bnhcrc.com.au

AN ANALYSIS OF HUMAN FATALITIES FROM CYCLONES, EARTHQUAKES AND SEVERE STORMS IN AUSTRALIA

Lucinda Coates, Katharine Haynes, Deirdre Radford, Rebecca D'Arcy, Chloe Smith, Rob van den Honert, Andrew Gissing

Risk Frontiers, Macquarie University
Bushfire and Natural Hazards CRC

Version	Release history	Date
1.0	Initial release of document	22/05/2017

Disclaimer:

Risk Frontiers and the Bushfire and Natural Hazards CRC advise that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, Risk Frontiers and the Bushfire and Natural Hazards CRC (including its employees and consultants) exclude all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Acknowledgments

This research was funded by a grant from the Bushfire and Natural Hazards Cooperative Research Centre. This research would not have been possible without the services and assistance of the National Coronial Information System based in Melbourne for the retrieval of coronial reports and all the help and assistance given. Thanks also to James O'Brien from Risk Frontiers who assisted with death rate calculations.

Publisher:
Bushfire and Natural Hazards CRC

May 2017

Citation: Coates, L., Haynes, K., Radford, D., D'Arcy, R, Smith, C., van den Honert, R., Gissing, A. (2017). An analysis of human fatalities from cyclones, earthquakes and severe storms in Australia. Report for the Bushfire and Natural Hazard Cooperative Research Centre

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report examines the socio-demographic and environmental circumstances surrounding fatalities from cyclones, earthquakes and severe storms (hail, gusts, lightning, rain and tornados). It is the second major milestone from the Bushfire and Natural Hazards Co-operative Research Centre (BNHCRC) funded project "*An analysis of human fatalities and building losses from natural disasters in Australia*".

The foundation for this work is the use of the Risk Frontiers' database *PerilAUS*, which contains historical data on the incidence (magnitude, affected locations, etc.) and consequences (property damage and fatalities, etc.) of natural hazard events in Australia. *PerilAUS* contains many of the names of the deceased which, during the course of this project, has enabled the collection of more detailed information on the circumstances of many of the fatalities from coronial inquest reports.

The data has been analysed to inform the understanding of the circumstances surrounding the deaths and how this information could best be utilised for emergency management policy and practice. This has included an examination of the data around the following themes: demographics, cause of death, location of the fatality and transport, activity and action prior to and at the time of death, capacity and awareness and, where possible, the severity of the event.

OVERVIEW OF THE SALIENT RESULTS

Key Results

- At least 406 deaths have occurred in Australia due to tropical cyclones, earthquakes and severe storms (gust, hail, lightning, rain and tornado) across the periods of study.
- From 1990-2015, over three-quarters of the 254 deaths identified have been due to severe storms and, of those deaths, over half were due to gusts.
- Of those hazard types with large numbers of fatalities (over 20), the majority of deaths have been amongst males (tropical cyclone 84%, gust 75% and lightning 79%).
- In the majority of natural hazards studied (cyclone, gust, hail, lightning, rain, tornado), the importance of (early) shelter in a sturdy building was noted.

Recommendations:

- Many of the trends resulting from our analysis of the data support current practices and recommendations of emergency management (EM) groups and the government. Future work should investigate the effectiveness of existing EM recommendations and/ or how they are communicated to the public.
- Community engagement/ education campaigns for the high-fatality hazards of tropical cyclone, gust and lightning should target males.
- Community engagement campaigns should discourage people from sheltering (standing or parking) and camping under large trees during severe weather conditions. Rather, people should be encouraged to shelter in sturdy buildings and, especially in the case of lightning, to do so at the earliest opportunity.

Tropical Cyclone

- At least 192 fatalities were recorded from 1970-2015, of which 84% were males.
- The annual average decadal death rate has fallen from a high of 1.15 per million population during the 1980s to the current 0.01 for the 2010s.
- Severity of a tropical cyclone doesn't necessarily have a bearing on likelihood of fatalities.

Recommendations:

- Emergency organisations should target, in their education/ outreach campaigns:
  - Males, especially 20-29yo;
  - females 0-9 and 20-29yo
- In warnings given out, consideration should be given to alerting the public to the dangers of any strength of cyclone.

Earthquake

- The Newcastle earthquake, which killed 14 people, provides an example of the vulnerability of Australian cities and towns to earthquakes.
- Most people died from the collapse of buildings and structures not built to withstand earthquake.
- Most people died from the collapse of just one building.
- Non-ductile concrete buildings and unreinforced masonry buildings have weak earthquake resistance (pers. comm., Paul Somerville)

Recommendations:

- Emergency service organizations should encourage members of the public and employers to find out (from their builder or an engineer) whether they live/ work in a building prone to earthquake damage
- Future research should examine those buildings/ areas which may pose a greater risk of dying in an earthquake: for example, places of mass gathering and/ or essential infrastructure facilities which do not meet current earthquake building regulations, such as older hospitals, clubs and shopping malls.

Severe storm

Gust

- At least 142 people have died from 1990-2015, 75% of them males.
- The annual death toll has ranged from zero to 13.
- The annual average decadal death rate has stayed fairly constant through time, from 0.25 per million population during the 1980s to 0.29 for the 2010s.
- The fatality record shows that people have heeded tropical cyclone warnings but do not treat strong wind with the same level of respect, often continuing with their intended activities.
- 36 (25% of) deaths were boating related.

Recommendations:

- Emergency service organisations should focus on the most effective means of engaging with the community in order to emphasize the dangers of storms.

- Attention should be paid by emergency service organisations to working collaboratively with marine risk groups, such as recreational boaters, and marine safety and rescue authorities to communicate key safety messages. Attention should be spread across both coastal and inland waterways.

Hail

- No fatalities from hail were identified from 1990 to 2015.
- Death by hail has occurred in Australia prior to 1990, and extreme hail sizes – for example, 6-7cm (tennis or baseball size) or greater in diameter – are possible.

Recommendations:

- Emergency service organisations should communicate key safety messages such as being aware that:
    - hail, in combination with rain, may cause roof/ awning collapse and so appropriate shelter should be sought,
    - a direct hit by a hailstone can be fatal (although this is very rare).

Rain

- PerilAUS lists few rain-related deaths (for example, drowning in a rain-filled excavation as distinct from a water course) for the period 1990-2015.
- Rain-related traffic accidents due to, for example, impeded visibility or slippery road conditions are a problematic, though common, issue that was unable to be investigated with the resources available for the current project.
- People may be overtaken by another peril type whilst sheltering from rain.

Tornado

- Although Australia has experienced destructive tornadoes, just three deaths were found from 1990-2015.

Recommendations:

- Emergency service organisations should communicate key safety messages such as the consideration of tornado hazard when sheltering from rain or lightning during the onset of a severe storm and in that case to consider sheltering in the sturdiest rooms of the building (e.g., the bathroom).

Lightning

- At least 48 people have died 1990-2015, 79% of them males.
- The annual death toll ranges from zero to three excepting in 2015, when five deaths occurred.
- The annual average decadal death rate has stayed fairly constant through time, from 0.11 per million population during the 1980s to 0.09 for the 2010s.
- About 15% of fatalities occurred whilst the deceased was recreating at a beach (near the water's edge; in the water; in the act of leaving the beach) and just over 10% took refuge under a tree.
- About 20% of fatalities occurred amongst outdoor workers (eg farmyard, training camp, building site, race course, near parked vehicle).

