Flood Fatalities in the United States

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ABSTRACT

This study compiles a nationwide database of flood fatalities for the contiguous United States from 1959 to 2005. Assembled data include the location of fatalities, age and gender of victims, activity and/or setting of fatalities, and the type of flood events responsible for each fatality report. Because of uncertainties in the number of flood deaths in Louisiana from Hurricane Katrina, these data are not included in the study. Analysis of these data reveals that a majority of fatalities are caused by flash floods. People between the ages of 10 and 29 and >60 yr of age are found to be more vulnerable to floods. Findings reveal that human behavior contributes to flood fatality occurrences. These results also suggest that future structural modifications of flood control designs (e.g., culverts and bridges) may not reduce the number of fatalities nationwide. Spatially, flood fatalities are distributed across the United States, with high-fatality regions observed along the northeast Interstate-95 corridor, the Ohio River valley, and near the Balcones Escarpment in south-central Texas. The unique distributions found are likely driven by both physical vulnerabilities for flooding as well as the social vulnerabilities.

1. Introduction

According to a recent National Weather Service (NWS) assessment examining 10 yr of weather-related fatality data (http://www.weather.gov/os/hazstats.shtml), floods—whether originating because of heavy rain, snowmelt, structural failure, or a combination of these factors—are the second deadliest (in comparison with heat) of all weather-related hazards in the United States. Kunkel et al. (1999) found that fatalities in the United States have generally increased during the past 25 yr in comparison with the early and middle part of the twentieth century. Moreover, flood damage costs for the United States steadily increased through the twentieth century (Pielke and Downton 2000; Pielke et al. 2002; Downton et al. 2005). Floods that significantly disrupt or incapacitate a society by causing a large number of fatalities and costly damage have primarily been associated with developing countries, for example, Bangladesh (Wisner et al. 2004). However, in recent decades, some of the most extensive, damaging, and costly floods have occurred in wealthy countries. A prime example of this occurred in 1993 in the United States along the Mississippi River basin and its major tributaries, where cities and towns located in the floodplain were devastated or entirely destroyed. More advanced economies, like the United States, quickly discovered that they were not immune to such natural phenomena despite governmental attempts to control natural processes through levees, concrete abutments, and the like (Smith and Ward 1998).

Floods are naturally occurring events that are dependent not only on rainfall amounts and rates, but also on the topography of the area, land use of the region, soil type of the watershed, and antecedent moisture conditions (Funk 2006). These periodic events are detrimental to a society when people are located in their pathways. In general terms, vulnerability means a potential for loss dictated by both a society's resilience and potential exposure to the hazard (Cutter 1996; Cutter et al. 2000). However, since the early 1980s there have been many variations of this definition since this term means different things to different people (Cutter 1996). Wisner et al. (2004) state that a combination of factors including the physical environment (e.g., house located on erodible or low-lying land), the local economy (e.g., low-income neighborhoods), and the performance of public actions (e.g., driving through a flooded street) and institutions (e.g., inadequate warn-

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ing dissemination) may contribute to unsafe conditions for the population. They add that specific social characteristics, such as economic class and/or gender, also enhance a person's vulnerability.

Flooding can be separated into three main categories: flash flooding, river flooding, and coastal flooding (French and Holt 1989). Flash flooding is defined by the NWS as "a flood that rises and falls quite rapidly, usually as a result of intense rainfall over a small area, in a short amount of time, usually under 6 hours," river flooding is defined as "the rise of a river to an elevation such that the river overflows its natural banks causing or threatening damage," and coastal flooding pertains to "flooding which occurs from storms where water is driven onto land from an adjacent body of water" (http://www.srh.noaa.gov/fwd/glossarynation.html). Coastal flooding can be generated from storms on a variety of scales, including a local thunderstorm to large midlatitude cyclones such as northeasters or tropical systems such as hurricanes.

Several past investigations have examined U.S. flood-related fatalities (French et al. 1983; Mooney 1983; Dittman 1994; Coates 1999; Rappaport 2000; Thomas and Mitchell 2001; Jonkman and Kelman 2005; Jonkman 2005). Examining fatalities by state for 1959–91, Dittman (1994) found that, on average, there were 119 flood deaths per year in the United States. French et al. (1983) determined that a majority of the flash floods during 1969–81 occurred during the warm season spanning July–September, with September representing the peak fatality month. French et al. (1983) also found that 93% of flash flood fatalities were due to drowning and 42% of these were vehicle-related.

Mooney (1983) examined fatalities during a relatively short time frame (1977–81) and found that 60% of the deaths in the United States occurred in either urban or suburban areas, with nearly 75% of the fatalities taking place in the evening or overnight hours. Of the fatality reports that included information on how and where they occurred, nearly one-half occurred in vehicles. Accordingly, Zevin (1994) reports that 80%–90% of annual flood deaths are caused by flash floods, with approximately 40% of these fatalities associated with pedestrian stream crossings or vehicles. Jonkman and Kelman (2005) investigated the causes of European and U.S. flood disaster deaths (1989–2002) as well as circumstances surrounding those fatalities. All of the above studies found that fatalities are highest among males, and that there is an enhanced vulnerability for those <21 yr old and >60 yr old. However, Jonkman and Kelman (2005) could not confirm these previous findings of an age-related vulnerability to floods.

Other studies have examined loss of life associated with tropical cyclone flooding (Rappaport 2000; Cerveny and Newman 2000). Rappaport (2000) compiled a database of tropical cyclone fatalities using newspapers and NWS publications and found a higher percentage of male deaths. Vehicle-related deaths only accounted for 23% of the resulting tropical cyclone fatalities. This is a lower percentage than that found by Mooney (1983), Zevin (1994), and Coates (1999) in their research of flood-related deaths. Disparities in the recent literature may be due to fundamental differences between the studies. For example, the periods of record differ from each study, varying from just 5 yr (Mooney 1983) to 33 yr (Dittman 1994). Moreover, the studies do not encompass *all* flood-related deaths but instead focus specifically on flash floods or tropical cyclone floods. In the case of Jonkman and Kelman (2005), their study is explicit to flood disasters (i.e., more than 10 people killed, more than 100 people affected, state of emergency declared, or call for international assistance).

From this limited body of research on flood-related deaths in the United States, no study has presented a *comprehensive* spatial and temporal analysis of flood-related deaths. Past studies are restricted by the number of years analyzed or by a limited focus on particular flood types. This study is the first to construct a database of fatalities associated with all flooding events in the United States (with related demographic information) from 1959 to 2005. Results highlight the specific vulnerabilities associated with floods in the United States, including social vulnerabilities (i.e., gender, age) and physical vulnerabilities (i.e., activity leading to fatality, structure where fatality occurred). These data are examined spatially so that regions of the United States that are most vulnerable to flood events may be defined. The underlying objective is to improve awareness and education of this hazard to emergency managers, forecasters, and, ultimately, the people of the United States.

