Environmental Science and Policy 76 (2017) 165–176

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Exploring the circumstances surrounding flood fatalities in Australia—1900–2015 and the implications for policy and practice

Katharine Haynes[a,b,c,*], Lucinda Coates[a,c], Rob van den Honert[a,c], Andrew Gissing[a,c], Deanne Bird[a,c,d], Felipe Dimer de Oliveira[a,c], Rebecca D'Arcy[a], Chloe Smith[a], Deirdre Radford[a]

[a] Risk Frontiers, Macquarie University, NSW 2109, Australia
[b] Department of Geography and Planning, Macquarie University, NSW 2109, Australia
[c] Bushfire & Natural Hazards CRC, 340 Albert St., East Melbourne, VIC 3002, Australia
[d] Institute of Life and Environmental Sciences, University of Iceland, 101 Reykjavik, Iceland

ARTICLE INFO

Keywords:
Vulnerability
Fatality
Flood
Hazard
Gender
Youth

ABSTRACT

This paper documents the analysis of the circumstances surrounding fatalities due to flooding in Australia between 1900 and 2015. This longitudinal investigation is important to understand changing trends in social vulnerability and to inform efficient and strategic risk reduction strategies. The basis of this analysis was *PerilAUS*, Risk Frontiers' database of historical natural hazard impacts in Australia. This data was augmented and verified using coronial inquest records which provide detailed data concerning the social, demographic and environmental circumstances of each fatality. A statistical analysis of the data was undertaken, examining demographics (age, gender), location (state), seasonality, circumstances surrounding the fatality, environmental factors (e.g. the event intensity) and social factors (e.g. the decisions or actions which led to death). Overall there have been 1859 fatalities identified, with distinct trends in relation to gender, age, activity and reason behind the activity. Flood deaths have been declining. The majority of the fatalities are male (79.3%): however, since the 1960s the proportion of female to male fatalities has increased. Children and young adults (< 29 years) make up the greatest proportion of the fatalities (53.8% of cases where age is known). The highest proportions of fatalities occurred while victims attempted to cross a flood-impacted bridge or road. The recommendations for emergency management policy and practice are discussed, outlining the need for a new approach that accounts for a continuum of measures including regulation and incentive, education and structural intervention.

1. Introduction and background

This paper updates and expands on previous work on Australian flood fatalities conducted by Coates (1999) and Haynes et al. (2009). This is particularly important as floods are ranked second, following heatwaves, in terms of the total number of natural hazard fatalities since 1900 (Coates et al., 2014).

The investigation explores the social and environmental circumstances surrounding all documented fatalities due to flooding in Australia from 1900 to 2015, presenting a longitudinal understanding of changes in vulnerability to flooding over time. This examination provides an evidence base for emergency management policy and resource allocation, and is a first step to enabling efficient and strategic risk reduction strategies. The methodology and analysis employed is based on similar published work on heatwaves (Coates et al., 2014) and bushfires (Haynes et al., 2010; Blanchi et al., 2014).

Globally, flooding is a significant cause of death (World Health Organization, 2014; Jonkman and Kelman, 2005; Ahern et al., 2005). According to the International Federation of Red Cross and Red Crescent Societies (2015) some 59,092 flood fatalities have occurred worldwide between 2005 and 2014. Substantial research into flood-related fatalities has been undertaken by Diakakis and Deligiannakis (2017), Hamilton et al. (2016), Haynes et al. (2009), Jonkman and Kelman (2005), Jonkman et al. (2009) and Kundzewicz and Kundzewicz (2005), Peden et al. (2017) amongst others. A full literature review is contained in the online Supplementary material (link).

2. Methodology

The foundation for this work is the use of the Risk Frontiers' database *PerilAUS*, which contains historical data on the incidence (magnitude and affected locations, etc.) and consequences (property damage and fatalities, etc.) of natural hazard events in Australia. Detailed data ranges from European settlement (1788) to the present day. *PerilAUS* is

* Corresponding author at: Department of Geography and Planning, Macquarie University, NSW 2109, Australia.
E-mail address: haynes.katharine@gmail.com (K. Haynes).

http://dx.doi.org/10.1016/j.envsci.2017.07.003
Received 2 March 2017; Received in revised form 4 July 2017; Accepted 4 July 2017
Available online 15 July 2017

based on material collected from news media, government reports, published literature, jurisdictional coroners' records, the Australian Bureau of Statistics, and registries of Births, Deaths and Marriages for Australia's states and territories.

The data covers the following natural hazards: floods, extreme heat, bushfires, tropical cyclones, earthquakes, hailstorms, landslides, lightning strikes, rainstorms, tornadoes, tsunamis and windstorms. A number of published studies have utilised *PerilAUS,* including: Blanchi et al. (2014), Coates (1999), Coates et al. (1993, 2014), Crompton et al. (2010) and Haynes et al. (2009, 2010).

An important component of the current project was the further detailed examination, where possible, of coronial data relating to flood fatalities. The availability of victims' names in the original Risk Frontiers' database allowed the retrieval of witness and police statements and forensic documents contained in coronial inquest reports. This process was found to be a crucial means of verification and adding further detail to the circumstances surrounding flood fatalities, especially by enabling a better determination of the social, demographic and environmental circumstances of the deceased.

The classification of the data followed the same numerical coding methodology as that developed and outlined in Haynes et al. (2010). The coding scheme was initially developed and refined by the two lead authors who worked together through a number of the fatality records. The wider team then completed the bulk of the coding, with cross-checking of the entire database conducted by the two lead authors.

The data was classified into the following categories:

2.1. Demographics

Age and gender.

2.2. Location, seasonality and flood characteristics

Details of the location where the fatality occurred, the date and time and the physical characteristics of the flood: flood type and severity (e.g. "a one-in-100 event"). Table 2 outlines the detailed coding categories used for flood type and severity.

2.3. Mode of transport

Details on the mode of transport used by the deceased prior to and at the time of their death: walking, in a closed or open vehicle, on a boat or ship, on a makeshift or inflatable raft etc.

2.4. Actions taken and reasoning, awareness and capacity to act

This category classifies the actions taken by the deceased at the time of their death. Where information from witness statements was available it categorises their level of awareness or knowledge of the flooding and possible dangers. Information on the capacity of the victim to act was also captured and coded. Inferring people's decision making, their level of awareness and their capacity to act is problematic, particularly due to the varying levels of detail in the fatality records early in the last century. Where there was not enough information available to make sensible judgments, these deaths were labelled as unknown. Tables 3–9 outline the detailed coding categories used for these classifications.

3. Results and discussion

The total number of individually identified flood-related deaths between 1900 and 2015 was 1859, with an average national annual death rate of 2.91 fatalities per 100,000 people per year.

3.1. Demographics

Fig. 1 shows a time series of fatalities by gender since 1900. The majority of the deaths have been males (79%), a percentage which is statistically significantly greater than 50% ($p < 0.0001$).

Death rates relative to the national population have declined over the years (Fig. 2).

Between 1900 and 1959 there is a significant decrease in the flood fatality rate (slope = -0.05449, $p < 0.02$). This means the fatality rate was decreasing by 0.55 deaths per 100,000 in the population per year. In contrast, from 1960 to 2015 the fatality rate has been decreasing by 0.0645 per 100,000 in the population per year. However, this decrease in flood fatality rate is not statistically significant. The ratio of male-to-female fatalities has steadily decreased over time, with a statistically significant decline ($p < 0.01$) from the 1960s. This indicates an increasing proportion of female fatalities in more recent times. The majority of deaths have occurred in events where two or less people died (67%, n = 1248 in 1076 flood events). Events where 5 or more people have died correspond to 19% of the fatalities (n = 352 in 35 flood events).

A total of 35 people of Australian indigenous heritage are listed within the data set, making up 2% of the total fatalities. However, it is likely that a large proportion of indigenous deaths, particularly during the first two thirds of the last century, were unrecorded and their deaths are underrepresented.

Given the differences in the way of life and the trends seen in the data since 1960, a detailed exploration of the data pre- and post-1960 was conducted. However, the trends seen in terms of demographics, locations and actions taken are very similar in both time periods. Therefore, the results presented below are for the full data set with only unique differences in the recent data, such as fatalities in motor vehicles, explored.