- Just under 10% of fatalities occurred whilst the deceased was recreating at a sportsfield, golf course or similar, and a similar number were in a small fishing vessel.

Recommendations:

- Ensure storm safety signage is displayed in prominent locations in large public spaces.
- Ensure that workplaces with outdoor workers consider lightning and severe weather in their work health & safety (WHS) practices.
- Ensure that sporting bodies have WHS policies in place for severe weather.

INTRODUCTION

The Bushfire and Natural Hazards Co-operative Research Centre (BNHCRC) has been set up to conduct applied research to reduce the risks and consequences of natural disasters and to build a disaster-resilient Australia. The *Scenarios and Loss Analysis* cluster project entitled "*An analysis of human fatalities and building losses from natural disasters in Australia*"[1] aims to measure and understand the impacts of natural hazards in terms of the toll on human health and the built environment.

This examination is a fundamental first step to providing an evidence base for future emergency management policy, practice and resource allocation and to enable efficient and strategic risk reduction strategies. Outputs will also feed into other ongoing research projects in the BNHCRC and elsewhere. The analysis underpinning the project will be based on an examination of the historical record of losses caused by natural hazards in Australia since 1900.

The overall objectives of the project are:

1. An analysis of fatalities, in terms of demographics and social and environmental circumstances surrounding deaths.
2. An analysis of people otherwise affected by natural hazards – injured, near-misses, rescued.
3. An analysis of building damage and losses arising from natural hazard events over the last century.

The hazards to be studied include: floods, cyclones, earthquakes, heatwaves, severe storms and bushfires[2].

This report focuses on the second deliverable of the project which is a detailed analysis of fatalities from cyclones, earthquakes and severe storms (gusts, hail, lightning, rain and tornados). The foundation for this work is the use of the Risk Frontiers' database *PerilAUS*. The database contains historical data (dating back to the earliest days of European settlement in Australia) on the incidence (magnitude, affected locations, etc.) and consequences (property damage and fatalities, etc.) of such events.

PerilAUS was deemed a good basis for this project due to the length of period covered, the wealth of descriptive detail concerning the hazard impact and the inclusion of data about any fatalities caused by that hazard. As part of this project this data has been augmented through extensive data collection from the print media and from the National Coronial Information Service.

[1] http://www.bnhcrc.com.au/research/economics-policy-and-decision-making/235

[2] Bushfire losses will be investigated for building losses only. A detailed analysis of bushfire fatalities has already been conducted in previous projects and will only be included here in terms of an overall analysis and comparison of the fatalities from all hazard events.

In particular, the original data contained many of the names of the deceased, which has enabled the collection of more detailed information on the circumstances of the death from coronial records.

The social and environmental factors of interest include:

Social - Age, gender, occupation, preparation, risk reduction activities, knowledge and warnings received, activities and decisions leading up to and at the time of death, capacity to act, mode of transport, medical cause of death etc.

Environmental - Details of the location and the severity of the hazard.

The report will begin with a literature review in order to explore and present relevant international research. A methodology will be presented followed by the results. The findings will then be discussed in relation to policy and practice recommendations.

LITERATURE REVIEW

TROPICAL CYCLONE FATALITIES

Tropical cyclones in the Australian region have been well recorded from 1909 (Lourensz, 1981) but it is only from the 1959-60 cyclone season and the advent of satellite imaging that all tropical cyclones affecting the region can be said to be captured (Ryan, 1993).

In Australia a tropical cyclone is defined as a non-frontal low pressure system of synoptic scale developing over warm waters, having organised convection and a maximum mean wind speed of 34 knots or more extending more than half-way around near the centre (i.e., having sustained winds of 63 km/h or greater and gusts in excess of 90 km/h near the centre) and persisting for at least six hours (BoM, 2016b). The gale force winds can extend hundreds of kilometres from the cyclone centre. If the sustained winds around the centre reach 118 km/h (gusts in excess of 165 km/h) then the system is called a severe tropical cyclone ("hurricanes" or "typhoons" in other countries) (BoM, 2016b).

Tropical cyclones have been included in *PerilAUS* on the basis of their inclusion in the BoM database (http://www.bom.gov.au/cyclone/history/#db) and if they have impacted on human health and/ or the built environment. Impacts from extra-tropical cyclones are generally analysed within the severe storms databases of *PerilAUS*.

In Australia, Ryan (1993) reported 1593 deaths to have occurred from tropical cyclone winds and floods from 1830 to 1989, with an average annual death toll from 1960-89 of just over four. Ryan noted that existing records used in this determination (from the Bureau of Meteorology (BoM), Insurance Council of Australia, newspapers and emergency management organizations) used to obtain this figure were imperfect. Ryan (1993) reported that fatalities had been decreasing steadily since 1900 due to more efficient warning systems, but noted that the trend could cease or be reversed with increasing population on the tropical coasts of Australia and with any increase in tropical cyclone frequency or intensity.

Coates (1996) examined tropical cyclone fatalities in Australia from 1827-1989, including the potential mechanisms for causing fatalities of rain and its associated flooding, storm surge, strong winds and high seas. Preliminary results were between 1863 to 2312 fatalities, with most fatalities due to high seas: these occurred in the earlier years of record, with the next most fatal peril type storm surge, then cyclonic rains. Coates (1996) noted the risk of dying in a tropical cyclone had increased with the push for coastal settlement.

King & Anderson-Berry (2010) tabulated the global death toll from tropical cyclones by continent during the period 1900-2010, with 3401 (0.26%) killed in Africa, 86,332 (6.50%) from the Americas, 1,237,484 (93.1%) from Asia, 201 (0.02%) from Europe and 1721 (0.13%) from Oceania. The cause of death was principally from storm surge and flooding (King & Anderson-Berry, 2010).

Rappaport (2014) examined the record of US cyclones from 1963-2012 and found cause of death for 2325 of the 2544 fatalities.

About 90% of fatalities occurred in water-related incidents: 49% from storm surge, 27% from freshwater floods and mudslides and 7% each from near the shoreline and offshore. About 8% were caused by non-tornadic winds and 3% by tornadoes. Six storms accounted for about two-thirds of the deaths. The deadliest storms were not necessarily the most severe at landfall: only three of the ten deadliest were category 3 (Saffir-Simpson Hurricane Wind Scale, SSHWS) over land and six were tropical storms or category 1 hurricanes. Rappaport (2014) found that, while drowning from cyclonic rains occurred in more tropical cyclones than from any other cause, the total number of fatalities from storm surge was almost double that from cyclonic rains. Rappaport also noted that, while the strongest winds usually occurred near the cyclone centre, rainfall events could be displaced from the centre both in space and time, often long after the cyclone had dissipated.

EARTHQUAKE FATALITIES

Daniell & Love (2010) noted that, on a global scale, Australia has experienced very few social losses as a result of earthquakes, with only three fatal earthquakes being recorded in Australia's history. They recorded 16 earthquake deaths in Australia from the year 1788, utilizing the CAT DAT Damaging Earthquakes database: two in the 1902 Warooka earthquake, one in the Gayndah 1935 earthquake and 13 in the Newcastle 1989 earthquake.