2. Data and methodology

a. Fatality database compilation

The database of 1959–2005 flood-related fatalities was compiled using monthly reports from volumes 1–47 of the National Climatic Data Center's (NCDC) *Storm Data*. *Storm Data* includes such information as storm occurrences or other weather phenomena that cause significant loss of life, injuries, property damage, and/or disruption to commerce. Although *Storm Data* (under the title of *Climatological Data*) was first issued in 1950, the information gathered was restricted to tornadic storms, although by 1955 hail and thunderstorm wind data were included. In 1959 the publication officially became known as *Storm Data* and incorporated all storm and weather data as available in the publication today. *Storm Data* is currently the primary source of severe weather event data used by atmospheric and hazard scientists for determining storm location and resulting casualties. Information is gathered predominantly through the NWS, although other sources may be used including media, law enforcement agencies, and governmental agencies as well as private companies and individuals.

For this study, any inaccuracies of fatality data found in *Storm Data* are assumed to be that of underreporting. For example, Curran et al. (2000) found that for "smaller impact" events, such as lightning, *Storm Data* typically underreports the number of casualties because these events draw less attention in comparison with "larger impact" events (e.g., tornadoes). Thus, larger-impact flood events (e.g., the Rapid City, South Dakota, 1972 flood event) should be reported more accurately in *Storm Data* because of the considerable number of people that were affected and the high-profile nature of the event. However, 85% (94%) of the flood fatality dataset is made up of smaller-impact flood events that attract little public or media attention since they only affect a small stream or single town and consequently kill one or two (<five) people. Nevertheless, *Storm Data* comprises the nation's best estimate of hazard-event casualty information; however, it is likely that the tallies reported in *Storm Data* and within any analysis of the dataset will produce a conservative estimate of human fatalities due to flooding.

In some instances, *Storm Data* did not indicate whether a fatality report from a tropical system (i.e., a tropical depression, tropical storm, or hurricane) was due directly to flooding or another aspect (e.g., wind) of the cyclone. Rappaport (2000) examined the inland threat to life from Atlantic Ocean tropical systems from 1970 to 1999 and found that 80% of all deaths were due to drowning. Of these drowning deaths, 72% (or almost 60% of all tropical system deaths in his database) were due to freshwater flooding and storm surge. Because he found that inland flooding caused a large majority of the tropical system deaths, the decision was made to include all tropical system fatalities that were unclear on the direct cause of death (e.g., wind or flooding). Because of this inclusion, it is expected that tropical system fatalities are inflated, but the exclusion would substantially underestimate the influence of tropical system flood-related fatalities in the United States.

Data from Rappaport (2000) were used to verify whether the deaths from 1970 to 1999 were due to inland flooding. Therefore, any report from *Storm Data* in which the cause of death was not determined [either through verification from the Rappaport (2000) dataset or through a detailed entry in *Storm Data*] was included in the dataset, although they were kept as a separate category for analysis. This separation can be identified in later figures and are labeled "unidentifiable tropical system" deaths. These fatalities may include deaths due to inland flooding, storm surge, rough seas, tornadoes, or wind.

The flood fatality database constructed for this study includes all deaths that are contributable directly to the flood event (e.g., death due to drowning or death due to physical trauma within water). Indirect, or secondary, flood fatalities (e.g., death due to electrocution or death due to rain-slicked roads from heavy rain) were not included in this analysis. Each report in the database consists of the following variables:

1) state, county, and city (if provided) of the fatality report,
2) date and time (local standard time) of incident,
3) flood event type,
4) activity/location surrounding the incident, that is, what the person was doing or where the person was located when he/she encountered the flood waters (if provided), and
5) demographic information of report (e.g., age and gender; if provided).

In general, *Storm Data* classifies the flood-related fatalities either as "flash floods" or "river floods"; therefore, each fatality was subdivided by flood type. A report was categorized as "unknown" if the description in *Storm Data* was specific enough to know that flooding was occurring, but not detailed enough to know whether it was a flash flood or river flood. This typically occurred in the 1960–1970s before standardized methods for report entry were instituted for *Storm Data*. Not included in this database were fatalities occurring in coastal waters or along a shoreline.

Storm Data is not a flawless source for casualty reports; however, the publication is unique and the only kind of dataset of its type and thus must be used for this type of analysis. The decision on inclusion/exclusion of cases in this study was made as judiciously as possible. Despite this inherent subjectivity, the results should not be altered significantly based on the inclusion or exclusion of a minimal number of reports relative to the total number within the database.

The exclusion of fatality estimates from Hurricane Katrina from the state of Louisiana was purposeful. Currently, these values have not been provided by the NWS, NCDC, or reported in *Storm Data*. This is because these tallies are still unknown. A Tropical Prediction Center (TPC) report indicated that the number of known fatalities in Louisiana is 1090 (Knabb et al. 2005). The report states that the fatalities may have been directly o*r indirectly* related to Katrina, but state that there were roughly 1000 directly related deaths due to Katrina. Additionally, the report indicates these fatality numbers are estimates and are "highly uncertain" and the true number "may never be known." This uncertainty arises because complete statistics on causes of death are not available from all counties affected by the storm. At the time the TPC report was written, not all the dead had been recovered, many more were still reported missing, and the causes of death were still being investigated. The report does speculate that a majority of the deaths in Louisiana were directly caused by the widespread surge-induced flooding and its aftermath.

In June 2006, the NWS released a service assessment on Hurricane Katrina estimating that direct deaths from Katrina are approximately 1353 (Johnson 2006). This estimate includes fatalities from all states impacted by Katrina. Until an accurate fatality estimate can be established, the inclusion of these estimates would add a substantial component of uncertainty to the analysis and are, therefore, not employed.

b. Geographic analysis

The flood-related fatalities were classified by each variable in the dataset (i.e., state, year, month, flood type, activity, gender, and age). Additionally, the fatalities were aggregated by event report and classified in addition to the raw fatality numbers. These classifications reveal the temporal distribution of floods in the United States, the most dangerous type of flood in the United States, the activities (or structures) that are most vulnerable to flood-related fatalities (vehicle versus home), as well as the demographic characteristics of those most vulnerable to floods in the United States.

Fatality data are mapped in a geographic information system (GIS) on a 40 km $\times$ 40 km grid using the latitude and longitude of the location of the report. A 40-km grid was chosen to best represent the size of a typical county or parish. Generally, a town or city is provided as the location of the report, although, at times, the data are provided by county only. In cases in which only the county is reported, the latitude and longitude of the county seat was utilized. From these maps, the geography of flood-related fatalities can be described and any regions with high or low numbers of fatalities can be determined. For many tropical system fatality reports, only a state (or multiple counties) was provided because of the large number of fatalities associated with the event. Therefore, fatalities by state are mapped (standardized by population) to include these reports. The state fatalities (standardized by population) are mapped separately by flood event type including flash flood, river flood, tropical system flood.

