher location or avoiding risky areas, suggesting that at least in theory,
542 they know how to protect themselves when a flash flood threatens (see also Grunfest et al.
543 2002). A closer examination of the responses, however, illustrates how even if one knows these
544 safety rules, deciding what specific actions to take can be complex. A person can seek higher
545 ground, for example, by climbing or running on foot outside, driving to a higher location,
546 entering a building and moving up, or even climbing a tree. Sometimes it may be best to move to
547 a different location or seek shelter inside. Which course of action is best depends on the specific
548 circumstances, which are often difficult to evaluate in the midst of a spatially variable, highly
549 uncertain, rapidly evolving flash flood threat (Ruin et al. 2014, Morss et al. 2015a). Thus, as
550 some respondents noted, it may also be important to assess the situation, be alert, or seek more
551 information.

552 In the driving scenario, responses were similar to those in Table 9, except that many
553 respondents mentioned that they would seek safety in the car (27%), out of the car (20%), or by

554 either staying in or leaving the car depending on the situation (13%).²³ Many of those who said
555 they would try to drive to safety discussed avoiding low-lying areas or driving through water,
556 suggesting that they recognized the potential hazards of trying to drive in a flash flood situation.
557 However, as indicated by the number of deaths and rescues of people caught in flash flooding in
558 cars, it is not always apparent what is hazardous and what is not until it is too late.

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

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.

571 experiences. ...”) are often important in conjunction with warnings, to help assess the risk that
572 the threat poses to oneself (Lindell and Perry 2012, Ruin et al. 2014, Morss et al. 2015a).

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

578 **6. Summary and discussion**

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

589 Public respondents’ estimates of the likelihood of flash flooding in Boulder varied widely,
590 as did their perceptions of the seriousness and controllability of flash flood impacts. Some public
591 respondents incorrectly believed that only areas of Boulder near Boulder Creek were at risk from
592 flash flooding, and many (especially students and renters) could not accurately identify whether
593 their residence was in a designated floodplain. Some also overestimated the depth of fast-flowing

594 water that is safe to cross by foot or automobile. In the regression analysis, however, these
595 measures of general flash flood risk perceptions and understandings were not significant
596 predictors of anticipated likelihood of taking protective action given a warning. Protective action
597 intentions in response to a warning were, however, higher for respondents who said they had
598 made preparations for flash flooding, such as planning an evacuation route or creating a
599 household plan. Protective action intentions were also higher for respondents who perceived a
600 greater likelihood of people being killed if a flash flood hit Boulder and those who believed they
601 were less safe from flash flooding. These latter results are consistent with other research showing
602 that more concrete and personalized perceptions of risks are stronger motivators for protective
603 behaviors (e.g., Mileti and Sorensen 1990, Lindell and Perry 2012, Bubeck et al. 2012, Zwickle
604 and Wilson 2014).

605 To contribute to discussions about improving weather alert messaging, we explored
606 respondents' understandings and interpretations of the two primary types of flash flood alerts
607 issued by the U.S. NWS, watches and warnings, using data from several survey questions. The
608 analysis indicates that a small segment of respondents did confuse a flash flood watch with a
609 warning. According to the regression analysis, respondents who correctly described the
610 difference between the two terms indicated higher likelihoods of taking protective action given a
611 warning (presented without additional information). However, when asked how they would
612 respond to a hypothetical U.S. warning message, nearly all respondents (even most of those who
613 reversed the terminology) mentioned engaging in some type of protection-related activity. The
614 analysis also indicates that flash flood watches and warnings have multi-dimensional,
615 situationally dependent meanings, for both members of the public and professionals, that are
616 difficult to convey with a single word or other piece of information. Thus, it is unlikely that any

617 simple alert classification scheme (e.g., terminology, color, symbol) will, on its own, be
618 sufficient to convey what people need to know to interpret the alert's meaning in a given
619 situation. Together, these results suggest that the term "warning" (or "watch") itself is not as
620 important as the overall information content, since recipients will interpret the meaning of the
621 words in the context of other available information.

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

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

640 go!”