In contrast, many countries experience devastating tolls from earthquake impacts. Guha-Sapir & Vos (2011) utilized the EM-DAT International Disaster Database and found a global annual average of 27,000 fatalities due to earthquakes since 1990, with the number of earthquakes causing significant human and economic loss increasing since the 1970s. They reported that earthquake risk increases with population growth, urbanization, poverty and low quality building construction and that over 80% of the deaths from 1970-2009 have occurred in Asia.

SEVERE STORM FATALITIES

The Australian Bureau of Meteorology (BoM) defines a severe storm as having any of:

- convective wind gusts of 90km/h or more at the ground,
- hailstones of 2cm diameter or more at the ground,
- flash flooding (resulting from rainfall exceeding the one in ten year one-hour fall) and/ or
- tornadoes (Mills & Colquhoun, 1998; BoM, 2016a).

Lightning activity is often attached to severe storms: however, it is not a requirement for severe storm status and can occur in the absence of severe storms. The deaths due to lightning noted in this report are not necessarily attributable to severe storms as per the above meteorological definition of severity (e.g., Ryan, 1993): thus, lightning is dealt with separately. Flooding, including flash flooding, was dealt with in a previous report (Haynes *et al*, 2016).

Severe storms are common in Australia and contribute about 45% of all weather-related losses (Crompton & McAneney, 2008). Studies have been undertaken on severe storm damage (e.g. Yeo *et al*, 1999; Harper *et al* 2000; Buckley *et al* 2010) and on economics and costs (e.g. Crompton & McAneney, 2008).

However, little work on nation-wide fatalities has been carried out to date. Early estimates of severe storm-related deaths were 650 lightning deaths from 1824-1991 (Coates *et al*, 1993) and 774 storm (mainly lightning) deaths from 1824-2003 (Blong, 2005).

Gust fatalities

To the authors' knowledge, no Australian studies have focused upon deaths due to non-cyclonic wind gusts.

Schmidlin, in a 2009 study focusing on fatalities from wind-related tree failures in the United States from 1995-2007, catalogued 407 fatalities. The fatal treefall was most commonly due to a thunderstorm (41% of cases), followed by non-convective high winds (35%), tropical cyclones (14%), tornadoes (7%) and snow/ ice (3%). 62% of fatalities were male. The most common location was in a vehicle, which was either struck by a tree or which crashed into a tree fallen across a road (44%), followed by those outdoors camping, in a tent or on a motorcycle or ATV (38%), in mobile homes (9%) and in houses (9%). However, it was more common for those killed (by treefall) during tropical cyclones and tornadoes to be at home, whereas only 13% of those killed (by treefall) during thunderstorms and non-convective high winds were at home.

Earlier studies found that tree-fall accounted for 10% of all tropical cyclone deaths, 71% during the period 1970-1999 (Rappaport, 2000) and 33% of non-convective high wind events (Ashley & Black, 2008). Schmidlin (2009) found that treefall accounted for 31% of tropical cyclone deaths (NOT including Hurricane Katrina), 46% of non-convective high wind events, 53% of all thunderstorm deaths and 4% of tornado deaths. One-third of the tornado treefall deaths were from tornadoes rated F0 or F1 (Fujita scale) – that is, the risk of death from treefall is greater than house/ vehicle destruction, as trees fail at a lower speed threshold (Schmidlin, 2009).

Schmidlin (2009) found that a tornado or hurricane warning causes people to seek shelter indoors but that during thunderstorms and non-convective high winds, people continue driving and other ordinary daily activities. As trees can be downed in much less severe events than would down a structure, this latter group are placing themselves unnecessarily at risk.

Hail fatalities

Hail is one of the severe storm phenomena that is capable of producing an intense event over a relatively small area. Where these occur in urbanized areas they can incur an exceedingly high financial loss – for example, in Sydney (Yeo *et al*, 1999), Melbourne and Perth (Buckley *et al*, 2010). It has previously been difficult to determine the frequency of damaging hailstorms over the country as a whole due to limited historical data in the sparsely populated inland areas of Australia, although financial loss has been used as an indication – for example, to agricultural areas (e.g. McMaster, (1999, 2001).

To the authors' knowledge, no Australian studies have focused upon deaths due to hail. However, some reports exist on hail fatalities overseas. Several hail events have killed people in India, e.g. that of 30 April 1888: hailstones "as large as pigeon eggs" killed 230 at Moradabad and 16 at Beheri, some 80km away (Eliot, 1899 in Talman, 1919).

Some of the deceased were killed directly by the hail but most were stunned and knocked down, then buried under drifts of hail, where they died of cold, exposure, and suffocation.

A severe hailstorm killed 200 people in China's western Honan province on 19 July 1932 and thousands more were injured as large hailstones fell for two hours, destroying homes, crops, trees and animals in some 400 villages (Hughes & Wood, 1993). The earliest known US hail fatalities occurred in Winnsborough, South Carolina, on 8 May 1784, when "pieces of ice nine inches in circumference" killed eight people (Hughes & Wood, 1993;). More recently, on 30 July 1979, grapefruit-size hailstones fell in Fort Collins, Colorado. One fractured the skull of a three-month-old boy who died of his injuries eight days later (Hughes & Wood, 1993).

Rain fatalities

The rainfall accompanying severe storms is in the main associated with flash flood deaths, and this has been dealt with previously (see Haynes et al, 2016). To the authors' knowledge, apart from the flash flooding link, no Australian studies have focused upon deaths due to rain.

Tornado fatalities

A thunderstorm will become tornadic under the key conditions of an intense, sustained updraught; strong wind shear and strong winds at cloud-top level: the thunderstorm's own air-flow pattern will then interact with the environmental winds and produce rotation within the updraught (BoM, 2016d). Tornadoes move with the thunderstorm cloud at about the same speed and direction (~ 30-50 km/h) but may reach speeds of 80-100 km/h if associated with thunderstorms near vigorous cold fronts (BoM, 2016d).

Tornadoes in Australia may be fairly infrequent – although that may be an artefact of the largely uninhabited areas in the interior of the continent – but they can be quite intense, as several case studies have shown (e.g., Phillips, 1965; Holcombe & Moynihan, 1978; Plukss, 1979; Minor *et al*, 1980).

Hanstrum *et al* (2002) reported that over 700 tornado events (and probably many more that go unrecorded due to the sparsely populated interior of the continent) have been recorded across Australia from 1788-2002 with over 40 associated deaths.

LIGHTNING FATALITIES

In Australia, very few studies have been carried out on the circumstances of lightning fatalities, with the exception of Prentice (1972) and Coates *et al.* (1993). However, the incidence of lightning-related mortality has been the subject of several international studies, the results of which are summarized below along with the Australian studies.

Globally, the incidence of lightning-related mortality varies widely both spatially and temporally. Considering total deaths – that is, not taking population statistics into account – over a similar period, national figures differ greatly.

For example, lightning-related mortality varies from 1 death in Northern Ireland to 263 in England and Wales over the same 40-year period (1941-1980 – Baker, 1984) or from approximately 600 deaths in the Netherlands over an 86-year period (1910-1995 – ten Duis, 1998) to 20,758 deaths in the United States over a 92-year period (1900-1991 – Lopez and Holle, 1998).

Annual mortality rates (per 1,000,000 population) have ranged from zero to 6.3 in different states of the USA over time (Lopez and Holle, 1998). Holle (2016) reported the annual fatality rate for the US over the period 2006-2015 at 0.1. Holle (2008, Table 11, p.7) lists a number of national lightning death rates for singular time periods.