The breakdown by age (Fig. 3, and Table S1 in the Supplementary material) demonstrates the distinct high-risk groups of children and young adults (< 29 years), who make up the greatest proportion of deaths (43%, n = 807 out of 1859). When the gender is examined, the highest proportion of male fatalities are seen in the 10–29 year age brackets (38% of all male fatalities in which age is known) and the highest proportion of female fatalities is seen in the younger 0–19 year age brackets (54% of all female fatalities in which age is known). For both genders these proportions are statistically significantly greater than what would be expected if fatalities were evenly distributed across age ranges. For both genders the proportion of fatalities then decreases steadily with age. Over 50% of the female deaths occur in those under 29 years of age (56%, n = 206) and over 50% of the male deaths occur in those under 39 years of age (51%, n = 756). A detailed examination of the fatalities under 18 years of age by gender shows the heightened vulnerability of males, particularly among two-year olds, children (8–11 years old) and young adults (18 years old). Interestingly, numbers of fatalities are raised for two-year old females and six- and seven-year old females.

In terms of cause of death, the majority died from drowning (57%, n = 1055), followed by those who were likely to have died from drowning (37%, n = 691). The latter group cannot be accurately categorised as drowned due to a lack of specific data about whether drowning, injury, exposure or heart attack was the root cause. As many of the early deaths were often classified as drowning without a proper autopsy it would be most correct to state that 94% of deaths were caused by drowning, with injury, exposure or heart attack likely to be a contributing factor in many of these.

3.2. Location and seasonality

When the location of deaths is examined across Australia (Fig. 4 and Fig. S1), Queensland (38%, n = 702) and New South Wales (37%, n = 683) account for 75% of the overall fatalities. The third highest number of fatalities occurred in Victoria, with 13% of fatalities (n = 245). When population size (Fig. S1) is considered, the heightened level of risk in the Northern Territory is revealed: the fatality rate is

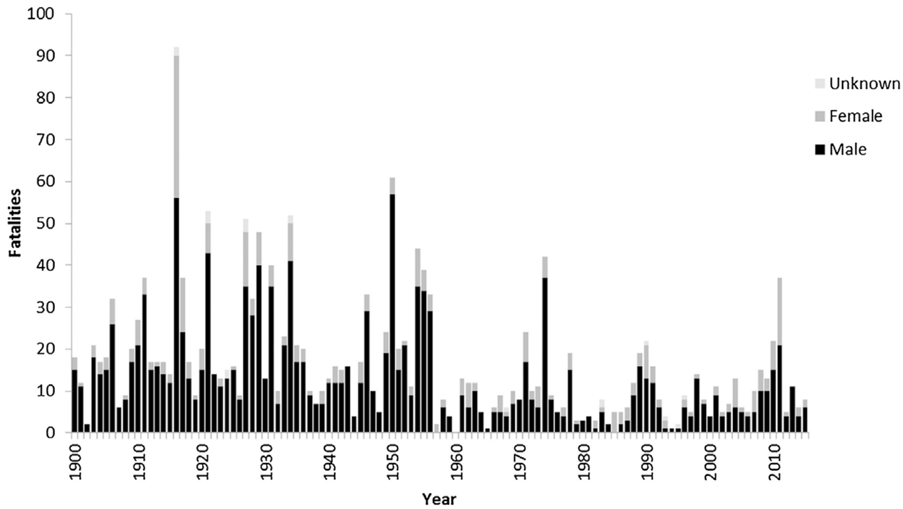

Fig. 1. Time series of fatalities by gender since 1900.

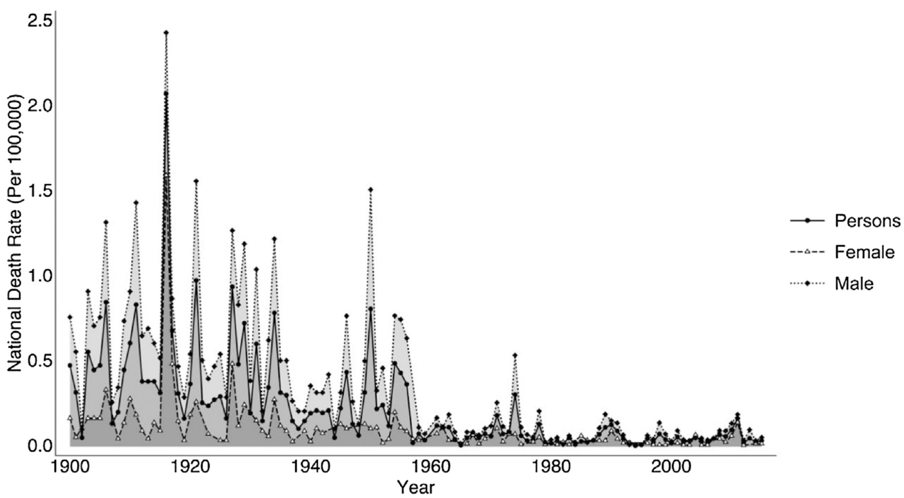

Fig. 2. National death rates due to flood 1900–2015.

almost double that of the state with the next highest fatality rate. When fatalities in the various jurisdictions are examined longitudinally, an expected downward trend in deaths over time is observed, apart from in the Northern Territory.

Most fatalities in Queensland, New South Wales and the Northern Territory occurred during the summer/monsoon season, predominantly in December, January, February and March, although there is a fairly high proportion of New South Wales deaths in June which are associated with winter storms (East Coast Lows). In contrast, flood deaths in South Australia, Victoria, Western Australia and Tasmania are more

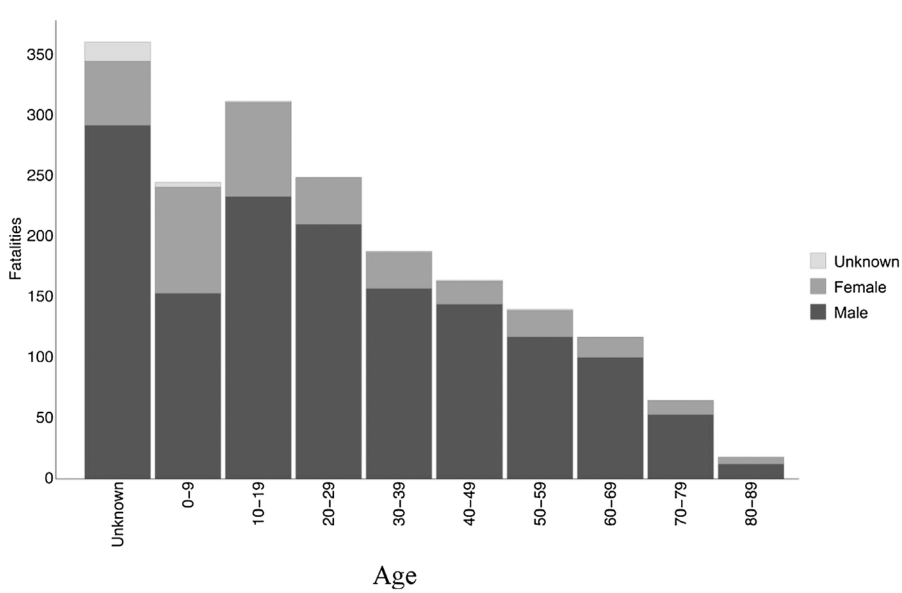

Fig. 3. Breakdown of fatalities by age and gender.

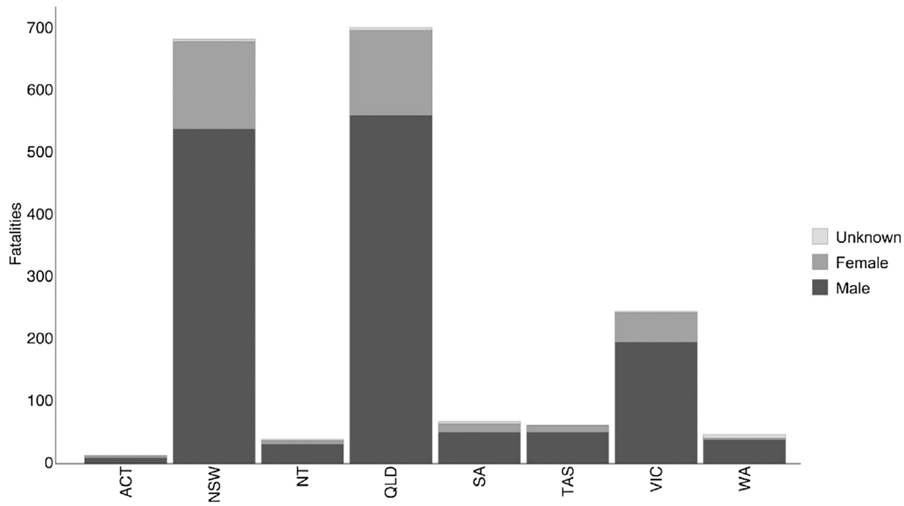

Fig. 4. Number of fatalities per states and territories from 1900 to 2015.

evenly distributed throughout the year.