3. Results: Flood fatality statistics

During the 47 yr of the study, a total of 4586 fatalities occurred in the contiguous United States. On average, there are approximately 97.6 fatalities per year. Comparatively, the NWS computes the average number of fatalities (from a 30-yr period) as 107 (http://www.weather.gov/os/hazstats.shtml), while Jonkman (2005) found the average to be 100 over a 28-yr period. The discrepancy in totals reported is due to the differing periods of records examined. The median value for reported fatalities is 81 yr^{-1}. The median is more representative because extreme values inflate the average. Ranking the data by state illustrates that Texas has the most fatalities for the United States, while Pennsylvania and South Dakota follow in ranking (Table 1). When the data are ranked by fatalities per flood event, it is evident that flash floods (especially those from dam failures) and floods associated with tropical storms are the flood types most typically associated with large fatality numbers (Table 2).

a. Frequency by year

The number of flood fatalities per year is highly variable, from a low of 23 in 1962 to a high of 451 in 1972 (Fig. 1). Moreover, no statistically significant trend in fatalities is evident over the period of record. Relative to other weather-related hazards the lack of a decreasing trend is unique. Both lightning and tornado fatalities were found to be decreasing over the second half of the twentieth century (López and Holle 1996; Brooks and Doswell 2002; Boruff et al. 2003). Curran et al. (2000) state that the reduction in lightning deaths may be due to improved medical care as well as emergency communication and transportation, while recent improvements in the watch–warning system and detection has decreased the threat to life from tornadoes (Doswell et al. 1999; Brooks and Doswell 2002). Despite these technological advancements, there has been no significant decrease for flood risk. Deadly flood events are also variable over the 47 yr, although no extreme years are evident.

Of the five anomalously high years, two of the years are characterized by a single large flash flood event. In 1972, a dam near Rapid City, South Dakota, failed, which flooded the entire downtown during the night (Maddox et al. 1978; Carter et al. 2002; Bryant 2005).

TABLE 1. The frequency of known flood (all types) fatalities, injuries, and casualties with their ranks, for the 48 contiguous states (plus DC) from 1959 to 2005. The table excludes Hurricane Katrina fatalities from Louisiana. Boldface font indicates the top 5 ranking states.

	Fatalities		Injuries		Casualties	
State	Frequency	Rank	Frequency	Rank	Frequency	Rank
Alabama	67	22	40	33	107	29
Arizona	68	21	115	19	183	24
Arkansas	121	15	140	17	261	16
California	241	**4**	322	9	563	7
Colorado	185	6	333	8	518	9
Connecticut	12	42	3	47	15	45
District of Columbia	4	47	5	44	9	47
Delaware	14	37	13	40	27	41
Florida	75	20	1884	**5**	1959	**5**
Georgia	120	16	93	21	213	19
Idaho	4	48	3	48	7	48
Illinois	51	27	41	32	92	30
Indiana	60	24	55	29	115	27
Iowa	45	29	202	15	247	17
Kansas	52	26	33	36	85	31
Kentucky	137	12	623	6	760	6
Louisiana	100	18	5473	**3**	5573	**3**
Maine	11	44	2	49	13	46
Maryland	96	19	99	20	195	23
Massachusetts	5	46	62	27	67	35
Michigan	27	35	35	35	62	36
Minnesota	46	28	244	11	290	14
Mississippi	170	7	5711	**2**	5881	**2**
Missouri	160	8	45	30	205	21
Montana	45	30	8	43	53	39
Nebraska	14	38	13	41	27	42
Nevada	29	34	80	23	109	28
New Hampshire	12	43	12	42	24	43
New Jersey	45	31	244	12	289	15
New Mexico	60	25	83	22	143	26
New York	125	14	257	10	382	13
North Carolina	154	9	244	13	398	12
North Dakota	13	41	5	45	18	44
Ohio	146	11	61	28	207	20
Oklahoma	102	17	131	18	233	18
Oregon	44	32	31	37	75	34
Pennsylvania	256	**2**	206	14	462	10
Rhode Island	0	49	4	46	4	49
South Carolina	64	23	467	7	531	8
South Dakota	244	**3**	2949	**4**	3193	**4**
Tennessee	128	13	71	24	199	22
Texas	760	**1**	6846	**1**	7606	**1**
Utah	22	36	36	34	58	37
Vermont	11	45	43	31	54	38
Virginia	236	**5**	179	16	415	11
Washington	34	33	19	39	53	40
West Virginia	14	39	69	26	83	33
Wisconsin	147	10	21	38	168	25
Wyoming	14	40	71	25	85	32

This event killed 237 and injured 2932. Of all single-county flood events in the dataset, this flash flood killed the most people. This event coincided with a year that was already experiencing a large number of fatalities, primarily from tropical storm Agnes. In 1976, the large number of fatalities occurred because of a flash flood in the Big Thompson Canyon, Colorado, which killed 156 and injured at least 250 (Henz et al. 1976; Maddox et al. 1977; Albertson et al. 1978; Caracena et al. 1979). In this unique orographic-induced thunderstorm case, ex-

TABLE 2. Top 10 deadliest multiple county flood events from 1959 to 2005 in the United States. The table excludes Hurricane Katrina fatalities from Louisiana.

Rank	Year	State	Month	Type of Flood	Fatalities
1	1972	South Dakota	June	Dam failure	237
2	1976	Colorado	July	Flash flood	156
3	1969	Mississippi	August	Hurricane Camille	132
4	1969	Virginia	August	Remnants of Camille	109
5	1977	Pennsylvania	July	Flash flood	74
6	1972	Pennsylvania	June	Tropical Storm Agnes	50
7	1969	California	January	Flood and mudslides	41
8	1977	Georgia	November	Dam failure	39
9	1985	West Virginia	November	Remnants of Juan	39
10	1964	Montana	June	Flood	36

treme elevation relief and a narrow canyon played an important role in the strength of the current as it moved down slope.

Furthermore, 1977 experienced several high-fatality events across the United States. The largest fatality event during this year occurred in Cambria County, Pennsylvania, with 74 deaths due to a flash flood event. Heavy rain and overtopping or bursting dams were the leading causes of this deadly event (Bosart and Sanders 1981). Additionally, there were 39 deaths (45 injuries) due to a dam failure and resulting flash flood in Toccoa Falls, Georgia (Sanders and Sauer 1979; Land 1980). The dam broke at night and the floodwaters washed through downtown Toccoa Falls, the Toccoa Bible College, and a mobile home park. A smaller-scale event in Jackson County, Missouri, added to this deadly year by killing 25 people during a September flash flood event in the Kansas City metropolitan area (NOAA 1977).

