A SITUATION-BASED ANALYSIS OF FLASH FLOOD FATALITIES IN THE UNITED STATES

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The circumstances in which people perished in flash floods suggest that situational rather than generic examination of vulnerability is required to realistically capture risky cases during short-fuse flood events.

Flash flooding happens quickly—within several minutes to several hours—usually over small drainage areas on the order of a few hundred square kilometers (AMS 2000). These are the most dangerous floods, since they can occur with little or no warning, restricting the anticipation time of effective response (Creutin et al. 2013). They are often associated with rapid rises in water levels and fast-moving waters that can sweep humans and their cars off their intended path (Montz and Gruntfest 2002; Jonkman and Vrijling 2008; Ruin et al. 2009).

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Human impact studies are sometimes hazard specific but only a few focus on flash floods (Mooney 1983; French et al. 1983; Staes et al. 1994). A review of the literature shows that i) in most of the natural hazard mortality studies worldwide, flash flood information is merged with other types of floods for analysis (e.g., Coates 1999; Ahern et al. 2005; Borden and Cutter 2008; Fitzgerald et al. 2010; Kellar and Schmidlin 2012); ii) many studies are case specific or are restricted to the analysis of fatality data obtained from a limited number of flood events in specific regions (e.g., Staes et al. 1994; Jonkman and Kelman 2005; Jonkman et al. 2009; Maples and Tiefenbacher 2009; Sharif et al. 2015); and iii) when fatal accident circumstances are investigated, studies either focus on one specific type of circumstance (often the vehicle-related one) or spatial and temporal patterns specific to the various circumstances are rarely addressed (Coates 1999; Ashley and Ashley 2008; Maples and Tiefenbacher 2009; Sharif et al. 2012; Diakakis and Deligiannakis 2013). Because flash flood events can be distinguished from riverine floods by their fast response to rainfall and resulting impacts signature (Jonkman 2005; Gourley at al. 2013), this paper proposes analyzing flash flood–specific impact datasets to identify the conjunction of social and physical circumstances leading to those impacts.

In this work, data on flash flood–related casualties from 1996 to 2014 are derived from the Storm Events Database maintained by the U.S. National Centers for Environmental Information. Although not unbiased, the Storm Events Database is the most comprehensive nationwide database for flash flood events and the resulting impacts (i.e., fatalities, injuries, and damages) (Gall et al. 2009). Currently, our study is restricted to the analysis of fatalities due to the availability of details concerning victims (e.g., age, gender, and location). Although sometimes included as comments in the event narratives of the Storm Events Database, details about other nonfatal impacts from flash floods, such as injuries or rescues, are not provided in a coherent database on the U.S. scale yet.

Rather than using the claim of the "deadliest flood type" to study flash floods, we address specific aspects of vulnerability that are not relevant in the case of general flooding (Terti et al. 2015). Terti et al. (2015) stated that the intersection of the spatiotemporal context of the flash flood phenomenon with the distribution of people and their sociodemographic characteristics reveals various paths of vulnerability through the expression of different accidents' circumstances (i.e., vehicle related, inside buildings, and open air). In their proposed conceptual vulnerability model, the authors use the term "coupled place–activity" to point out that the nature and dynamics of the individuals' reactions will differ according to the location and activity they were performing when they felt the need for action, and their capability to connect with their relatives or to have social interactions, allowing a group response (Ruin et al. 2014).

Previous analyses highlighted the importance of the location and activity of the exposed individuals during a flash flood event on the distribution of impacts (Ashley and Ashley 2008; Ruin et al. 2009). Ashley and Ashley (2008) analyzed 4,586 flood fatalities included in the Storm Events Database for the period 1959–2005 to provide conclusions on the vulnerable states and populations in the contiguous United States. Examining the frequency of all flood-related fatalities by location revealed that 63% were associated with vehicles, whereas a number of deaths happened "in water" (9%) in cases where the victims intentionally entered the flood waters. Špitalar et al. (2014) used a unified flash flood observational database compiled at the National Severe Storms Laboratory (NSSL) (Gourley et al. 2013) to analyze spatial, temporal, and hydrological parameters with human impacts. In their study, physical attributes related to 21,549 events in the United States (2006–12) were cross analyzed with the aggregated number of fatal events weighted with the fatalities. Their findings propose late evening flash flood occurrences as the most devastating in terms of injuries and fatalities. Further investigation of the vehicle-related casualties showed that visibility and rush-hour habits contribute to more impactful flash floods. The aforementioned studies do not analyze the profile of victims in certain circumstances. However, they reveal that certain behaviors and attitudes are embedded in the fatal scene, inviting future research on the socio-spatiotemporal characteristics of the circumstances and identification of the vulnerability factors.

Jonkman and Kelman (2005) proposed a categorization of the causes and circumstances for 247 deaths caused by 13 small-scale flood events in Europe and the United States. Their classification is a valuable contribution toward a more consistent comparison between different fatal flood events. The reclassification of the fatalities' circumstances in the present study does not intend to present statistics on the exact reason or location of the losses; rather, we attempt to contextualize prominent responses and behaviors of the victims using a smaller number of classes that will facilitate more targeted warning and prediction approaches in the future. The purpose is to identify the circumstances that can be described by certain physical attributes of the exposed environment (e.g., road network, campsites, and mobile homes) and/or sociodemographic characteristics of the exposed population (e.g., family status and work travel) to serve as vulnerability predictors.

Today, very little is known about the distribution of flash flood–specific human losses under certain circumstances and/or on a subdaily basis in the United States. Unlike previous work in mortality data analysis, information about the victims and the spatiotemporal context of the fatal flash flood events are disaggregated for each of the circumstances. The analysis addresses the following questions:

- What are the predominant circumstances associated with the occurrence of fatalities during flash flood events?
- What is the temporal distribution of flash flood fatalities for the different circumstances?
- Who is the most vulnerable to flash flooding in terms of loss of life; are the same patterns revealed when discretizing by circumstance and/or time of the day?
- What is the substate and subcounty distribution of circumstance-specific fatalities across the entire United States?