Most studies based in developed countries (e.g., Coates, 1993; Elsom, 2001; Mills *et al*, 2014) have observed a trend towards fewer lightning fatalities in more recent times. This has been attributed to patterns of fewer people working outdoors in the open, the movement of the rural population towards more urbanized areas and the expansion of urban areas with increased lightning-protected structures, a better understanding of first aid procedures by bystanders and improved weather forecasts.

Studies in developing countries have been of insufficient period to determine trends but some (e.g., Cardoso *et al*, 2014; Navarrete-Aldana *et al*, 2014) have found that the highest fatality rates occur in the rural population, which tends to be involved in high exposure agriculture and with housing that does not in general provide adequate lightning safety. Others (e.g., Zhang *et al*, 2010) noted an increase in death rate during the study period, with only the most recent couple of years showing a decrease.

Most studies have found that males account for the majority of lightning strike victims (from ~65% to 85% in most of the studies mentioned in this review), regardless of the economic and developmental level of the country (e.g., Curran *et al*., 2000; Holle *et al*., 2005; Cooper *et al*., 2012). The reason has been attributed to factors such as the tendency for greater risk taking by males, and greater exposure to the outdoors through work or recreational practices. The age range of those most likely to die by lightning varies from study to study but is in the range of 15-39.

Most studies have noted that the vast majority of fatal incidents occur in outdoor environments, although the chief activities being carried out are nowadays more recreation- than occupation-based (Pakiam *et al*., 1981; Coates *et al*, 1993; ten Duis, 1998; Holle *et al*., 2005). However, as noted above, in developing countries most deaths occur amongst people working in agriculture or construction (Murty *et al*., 2009; Cardoso *et al*., 2014; Navarrete-Aldana *et al*., 2014).

Curran *et al.* (2000) noted that the activities most commonly engaged in in the US were in open fields and then in ballparks and playgrounds; under trees; water-related e.g., fishing, boating, swimming; golfing; operating tractors, farm equipment and heavy road equipment; on the telephone; and touching a radio, transmitter or antenna. A similar distribution was found by Elsom (2001) in the United Kingdom. The percentage of people killed while under a tree is noteworthy across some studies: Australia 24% (Coates *et al*, 1993), UK & Ireland 20% (Elsom & Webb, 2014), US 19% (Holle, 2008), Brazil 12% (Cardoso *et al*, 2014), Singapore 9% (Pakiam *et al*, 1981) and Greece 5% (Agoris *et al*, 2012). Note that the time periods differed for these studies.

METHODOLOGY

The project was completed in two steps: 1) updating the data held within *PerilAUS* relating to human fatalities from earthquake, tropical cyclone and severe storm (gust, hail, lightning, rain and tornado) events, and 2) statistical analysis to determine the lives lost and the environmental and social circumstances surrounding those fatalities.

PerilAUS, a database of impacts and consequences of natural hazards in Australia held by Risk Frontiers, was deemed a good basis for this project due to the range of data sources, the wealth of descriptive detail concerning the hazard impact and the inclusion of data about any fatalities caused by that hazard. To meet the needs of this project, however, it was recognized that the database needed to be enriched in breadth and detail. The following describes *PerilAUS* prior to the commencement of the BNHCRC project and how the data has been updated.

DATA SOURCES

PerilAUS prior to project commencement

PerilAUS contains detailed information on natural hazard events impacting Australia from European settlement (1788) and before, but with good confidence from 1900. The data includes information relating to fatalities, injuries, near misses, damage to the built environment, costs and event physical attributes.

Fatality data includes, where available, the demographics of the deceased; date, time and cause of death; and occupation and circumstances at time of death – for example, what the deceased was doing at the time of/ just before death.

The data is based on material collected from news media, government departments and the published literature. A total of 23,458 references have been included in *PerilAUS* thus far. There is a total of 15,607 event records from the year 1900 to 2015. The data covers 12 peril types: bushfire, earthquake, flood, hailstorm, extreme heat, landslide, lightning strike, rainstorm, tornado, tropical cyclone, tsunami and windstorm. The database has served to underpin some twenty other hazard- and risk-related studies: for example, Coates *et al.* (1993), Coates (1996), Coates (1999), Blong (2005), Haynes *et al.* (2009), Haynes *et al.* (2010), Crompton *et al.* (2010), Blanchi *et al.* (2014) and Coates *et al.* (2014).

The dominant sources used initially for *PerilAUS* were The *Sydney Gazette* and the *Sydney Morning Herald* (the colony's first newspapers, dating from 1803 and 1831 respectively). In more recent years events drawn from the main newspaper of each Australian state and the Australian Capital Territory from the mid-1990s have been included via Factiva - an online search tool and current international news database that provides access to sources such as newspapers, newswires, journals, industry publications, websites, company reports, television and radio transcripts and more.

The increase in the availability of scanned newspaper reports available online through such information resources as Trove (National Library of Australia) and the advent of the World Wide Web has ensured that *PerilAUS* now includes at least the major hazard impacts in all states and territories. In recent years, Factiva has included local (suburban) news media in its available online resources of event coverage – often these data sources provide valuable detail around human health impacts.

Depending on the hazard type and data availability, government and other official reports have been accessed. This has included publications by the Bureau of Meteorology (BoM), Geoscience Australia, the Australian Bureau of Statistics (ABS) and the Australian Institute of Health and Welfare (AIHW). In particular, the BoM Significant Weather Summaries, Monthly Weather Reviews and Severe Storm Archive were utilized.

In order to make a scientific analysis for policy and emergency management reform, the existing *PerilAUS* data needed to be further augmented and verified as detailed below.

Updating *PerilAUS*

Feedback received from end-users following the completion of the flood fatality component of this project (see Haynes *et al*, 2016) demonstrated that the data and its analysis were of most use when recent time periods were considered in detail. As building codes were amended significantly following Cyclone Tracy in 1974 it was decided to focus on tropical cyclone fatalities from this time onward. For earthquakes, the focus was the Newcastle event of 1989 and as the best data on storms was available from 1990 onward this became the focus. Therefore in summary data was collected and analysed for the following time-periods:

- tropical cyclone events from 1970,
- severe storm events from 1990, and
- the Newcastle earthquake event of 1989.

In addition, records from 2000 were focussed on by utilizing the National Coronial Information Service (NCIS), rather than spending resources on attempting to gather records from the disparate state and territory archives offices. In addition, Factiva was employed to gain more local insights into the events already within *PerilAUS*, to locate names of the deceased and to add any instances of fatalities not already uncovered.

Table 3.1 summarizes the improvements that have been made to the hazard databases of current interest since project commencement. It should be noted that this table simply displays the *number* of events recorded in *PerilAUS*: it does not imply that all of these events have impacted human health. Table 3.2 focuses on those events that have caused fatalities. The Earthquake, Tropical Cyclone and Severe Storm (Gust, Hail, Lightning, Rain and Tornado) databases have increased in total number of events (covering the years 1900 to 2015) by 9%.