The other two years with high-fatality reports were 1969 and 1973. During 1969, category-5 Hurricane Ca-

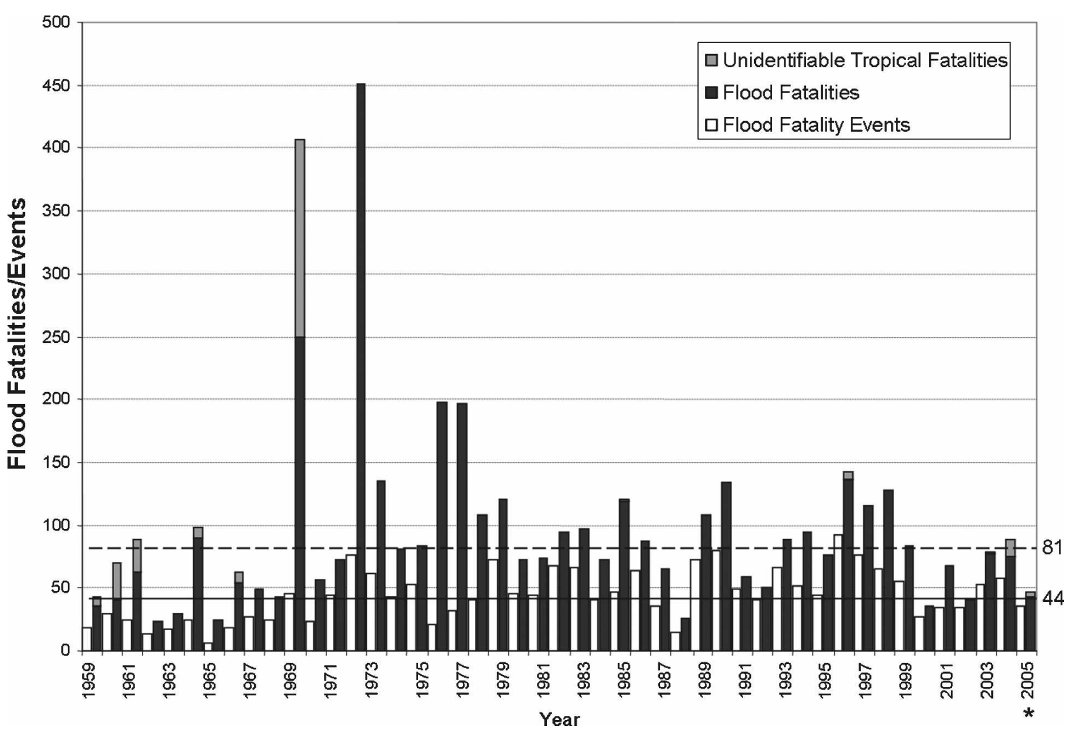

FIG. 1. The frequency of flood fatalities and fatality events (excluding indirect) from 1959 to 2005. Black bars represent deaths due strictly to flooding for all event types in the study. Gray bars represent deaths due to tropical systems but not to flooding alone. Light gray bars represent deadly events. The dashed horizontal line represents yearly fatality median, and the nondashed horizontal line represents yearly fatality event median. The asterisk indicates that 2005 data are preliminary and do not include Hurricane Katrina fatalities from Louisiana.

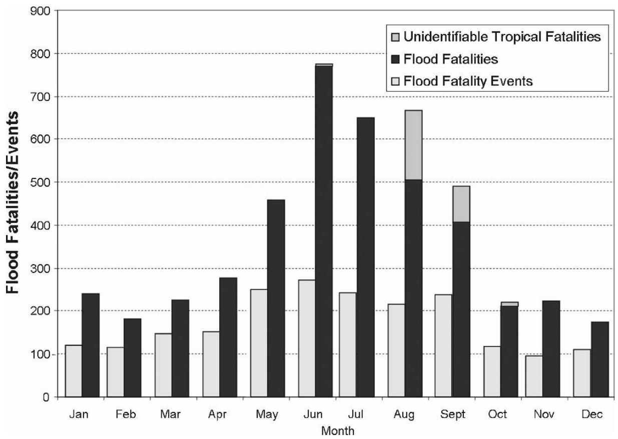

FIG. 2. The frequency of flood fatalities and fatality events by month (excluding indirect fatalities). Black bars represent deaths due strictly to flooding for all event types in the study. Gray bars represents deaths due to tropical systems but not to flooding alone. Light gray bars represent flood events with at least one fatality. The figure excludes Hurricane Katrina fatalities from Louisiana.

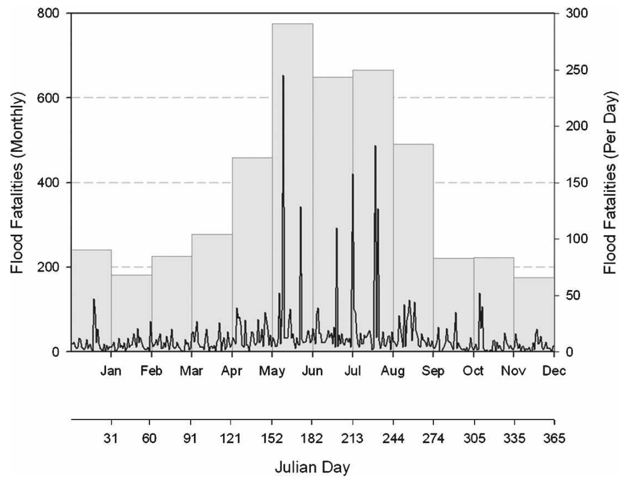

FIG. 3. The frequency of flood fatalities by month (bar chart) and yearday (line chart; 1 Jan represents yearday 1 and continues with sequential numbers through the year). The figure excludes Hurricane Katrina fatalities from Louisiana.

mille impacted the Gulf Coast, causing a large number of deaths as it came ashore. Additionally, heavy rain, flooding, and landslides were widespread across Camille's inland path: especially hard hit were the western and central portions of Virginia where more than 82 cm of rain fell in Nelson County in 24 h (NOAA 1999). In Virginia, 109 people were killed from the combination of flooding and landslides from the remnants of this hurricane. During 1973 there was no single event responsible for a large fatality frequency, but the year was characterized by numerous instances of heavy rain-induced floods and flash floods. A majority of these high-fatality years can be attributed to either a dam failure or flash flood that occurred at night.

b. Frequency by month

June represents the peak month for deaths from floods in the contiguous United States, and July and August are also high-fatality months (Figs. 2 and 3). A one sample chi-square test ($p < 0.01$) reveals that this distribution of fatalities among months does not occur by chance but instead peaks during certain months of the year (Rogerson 2001). This result differs from French et al. (1983), who found a September peak in fatalities. A reason for this disparity is due to French et al.'s inclusion of only 1969–81 data and their concentration on flash flood events. The high number of flood deaths in June and July can be explained by the prevalence of convective thunderstorms throughout the central and eastern half of the United States (Brooks and Stensrud 2000; Changnon 2001a,b; Ashley et al. 2003; Doswell et al. 2005). Fatal flood events show a similar pattern with a peak in June and high-event months occurring from May to September. The large frequencies of fatalities in August and September are largely from tropical storms in the Southeast, and the "monsoon" rains of the desert Southwest (see also Higgins et al. 1997). These two storm types alone make up 55% of the fatalities during these two months. The peak frequency for tropical systems is September (Landsea 1993); however, the peak frequency for tropical system flood-related deaths is August, with 41% of the deaths occurring during this month. Finally, there is a modest rise in fatalities from December to January, which is due to both rain-on-snow events in northern states (see also Branick 1997) and heavy rain events along the west coast (California, Oregon, Washington) resulting in landslides. These heavy rain and flood-induced landslides along the West Coast and rain-on-snow events in the north were responsible for 57% of all flood deaths in January.