The authors believe that having the circumstances as the center point of the analysis is fundamental to superimposing situational against generic vulnerability assessment. The spatial analysis improves the picture of the geographic distribution of flash flood fatalities in the United States. The results of this research can contribute to the development of more targeted warning and prediction approaches to prevent human losses during flash floods.

DATA SOURCE AND PROCESSING.

Flash flood event and fatality data. Information on flash flood fatalities and the related events are extracted from the Storm Events Database online (available at www.ncdc.noaa.gov/stormevents/ftp.jsp). According to NWS (2016), a recorded flash flood must have posed a potential threat to life or property and had a report of moving water with a depth greater than 0.15 m or more than 0.91 m of standing water. From 1996 to 2014 there have been 63,176 flash flood reports across the entire United States, including the noncontiguous states of Alaska, Hawaii, and the territory of Puerto Rico. However, low-impact events (i.e., with small spatial extension or very few losses), not well documented by the media or public, can be underreported (Curran et al. 2000). This source of inaccuracy in the Storm Events Database is discussed in previous studies (e.g., Ashley and Ashley 2008) and is assumed to be the main uncertainty source, taking into account that almost 97% of the flash flood events between 1996 and 2014 are events in which fewer than five people died. From the 63,176 reported flash flood events, 1.6% includes at least one human impact (i.e., direct or indirect injury or fatality). There were 705 flash flood events with fatalities and 417 with injuries in the database, yielding a total of 1,075 fatalities and 6,028 injuries.

The Storm Events Database consists of three files for each year: i) an event-details file with information about the weather event and the respective event narratives, ii) a fatality file with details about each death resulting from the events, and iii) a location file with geographic information about the location of the event. The database that is used for analysis in this study was compiled based on annual fatality files with extra records and details added when available for specific flash flood events (see www.ncdc.noaa.gov/stormevents/). Because the date and time of the fatal incidents are not consistently determined in the original fatality database, these fields are supplemented based on the event-details files to cross analyze the fatalities with the temporal context of the flash flood event that led to them. The final database used for analysis consists of 1,075 individual fatalities with the following attributes:

i) The circumstance that the fatality occurred (reclassified as presented in the next section) that explains where the victim was (e.g., inside a building or driving on the road) and what the victim was doing (e.g., working or trying to reach home) at the time of the fatal incident
ii) The age and gender of the victim (if provided)
iii) The year and month of the fatality
iv) The state and county that the fatality occurred within
v) The local beginning and end times of the flash flood event responsible for the fatality that provides the onset of the flash flood occurrence and the duration of the event

Reclassification of individual fatalities. In this study, we examine the individual-by-individual fatality records for both direct (98%) and indirect (2%) losses, and

Table 1. Categories of flash flood fatalities' location and/or activity before and after reclassification.

Category	Code
Location defined in the Storm Events Database before reclassification	
Vehicle/towed trailer	VE
In water	IW
Outside/open areas	OU
Permanent home	PH
Mobile/trailer home	MH
Camping	CA
Boating	BO
Permanent structure	PS
Business	BU
Ball field	BF
Under tree	UT
Other	OT
Unknown	NA
Circumstance defined in the compiled database after reclassification	
Vehicle-related	VE
Outside/open or close-to-streams areas related	OU
Camping/recreational areas related	CA
Permanent building related	PB
Mobile home related	MH
Other/unknown	OT

based on additional details noted in the corresponding flash flood event narrative (when available in the event details files), we generalize the 13 categories of the location and/or activity of the perished people into six circumstances that adequately explain the framework of the majority of deaths (Table 1).

The in-water category was mainly distinguished from the "outside" category in the Storm Events Database depending on whether the victim had purposely entered flash flood waters or had fallen or swept into them accidentally (Ashley and Ashley 2008). In terms of vulnerability, however, these two categories are identical, since they are both dominated by situations in which people underestimated the danger of the flash floods in areas close to streams or rivers and walked through the floodwaters to reach some destination, such as home. In the in-water category, there were also many cases of children or teenagers who walked or played in the floodwaters close to streams. All these cases were therefore assigned to the "outside/open or close-to-streams areas" class (Table 2).

When people entered the flood to escape, for example, from a trapped vehicle or a flooded home, the deaths were reclassified as "vehicle related" and "permanent building related," respectively, to better explain the original causative circumstances. Vehicle-related circumstances in the Storm Events Database represent weather-induced fatal incidents rather than traffic accidents. The "permanent home," "permanent structure," and "business" categories were merged into the permanent building–related circumstance. Finally, cases for which there was no clear information for the location or the context of the fatality (although other important details of the victim's profile were available) were registered as "other/unknown" to be further considered in the analysis of the available fatality- and event-related variables.

STATISTICAL ANALYSIS OF FLASH FLOOD FATALITIES.

Circumstances of the fatalities. After reclassification, 61% of the total 1,075 fatalities occurred in circumstances related to vehicles (Table 2). If we remove the 39 fatalities for which the location or activity of the victim could not be defined (Table 2), then the vehicle-related circumstances account for 63% of the fatalities with known circumstance (Fig. 1a). Despite differences in the exact percentages due to the data temporal and spatial coverage, these findings agree with previous studies stating that most of the flood fatalities in the Unites States (Mooney 1983; Staes et al. 1994; Ashley and Ashley 2008; Maples and Tiefenbacher 2009; Sharif et al. 2015; Špitalar et al. 2014), Australia (Coates 1999; Fitzgerald et al. 2010), and Europe (Jonkman and Kelman 2005; Diakakis and Deligiannakis 2013) are vehicle related with drowning being the main cause of death (French et al. 1983; Ryan and Hanes 2009).