Peril type	Qld	NSW	ACT	Vic	Tas	SA	WA	NT	>1 State	Total Events
Earthquake	6/2	19/0	2/0	9/1	3/1	8/-1	21/0	6/0	4/0	78/3
Gust	287/61	1159/240	11/3	565/73	18/35	241/1	741/68	115/4	3/-1	3140/484
Hail	304/20	1322/40	9/1	321/22	15/0	82/2	253/6	15/1	1/0	2322/92
Lightning	223/51	494/46	14/0	145/17	29/4	63/11	65/25	15/9	11/0	1059/163
Rain	83/11	495/105	3/1	559/2	30/1	125/2	173/0	7/1	4/0	1479/123
Tornado	41/4	310/10	3/0	135/3	20/0	69/3	90/3	8/0	1/0	677/23
Tropical cyclone	148/13	7/1	0/0	0/0	0/0	0/0	118/8	30/9	23/-6	326/25
Total	1092/162	3806/442	42/5	1734/118	115/41	588/ 18	1461/110	196/24	47/-7	9081/913

Table 3.1: Number of natural hazard event records in *PerilAUS* by state, 1900-2015: total prior to project commencement (March 2014)/ new since project commencement (as at 28-12-2016).

Table 3.2 displays the respective numbers of fatal event records of current interest and named fatalities included in *PerilAUS*. Figures at project commencement are compared to those of 28 July 2016. The number of fatal events in the Tropical Cyclone, Earthquake, and Severe Storm (Gust, Hail, Lightning, Rain and Tornado) databases has increased by 156% over the length of the project. The number of fatalities has increased by 31%. Importantly, the percentage of named fatalities has increased from 11% to 45%, in addition to an increase in the overall numbers of fatalities. This extra research has enabled a far greater percentage of fatalities to be verified and a more detailed picture of the circumstances surrounding their death to be gleaned from coronial inquests.

Hazard type	Trop. Cyc.	Earth-quake	Gust	Hail	Light-ning	Rain	Tornado	Total
Tot number fatal event records	71/1	3/0	75/ 33	10/ 0	103/ 84	14/ -6	23/0	759/ 153
Total number of deaths	1285/ -106[2]	16/0	101/ 72	16/ -12	109/ 90	16/ -4	52/ 52	4057/ 237
Number of named deaths	56/ -194[2]	10/ 0	38/ 66	5/ -3	52/ 98	1/ 7	20/ 18	1069/ 186

[1]SOME DEATHS FORMERLY ATTRIBUTED TO HAIL WERE MOVED TO THE CORRECT DATABASE
[2]TC-RELATED FLOOD DEATHS WERE TRANSFERRED TO FLOODS DURING THE PREVIOUS PROJECT.

Table 3.2: Number of fatal event records and named fatalities in *PerilAUS*, 1900-2015: total prior to project commencement (March 2014)/ new since project commencement (as at 28-7-2016).

Coronial inquests

An important component of the current project was the detailed examination, where possible, of recent coronial data. A coronial inquest may be carried out if a death is sudden or untimely (amongst other reasons), but it should be understood that inquests will not be carried out for every natural hazard fatality that has occurred.

The data required in order to locate an inquest file are generally the name of the deceased and the date of death, although sometimes other data such as location of death are helpful.

In general, inquests include a coroner's report and witness statements. The coroner's report lists the correct name, occupation and location of the deceased, the people who were with the deceased and other witnesses and the time and date of death and when found. The witness statements give a fuller account of the deceased and details up to the time of death, including age, name of relatives, where the deceased came from, the reasoning behind decisions made which led to the death, the actions of the deceased, their knowledge or forewarning about the natural hazard dangers and details of weather and the environment.

As previously stated, rather than spending resources on attempting to gather records from the disparate state and territory archives offices, the more recent records from 2000 were focussed on by utilizing the National Coronial Information Service (NCIS).

Weather data

Despite the employment of Bureau of Meteorology (BoM) references, at the start of this project the *PerilAUS* database was deficient in some of the physical characteristics data from severe storm and tropical cyclone events. Many of these events were originally researched and entered from the mid to late 1990s and, at that stage, records available via the internet were quite limited. Notwithstanding the relative abundance of such freely available data sources now, there is limited availability of specific physical characteristic information through BoM, especially in relation to severe storm events.

Tropical cyclones are generally described in relation to the maximum severity (Australian Cyclone Severity Scale, ACSS) reached over a cyclone's life cycle. However, these intensities vary, sometimes quite widely, over the duration of the cyclone, both in space and time. With this in mind, every effort was made to determine the ACSS at the exact location of each fatality. This was more successful for those cyclones of more recent times.

Severe storms were more problematic. Such events are mainly reported and discussed by the news media in terms of human effects rather than precise physical aspects: there have been a high incidence of articles which exist purely to record the deaths of individuals. BoM reports, while focussing on the physical aspects, did not always include some of the more local or minor events, or sufficient detail regarding any fatalities to enable cross-checking. Varying reports of wind speeds (both sustained winds and maximum wind gusts), total rainfall and rainfall intensities made assigning severities problematic.

BIASES AND DATA LIMITATIONS

Newspaper articles, while containing valuable narrative detail, can contain inaccuracies and bias towards newsworthy events. The *PerilAUS* record in the early 1990s contains a certain spatial bias towards New South Wales (NSW), especially Sydney, as the main and local newspapers from states other than NSW were not available online until the mid to late 1990s. The inclusion of government, scientific, historical and other reports has helped balance the bias.

The verification of the data through the searching of inquest reports has allowed the majority of inaccuracies from the news media to be identified and removed.

It is impossible to assert that *PerilAUS* has captured every detail or fatality. It can be asserted, though, that it represents the best collection of such data in Australia, over the various time-periods studied.

RESULTS

A total of 406 deaths have been identified across the periods under study for tropical cyclones, earthquakes and severe storms. Table 4.1 gives the breakdown of these figures. Since 1990 (to 2015), over three quarters of the 254 deaths identified have been due to severe storms and, of those deaths, over half were due to the severe storm hazard of gusts.

Hazard	Date range	Total fatalities	% fatalities 1990-2015
Earthquake	1989 event	14	0
Tropical Cyclone	1970-2015	192 (54 from 1990)	21.2
Severe Storms:	1990-2015	200+	78.8
• Gusts	1990-2015	142	55.9
• Hail	1990-2015	0	0
• Lightning	1990-2015	48	18.9
• Rain	1990-2015	7+[1]	2.8+
• Tornado	1990-2015	3	1.2
Total		**406+**	**100**

[1]THIS INCLUDES A FEW RAIN-CAUSED TRAFFIC ACCIDENTS – SEE P.47 FOR DETAILS

Table 4.1: Hazards and date ranges investigated and the total death toll

TROPICAL CYCLONE

A total of 192 fatalities from tropical cyclones were identified from 1970 to 2015. Both the numbers of fatalities (Figures 4.1, 4.2; Table 4.2) and the death rates (Figure 4.3) due to tropical cyclone fatalities show a general decrease over time, punctuated by periodic excursions into higher values. A regression line calculated from the data in Figure 4.3 showed a statistically significant decreasing trend in fatalities across time ($F_{1,44}$=0.5.905, $p<0.02$).

Total numbers of deaths range from a high of 70 in 1974 (due to Cyclone Tracy) to several years of zero deaths: for example, since 2000, deaths have occurred in only three years. The annual death rate (averaged over the decade) has decreased from 0.87 per million population in the 1970s to less than 0.01 per million population in the current decade (2010-2015).