A regional analysis of flood deaths, as well as the events that caused them, illustrates seasonal differences in fatality occurrences between the six regions delineated (Figs. 4a–f). For each region a one-sample chi-square test ($p < 0.01$) reveals that the fatality data are not randomly distributed across the months but instead are distributed according to a pattern of preference (Rogerson 2001). The Rocky Mountain (Fig. 4b) and Midwest (Fig. 4c) states have peaks in fatalities during the summer months, while the Pacific Coast states (Fig. 4a) show a peak during the winter months. The extremely high frequency of flood fatalities in June for the Midwest is due to the previously mentioned dam failure flash flood that occurred in South Dakota. The summer

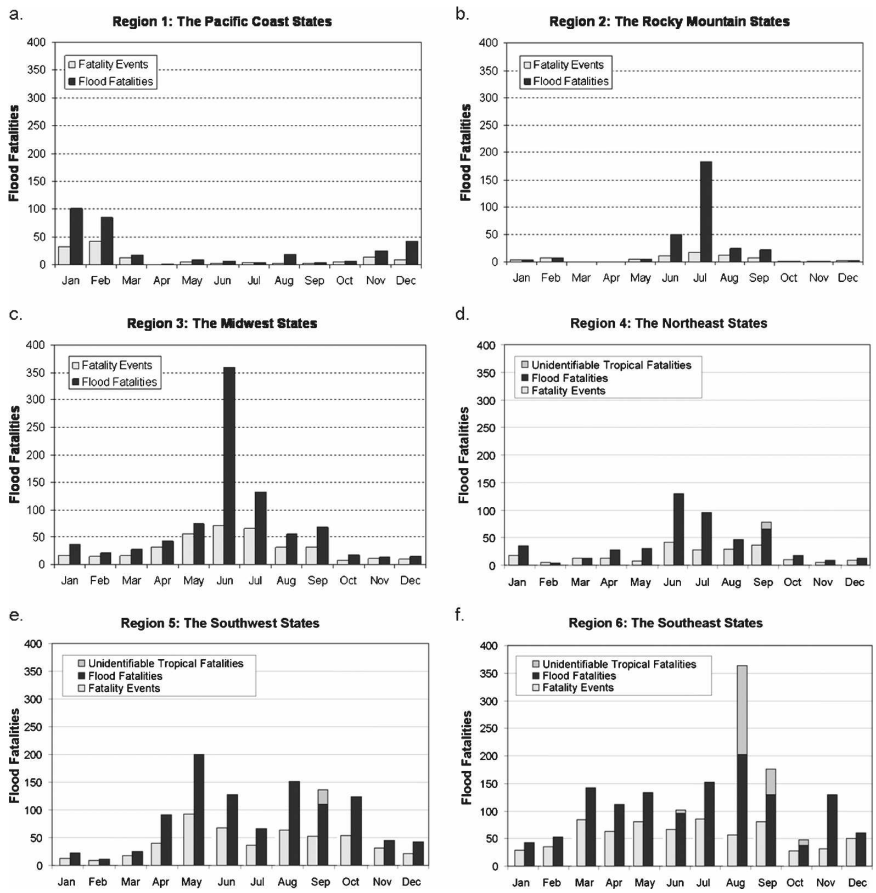

FIG. 4. The frequency of all flood deaths and fatality events (excluding indirect) by month for six regions of the United States, excluding Hurricane Katrina fatalities from Louisiana. Region 1: OR, WA, CA. Region 2: MT, ID, WY, NV, UT, CO. Region 3: ND, SD, NE, KS, MO, IA, MN, IL, WI, MI, IN, OH. Region 4: ME, VT, NH, NY, PA, NJ, MA, CT, RI. Region 5: TX, OK, NM, AZ. Region 6: MD, WV, VA, KY, TN, NC, SC, GA, MS, AL, FL, LA, AR.

maximum for the Midwest and Rocky Mountain region is also likely due to the propensity of convective storms in these areas during this time period. The winter maximum for the Pacific Coast states coincides with the region's climatological high-precipitation season (Koeppen 1936; Robinson and Henderson-Sellers 1999). Fatalities in the Northeast (Fig. 4d) peak in the summer with a smaller secondary peak in the fall from the influence of tropical systems. The Southeast (Fig. 4f) and Southwest (Fig. 4e) have a large number of deaths spread throughout the spring, summer, and autumn months, although the influence from tropical systems in the Southeast creates a pronounced peak in the late summer (Figs. 4e,f).

c. Frequency by event type

As expected, flash flood deaths and events exceed that of the other categories, although tropical systems are responsible for almost one-fifth of all fatalities (Fig. 5). Because flash floods are a major contributor of flood-related deaths, further investigation is warranted into the exact cause of these events. Out of all flash flood fatalities, the majority of deaths occurred from floods that originated solely from heavy rain in a short amount of time, while fewer than 1% of the deaths were from a combination of heavy rain and rapid snowmelt. The only other cause of flash floods found in this study was from structural failures, including dam and levee collapses or "overtoppings." These failures were a result of heavy rain and account for approximately 12% of all fatalities. Nine structural failure events resulted in 309 deaths, or an average of about 35 deaths per failure. There were a total 1028 heavy rain flash flood events with 1965 fatalities, averaging only two deaths per event. The ratio of deaths-to-events is much larger for the structural failure events because of their sudden and unpredictable nature. This does not suggest that flash floods from heavy rains alone are a lesser

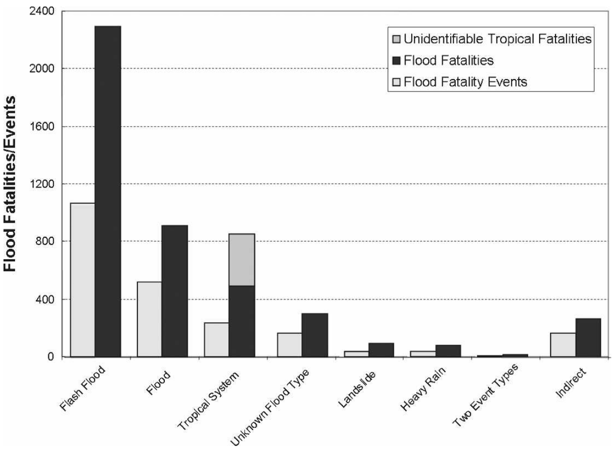

FIG. 5. The frequency of fatalities and fatal events by flood event type. Black bars represent deaths due strictly to flooding for all event types in the study. The gray bar represents the deaths due to tropical systems but not to flooding alone. Light gray bars represent flood fatality events. The figure excludes Hurricane Katrina fatalities from Louisiana.