641 These results, together with related work, identify several important areas for future
642 research. First, more in-depth investigation of how different people perceive, interpret, and
643 respond to hydrometeorological alerts is needed, in realistic informational, social, and decision
644 contexts. More specifically, our findings suggest that it is important to understand what
645 influences people’s trust in flash flood warnings, what underlies their beliefs about whether they
646 are safe from flash flooding or not, and how these interact with their warning interpretations and
647 decisions. In addition, the study reported here focused on investigating cognitive risk perceptions
648 (e.g., perceived likelihood of threat, severity of impacts, and controllability). As other research
649 suggests, it is also important to investigate people’s affective responses (such as fear and worry)
650 to flash flood threats and their perceived efficacy (or coping appraisal), since these can have
651 important influences on decisions (e.g., Witte 1992, Loewenstein et al. 2001, Slovic et al. 2004,
652 Grothmann and Reusswig 2006, McComas 2006, Terpstra 2011, Keller et al. 2011, Bubeck et al.
653 2012).

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

663 especially valuable as flash flood detection, forecasting, and warning capabilities continue to
664 improve, providing more detailed information about approaching and evolving threats.

665

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902 **Table captions**

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

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

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

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

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

923 **Table 6.** Perceived importance of different factors in contributing to flash flooding^a, for the
924 Boulder public sample (N=394-404) and for the NWS forecasters (N=6), public officials (N=8),

925 and broadcasters (N=6). In the table, contributing factors are presented in decreasing order of
926 importance for the public sample (not the order presented in the survey).

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

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

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

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946 **Figure captions**

947 **Figure 1.** Residence locations for respondents in the geolocated subsample (N=372), overlaid on
948 a map of the Boulder-area landscape and the designated Boulder County 100-year (light blue)
949 and 500-year (dark blue) floodplains. The large floodplain that runs from west to east near the
950 center of Boulder is along Boulder Creek. Boulder Creek has a drainage area of approximately
951 1160 km². In the geolocated subsample, 21 respondents (6%) lived in the 100-year floodplain, 15
952 (4%) lived in the 500-year floodplain, and 336 (90%) lived outside the designated 100- or 500-
953 year floodplain. The symbol color depicts the respondents' perceived location: in 100-year or
954 500-year floodplain (yellow), not in 100-year or 500-year floodplain (pink), don't know
955 (orange), and missing response (white); see also Table 4.

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

965 **Figure 3.** Respondents' perceptions of the depth of fast-flowing water that is safe to cross by
966 foot or by car. Survey question 17: "The deepest amount of fast-flowing water that is safe to
967 cross by foot is _____" (N=376) and survey question 18: "The deepest amount of fast-flowing

968 water that is safe to cross by automobile is _____” (N=373) [Open-ended responses]. These
969 questions were not included on the professional version of the questionnaire.

970 **Figure 4.** Flash flood warning message provided in questionnaire, for survey question 27. The
971 message was adapted from previously issued NWS warning products for the Boulder area.

972 **Figure 5.** Respondents’ estimates of the likelihood of flash flooding in Boulder if a warning
973 (N=405) is issued for Boulder. The graph depicts results for the public sample, and the table in
974 the upper right depicts the median and range of the estimates for the public and professional
975 samples, as in Figure 2. Survey questions 6: “If a flash flood warning is issued for Boulder,
976 please put an “X” on the line that describes your best estimate of how likely it is that flash
977 flooding will occur in Boulder in the next 24 hours.” [Respondents were given a diagram with a
978 scale ranging from 0% to 100%, with a magnified section between 0% and 1%.] **Figure 6.**

979 Respondents’ likelihood of taking protective action if they received a flash flood warning
980 (N=393). The graph depicts results for the public sample, and the table in the upper left depicts
981 the median and range of the estimates for the public and professional samples, as in Figure 2.

982 Survey question 24: “How likely is it that you would take protective action if you were to receive
983 the following flash flood notifications for your location? Flash flood warning, ...” [Response
984 options: Not at all likely, Not very likely, Somewhat likely, Very likely, Extremely likely (coded
985 on a 1-to-5 scale), or Don’t know].

986

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

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; U.S. 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.

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%)

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. (2015a). 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.

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 hours	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 U.S. 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, excluding missing responses to question.

Category of description of watch/warning difference	% of public respondents	Example public response
<i>Likelihood</i>	56%	"Watch - flooding possible; warning - flooding likely."
<i>Imminence</i>	30%	"Warning is immediately, watch is the potential."
<i>Occurrence</i>	20%	"Warning: flash flooding already occurring upstream, watch: conditions favorable to flash flooding, but not occurring yet."
<i>Environmental conditions</i>	18%	"Warning--flash flood likely. Watch--conditions for flash flood present."
<i>Actions required</i>	13%	"Flood watch puts us on alert/standby, warning triggers flood action plan."
<i>Seriousness</i>	10%	"Warning means likely enough for great danger; watch is much less serious, but reason to keep tuned for potential warning."
<i>Certainty</i>	5%	"Watch=may be building but no confirmation. Warning=it's coming, and we are pretty certain."
<i>Timing</i> (including temporal coverage and lead time)	4%	"The warning precedes the watch? Or is it the other way? ..."
<i>Location</i> (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."
<i>Accuracy</i>	0.5%	"A warning is more accurate than a watch. A watch is less certain."
<i>Other</i>	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].