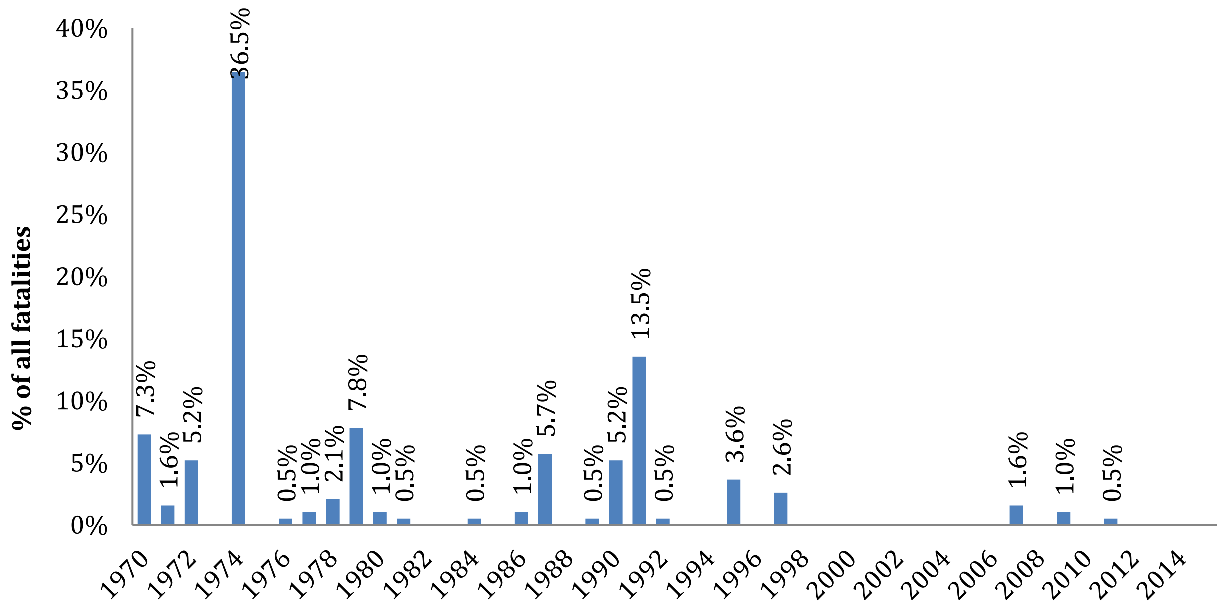

Figure 4.1 Tropical Cyclone: Fatalities over time (by year)

	Total
1970-1974	97 (50.5%)
1975-1979	22 (11.5%)
1980-1984	4 (2.1%)
1985-1989	14 (7.3%)
1990-1994	37 (19.3%)
1995-1999	12 (6.3%)
2000-2004	0 (0.0%)
2005-2009	5 (2.6%)
2010-1015	1 (0.5%)
	192 (100.0%)

Table 4.2 Tropical Cyclone: Fatalities over time (by 5-year interval)

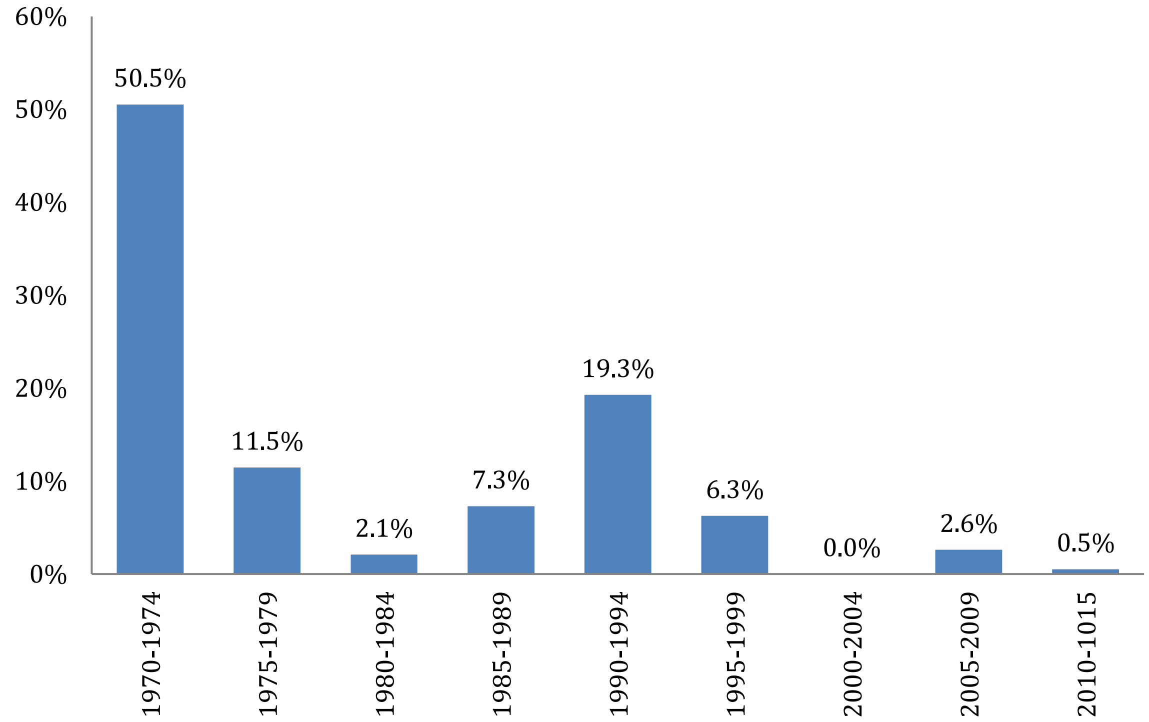

Figure 4.2 Tropical Cyclone: Fatalities over time (by 5-year interval)