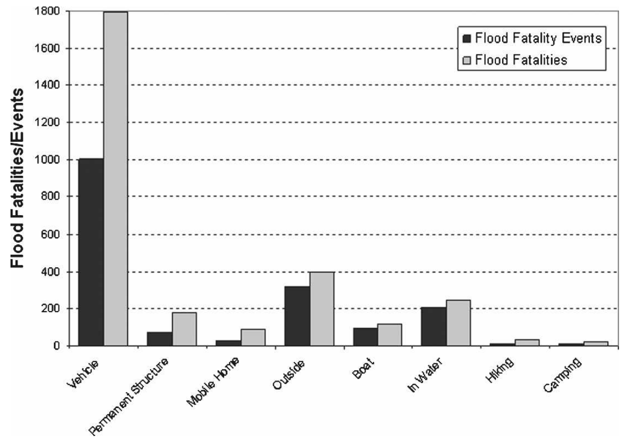

FIG. 6. The frequency of flood fatality events (black bars) and flood fatalities (gray bars) by activity/location, excluding Hurricane Katrina fatalities from Louisiana.

threat, but instead signifies that one structural failure event can impact more people in a single instance. Nonstructural events, although typically only affecting one or two people an event, are en masse the primary flash flood killer.

d. Frequency by activity or setting of occurrence

Out of all deaths reported, 64% have a known activity or setting of occurrence (e.g., vehicle or permanent structure). These data illustrate that 63% of fatalities with known activities or locations occurred in vehicles (Fig. 6). This is a much higher percentage than the 42% and 40% found previously by French et al. (1983) and Zevin (1994), respectively, as well as the 50% found by Mooney (1983). Other locations with relatively high percentages of fatalities include permanent structures and "outside" (e.g., standing on the banks of a flooded stream), which together made up about 19% of flood-related fatalities with known activities/locations.

After vehicle-related fatalities, deaths occurring outside (14%) and in water (9%) were the leading activities/locations. When a person accidentally fell or was swept into the flood waters the location was labeled "outside," while "in water" denotes people who intentionally walked through the floodwaters. Out of all of the deaths where people purposely walked through floodwaters, only 16% of them entered the waters in order to evacuate or to rescue someone else. Another 43% walked through the high water to reach some destination (e.g., a house or a car) in the floodwaters. All of these victims were over the age of 12. Therefore, almost one-half of these "in water" deaths could have been avoided because they were not going in the water for evacuation purposes or rescue. The remaining deaths (with age data) in the "in water" category were mostly children (<12 yr old) who may not have understood the dangers of the waters and either walked into or were playing in the floodwaters. These findings illustrate further that people often do not perceive flooding situations as life threatening (Drobot et al. 2007). This misguided perception or complacency leads to these unfortunate, and often preventable, deaths.

e. Frequency by gender and age

Unfortunately, gender and age characteristics of reports were less frequently reported than that of activity. A majority (63%) of fatalities had unknown age, while nearly one-half (49%) had unknown gender. The percentage of flood fatalities with known ages stratified by age category shows that young adults (age 10–19), those in their twenties, and those > than 60 yr of age have a higher vulnerability to flooding (Fig. 7). Each of these age categories shows a statistically greater percent of fatalities relative to the percent of the U.S. population (United States Census Bureau 2000) in that category using a one-sample test for proportions (95% confidence interval), revealing vulnerability in these age categories. This specific age vulnerability is similar to findings reported by Coates (1999), French et al. (1983), and Mooney (1983). Each of these studies found an increased vulnerability in both the young (<21 yr old) and those >60 yr old. Moreover, the three age categories between 30 and 59 show a statistically lower percent of fatalities relative to the percent of the U.S.

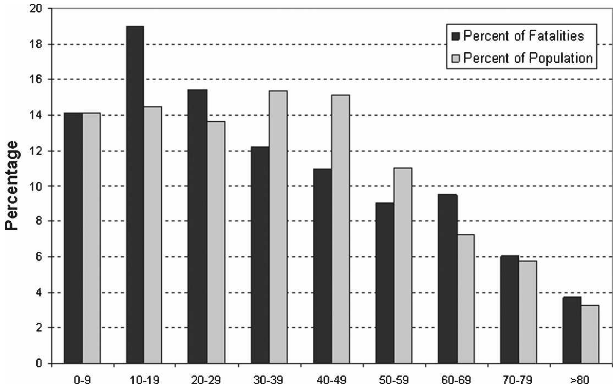

FIG. 7. The percentage of flood fatalities and population by age classification. Black bars represent the percentage of fatalities in that age category to all fatalities with *known* ages (37% of flood fatalities have known ages). Gray bars represent the percentage of the U.S. population in that age category to the total U.S. population (U.S. Census Bureau 2000). The figure excludes Hurricane Katrina fatalities from Louisiana.

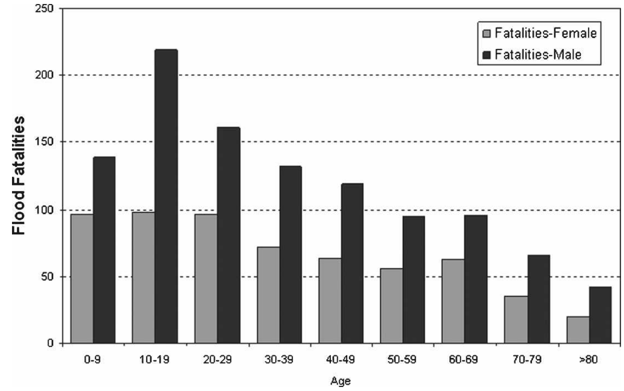

FIG. 8. The frequency of flood fatalities by gender (female, gray bars; male, black bars) and age classification. These frequency values are only of flood fatalities with *known* gender characteristics (51% of flood fatalities have known gender). The figure excludes Hurricane Katrina fatalities from Louisiana.

population (95% confidence interval), revealing a lower vulnerability to flood events. Supporting previous findings (Mooney 1983; French et al. 1983; Coates 1999; Jonkman and Kelman 2005), the majority of flood deaths with known gender were men. Moreover, 35% of the male fatality victims were between the ages of 10 and 29 (Fig. 8).

4. Results: Spatial analysis

To examine the spatial distribution of flood-related fatalities in the United States, a series of maps have been created aggregating the data at different geographic levels (e.g., state). When examining fatality frequency by state, Texas, Pennsylvania, South Dakota, California, and Virginia have the highest fatalities (Fig. 9). Low-fatality states (i.e., fewer than 50 for the 47-yr period of record) are found in the northern United States from the West Coast to Michigan, with the exception of South Dakota. Additionally, the New England region has relatively low numbers of fatalities. When state fatalities are standardized by population, the highest-ranking states include South Dakota, Montana, Mississippi, and West Virginia.