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
<i>Sociodemographic characteristics</i>		
Age (years)	0.010 (0.004)	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
<i>Flash flood experience and preparations</i>		
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)	p=0.01
<i>Perceptions and understandings of flash flood risks</i>		
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)	p=0.04
Personal safety from flash flooding (1-5 scale)	-0.13 (0.04)	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-hour rain (1-5 scale)	0.02 (0.07)	p=0.65
Importance of 1-hour rain (1-5 scale)	0.02 (0.06)	p=0.68
<i>Perceptions and interpretations of warnings</i>		
Watch/warning difference (correct=1; other=0)	0.40 (0.09)	p<0.0001
Likelihood of flash flood if warning (%)	0.004 (0.001)	p=0.007
Trust in forecasts and warnings (1-5 scale)	0.49 (0.06)	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, excluding missing responses to question.

Action	% of respondents	Example public response(s)
Move to higher location	84%	<ul style="list-style-type: none"> “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%	<ul style="list-style-type: none"> “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%	<ul style="list-style-type: none"> “Stay away from creeks + rivers” “Move away from creek areas” “Find higher ground away from electric lines”
Go inside	10%	<ul style="list-style-type: none"> “Get inside a strong building” “Go in a commercial building or knock on a door”
Assess situation	4%	<ul style="list-style-type: none"> “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%	<ul style="list-style-type: none"> “Raise alert level and make plan for possible action” “Be aware of nearby floodways/drainages”
Seek more information	1%	<ul style="list-style-type: none"> “Try to obtain more info about where to go for safety”
Depends	7%	<ul style="list-style-type: none"> “Go to higher place or leave area if there is time” “It depends on where you are?”
Don't know	1%	<ul style="list-style-type: none"> “Honestly, I have no idea”
Other	8%	<ul style="list-style-type: none"> “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 _____”.