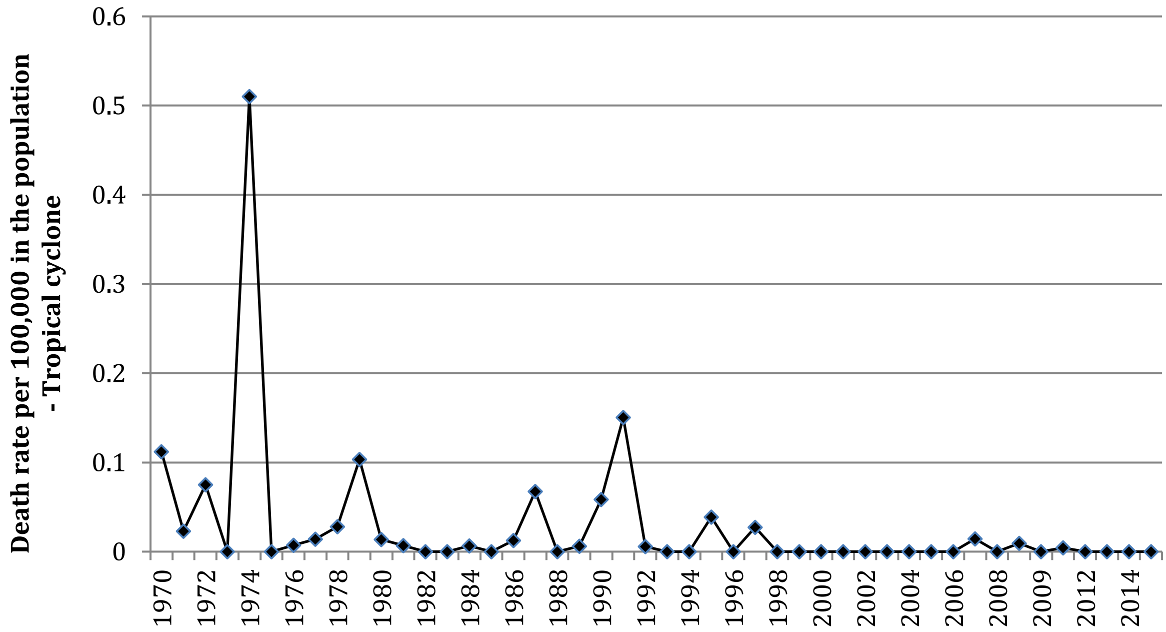

Figure 4.3 Tropical Cyclone: Death rates over time

Demographics

Tables 4.3 and 4.4 show that the majority of the fatalities were male 84% (n161) with the highest proportion of the fatalities amongst those aged 20-39 (24% of male fatalities and 35% of female fatalities). Amongst females, the 0-9 years age group had the highest proportion of fatalities (23%; n6), although the distribution of fatalities was more even amongst females than males.

	Total
Males	161 (83.9%)
Females	26 (13.5%)
Unknown	5 (2.6%)
	192 (100.0%)

Table 4.3 Tropical Cyclone: Gender

	Male	**Female**	**Unknown**	**Total**
0-9	8 (5.0%)	6 (23.1%)	3 (60.0%)	17 (8.9%)
10-19	4 (2.5%)	2 (7.7%)	0 (0.0%)	6 (3.1%)
20-29	18 (11.2%)	5 (19.2%)	0 (0.0%)	23 (12.0%)
30-39	21 (13.0%)	4 (15.4%)	0 (0.0%)	25 (13.0%)
40-49	9 (5.6%)	2 (7.7%)	0 (0.0%)	11 (5.7%)
50-59	4 (2.5%)	0 (0.0%)	0 (0.0%)	4 (2.1%)
60-69	6 (3.7%)	1 (3.8%)	0 (0.0%)	7 (3.6%)
70 or older	7 (4.3%)	2 (7.7%)	0 (0.0%)	9 (4.7%)
Unknown	84 (52.2%)	4 (15.4%)	2 (40.0%)	90 (46.9%)
Total	**161 (100.0%)**	**26 (100%)**	**5 (100.0%)**	**192 (100.0%)**

Table 4.4 Tropical Cyclone: Age vs gender

Cause of death

The majority of fatalities (66%) were killed by drowning, injury or exposure at sea (Table 4.5) while on a boat or vessel. Another 18% were killed by either a building (or other structure) collapse or by wind-driven projectiles – that is, land based due to wind hazard.

	Total
Drowning/injury/exposure	126 (65.6%)
Injury – from fall	2 (1.0%)
Injury – building/structure collapse	12 (6.3%)
Injury – hit: by debris or projectiles etc	1 (0.5%)
Injury – Vehicle accident	1 (0.5%)
Injury – Tree-/ tree limb fall	1 (0.5%)
Heart attack, stroke, overexertion, shock, collapse	2 (1.0%)
Electrocution (fallen power lines etc)	1 (0.5%)
Asphyxiation – other (failure of breathing apparatus due to power outage, mud, CO_2 poisoning)	2 (1.0%)
Injury – either building/ structure collapse OR hit by debris/ projectiles	21 (10.9%)
Unknown	23 (12.0%)
Total	**192 (100.0%)**

Table 4.5 Tropical Cyclone: Cause of death

Spatial distribution, location, transport and seasonality

As Table 4.6 shows, the states/territories with the highest proportion of fatalities are Western Australia (WA) and the Northern Territory (NT) with 41% (n79) and 37% (n71) respectively, followed by Queensland with 21% (n41). Table 4.7 shows the fatalities by state and month. The highest numbers of fatalities occurred in December: however, this is predominantly the fatalities caused by Cyclone Tracy in 1974 when 70 people were killed. As a point of interest, Althea was the other fatal cyclone that occurred in the month of December – coincidentally, also on Christmas eve (killing 3 people).

Most of the WA fatalities occurred in March and April. The majority of NT fatalities occurred in December (again, this is biased by the large TC Tracy event). Qld suffered most of its fatalities from January to March.

A majority of 65% of people died outside while on a boat (n125) (see Table 4.8 and Table 4.9).

State	
NSW	1 (0.5%)
Victoria	0 (0.0%)
South Australia	0 (0.0%)
Western Australia	79 (41.1%)
Northern Territory	71 (37.0%)
Queensland	41 (21.4%)
Tasmania	0 (0.0%)
ACT	0 (0.0%)
Total	**192 (100.0%)**

Table 4.6 Tropical Cyclone: State

	NSW	WA	NT	Qld	Total
January	1 (100.0%)			16 (39.0%)	17 (8.9%)
February		9 (11.4%)		7 (17.1%)	16 (8.3%)
March		32 (40.5%)	1 (1.4%)	15 (36.6%)	48 (25.0%)
April		38 (48.1%)			38 (19.8%)
May					
June					
July					
August					
September					
October					
November					
December			70 (98.6%)	3 (7.3%)	73 (38.0%)
	1 (100.0%)	**79 (100.0%)**	**71 (100.0%)**	**41 (100.0%)**	**192 (100.0%)**

Table 4.7 Tropical Cyclone: Month vs State

	Total
Outside – open ground (open park, paddock, sheep yard)	0 (0.0%)
Outside – on or in the water (sea or river)	126 (67.2%)
Outside – adjacent to the ocean – beach or shore	0 (0.0%)
Outside – near house/ structure (e.g. in the garden or yard – hanging washing)	2 (1.0%)
Outside – adjacent to house/ structure (in doorway or on roof)	2 (1.0%)
In a house/ structure – destroyed	7 (3.6%)
In a house/ structure – not destroyed	2 (1.0%)
Other	1 (0.5%)
Unknown	52 (27.1%)
	192 (100.0%)

Table 4.8 Tropical Cyclone: Location of fatality

	Total
In a house – i.e. no transport involved	14 (7.3%)
On foot	2 (1.0%)
On a horse	0 (0.0%)
In a vehicle - car or truck	0 (0.0%)
On the water – in a boat	125 (65.1%)
On a motorbike	1 (0.5%)
Other	2 (1.0%)
Unknown	48 (25.0%)
Total	**192 (100.0%)**

Table 4.9 Tropical Cyclone: Form of transport at the time of death

Capacity and awareness

In terms of capacity (Table 4.10), the majority were considered to be following the decision making of others as they were passengers on a boat (53%, n101). In terms of awareness (Table 4.11), the highest proportion were considered to know there was a hazard or imminent risk of a hazard but did not expect to encounter it (38% n73).