The greater level of detail included in coronial data between 2000 and 2015 enabled a spatial analysis on the location of each fatality compared to distance from home. Of the total 178 records, 121 contained data on the location of the fatality and their home address. Of these 121 fatalities, more than a quarter occurred within 5 km of their home (26%, n = 32) and 58% (n = 70) were within 20 km. Fewer than 22% of fatalities occurred more than 100 km from the victim's home (n = 26). There were no age or gender trends evident in this data, with 57% male (n = 45) and 60% female (n = 25) fatalities occurring within 20 km of their home ($p > 0.5$, no statistically significant difference in proportion between males and females).

3.3. Flood type and severity

Most fatalities (71%, n = 1325) occurred close to the coast, either on short coastal rivers (54%, n = 1005) associated with heavy rainfall within a small catchment, causing a short duration rapid flood or flash flood event, or longer coastal rivers (17%, n = 320), where floodwater rose rapidly over a longer period (up to 4 days) (Table 1). A further 295 (16%) deaths occurred along inland rivers, where extensive but slow moving flooding was caused by widespread rainfall, followed by those in an urban setting in a local flash flood or low-level short duration flood (8%, n = 142).

Table 1 shows that a statistically significant higher proportion of females died than males in floods on short coastal rivers during short duration heavy rains ($z = -2.02$, $p < 0.05$) and in local urban flash floods or low-level short duration flooding ($z = -5.22$, $p < 0.001$). By contrast, statistically significantly higher proportions of males than females died on inland rivers which experienced long duration, low moving floods ($z = 3.51$, $p < 0.005$), and in floods on normally dry inland rivers involving sudden rapid runoff ($z = 2.54$, $p < 0.02$).

3.4. Activity prior to death, gender, age and reason behind action

Tables 2–6 display two-way cross-tabulations of the numbers of fatalities by activity prior to death, the reason behind the action, and the victim's gender and age.

The highest proportions of both men and women died while attempting to cross a bridge, causeway, culvert, road, etc. (men: 47%, n = 689; women: 41%, n = 149) (Table 2). The majority of these people (60%, n = 507) were en route to a destination at the time (Table 3).

For females, the second highest activity at the time of death, accounting for nearly a quarter of all female fatalities, was being engaged in an activity not near a usual watercourse, e.g. driving through town or in their home and unaware of the flood waters (23%, n = 82). In general, this group did not attempt to cross floodwaters but were surprised by flash flooding outside of a usual water channel. For men, this was the third highest cause of death (10%, n = 143).

A test of association between activity at time of death and gender shows a highly significant relationship ($\chi^2_6 = 43.8$, $p < 0.0001$). Further investigation of Table 2 shows that a significantly higher proportion of males died than females whilst crossing a bridge, causeway or other watercourse crossing ($z = 2.02$, $p < 0.05$), whilst a significantly higher proportion of females died than males whilst engaged in an activity not near a usual watercourse (for example in their own home or garden) ($z = -6.67$, $p < 0.001$). For other activities, the proportions of male and female victims were not significantly different.

Of the total number engaged in an activity not near a usual watercourse at the time of death (n = 228), 47% (n = 107) were in a house (71%, n = 76 of these were in a house that was destroyed), 13% (n = 30) were *on* a house (87%, n = 26 of these were on a house that was destroyed) and 24% (n = 54) were outside. Prior to death, the majority of these victims were in their home and taken by surprise or engaged in a last minute evacuation or a vertical evacuation (45%,

Table 1
Fatalities by 'flood type/severity' and gender (% of column totals)[a].

	Male	Female	Unknown	Total
Short coastal rivers, heavy rain over small catchment, rapid rise, short duration	782 (53%)	215 (59%)	8 (42%)	1005 (54%)
Longer coastal rivers, larger catchment, rapid rise, longer duration (up to 4 days)	265 (18%)	50 (14%)	5 (26%)	320 (17%)
Inland rivers, long duration, widespread rains, extensive floods, slow moving	256 (17%)	36 (10%)	3 (16%)	295 (16%)
Normally dry inland rivers, sudden quick runoff	61 (4%)	5 (1%)	2 (11%)	68 (4%)
Dam failure	12 (1%)	4 (1%)	0 (0%)	16 (1%)
Urban, flash, local, low-level, short duration, nuisance	90 (6%)	52 (14%)	0 (0%)	142 (7%)
Unknown	9 (1%)	3 (1%)	1 (5%)	13 (1%)
Total	1475 (100%)	365 (100%)	19 (100%)	1859 (100%)

[a] There may be small rounding errors in tables.

Table 2
Fatalities by 'activity prior to death' and gender (% of column totals).

	Male	Female	Unknown	Total
Attempting to cross bridge/causeway/crossing/culvert/ford/watercourse	689 (47%)	149 (41%)	6 (32%)	844 (45%)
Attempting to cross floodwaters away from watercourses (water over fields/town)	73 (5%)	11 (3%)	0 (0%)	84 (5%)
Engaged in an activity near the water (on the bank/bridge)	191 (13%)	45 (12%)	0 (0%)	236 (13%)
Engaged in an activity in/near stormwater drain	40 (3%)	13 (4%)	0 (0%)	53 (3%)
Engaged in an activity in the water (rescue, swimming)	98 (7%)	23 (6%)	0 (0%)	121 (7%)
Engaged in an activity on the water (boat)	82 (6%)	16 (4%)	0 (0%)	98 (5%)
Engaged in an activity not near usual watercourse (e.g. in their home)	143 (10%)	82 (23%)	3 (16%)	228 (12%)
Other	5 (0%)	1 (0%)	0 (0%)	6 (0%)
Unknown	154 (10%)	25 (7%)	10 (53%)	189 (10%)
Total	1475 (100%)	365 (100%)	19 (100%)	1859 (100%)

n = 102) (Table 3).

Being engaged in an activity near the water (i.e. on the creek or river bank) was the second highest cause of death for men (13%, n = 191) and the third highest for women (12%, n = 45) (Table 3). Most of these victims were participating in recreational activities at the time (41%, n = 96) (Table 3).

A test of association between activity at the time of death and the reason behind the action taken shows a very highly significant relationship between these two variables (χ^2_{96} = 1,793.3, $p < 0.0001$). When the reasons behind the actions taken prior to death are examined in detail (Table 3), the highest numbers of fatalities occurred en route to a destination (32%, n = 598). Of these, where information is known, the greatest proportion were on their way home (10%, n = 192), followed by those who were en route from home (6%, n = 112). When this data is examined by gender (Table 4), a very similar proportion of fatalities are seen for both men (32%, n = 472) and women (33%, n = 120). The second highest reason behind death for both genders is recreating (16%, n = 296). However, the highest proportion of these deaths is seen among females with 21% (n = 75), compared to 15% for males (n = 221). For men, the third highest reason leading to flood deaths is rescuing people, property, pets or livestock (11%, n = 157). The third highest reason for death amongst women is evacuating (including vertical evacuation, being rescued, awaiting a rescue and late evacuation), which accounts for 16% (n = 60), followed by those who were in their homes and unaware, and therefore made no attempt at evacuation (8%, n = 29).