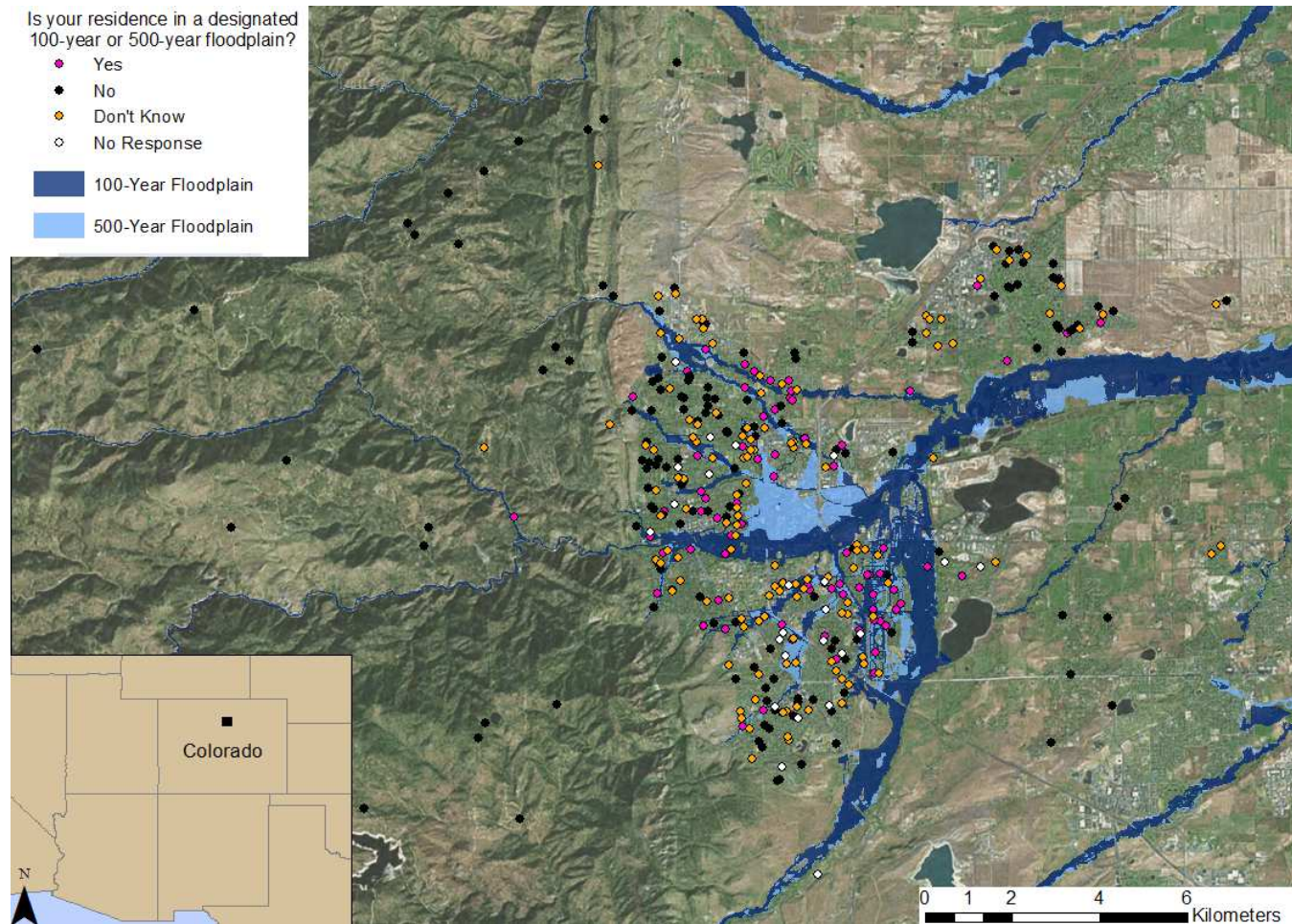


Figure 1. Residence locations for respondents in the geolocated subsample (N=372), overlaid on a map of the Boulder-area landscape and the designated Boulder County 100-year (light blue) and 500-year (dark blue) floodplains. The large floodplain that runs from west to east near the center of Boulder is along Boulder Creek. Boulder Creek has a drainage area of approximately 1160 km². 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: in 100-year or

500-year floodplain (yellow), not in 100-year or 500-year floodplain (pink), don't know (orange), and missing response (white); see also Table 4.

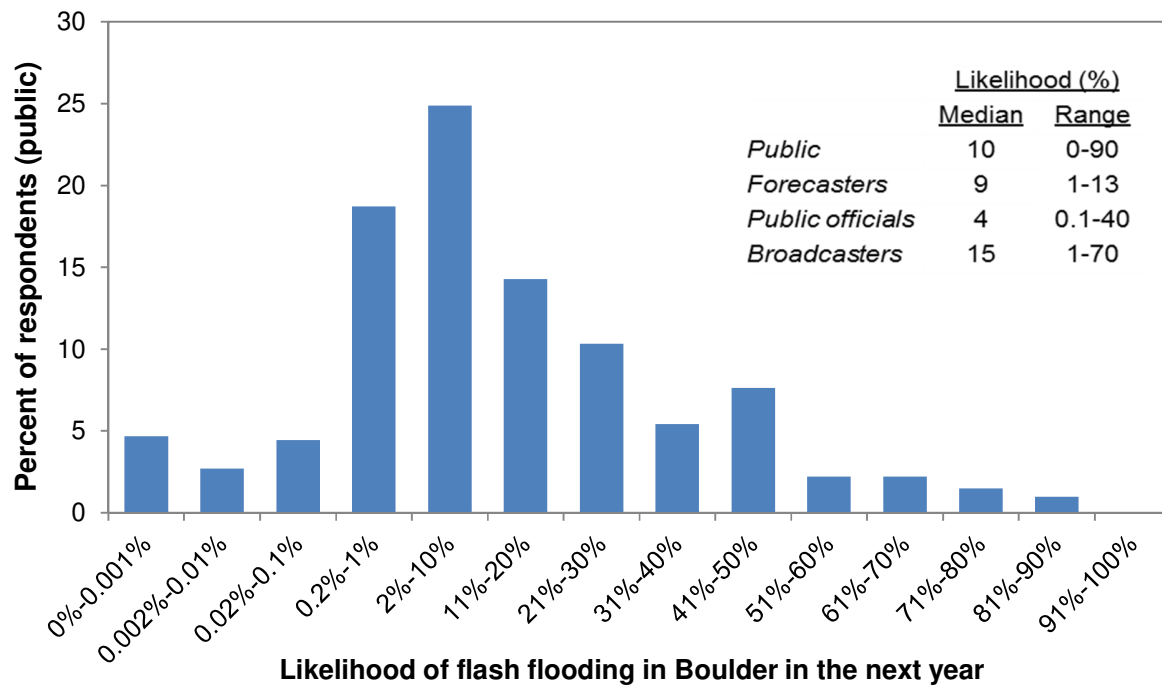


Figure 2. Respondents’ estimates of the likelihood of flash flooding in Boulder in the next year. The graph depicts results for the public sample (N=406, excluding missing responses). The table in the upper right of the graph depicts the median and range of the estimates for the public sample and for 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. 2015a). 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).]