State fatalities mapped by flood type show high values of flash flood fatalities (standardized by population) in the states along the Ohio and Tennessee Rivers as well as in many southwestern states (Fig. 10), while high values of river flood fatalities (standardized by population) are found predominately in West Virginia, Kentucky, Vermont, and Montana (Fig. 11). As expected, states with high numbers of tropical system fatalities (standardized by population) are noticeable in the East Coast states and the states bordering the Gulf of Mexico (Fig. 12).

The gridded fatality data reveal that the eastern United States has more deaths than the western states (Fig. 13). However, disastrous floods do occur in the western United States, predominately because of steeper topography of the Rocky Mountains, Cascades, and other mountain ranges in this region. The existence of more heavily populated urban centers, steep topographical relief, and higher precipitation totals in the eastern United States may contribute to the spatial distribution of flood fatalities found in this area.

The large number of fatalities in central Texas is unique when compared with the rest of the United

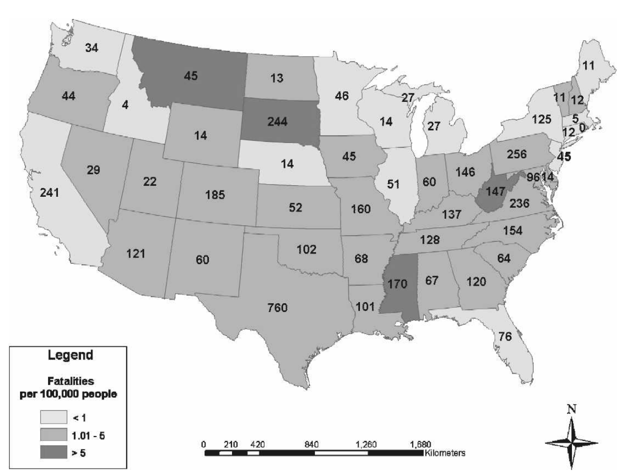

FIG. 9. All U.S. flood fatalities by state standardized by population (per 100 000 people). The number in each state represents the raw number of total fatalities from 1959 to 2005, excluding Hurricane Katrina fatalities from Louisiana.

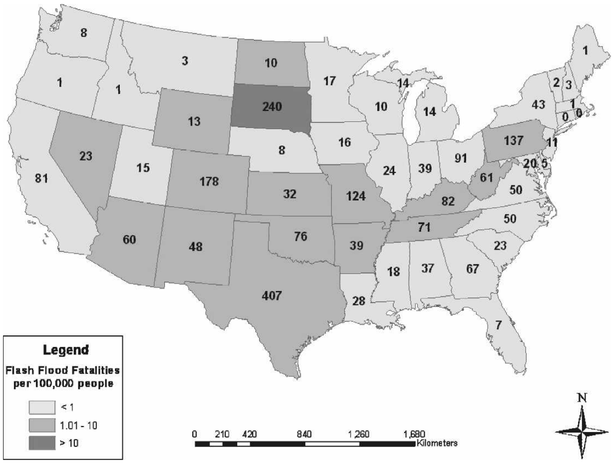

FIG. 10. All flash flood fatalities by state standardized by population (per 100 000 people). The number in each state represents the raw number of total fatalities from 1959 to 2005.

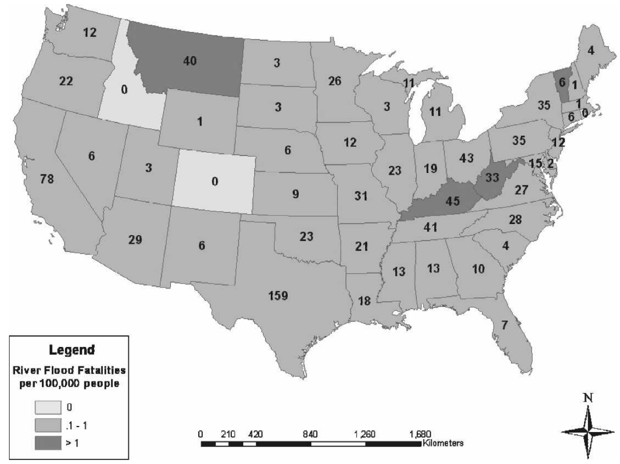

FIG. 11. As in Fig. 10, but for river floods.

States. Although no extremely large flood fatality event occurred during the study period, many events with fewer than 20 fatalities occurred regularly. Coinciding with this region of high fatalities is the edge of the Balcones Escarpment, where elevated topography descends dramatically to the flat lands of the coastal plain. Many of the deaths in this region are found along this escarpment from its northern extent near the Dallas–Fort Worth area south to Austin and west toward Mexico. Floods in the region have shorter lag times between peak discharge and the time centroid of basin-average rainfall (i.e., the time that equally divides the rainfall amount in half) and require much less rainfall and runoff to reach similar peak discharges as floods occurring in the neighboring coastal plains of Texas (Leopold 1991; Smith et al. 2000).

Two additional regions with high numbers of flood fatalities include 1) the Ohio River valley along the eastern and southern border of Ohio and 2) the counties along the heavily populated I-95 corridor from southern New England south to Washington D.C. Because of lack of county and/or city information provided by *Storm Data*, tropical systems are not well represented in Fig. 13. A majority of the tropical system fatalities did not have spatially explicit information on the cities or counties where the deaths occurred and therefore could not be mapped at this scale.

5. Summary and conclusions

Floods are the second-deadliest U.S. weather-related hazard. Therefore, a detailed examination that answers where, how, and why these deaths are occurring is imperative. By constructing a new, comprehensive flood dataset for 1959–2005, some of these questions were answered both quantitatively and spatially. For the 47 yr of the study, 4586 reported fatalities occurred across the contiguous United States. The number of fatalities varied from year to year, with anomalously high years coinciding with either tropical system–produced floods or sudden flash floods, often associated with structural failures of dams or levees. Flash floods from structural failure caused over 300 fatalities from only nine dam and levee failures. Despite these large fatality events, the database is dominated by single- and two-person events, similar to that found by Curran et al. (2000) for lightning casualties.

For all flood types, a majority of fatalities occurred in vehicles (63%). An interesting result found during this analysis was the percent of "in water" deaths that are

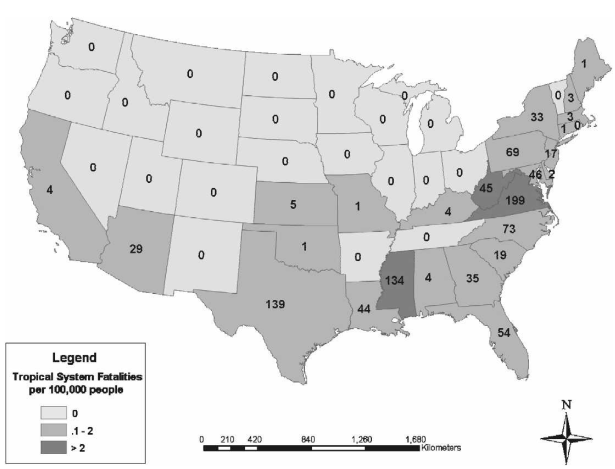

FIG. 12. As in Fig. 10, but for tropical system floods, excluding Hurricane Katrina fatalities from Louisiana.