The second dominating circumstance is the outside/open-air or close-to-streams areas. This category is mainly composed of cases in which people were

TABLE 2. Number of reclassified cases of flash flood fatalities' location and/or activity and percentages relative to the total 1,075 reported fatalities.

	Circumstance after reclassification							
Previous location	**VE**	**OU**	**CA**	**PB**	**MH**	**OT**	**TOTAL**	**TOTAL (%)**
VE	496	3	—	—	3	—	502	46.7
IW	99	116	26	14	1	22	278	25.9
OU	12	66	11	2	2	—	93	8.7
PH	—	2	—	37	—	—	39	3.6
MH	—	—	—	—	21	2	23	2.1
CA	—	—	30	—	—	—	30	2.8
BO	—	4	4	—	—	—	8	0.7
PS	—	—	-	5	—	—	5	0.5
BU	—	—	—	1	—	—	1	0.1
BF	1	—	—	—	—	—	1	0.1
UT	1	—	—	—	—	—	1	0.1
OT	3	19	1	—	—	5	28	2.6
NA	42	10	—	2	2	10	66	6.1
TOTAL	654	220	72	61	29	39	1,075	100
TOTAL (%)	60.8	20.5	6.7	5.7	2.7	3.6	100	

swept into creeks while trying to walk through swollen portions of a creek or already flooded intersections to reach their relatives and/or belongings (e.g., home). Out of the 84 (from the total 220) deaths for which additional information could be extracted for the motivation of the activity, only 13% of them were related to rescue or evacuation processes. Qualitative analysis of actual behavioral response to flood has shown that such conflicting priorities (e.g., staying safe vs saving your belongings or livelihood) are common and often require the intervention of a third party who has no emotional nor financial involvement in the situation for people to be restored to their common sense (Jonkman and Kelman 2005, Ashley and Ashley 2008; Ruin et al. 2014).

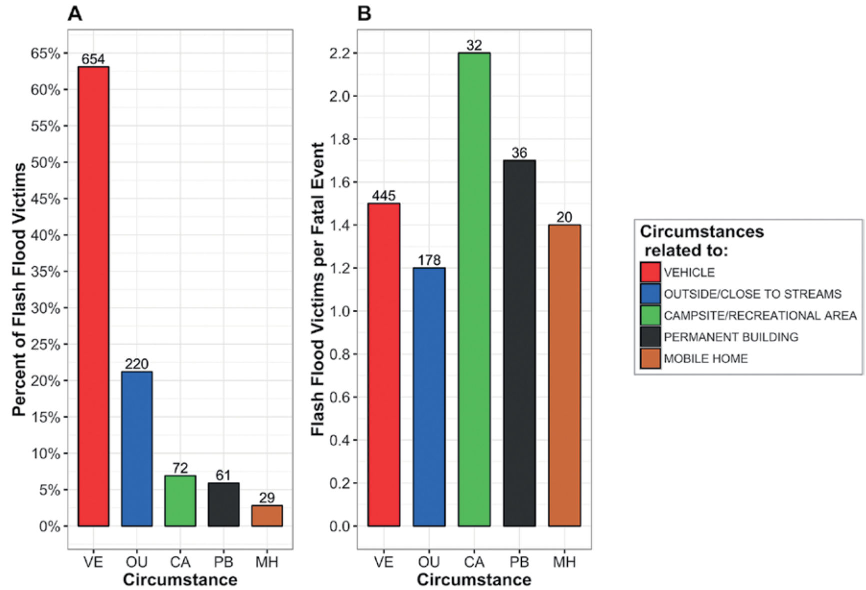

Fig. 1. (a) Percentage of flash flood victims by circumstance. Percentages are determined using the total 1,036 fatalities with the defined circumstance. The values on the top of the bar indicate the row number of fatalities in each circumstance. (b) Ratio of flash flood victims per event with fatalities in each circumstance. The values on the top of the bar indicate the raw number of fatal flash flood events in each circumstance. Some of the total 679 unique fatal events led to fatalities in more than one circumstance.

Although fewer events are associated with campsite/recreational area–related circumstances, when they happen they lead to more losses per event compared to the other circumstances (Fig. 1b). Given the fast onset of flash flood events, people in recreational areas may be more subject to surprise, as their remote locations lower their chances to be weather aware and warned, limiting the speed of their response. Moreover, people are more likely to be grouped together in campsites rather than traveling alone. However, the outside/open-air or close-to-streams events are more typical for impacting individuals rather than groups of people.

Temporal characteristics of the fatalities. The annual number of flash flood fatalities varies significantly from a minimum of 19 in 2012 to a maximum of 118 in 1998 with an average of 57 fatalities per year from 1996 to 2014. The most deadly events in 1998 were related to the great October flood that drowned at least 25 people in multiple counties in south-central Texas (NOAA 1999). According to the Storm Events Database episode narratives, huge livestock losses on the order of tens of thousands, and almost 3,000 destroyed homes and 8,000 damaged homes characterized that event. Nearly 1,000 mobile homes were destroyed and another 3,000 mobile homes were damaged.

Flash flood events and associated fatalities show no clear trend from 1996 to 2014 (figure not shown). A similar observation was noted for the flood fatalities from 1959 to 2005 and for vehicle-related flood fatalities from 1995 to 2005 across the United States, presented by Ashley and Ashley (2008) and Kellar and Schmidlin (2012), respectively. As the Storm Events Database continues to grow after the execution of the current analysis, 118 more human losses related to 70 reported flash flood events were recorded for the study area in 2015 (data available at www.ncdc.noaa.gov/stormevents/ftp.jsp). The lack of decreasing fatalities can be partly explained by increases in exposure due to population growth especially in the South and West during the study period (U.S. Census Bureau 2016). However, it also indicates that despite recent technological improvements in the forecasting and watch-warning system, they did not necessarily lead to prevention of losses from flash floods. This flash flood–specific finding is in contrast to other weather-related hazards losses, such as tornadoes (Brooks and Doswell 2002) and lighting (Ashley and Gilson 2009), in the United States, which show a stabilized or even decreasing trend with time, respectively (Ashley 2007; Ashley and Strader 2016).