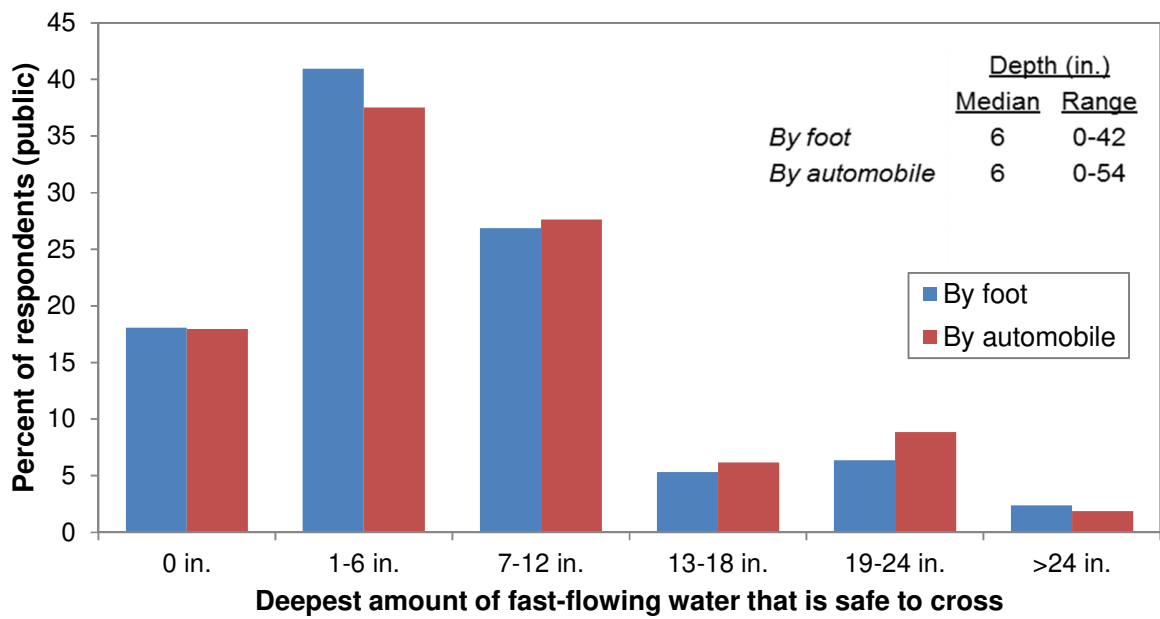


Figure 3. Respondents’ perceptions of the depth of fast-flowing water that is safe to cross by foot or by car. Survey question 17: “The deepest amount of fast-flowing water that is safe to cross by foot is _____” (N=376) and survey question 18: “The deepest amount of fast-flowing water that is safe to cross by automobile is _____” (N=373) [Open-ended responses]. These questions were not included on the professional version of the questionnaire.

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.

Figure 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.