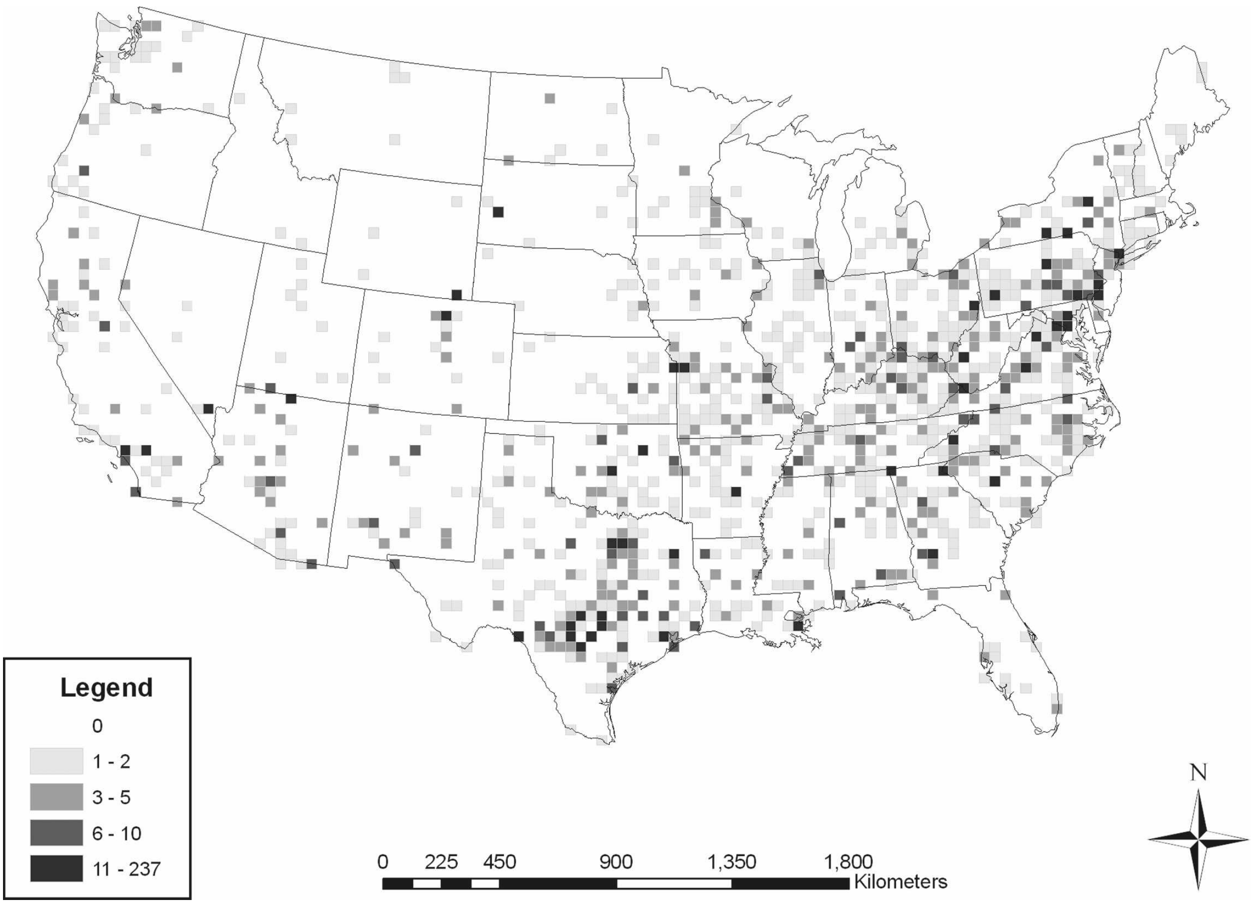

FIG. 13. Tallies of all flood fatalities with known locations on a 40 km × 40 km grid from 1959 to 2005 using the lat and lon of given city (or county seat if only county was given in *Storm Data*). The figure excludes Hurricane Katrina fatalities from Louisiana.

attributable to people walking purposely through the flood waters. This indicates further the need of safety awareness of the dangers of floodwaters. Fatalities examined by age reveal that people between the ages of 10 and 29 and those older than 60 are most vulnerable to flood-related deaths. These findings suggest that human behavior is integral in causing flood fatalities. These results also suggest that future structural modifications of flood control designs (e.g., culverts and bridges) may not dramatically reduce the number of fatalities.

Spatially, flood deaths are dominant in the eastern states. It is hypothesized that there are more flood fatalities in the eastern United States because this region experiences a larger percentage of heavy rain–producing weather systems (especially those of tropical origin) through a given year than does the western United States, therefore increasing the number of fatalities. In addition the population density in the floodplains of the eastern United States is greater than the western United States. The western United States is not immune to flood-related fatalities, as seen by the Big Thompson Canyon flood and the Rapid City dam failure. Many deaths also occur along the West Coast from Oregon to southern California during the region's winter rainy season.

Future research should attempt to bring together the results from national studies (such as this one) with regional studies examining localized flood storm types, human perception, and socioeconomic characteristics of flood casualties. To accomplish this goal, a concerted effort must be extended toward creating a program to assess and measure the losses from weather events nationwide. Similar suggestions have been voiced by Cutter (2001), Changnon (2003), and Cutter and Emrich (2005) to develop and implement a standardized accounting of hazard events and losses in order to reduce flood-related fatalities in the United States. In addition, future research and policy dissemination efforts should focus on providing local flood safety education programs. The findings indicate that the public's general knowledge of the awareness of flood threats is inadequate; therefore, the following recommendations to flood policy makers are suggested:

- Target specific groups, especially those that may be more vulnerable to flood events than others, with flood safety awareness programs to include local citizen involvement. 1) Educate parents on flood dangers through the parent–teacher groups. Highlight the fact that many children are killed by floods when they are driven into floods by a parent or guardian. 2) Provide flood safety programs to children within kindergarten–grade 12 schools that illustrate the hazards of playing in and around culverts and floodwaters. 3) Target the specific vulnerabilities of the elderly sector of the population through organizations such as the Association for the Advancement of Retired Persons. This information may be disseminated through their newsletter or via their Web site (http://www.aarp.org/).

Ultimately, the results of this study suggest that the U.S. population is still largely unaware of the life-threatening powers of floodwater. Therefore, these aforementioned proactive preparedness programs will be useful in reducing flood fatalities (American Meteorological Society 2000).

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