The monthly analysis indicates that the peak in fatalities and fatal events occurs from May through

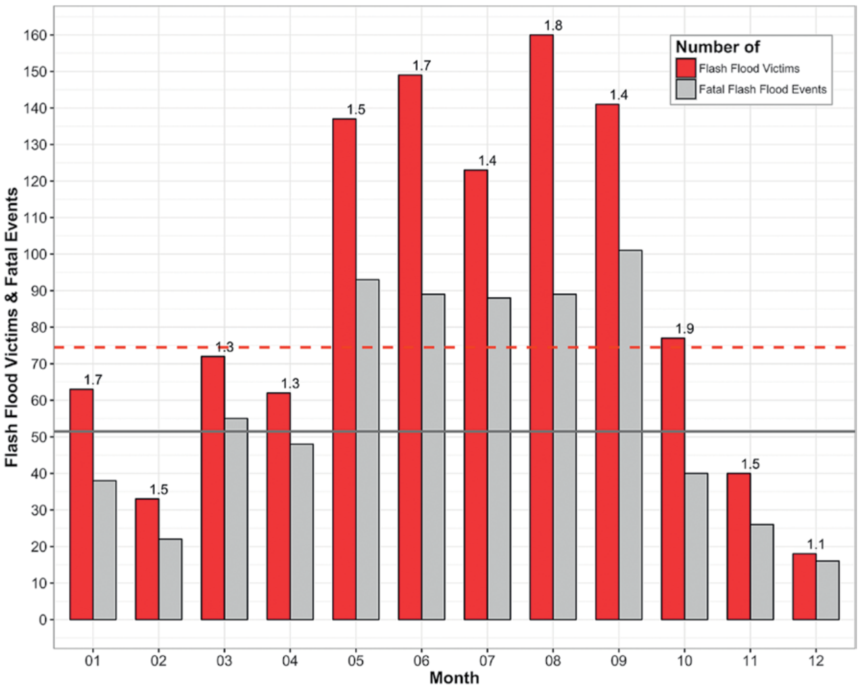

Fig. 2. Monthly frequency of flash flood victims (*n* = 1,075) and fatal events (*n* = 705) from 1996 to 2014. The dashed red horizontal line represents the monthly fatality median, and the solid gray line represents the monthly fatal event median. The values on the top of the fatality bars indicate the ratio of flash flood victims per fatal event for each month.

specific to rare, individual events, and that additional investigation into social spatiotemporal behaviors is warranted.

Flash flood duration is estimated as the difference between the beginning and the end times of the causative event available for 954 out of the total 1,075 fatalities in our dataset. The calculated duration is rounded to closest hour. The event durations are often reported for an entire episode rather than the specific causative flash flood event. For instance, a land-falling tropical storm can take days to traverse a region and yield multiple impacts and fatalities. This type of flash flood event will be handled with a single report in the Storm Events Database that will inevitably cover the event's duration from landfall until the time of its final impact. As such, caution is warranted when interpreting results for the long-duration reports in contrast to the event durations that occur within approximately 10 h.

The cumulative percentages of the flash flood fatalities per hour illustrates that 54% of the fatalities are associated with very short events (5 h or less), whereas 77% happened in events that lasted 10 h or less. There are differences between fatalities that are related to outside and inside activities (Fig. 4). Specifically, on average, people in outdoor circumstances such as the vehicle-related, open-air/close-to-streams, and camping/recreational categories drowned in very fast and dynamic flash flood events with durations close to 5 h. The distribution of the flash flood duration in the camping circumstance presents much less variation, indicating that it is the very fast-reacting events that surprise and trap people in recreational areas. Rapid flash floods imply limited time for warning, anticipation, and reaction (Creutin et al. 2009; Špitalar et al. 2014). On the other hand, fatalities that are related to permanent buildings or mobile homes have durations with central tendencies of more than 7.5 h. The median of the distribution of victims being in a permanent structure is about 8 h, meaning that longer-duration flash floods are the threatening ones for people inside.

September with a peak in August (Fig. 2). Sixty-six percent of the annual fatalities and 65% of the flash flood fatal events occurred during this warm-season period. The warm-season preference of both flash flood fatalities and fatal events has been attributed to the spatiotemporal distribution of heavy precipitation in previous analyses (Ashley and Ashley 2008; Sharif et al. 2015; Špitalar et al. 2014). Figure 2 also shows that although fewer in number, fall events during October were particularly deadly with almost two fatalities per event. A total of 77 fatalities were recorded in 40 flash flood events that happened in the states of Texas, Missouri, and Puerto Rico throughout the 19-yr period. Almost half of these fatalities resulted from just three meteorological episodes, all of which occurred in 1998: the great October flood in Texas, the 4 October event in Missouri, and the 22 October tropical storm–related flash flood in Puerto Rico (NOAA 1998, 43, 44, 73, 88–91).