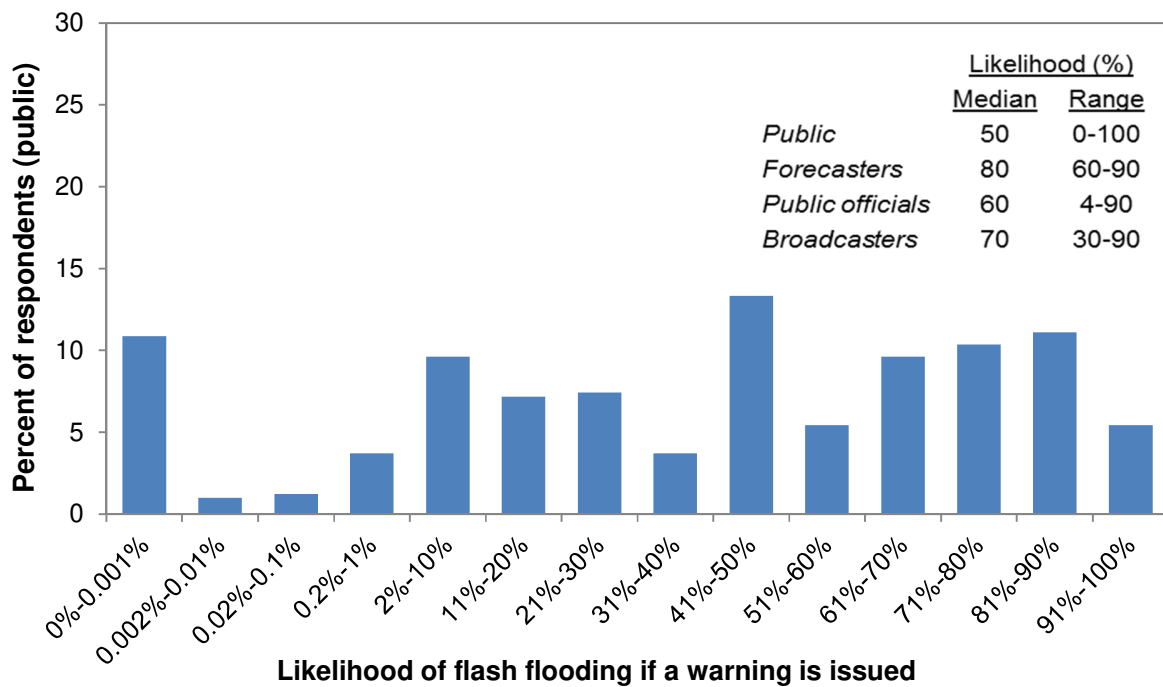


Figure 5. Respondents' estimates of the likelihood of flash flooding in Boulder if a warning (N=405) is issued for Boulder. The graph depicts results for the public sample, and the table in the upper right depicts the median and range of the estimates for the public and professional samples, as in Figure 2. Survey questions 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 hours." [Respondents were given a diagram with a scale ranging from 0% to 100%, with a magnified section between 0% and 1%.]

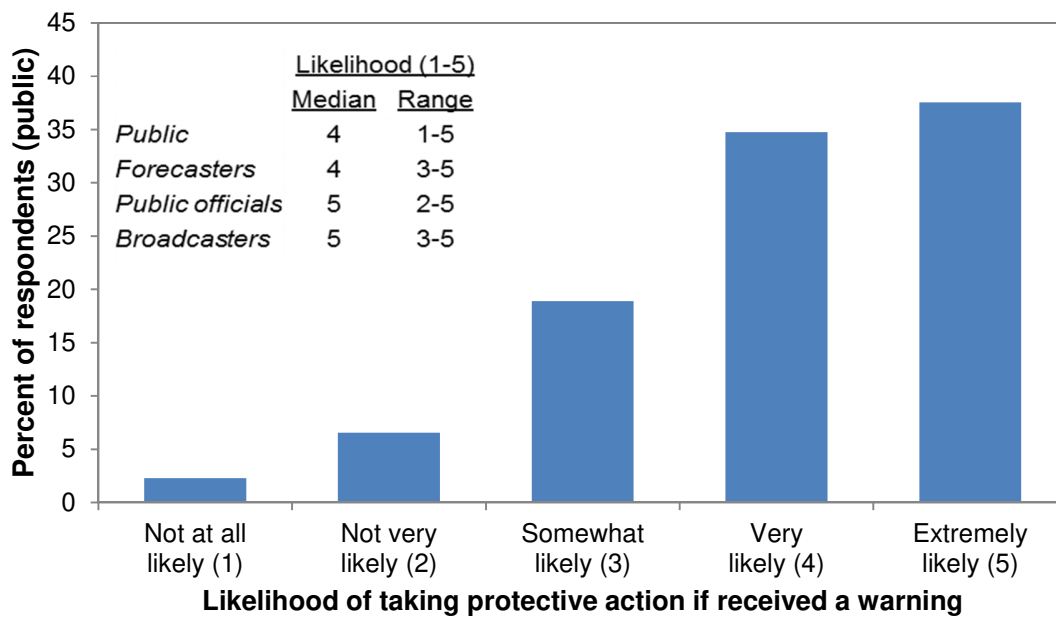


Figure 6. Respondents' likelihood of taking protective action if they received a flash flood warning (N=393). The graph depicts results for the public sample, and the table in the upper left depicts the median and range of the estimates for the public and professional samples, as in Figure 2. Survey 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].