A test of association between activity at the time of death and gender shows a very highly significant relationship (χ^2_{16} = 137.3, $p < 0.0001$). A closer examination of the data in Table 3 shows that a statistically significantly higher proportion of males died than females whilst working or carrying out livelihood activities ($z = 4.63$, $p < 0.0001$), and whilst carrying out attempted rescues of other people, property, pets and livestock ($z = 4.53$, $p < 0.0001$). A significantly higher proportion of females died than males whilst attempting to evacuate (including vertical and late evacuations) ($z = -7.36$, $p < 0.0001$), and whilst recreating ($z = -2.59$, $p < 0.01$). For other activities, the proportions of male and female victims were not significantly different.

A test of association between activity at the time of death and age (Table 5) shows a very highly significant relationship (χ^2_{36} = 234.6, $p < 0.0001$), implying a very strong relationship between age and activity at the time of death.

For those attempting to cross a flooded bridge, causeway, culvert, road or watercourse, the risk is broadly split across all age ranges, although the highest number of fatalities are seen within the 10–29 year age groups (32%, n = 269) (Table 5).

The data shows that there are high *numbers* of fatalities in the 0–9 and 10–19 year age ranges for victims engaged in this activity type. However, the *proportions* of victims in the 0–9 and 10–19 year age ranges in this activity type are smaller than for all the other age ranges, except the oldest range (80–89 years). Thus, fatalities in the younger age groups are more evenly spread across the various activity types. In particular, those in the 0–9 year age range are relatively evenly split across activities, with 26% (n = 64) attempting to cross a flooded bridge, causeway, culvert, road or watercourse, 27% (n = 66) engaged in an activity near the bank, and 17% (n = 41) engaged in an activity not near a usual watercourse. In the 10–19 year age range a higher proportion are attempting to cross a flooded bridge, causeway, culvert, road or watercourse (41%, n = 129) than any other activity. However, this age group also has the highest proportion of all those engaged in an activity in the water (18% of all fatalities in this age group, n = 55).

In terms of other activities engaged in at the time of death, the highest proportion of fatalities occurring in activities near the water (e.g. bank or bridge) and in or near a stormwater drain are in the 0–19 year age ranges (51%, n = 119; 72%, n = 38, respectively). For those engaged in activities in the water, the majority of fatalities (65%, n = 79) are in the 10–29 year age range. The highest proportion of victims engaged in an activity not near a usual watercourse, e.g. being driven through town or in their home and unaware of the floodwaters, is in the 0–9 year age range (18%, n = 41).

When the 'reason behind action' is explored by age ranges (Table 6), the highest proportions of those in the 0–19 year age groups were recreating at the time of their death (35%, n = 195), followed by those en route to a destination (27%, n = 151). For all older age groups where the reason behind the action could be identified, the highest proportions were en route to a destination, from between 36% to 49% of all fatalities in the age range.

3.5. Capacity and awareness

Table 7, and Tables S2 and S3 display two-way cross-tabulations of the numbers of fatalities by the victim's awareness of the flood, the victim's capacity to act in the event of a flood, and the victim's gender and age.

The largest proportion of victims were aware of the flood but the depth and/or speed of the water took them by surprise (44%, n = 811) (Table 7). In terms of the victim's 'capacity to act', the majority of fatalities were considered to be capable of independent action (54%, n = 1001): i.e., not following the decision making of others. Of these, 59% (n = 593) of victims were aware of the flood but the depth and/or speed of the water took them by surprise. In terms of 'capacity to act', the second highest proportion of victims were those following the decision making of others (such as children, or passengers in a car) (16%, n = 293), followed by a child or group of children on their own who are under the age of 11 (9%, n = 173).

When the age ranges of those following the decision making of others are examined (Table S2), 37% (n = 108) of fatalities were found to be in the 0–9 category and 21% (n = 62) in the 10–19 category: i.e., children under the supervision of others − generally adults. The breakdown of 'capacity to act' by gender (Table S3) shows that the majority of male victims (60%, n = 879) were capable of independent action, a far higher proportion than for females (33%, n = 119). This

Table 3
Fatalities by 'reason behind action' and 'activity prior to death' (% of column totals).

	Attempting to cross bridge/causeway/crossing/culvert/ford/road/watercourse	Attempting to cross floodwaters	Engaged in an activity near the water (bank/bridge)	Engaged in an activity in/near a stormwater drain	Engaged in an activity in the water (rescue, swimming, joyride etc)	Engaged in an activity on the water (boat)	Engaged in an activity not near a usual watercourse	Other	Unknown	Total
Attempting vertical evacuation	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	41 (18%)	0 (0%)	0 (0%)	41 (2%)
Being rescued/evacuated	0 (0%)	8 (10%)	2 (1%)	0 (0%)	0 (0%)	11 (11%)	9 (4%)	0 (0%)	1 (1%)	31 (2%)
Awaiting a planned rescue/evacuation	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (2%)	0 (0%)	0 (0%)	5 (0%)
Refused to be evacuated	1 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6 (3%)	0 (0%)	1 (1%)	8 (0%)
Evacuating	7 (1%)	9 (11%)	2 (1%)	0 (0%)	1 (1%)	0 (0%)	24 (11%)	0 (0%)	3 (1%)	46 (3%)
Late evacuation	0 (0%)	0 (0%)	0 (0%)	5 (9%)	0 (0%)	0 (0%)	8 (4%)	0 (0%)	0 (0%)	13 (1%)
No attempt at evacuation as unaware	0 (0%)	1 (1%)	17 (7%)	0 (0%)	0 (0%)	0 (1%)	53 (23%)	0 (0%)	0 (0%)	71 (4%)
En route	242 (29%)	13 (16%)	10 (4%)	4 (8%)	0 (0%)	14 (14%)	4 (2%)	0 (0%)	7 (4%)	294 (16%)
En route from home	97 (12%)	3 (4%)	7 (3%)	2 (4%)	0 (0%)	1 (0%)	2 (1%)	0 (0%)	0 (0%)	112 (5%)
En route to home	168 (20%)	8 (10%)	3 (1%)	2 (4%)	2 (2%)	3 (3%)	1 (0%)	0 (0%)	5 (3%)	192 (10%)
Recreating	38 (5%)	2 (2%)	96 (41%)	27 (51%)	94 (78%)	27 (28%)	8 (4%)	1 (17%)	3 (1%)	296 (16%)
Carrying out repairs due to flood damage etc	4 (1%)	0 (0%)	11 (5%)	2 (4%)	0 (0%)	2 (2%)	1 (0%)	0 (0%)	1 (1%)	21 (1%)
Collecting provisions	20 (2%)	2 (2%)	1 (0%)	0 (0%)	0 (0%)	2 (2%)	0 (0%)	0 (0%)	0 (0%)	25 (1%)
Attempting to retrieve flotsam	0 (0%)	0 (0%)	8 (3%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	9 (1%)
Collecting people	2 (0%)	0 (0%)	1 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (0%)
Rescuing People, Property Livestock	79 (9%)	22 (26%)	20 (9%)	1 (2%)	18 (15%)	18 (18%)	6 (3%)	1 (17%)	3 (1%)	168 (9%)
Working, attending livestock or livelihood	54 (6%)	6 (7%)	24 (10%)	3 (6%)	0 (0%)	8 (8%)	19 (8%)	0 (0%)	4 (2%)	118 (6%)
Other	2 (0%)	0 (0%)	4 (2%)	0 (0%)	1 (1%)	3 (3%)	0 (0%)	1 (17%)	0 (0%)	11 (1%)
Unknown	130 (15%)	10 (12%)	30 (13%)	7 (13%)	4 (3%)	9 (9%)	41 (18%)	3 (50%)	161 (85%)	395 (21%)
Total	844 (100%)	84 (100%)	236 (100%)	53 (100%)	121 (100%)	98 (100%)	228 (100%)	6 (100%)	189 (100%)	1859 (100%)

Table 4
Fatalities by 'reason behind action' and gender (% of column totals).