When monthly fatalities are examined by circumstance, it reveals that in all months except for July more than the half of the monthly fatalities are related to vehicles (Fig. 3). The domination of vehicle-related incidents through the years and months confirms that the association of the majority of fatalities in the dataset with vehicle-related circumstances (Fig. 1a) is not

To better understand the social risk factors, the distribution of fatalities by the local hour of day of the flash flood occurrence is presented by circumstance in Fig. 5. Flash floods occur at any time of day, but when associated with the hours of twilight and darkness, they become more severe in terms of lethal impacts (Špitalar et al. 2014). In our study, 38% of the 1,075 fatalities occurred during nighttime hours [after 2100 until 0600 local time (LT)]. When viewing flash flood fatalities by circumstance, however, differences appear in the timing of the vehicle-related and outside/open-air events. In this study, 41% of the vehicle-related fatalities are associated with nighttime events, whereas only 24% of the outside/open-air fatalities occur in darkness. Being unable to view the details of the floodwaters, such as its mere presence, depth, or movement, yields greater vehicle-related flash flood fatalities during darkness. The secondary peaks of vehicle-related fatalities in events that occurred early in the morning (between 0500 and 0600 LT) and late evening (between 1900 and 2100 LT) indicate that people often refuse to change their daily mobility schedule (i.e., commuting to/from work) even with the occurrence of floodwaters on the roadways. In many cases, victims did not enter the flooded roads accidently; rather, they intended to drive through low-water crossings or bridges to reach their homes, probably motivated by their confidence in their vehicles and driving capabilities in a familiar area (Drobot et al. 2007; Ashley and Ashley 2008; Maples and Tiefenbacher 2009).

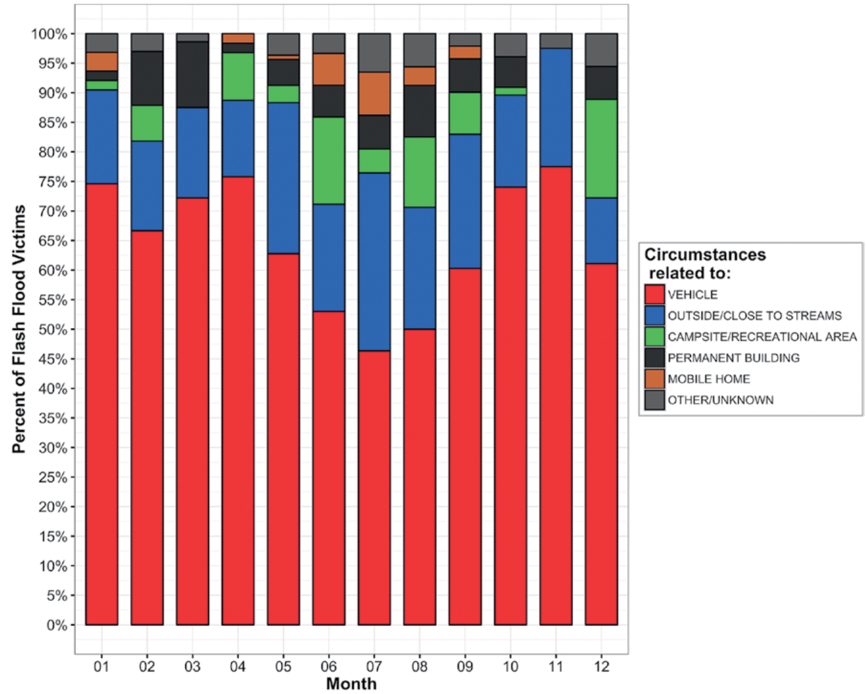

Fig. 3. Percentage of flash flood victims by circumstance of the death for each month. The proportions of each circumstance (if it exists) in a certain month are calculated by dividing the victims in that month by circumstance to the total victims in the specific month.

On the other hand, 76% of the outside/open-air events occur during daylight hours. The Storm Events Database narratives reveal that in many outside/open-air circumstances, adults were swept away while performing some cleanup operation to protect their respective properties. Also, children and teenagers were swept into creeks while playing near high waters. The daylight conditions probably enabled the victims to participate in such outdoor activities. Risky behaviors can occur when people feel familiar with their environment or prioritize their property savings (Ruin et al. 2014). Concerning camping/recreational area fatalities, there are two maxima in the timing of flash flood events. The secondary maximum occurs during daylight hours closer to the climatological peak of heavy rainfall and flash flooding. These are events that trap people in recreational areas, such as in canyons in the desert Southwest. The primary nocturnal peak occurs between 0100 and 0200 LT. These are nighttime rest hours, where the surprising nature of the flash flood is exacerbated by low visibility and rescue operations are further hindered.

Sociodemographic profile of the victims. Age and gender of the victims are known for 94% and 98% of the flash flood fatalities, respectively. Sixty-one percent of the victims with defined gender were males. A one-sample chi-square test with proportions predefined according to the distribution of males and females in the U.S. population (U.S. Census Bureau 2010) reveals that the vulnerability of males is statistically significant at $\alpha = 0.05$ ($p \leq 0.05$). Further analysis has shown that males exceed the number of females in all the fatality circumstances, except for a small difference in mobile home cases. In the literature, overrepresentation of males is usually assigned to risky behavior or the fact that they are more exposed, as they are frequently employed in emergency services (Coates 1999; Jonkman and Vrijling 2008; Doocy et al. 2013).

The victims' age ranges from baby (noted as 1 year old in the dataset) to elderly (i.e., 93 years old). Ashley and Ashley (2008) found enhanced vulnerability for those in the 10–29-year-old and >60-year-old categories when compared with the U.S. Census data in 2000. Box plots of age distribution for males and females in each fatality circumstance show that almost 50% of the males in vehicle-related fatalities were between 24 and 62 years old (Fig. 6). This finding can be partly explained by the fact that 80% of licensed drivers are between 20 and 64 years old according to the Federal Highway Administration (FHWA 2009). The outside/open-air circumstances are more likely to take the lives of younger people, with a median age for females of 29 and just 22 for males. Many of the outside/open-air events are a result of children who either investigate or even play in dangerous floodwaters; these fatalities could be largely preventable through educational campaigns (Ronan and Johnston 2001). Vehicle-related events tend to strike the middle-aged; outside/open-air events are connected to the young; the permanent building events tend to impact the elderly. The median ages for female and male victims in this category are 65 and 53, respectively. Elderly people inside buildings may have limited mobility, be emotionally attached to their belongings, or be unaware of the dangerous situation, which makes them vulnerable to flash flood events even in their own homes (Gladwin and Peacock 1997).

Spatial distribution of flash flood fatalities. From 1996 to 2014, there were fatalities reported in 49 U.S. states and territories with the exception of Rhode Island, Massachusetts, and the District of Columbia. The state-based analysis of vehicle-related fatalities reveals some patterns (Fig. 7a). First, there is a dearth of reports in a large swath of the Intermountain West. The hot spot for vehicle-related fatalities extends from Texas eastward into the South, reaching maximum positive anomalies in Alabama (33%) and Mississippi (32%). Central and south-central Texas hold records for extreme rainfall rates that have led to some of the greatest flood peaks nationwide (O'Connor and Costa 2004). In the literature, the domination of vehicle-related flash flood fatalities in those areas have been mainly attributed to increases in exposure associated with rising population densities in urban areas with physiography susceptible to flash flooding (i.e., Flash Flood Alley) (Sharif et al. 2012). While additional research is warranted on this topic, it is likely that this increased exposure combined with intense rainfall rates and the prevalence of low-water crossings extends vehicle-related fatality occurrences eastward across the South. The outside/open-air circumstance in Fig. 7b reveals no significant regional preferences, indicating risky behaviors such as playing in floodwaters, taking photographs, or cleaning out a drain are problematic on a national basis.

The sample sizes with the camping/recreational area events in Fig. 7c are smaller, but there are very clear regions that are particularly vulnerable to flash flood fatality events in recreational settings. Canyon hiking and camping in the states of Utah and Arizona claim the lives of many during the warm season. Most of these victims, several of whom are foreign, are not familiar with their environment and do not readily recognize a

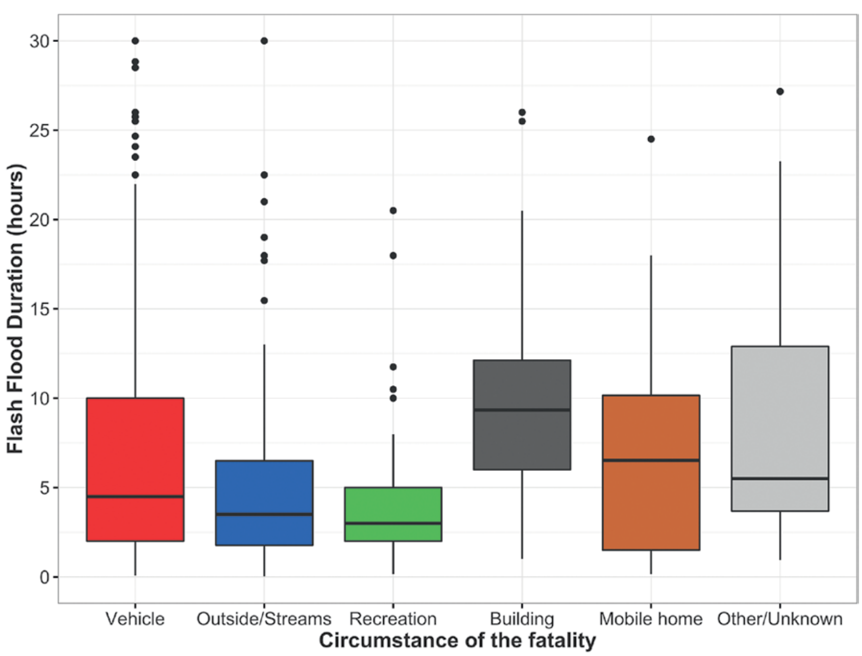

Fig. 4. Distribution of the flash flood duration discretized by the circumstance of the related deaths. Box plots are constructed for each circumstance separately for the fatalities for which the duration of the causative event can be estimated and it is less than or equal to 30 h (*n* = 921).