	Male	Female	Unknown	Total
Attempting vertical evacuation	20 (1%)	21 (6%)	0 (0%)	41 (2%)
Being rescued/evacuated	15 (1%)	16 (4%)	0 (0%)	31 (2%)
Awaiting a planned rescue/ evacuation	5 (0%)	0 (0%)	0 (0%)	5 (0%)
Refused to be evacuated	7 (1%)	1 (0%)	0 (0%)	8 (0%)
Evacuating	25 (2%)	18 (5%)	3 (16%)	46 (3%)
Late evacuation	9 (1%)	4 (1%)	0 (0%)	13 (1%)
No attempt at evacuation as unaware	42 (3%)	29 (8%)	0 (0%)	71 (4%)
En route	238 (16%)	52 (14%)	4 (21%)	294 (16%)
En route from home	77 (5%)	33 (9%)	2 (11%)	112 (6%)
En route to home	157 (11%)	35 (10%)	0 (0%)	192 (10%)
Recreating	221 (15%)	75 (21%)	0 (0%)	296 (16%)
Carrying out repairs due to flood damage	21 (1%)	0 (0%)	0 (0%)	21 (1%)
Collecting provisions	23 (2%)	2 (1%)	0 (0%)	25 (1%)
Attempting to retrieve flotsam	8 (1%)	1 (0%)	0 (0%)	9 (1%)
Collecting people	1 (0%)	2 (1%)	0 (0%)	3 (0%)
Rescuing people, property, pets	157 (11%)	11 (3%)	0 (0%)	168 (9%)
Working, attending to livestock or livelihood	114 (8%)	4 (1%)	0 (0%)	118 (6%)
Other	8 (1%)	3 (1%)	0 (0%)	11 (1%)
Unknown	327 (22%)	58 (16%)	10(53%)	395 (21%)
Total	1475 (100%)	365 (100%)	19 (100%)	1859 (100%)

difference is statistically highly significant ($z = 9.27$, $p < 0.0001$). By comparison, the highest proportion of female victims were following the decision making of others (36%, n = 133). For males, only 10% of victims were following the decision making of others (n = 152), a highly significantly lower proportion than for females ($z = -12.36$, $p < 0.0001$). In terms of young children who were on their own or in a group of children, 69% were male (n = 120) and 29% were female (n = 50). This difference in proportions between the genders of young children is statistically highly significant ($z = -3.29$, $p < 0.001$). Similarly, the proportion of young female victims (as a percentage of all female victims) is significantly greater than the proportion of young male victims (as a percentage of all male victims) ($z = -7.28$, $p < 0.0001$).

3.6. Time of day and flood awareness

Table 8 displays counts of fatalities by the victim's awareness of the flood and the time of day of death. The data shows that a greater proportion of fatalities, 37%, occurred in daylight (n = 685), compared to 24% (n = 436) that occurred during twilight or darkness ($z = 8.90$, $p < 0.0001$, proportions significantly different).

Of interest is that almost half of all fatalities (44%, n = 811) were aware that there was a flood or imminent risk of a flood, but its depth, speed, debris and/or a stormwater drain surprised them.

A test of association between awareness of the flood and time of day of death (Table 8) shows a statistically significant relationship ($\chi^2_4 = 13.1$, $p < 0.05$). On closer examination, it is evident that a significantly greater proportion of victims who were aware of the flood but did not respond to the danger died during darkness ($z = 1.96$, $p < 0.05$), and a significantly greater proportion of children under 11 years old died during daylight hours (it was assumed that young children would not consciously be aware of flooding) ($z = -3.11$, $p < 0.002$).

3.7. Fatalities using transport at the time of death

The majority of flood victims were using a form of transport at the

Table 5
Fatalities by 'activity at time of death' and age (% of column totals).

	Attempting to cross bridge/ causeway/crossing/culvert/ ford/road/watercourse	Attempting to cross floodwaters. (fields, town)	Engaged in an activity near the water (bank)	Engaged in an activity in/near stormwater drain	Engaged in an activity in the water (rescue, swimming)	Engaged in an activity on the water (boat)	Engaged in an activity not near usual watercourse	Other	Unknown	Total
0–9	64 (8%)	5 (6%)	66 (28%)	22 (42%)	14 (12%)	13 (13%)	41 (18%)	2 (33%)	18 (10%)	245 (13%)
10–19	129 (15%)	15 (18%)	53 (22%)	16 (30%)	55 (45%)	12 (12%)	15 (7%)	1 (17%)	16 (8%)	312 (17%)
20–29	140 (17%)	12 (14%)	20 (9%)	6 (11%)	24 (20%)	17 (17%)	16 (7%)	1 (17%)	14 (7%)	250 (13%)
30–39	104 (12%)	11 (13%)	16 (7%)	1 (2%)	13 (11%)	16 (16%)	11 (5%)	1 (17%)	15 (8%)	188 (10%)
40–49	96 (11%)	10 (12%)	22 (9%)	1 (2%)	5 (4%)	6 (6%)	15 (7%)	0 (0%)	9 (5%)	164 (9%)
50–59	79 (9%)	10 (12%)	12 (5%)	1 (2%)	4 (3%)	2 (2%)	20 (9%)	0 (0%)	12 (6%)	140 (8%)
60–69	50 (6%)	4 (5%)	13 (6%)	3 (6%)	2 (2%)	9 (9%)	16 (7%)	1 (17%)	20 (11%)	118 (6%)
70–79	40 (5%)	3 (4%)	6 (3%)	1 (2%)	0 (0%)	2 (2%)	8 (4%)	0 (0%)	5 (3%)	65 (4%)
80–89	6 (1%)	1 (1%)	4 (2%)	0 (0%)	0 (0%)	2 (2%)	4 (2%)	0 (0%)	1 (1%)	18 (1%)
Unknown	136 (16%)	13 (16%)	24 (10%)	2 (4%)	4 (3%)	19 (19%)	82 (36%)	0 (0%)	79 (42%)	359 (19%)
Total	844 (100%)	84 (100%)	236 (100%)	53 (100%)	121 (100%)	98 (100%)	228 (100%)	6 (100%)	189 (100%)	1859 (100%)

Table 6
Fatalities by 'reason behind action' and age (% of column totals).

	0 – 9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	Unknown	Total
Attempting vertical evacuation	6 (2%)	1 (0%)	0 (0%)	1 (1%)	5 (3%)	3 (2%)	0 (0%)	1 (2%)	2 (11%)	22 (6%)	41 (2%)
Being rescued/evacuated	14 (6%)	4 (1%)	2 (1%)	1 (1%)	2 (1%)	1 (1%)	2 (2%)	2 (3%)	1 (6%)	2 (1%)	31 (2%)
Awaiting a planned rescue/evacuation	1 (0%)	0 (0%)	1 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (2%)	0 (0%)	0 (0%)	1 (0%)	5 (0%)
Refused to be evacuated	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (2%)	1 (1%)	1 (2%)	0 (0%)	3 (1%)	8 (0%)
Evacuating	8 (3%)	3 (1%)	7 (3%)	5 (3%)	2 (1%)	6 (4%)	3 (3%)	3 (5%)	0 (0%)	9 (3%)	46 (3%)
Late evacuation	7 (3%)	1 (0%)	2 (1%)	1 (1%)	0 (0%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)	1 (0%)	13 (1%)
No attempt at evacuation as unaware	17 (7%)	8 (3%)	3 (1%)	4 (2%)	6 (4%)	6 (4%)	7 (6%)	2 (3%)	1 (6%)	17 (5%)	71 (4%)
En route	25 (10%)	40 (13%)	47 (19%)	32 (17%)	31 (19%)	25 (18%)	24 (20%)	11 (17%)	4 (22%)	55 (15%)	294 (16%)
En route from home	14 (8%)	24 (8%)	16 (6%)	12 (6%)	10 (6%)	12 (9%)	2 (2%)	7 (11%)	2 (11%)	13 (4%)	112 (6%)
En route to home	23 (9%)	21 (7%)	28 (11%)	23 (12%)	23 (14%)	18 (13%)	17 (14%)	14 (22%)	2 (11%)	23 (6%)	192 (10%)
Recreating	88 (36%)	107 (34%)	39 (16%)	20 (11%)	14 (9%)	6 (4%)	9 (8%)	1 (2%)	3 (17%)	9 (3%)	296 (16%)
Carrying out repairs due to flood damage etc	0 (0%)	3 (1%)	4 (2%)	2 (1%)	2 (1%)	2 (1%)	3 (3%)	1 (2%)	0 (0%)	4 (1%)	21 (1%)
Collecting provisions	2 (1%)	8 (3%)	4 (2%)	3 (2%)	1 (1%)	0 (0%)	1 (1%)	1 (2%)	0 (0%)	5 (1%)	25 (1%)
Attempting to retrieve flotsam	2 (1%)	6 (2%)	0 (0%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	9 (1%)
Collecting people	1 (0%)	0 (0%)	0 (0%)	1 (1%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (0%)
Rescuing People, Property Livestock	3 (1%)	33 (11%)	40 (16%)	23 (12%)	17 (10%)	15 (11%)	8 (7%)	2 (3%)	2 (11%)	25 (7%)	168 (9%)
Working, attending livestock or livelihood	1 (0%)	8 (3%)	25 (10%)	19 (10%)	17 (10%)	16 (11%)	5 (4%)	6 (9%)	0 (0%)	21 (6%)	118 (6%)
Other	1 (0%)	3 (1%)	0 (0%)	3 (2%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (1%)	11 (1%)
Unknown	32 (13%)	42 (13%)	32 (13%)	38 (20%)	31 (19%)	27 (19%)	33 (28%)	13 (20%)	1 (6%)	146 (41%)	395 (21%)
Total	245 (100%)	312 (100%)	249 (100%)	188 (100%)	164 (100%)	140 (100%)	117 (100%)	65 (100%)	18 (100%)	361 (100%)	1859 (100%)

time of their death − only 8% (n = 146) of victims were in or on a house or caravan at the time of death (Table S4).

Forms of transport have been categorised as:

- pedestrian transport
- water transport
- horse-borne transport
- vehicular transport, or
- other transport (e.g. bicycle).

The highest proportion of fatalities were amongst those on foot or being carried by another person (28% of all fatalities, n = 516). Fatalities using vehicular transport account for 19% (n = 351) of all fatalities, followed by fatalities using horse-borne transport (18%, n = 326). 16% (n = 297) of fatalities were using a form of transport in or on the water (on the water: e.g., a boat, canoe etc. − 8%, n = 139; in the water: e.g., swimming, bodyboarding etc. − 9%, n = 158). Furthermore, eight fatalities were on a pushbike/bicycle, and eight on a rope or cable above or in the water (Table S4). The majority of flood deaths when pedestrian transport, swimming, watercraft, horse-borne transport and vehicular transport have been involved have been males, with a statistically significant percentage above 50% ($p < 0.0001$). A greater proportion of female deaths have occurred when no transport was involved ($z = -6.28$, $p < 0.0001$) (Table S4).

Of those who were driving a vehicle (i.e. capable of independent action), 84% were men (n = 130) and 15% were females (n = 23), a statistically significant difference ($z = 12.29$, $p < 0.0001$). Of those who were passengers (i.e. following the decision making of others), 53% were males (n = 74) and 46% were females (n = 65) ($z = 1.07$, not significantly different). That is, most flood-related vehicle fatalities have involved male drivers, with passengers roughly equally distributed between the genders.

Table S5 displays mode of transport amongst flood fatalities and decade of death. This is useful to examine whether the mode of transport involved in flood fatalities has changed over the past century. Table S6 is a subset of the data in Table S5 (only the five transport categories defined previously) summarised into two non-overlapping periods: 1900–1959 and 1960–2015.

Overall, 69% (n = 1038) of flood fatalities involving transport occurred in the 50 years before 1960, and 471 in the 55 years from 1960 to the present. These translate to 20.8 deaths per year before 1960 and 8.4 deaths per year from 1960 onwards, a statistically very significant decrease in deaths due to flooding.

Table S6 points to a change in transport-related flood death rates due to technology. In the early part of the twentieth century, horses and horse-drawn transport were common, and 315 deaths were recorded (30% of all deaths are transport related). Since 1960, deaths due to this form of transport have reduced to only 11 (3% of all transport related deaths), a very highly statistically significant decrease ($z = 12.25$, $p < 0.0001$). Similarly, flood fatalities mirror the recent popularity in four-wheel drive and pick-up vehicles: these were involved in just two deaths prior to 1960, but 51 since 1960 (11% of transport related deaths), a very highly statistically significant increase ($z = -10.40$, $p < 0.0001$). The ubiquity of the sedan car is also evident here: flood fatalities involving sedan cars have been recorded in 76 deaths before 1960 (7% of transport-related deaths during that period), but 147 since 1960 (31% of deaths from a known form of transport), a very highly statistically significant increase ($z = -12.12$, $p < 0.0001$).

Flood deaths involving pedestrian transport have decreased significantly since 1960: there were 348 deaths before 1960 (36% of transport-related deaths), but 138 since 1960 (29% of transport related deaths) ($z = 2.70$, $p < 0.01$). There has been no change in the relative incidence of flood deaths due to swimming or boating between the two periods ($z = 0.50$, $p > 0.4$).

Table 9 displays flood fatalities by 'mode of transport' and 'capacity to act'. In cases where a form of transport was involved, a total of 5% of

Table 7
Fatalities by 'capacity to act' and 'awareness of the flood' (% of column totals).

	Aware but did not expect to encounter the flood	Aware but depth and or speed took them by surprise	Unaware and taken by surprise	Not applicable – child under 11	Not applicable – other	Unknown	Total
Capable of independent action	160 (67%)	593 (73%)	148 (60%)	2 (1%)	10 (59%)	88 (34%)	1001 (54%)
Physically and or mentally disabled or incapable	3 (1%)	13 (2%)	4 (2%)	1 (0%)	3 (18%)	4 (2%)	28 (2%)
Cannot swim	14 (6%)	28 (4%)	7 (3%)	1 (0%)	2 (12%)	2 (1%)	54 (3%)
Influenced by drugs or alcohol	9 (4%)	49 (6%)	20 (8%)	0 (0%)	0 (0%)	7 (3%)	85 (5%)
Following the decision making of others	40 (17%)	81 (10%)	39 (16%)	126 (44%)	2 (12%)	5 (2%)	293 (16%)
A child or group of children on their own under 11 years old	6 (3%)	6 (1%)	1 (0%)	156 (54%)	0 (0%)	4 (2%)	173 (9%)
Unfamiliar with the area	1 (0%)	13 (2%)	11 (5%)	0 (0%)	0 (0%)	1 (0%)	26 (1%)
Encumbered with clothing, possessions or equipment	1 (0%)	11 (1%)	2 (1%)	0 (0%)	0 (0%)	0 (0%)	14 (1%)
Looking after dependents	0 (0%)	5 (1%)	3 (1%)	0 (0%)	0 (0%)	0 (0%)	8 (0%)
Not applicable	0 (0%)	0 (0%)	3 (1%)	0 (0%)	0 (0%)	0 (0%)	3 (0%)
Unknown	6 (3%)	12 (1%)	7 (3%)	2 (1%)	0 (0%)	147 (57%)	174 (9%)
Total	240 (100%)	811 (100%)	245 (100%)	288 (100%)	17 (100%)	258 (100%)	1859 (100%)

victims (n = 79 out of 1509) were influenced by drugs (including recreational and/or above-normal doses of prescription drugs) or alcohol at the time of death. Of these, 80% (n = 63) were male, a proportion not statistically different from the overall gender split in flood fatalities ($p > 0.2$).

38% (n = 30) of drug- or alcohol-influenced victims were on foot, while 41% (n = 32) were in a vehicle. Of all those victims who were in a four-wheel drive vehicle at the time of death, 27% (n = 12) were influenced by drugs or alcohol, accounting for a high portion of recent vehicle-related deaths in floods.

Where the time of day of the fatality was known, the highest proportions of those on foot perished during daylight hours (70%, n = 242). In contrast, the highest proportion of those in a motorised vehicle perished at night or during twilight (65%, n = 154).

4. Discussion and recommendations for policy and practice

1859 individually identified flood fatalities have been recorded in Australia from 1900 to 2015 and, of these 79% have been males. Death rates have steadily declined over this time. However, while there was a steep statistically significant decline up to 1960, the death rates over the most recent 55 years have remained at a more constant level. It is likely that investments in flood mitigation, technology, warning and communication systems, and the work of emergency service organisations such as the Australian State Emergency Services (SES), have had a major impact on death rates, particularly in the years following World War II. The SES is a largely volunteer run organisation assisting with all emergencies, but particularly floods and storms. However, the negligible decrease in flood fatalities since the 1960s raises questions about the efficacy of current risk mitigation strategies – particularly efforts related to flood mapping, land-use planning and the implementation of community education programs. It is likely that structural mitigation, such as levees, have actually increased risks – as development continues people may assume they are protected and as such do not prepare or evacuate in time. Furthermore, the female-to-male fatality ratio has steadily increased, indicating a greater proportion of female fatalities over time. Although this certainly reflects the fact that women and men in Australia now face similar levels of flood risk exposure, the fact that there are distinct differences in the activities and reasons behind their deaths warrants the need for a gendered approach to risk mitigation. This trend reflects that seen in Australian bushfire fatalities where similar calls for policy change have been made (see Whittaker et al., 2016).