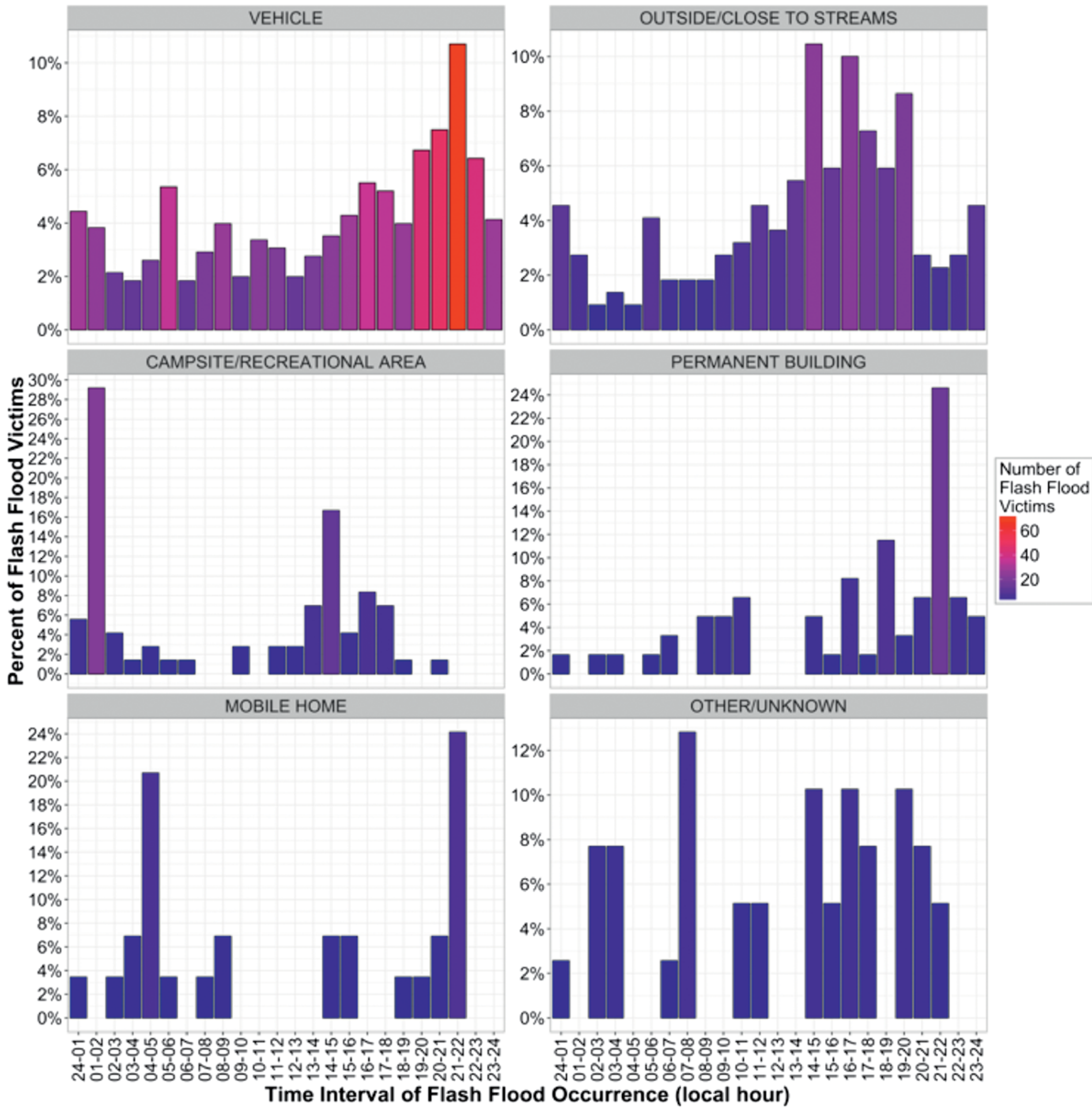

Fig. 5. Percentage of flash flood victims by the local timing of flash flood occurrence discretized by the circumstance of the related deaths. The flash flood occurrence time is represented by hourly intervals [e.g., a flash flood event occurring between 2400 (i.e., 0000) and 0100 LT is assigned to the interval 24-01]. Percentages of flash flood victims (gradient colored bars) in each hourly interval are calculated using the total fatalities in each circumstance. The color in the bars depicts the number of victims associated with events occurring in that hourly interval and that circumstance.

hazardous situation. This problem is exacerbated by the nature of the flash flood events that can cause damage and impacts to areas well downstream from the causative rainfall. Many canyons have sheer, steep walls, making a quick escape very difficult. The states of Arkansas and Hawaii also appear as being vulnerable to camping/recreational area flash flood events. Arkansas stands our primarily due to the Albert Pike campground flood that killed 20 people on 10 June 2011 (Holmes and Wagner 2011). These camping-related fatalities could be mitigated through more active local awareness activities, alerting systems, and escape routes (e.g., permanently placed ropes). There are no strong regional signals with permanent building or mobile home fatalities. However, the states of Hawaii and Ohio have large positive anomalies for permanent building fatalities, and Colorado stands out in mobile home fatality circumstances.

DISCUSSION AND CONCLUSIONS. In the twenty-first century, the prediction of and subsequent response to impacts due to sudden onset and localized flash flood events remain a challenge for forecasters and emergency managers. Structural measures and/or advances in hydrologic forecasting systems alone do not guarantee reduction of fatalities during short-fuse flood events (Ashley and Ashley 2008). Additional factors related to social and behavioral processes need to be integrated to capture the vulnerability of people during flash floods. Therefore, identifying the social, spatial, and temporal framework of the historic losses of life during flash floods is key to gaining a deeper understanding of the contextual risk factors and to advance vulnerability assessment and future prevention policies.

In this study 1,075 flash flood–specific human losses from 1996 to 2014 on the scale of the United States were assigned to six main categories/circumstances and were investigated correspondingly. This database is now part of the unified flash flood database described in Gourley et al. (2013) and is publicly available online (http://blog.nssl.noaa.gov/flash/database/). One recommendation coming out of this study is for the National Weather Service to consider classifying each flash flood fatality into the categories developed herein. The purpose of our analysis was to explore whether different vulnerability paths occur depending on the situation, as determined by the victims' profile and activity and the spatiotemporal context of the flash flooding. Indeed, we find that the circumstances associated with flash flood fatalities have certain characteristics related to season, time of the day, duration of the flood, location, and tends to be associated with specific age and gender groups. We have conducted this analysis in preparation for more sophisticated and targeted alerting systems that will incorporate these sociodemographic characteristics. Future targeted alerts can be communicated when we can collocate the location of risky incidents in space (e.g., roads, campsites, and mobile homes) with specific vulnerable groups (e.g., certain age groups and gender). The findings highlight the importance of situation-specific assessment of flash flood fatalities to guide the development of flash flood–specific vulnerability and impacts modeling. In this direction, recording as many details as possible for the life-threatening scene in the Storm Events Database, and especially placing emphasis on the profile and intensions of people involved, is of high importance for future methodological developments.