The data highlights the distinct high-risk groups of children and young adults (< 29 years of age) who make up the greatest proportion of deaths (44%). Across all ages, male fatalities are higher apart from two, six and seven year olds, where deaths are more gender balanced. In particular, both genders show a high and equal death rate for those who are two years old and it is likely that this is when children have learnt to walk and are able to quickly wander from adult supervision.

The greatest number of fatalities occurred in Queensland and New South Wales, accounting for 75% of the overall fatalities across the nation. However, when deaths are examined in relation to the per capita population, the heightened level of risk in the Northern Territory is shown. This is particularly the case in recent years where an increasing proportion of flood deaths are seen in the Northern Territory. This warrants further detailed investigation, particularly around the efficacy of current mitigation and education strategies employed within the Northern Territory.

A spatial analysis of fatalities between 2000 and 2015 shows that 58% of victims died within 20 km of their home. This suggests that the victims knew the areas well and, for the majority of people who died while en route, had likely travelled on those roads before. Although the highest proportions of children and youth perished while attempting to

Table 8
Fatalities by 'awareness of the flood' and 'time of day' (% of column totals).

	Dark	Daylight	Unknown	Total
Aware, but did not expect to encounter the flood	73 (17%)	86 (13%)	81 (11%)	240 (13%)
Aware, but depth and or speed took them by surprise	192 (44%)	317 (46%)	302 (41%)	811 (44%)
Unaware and taken by surprise	73 (17%)	97 (14%)	75 (10%)	245 (13%)
Not applicable – child under 11 years old	59 (14%)	143 (21%)	86 (12%)	288 (16%)
Not applicable – other	4 (1%)	4 (1%)	9 (1%)	17 (1%)
Unknown	35 (8%)	38 (6%)	185 (25%)	258 (14%)
Total	436 (100%)	685 (100%)	738 (100%)	1859 (100%)

Table 9
Fatalities by 'mode of transport' and 'capacity to act' (% of column totals).

	Capable of independent action	Physically and or mentally disabled or incapable	Cannot swim	Influenced by drugs or alcohol	Following the decision making of others	A child or group of children on their own < 11 years old	Unfamiliar with the area	Encumbered with clothing, possessions, equipment	Looking after dependents	Not applicable	Unknown	Total
Pedestrians												
On foot	252 (25%)	15 (54%)	16 (30%)	30 (35%)	29 (10%)	127 (73%)	8 (31%)	4 (29%)	1 (13%)	0 (0%)	22 (13%)	504 (27%)
Carried by others	1 (0%)	0 (0%)	0 (0%)	0 (0%)	9 (3%)	2 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	12 (1%)
In/on the water												
Swimming	106 (11%)	0 (0%)	10 (19%)	10 (12%)	1 (0%)	21 (12%)	6 (23%)	2 (14%)	0 (0%)	0 (0%)	2 (1%)	158 (9%)
On boat/watercraft	81 (8%)	1 (4%)	6 (11%)	4 (5%)	36 (12%)	1 (1%)	1 (4%)	2 (14%)	1 (13%)	0 (0%)	6 (3%)	139 (8%)
Horse-borne transport												
On a horse	156 (16%)	2 (7%)	16 (30%)	1 (1%)	5 (2%)	1 (1%)	2 (8%)	5 (36%)	1 (13%)	0 (0%)	8 (5%)	197 (11%)
Horse-drawn vehicle	91 (9%)	2 (7%)	3 (6%)	1 (1%)	24 (8%)	0 (0%)	2 (8%)	0 (0%)	0 (0%)	0 (0%)	6 (3%)	129 (7%)
Vehicular transport												
Sedan car	103 (10%)	3 (11%)	0 (0%)	16 (19%)	91 (31%)	2 (1%)	0 (0%)	0 (0%)	0 (0%)	2 (67%)	6 (3%)	223 (12%)
4-wheel drive	13 (1%)	1 (4%)	0 (0%)	12 (14%)	16 (6%)	0 (0%)	0 (0%)	0 (0%)	1 (13%)	0 (0%)	2 (1%)	45 (2%)
Truck	7 (1%)	0 (0%)	0 (0%)	0 (0%)	18 (6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)	26 (1%)
Pick-up truck	4 (0%)	0 (0%)	0 (0%)	3 (4%)	1 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	8 (0%)
Train	5 (1%)	0 (0%)	1 (2%)	0 (0%)	6 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (33%)	0 (0%)	13 (1%)
Other vehicle (e.g. bus, tractor etc)	11 (1%)	0 (0%)	2 (4%)	0 (0%)	4 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	17 (1%)
Unknown vehicle type	10 (1%)	1 (4%)	0 (0%)	1 (1%)	5 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (1%)	19 (1%)
Other												
Push bike/ bicycle	6 (1%)	0 (0%)	0 (0%)	1 (1%)	0 (0%)	1 (1%)	0 (0%)	0 (0.%)	0 (0%)	0 (0%)	0 (0%)	8 (0%)
On a rope/cable	6 (1%)	0 (0%)	0 (0%)	0 (0%)	2 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0.0%)	0 (0%)	0 (0%)	8 (0%)
Other transport	3 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (0%)
Not applicable – no transport involved	66 (7%)	3 (11%)	0 (0%)	5 (6%)	40 (14%)	4 (2%)	4 (15%)	1 (7%)	4 (50%)	0 (0%)	19 (11%)	146 (8%)
Unknown	80 (8%)	0 (0%)	0 (0%)	1 (1%)	6 (2%)	14 (8%)	3 (12%)	0 (0%)	0 (0%)	0 (0%)	100 (58%)	204 (11. %)
Total	1001 (100%)	28 (100%)	54 (100%)	85 (100%)	293 (100%)	173 (100%)	26 (100%)	14 (100%)	8 (100%)	3 (100%)	174 (100%)	1859 (100%)

cross a watercourse, the overall data also shows their heightened vulnerability to activities in or near the water whilst recreating. For those between the age of 10 and 29 years, these latter activities become the dominant actions at the time of death when the data between 2000 and 2015 is examined in isolation. Higher proportions of deaths occurred among children and females who were following the decisions of others and among children and youths who were on their own or in a group of children. Of this latter group the majority were boys (69%).

The increase in fatalities associated with four-wheel drive (4WD) vehicles from the year 2000 likely reflects a combination of increased 4WD ownership and the more detailed information available in coronial inquest reports over this period. The vast majority of those driving a vehicle were men (85%), while the gender breakdown of the passengers shows slightly more men. A quarter of the fatalities in vehicles were children and youth, the majority of whom were passengers. The highest proportion of those in a vehicle perished at night or during twilight (45%). Explanations within the wider literature for motorists deliberately entering floodwater include: not taking warnings seriously and not understanding the dangers (Drobot et al., 2007), underestimating the risk (Diakakis and Deligiannakis, 2013; Maples and Tiefenbacher, 2009), being impatient and thinking that they are invincible (Franklin et al., 2014), considering that risks do not apply to them (Pearson and Hamilton, 2014), having previous experience in successfully driving through floodwater (Pearson and Hamilton, 2014; Royal Life Saving, 2016), being under pressure to reach a destination, being under pressure from other drivers to go through, receiving encouragement from passengers, having a sense of security that they would be rescued if something went wrong, witnessing other motorists successfully drive through floodwater, and making self-efficacy judgements where drivers had belief in themselves and their vehicle to successfully drive through floodwater (Royal Life Saving Society, 2016).

It is likely that many motorists may not fully appreciate flood conditions such as the depth and speed of floodwaters and the influence such conditions may have on safety (Diakakis and Deligiannakis, 2013; Yale et al., 2003). However, the results presented here show that a significant proportion of motorists died while entering floodwaters in the dark or twilight when visibility would have been poor. It is therefore likely that they were unaware of the extent of the danger and may not have known that they were actually entering floodwater until it was too late. This points to the need for structural measures including barricades and road design, as risk communication and education may have little impact in such situations.