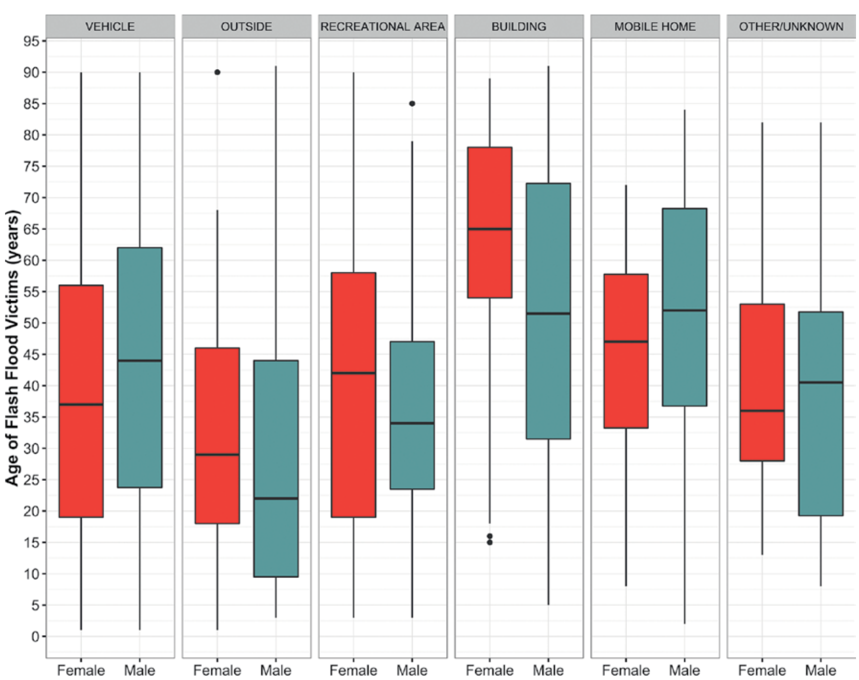

Fig. 6. Distribution of age by the gender of flash flood victims discretized by the circumstance of the death. Box plots are constructed for each circumstance separately for the victims with known age and gender from 1996 to 2014 (*n* = 1,003).

Further work will focus on supplementing the reclassified fatality dataset with other variables describing the storm event, the spatial distribution and sociodemographics of the exposed population, and the exposed built environment. Then, a statistical classification model can be applied to obtain trends and patterns in the probability of a fatality to occur in certain circumstances. Such a probabilistic approach serves as a promising method to quantify the time- and space-dependent vulnerability factors using representative indicators. We expect that this human-impact-based predictive approach will contribute to renewing alerting systems, making them more specific and effective in triggering timely preventive actions by

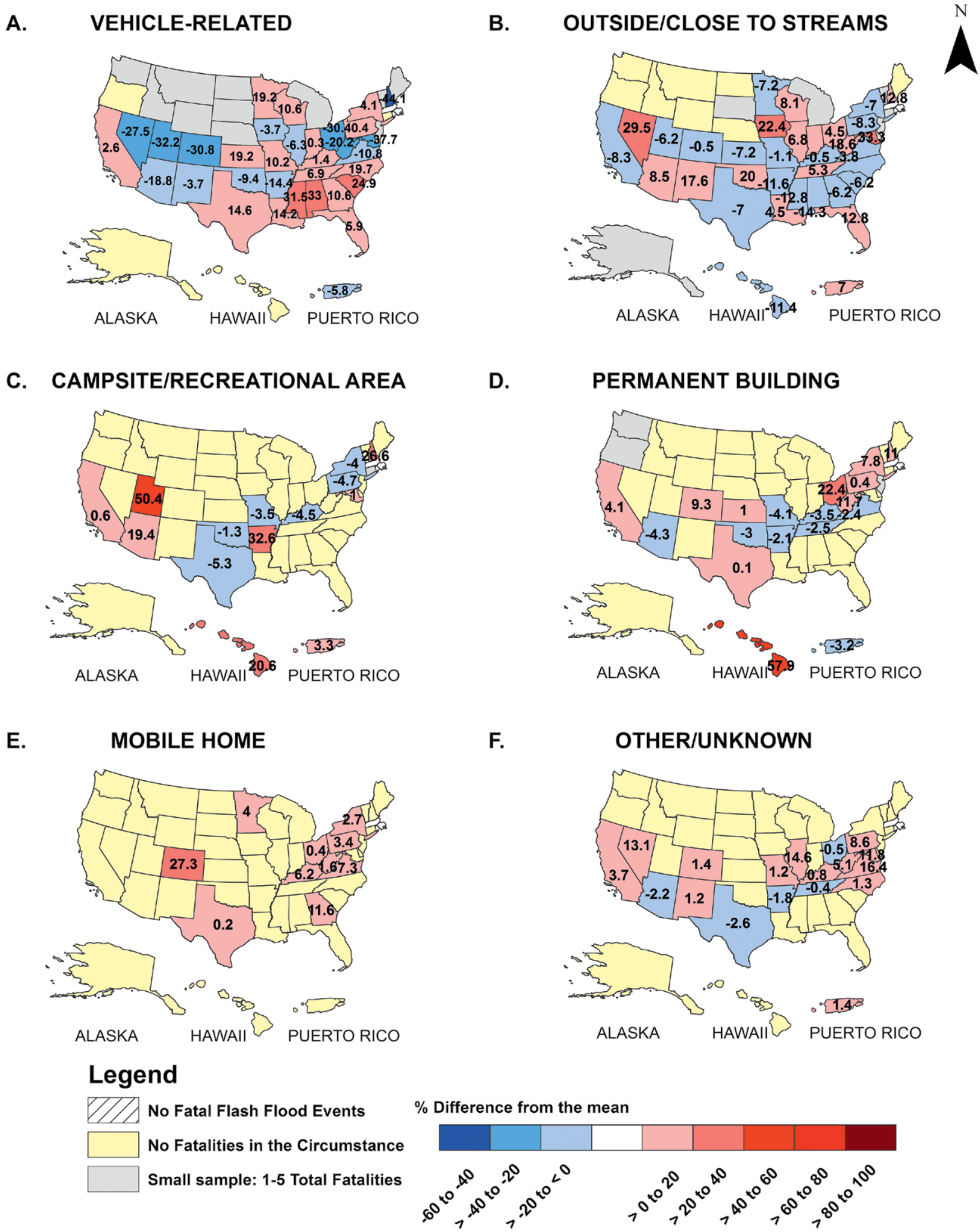

Fig. 7. State-level flash flood fatalities for each circumstance represented as the difference between the percentage of fatalities in each state and the percentage of the fatalities in the entire United States . The number in each state indicates the exact value of the percentage of difference for the states that had fatalities occurring in the depicted circumstance and refer to states with more than five fatalities in total from 1996 to 2014.

the public, finally leading to a decrease in the trend of fatalities caused by flash flooding.

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