4.1. Specific recommendations for policy and practice

There is limited research evaluating the many initiatives utilised to reduce the instances of people entering floodwater (Gissing et al., 2016). Typically, flood risk management strategies have relied upon education and rescue interventions. However, a more holistic behavioural change focus implementing a continuum of measures is required, such as that recommended by Rothschild (1999). Such an approach should include:

- Education – containing messages to attempt to voluntarily change behaviour

Typically, flood safety campaigns comprise signs, commercials, digital media and broadcast media engagement. However, few outreach campaigns have been properly evaluated or actively target specific groups with tailored messaging. Media engagement is also necessary to ensure images of risky behaviour portrayed as “cool and fun” are not broadcast. Education programs should also address the motivations for people entering floodwater and their perceptions of the dangers (Pearson and Hamilton, 2014; Hamilton et al., 2016).

- Incentives and consequences – to encourage voluntary behaviour change

Regulation is often used to change behaviour: for example, enforcing speed limits, seat belt use and swimming pool fencing. Regulation, however, has not been widely employed to stop motorists from driving though floodwater, although examples do exist from Australia and the USA (Gissing et al., 2016; Wogan, 2013).

- Structural intervention

Due to the portable nature of barricades, motorists are able to relocate them or possibly drive around them, although often flooding may also occur before authorities can establish barriers. The manning of barricades and the establishment of automatic gates in high-risk areas may enhance their effectiveness. Road design in flood prone areas could have a critical influence on the survival outcomes of motorists once their vehicle becomes buoyant and should be an area of further research.

In conclusion, many communities have inherited the legacy of poor land use planning decisions that do not sufficiently address the safety of people living, working and traveling across floodplains. The risks associated with any densification or new development on floodplains must be considered in a holistic manner, including any resulting increase in the flow of traffic on access roads that are liable to flooding and the consequences of extreme events. In terms of existing risks, it is critical that safety strategies, as outlined above, are implemented to reduce the number of lives lost. Rigorous research on the efficacy of these strategies will form the much needed evidence base on which further policy decision can be made.

Acknowledgments

This research was funded by a research grant from the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC). Ethical approval for the project was granted from the Macquarie University Human Research Ethics Committee, reference no. 5201400073. This research would not have been possible without the services and assistance of the National Coronial Information System based in Melbourne, the Victorian Department of Justice Human Research Ethics Committee, the Victorian Public Archives Services, the Public Records Office of Tasmania, the coronial office and State Records Authority New South Wales, The Northern Territory Archives Centre, Queensland State Archives and State Records of South Australia. Thanks to Kerrie Sydee, Justin Hendry and Avianto Amri who assisted with data entry. Thanks are also due to Michael Rumsewicz BNHCRC, New South Wales SES, Tasmanian SES and Chas Keys for comments and advice on earlier drafts.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2017.07.003.

References

Blanchi, R., Leonard, J., Haynes, K., Opie, K., James, M., Dimer de Oliveira, F., 2014. Environmental circumstances surrounding bushfire fatalities in Australia 1901–2011. Environ. Sci. Policy 37, 192–203.

Coates, L., Blong, R.J., Siciliano, F., 1993. Lightning fatalities in Australia, 1824–1991. Nat. Hazards 8, 217–233.

Coates, L., Haynes, K., O'Brien, J., McAneney, K., Dimer de Oliveira, F., 2014. Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010. Environ. Sci. Policy 42, 33–44. http://dx.doi.org/10.1016/j.envsci.2014.05.003.

Coates, L., 1999. Flood fatalities in Australia, 1788–1996. Aust. Geogr. 30 (3), 391–408.

Crompton, R., McAneney, K., Chen, K., Pielke Jr., R., Haynes, K., 2010. Influence of location, population, and climate on building damage and fatalities due to Australian bushfire: 1925–2009. Weather Clim. Soc. 2, 300–310.

Diakakis, M., Deligiannakis, G., 2013. Vehicle-related flood fatalities in Greece. Environ.

Hazards 12, 278–290.
Diakakis, M., Deligiannakis, G., 2017. Flood fatalities in Greece: 1970–2010. J. Flood Risk Manage. 10, 115–123. http://dx.doi.org/10.1111/jfr3.12166.
Drobot, S.D., Benight, C., Gruntfest, E., 2007. Risk factors for driving into flooded roads. Environ. Hazards 7, 227–234.
Franklin, R.C., King, J.C., Aitken, P.J., Leggat, P.A., 2014. Washed away—assessing community perceptions of flooding and prevention strategies: a North Queensland example. Nat. Hazards 73, 1977–1998.
Gissing, A., Haynes, K., Coates, L., Keys, C., 2016. Motorist behaviour during the 2015 Shoalhaven floods. Aust. J. Emergency Manage. 31, 23–27.
Hamilton, K., Peden, A., Pearson, M., Hagger, M., 2016. Stop there's water on the road! Identifying key beliefs guiding people's willingness to drive through flooded waterways. Saf. Sci. 89, 308–314.
Haynes, K., Coates, L., Leigh, R., Handmer, J., Whittaker, J., Gissing, A., Mcaneney, J., Opper, S., 2009. 'Shelter-in-place' vs. evacuation in flash floods. Environ. Hazards 8, 291–303.
Haynes, K., Handmer, J., McAneney, K., Tibbits, A., Coates, L., 2010. Australian bushfire fatalities 1900–2008: exploring trends in relation to the 'prepare, stay and defend or leave early' policy. Environ. Sci. Policy 13 (3), 185–194.
International Federation of Red Cross and Red Crescent Societies, 2015. World Disasters Report. Geneva, Switzerland.
Jonkman, S., Kelman, I., 2005. An analysis of the causes and circumstances of flood disaster deaths. Disasters 29, 75–97.
Jonkman, S., Maaskant, B., Boyd, E., Levitan, M.L., 2009. Loss of life caused by the flooding of New Orleans after Hurricane Katrina: analysis of the relationship between flood characteristics and mortality. Risk Anal. 29, 676–698.
Kundzewicz, Z., Kundzewicz, W., 2005. Mortality in flood disasters. Extreme Weather Events and Public Health Responses. Springer.
Maples, L., Tiefenbacher, J., 2009. Landscape, development, technology and drivers: the geography of drownings associated with automobiles in Texas floods, 1950–2004. Appl. Geogr. 29, 224–234.
Pearson, M., Hamilton, K., 2014. Investigating driver willingness to drive through flooded waterways. Accid. Anal. Prev. 72, 382–390.
Peden, A.E., Franklin, R.C., Leggat, P., Aitken, P., 2017 May 18. Causal Pathways of Flood Related River Drowning Deaths in Australia. PLOS Currents Disasters. http://dx.doi.org/10.1371/currents.dis.001072490b201118f0f689c0fbe7d437. Edition 1.
Rothschild, M., 1999. Carrot, sticks and promises: a conceptual framework for the management of public health and social issue behaviours. J. Marketing 63, 24–37.
Royal Life Saving, 2016. Deciding to Drive Through Floodwater – A Qualitative Analysis Through the Lived Experience. [Available Online] www.royallifesaving.com.au. (Accessed 14 December 2016).
Whittaker, J., Eriksen, C., Haynes, K., 2016. Gendered responses to the 2009 Black saturday bushfires in Victoria, Australia. Geogr. Res. 54, 203–215. http://dx.doi.org/10.1111/1745-5871.12162.
Wogan, J., 2013. More States Consider Billing Rescues to Make Thrill Seekers Think Again. [Available Online] http://www.governing.com/topics/public-justice-safety/gov-states-consider-billing-reckless-rescues.html (Accessed 16 December 2015).
World Health Organization, 2014. Global Report on Drowning – Preventing a Leading Killer. World Health Organisation, Geneva, Switzerland.
Yale, J.D., Cole, T.B., Garrison, H.G., Runyan, C.W., Ruback, J.K.R., 2003. Motor vehicle-related drowning deaths associated with inland flooding after Hurricane Floyd: a field investigation. Traffic Inj. Prev. 4, 279–284.