	Total
Capable of independent action	41 (21.4%)
Following decisions of others	101 (52.6%)
Unknown	50 (26.0%)
Total	**192 (100.0%)**

Table 4.10 Tropical Cyclone: Capacity

	Total
Knew there was a hazard or imminent risk of a hazard but did not expect to encounter it	73 (38.0%)
Knew there was a hazard or imminent risk of a hazard but did not expect it to be as strong/damaging	30 (15.6%)
Unaware and taken by surprise/ too little time to enact survival strategy	1 (0.5%)
Child under 11 years old	17 (8.9%)
Unknown	0 (0.0%)
Total	**192 (100.0%)**

Table 4.11 Tropical Cyclone: Awareness

Actions taken

Most of the deceased were either en route (20%, n38) or preparing for onset of the hazard (17%, n32) prior to its advent (Table 4.12): most males were preparing property (20%, n32) or en route (23%, n37) (Table 4.13). Once the hazard became apparent (Table 4.14), most (46%, n74) males were en route; a small number (4%, n7) took evacuation action too late and some (3%, n5) were preparing property.

	Recreating	Carrying out everyday work-related activities	Preparing property – household/ car	Preparing property - livelihood	Sheltering from storm	Preparing for onset of hazard event (general, collecting provisions, materials etc)	En route	Other	Unknown	Total
Waiting to see/very late evacuation							7 (18.4%)			**7 (3.6%)**
Sheltering from storm					5 (100.0%)					**5 (2.6%)**
Collecting / securing items due to impending rain and wind				5 (100.0%)						**5 (2.6%)**
Recreating	1 (11.1%)									**1 (0.5%)**
Carrying out repairs / maintenance due to hazard damage etc						1 (100.0%)			2 (2.4%)	**3 (1.6%)**
En route	2 (22.2%)		31 (96.9%)				26 (68.4%)	6 (35.3%)	10 (11.9%)	**75 (39.1%)**
Taken by surprise - No attempt at evacuation/ Very late evacuation			1 (3.1%)							**1 (0.5%)**
Other								11 (64.7%)		**11 (5.7%)**
Unknown	6 (66.7%)	1 (100.0%)					5 (13.2%)		72 (85.7%)	**84 (43.8%)**
Total	**9 (100.0%)**	**1 (100.0%)**	**32 (100.0%)**	**5 (100.0%)**	**5 (100.0%)**	**1 (100.0%)**	**38 (100.0%)**	**17 (100.0%)**	**84 (100.0%)**	**192 (100.0%)**

Table 4.12 Tropical Cyclone: Actions taken prior to the onset of the hazard (top row) vs actions taken once hazard became apparent (first column)

	Male	Female	Unknown	Total
Recreating	9 (5.6%)	0 (0.0%)	0 (0.0%)	**9 (4.7%)**
Carrying out everyday work-related activities	1 (0.6%)	0 (0.0%)	0 (0.0%)	**1 (0.5%)**
Preparing property – household/ car	32 (19.9%)	0 (0.0%)	0 (0.0%)	**32 (16.7%)**
Preparing property - livelihood	5 (3.1%)	0 (0.0%)	0 (0.0%)	**5 (2.6%)**
Sheltering from storm	4 (2.5%)	1 (3.9%)	0 (0.0%)	**5 (2.6%)**
Preparing for onset of hazard event (general, collecting provisions, materials etc)	1 (0.6%)	0 (0.0%)	0 (0.0%)	**1 (0.5%)**
En route	37 (23.0)	1 (3.9%)	0 (0.0%)	**38 (19.8%)**
Other	15 (9.3%)	2 (7.7%)	0 (0.0%)	**17 (8.9%)**
Unknown	57 (35.4%)	22 (84.6%)	5 (100.0%)	**84 (43.8%)**
Total	**161 (100.0%)**	**26 (100.0%)**	**5 (100.0%)**	**192 (100.0%)**

Table 4.13 Tropical Cyclone: Actions taken prior to the onset of the hazard (first column) vs Gender (top row)

	Male	Female	Unknown	Total
Waiting to see/very late evacuation	7 (4.4%)	0 (0.0%)	0 (0.0%)	**7 (3.6%)**
Sheltering from storm	4 (2.5%)	1 (3.8%)	0 (0.0%)	**5 (2.6%)**
Collecting / securing items due to impending rain and wind	5 (3.1%)	0 (0.0%)	0 (0.0%)	**5 (2.6%)**
Recreating	1 (0.6%)	0 (0.0%)	0 (0.0%)	**1 (0.5%)**
Carrying out repairs / maintenance due to hazard damage etc	3 (1.9%)	0 (0.0%)	0 (0.0%)	**3 (1.6%)**
En route	74 (46.0%)	1 (3.8%)	0 (0.0%)	**75 (39.1%)**
Taken by surprise - No attempt at evacuation/ Very late evacuation	1 (0.6%)	0 (0.0%)	0 (0.0%)	**1 (0.5%)**
Other	10 (6.2%)	1 (3.8%)	0 (0.0%)	**11 (5.7%)**
Unknown	56 (34.8%)	23 (88.5%)	5 (100.0%)	**84 (43.8%)**
Total	**161 (100.0%)**	**26 (100.0%)**	**5 (100.0%)**	**192 (100.0%)**

Table 4.14 Tropical Cyclone: Actions taken once the hazard became apparent (first column) vs Gender (top row)

Fatalities by classification of TC event severity

The severity of a tropical cyclone is described in terms of categories on a scale of 1 (weakest) to 5 (strongest) based on the maximum mean wind speed (BoM, 2016c). Severe tropical cyclones refer to categories 3, 4 and 5, having sustained surface winds of at least 118 km/h near the centre and gusts of at least 165 km/h (BoM, 2016c). In our analysis, severity classifications of a more generic nature were used as we initially attempted to classify all hazard types considered here, but the categories listed in Table 4.15 do correspond directly to the BoM classification. The majority of fatalities (73%, n143) occurred during events classed as severe at incident location and 27% (n52) lost their lives due to events classed as non-severe at incident location (Table 4.15 and Figure 4.4).

The previous report (Haynes *et al*., 2016) included flood deaths caused by tropical cyclones, which rain-producing events are often non-severe. The current report focuses on deaths from high winds, high seas and storm surge, and the BoM classification system can be regarded as a good indication of the severity of the event in terms of human life lost. The record is biased by TC Tracy (a cat 4 cyclone) but there have been a relatively large number of fatal cyclones classed as non-severe (and cat 2) at incident location – eight – as opposed to six cat 3 cyclones, three cat 4 and two cat 5 (which killed very few people).

Tables 4.16 and 4.17 show that most people killed by tropical cyclones since 1970 perished due to high seas (66%, n127), the vast majority of these (97%, n119) males. Wind (on land) has killed 30% (n58) of people, with a more even distribution between the sexes: 64% (n37) of males and 36 % (n21) of females. Looked at another way, the majority of females have died, in a tropical cyclone, by the action of wind on land.

37% (n47) of the deaths due to high seas have been caused by a non-severe (at incident location) cyclone and 63% (n80) by a severe cyclone. In cyclone events classed as severe at incident location, 56% (n80) of the deaths have occurred in high seas and 41% (n58) through wind on land (Table 4.18).

Figure 4.5 tracks deaths by hazard type over time and shows the record is dominated by Cyclone Tracy, where the majority of deaths occurred via wind on land. The middle period of record shows high seas to be the main cause of death. In more recent times, during the last decade, deaths from all peril types have fallen markedly but there are a few more deaths caused by wind on land than by high seas.

	Total
Low	3 (1.6%)
Minor-moderate	49 (25.5%)
Major/ extensive	20 (10.4%)
Severe/ disastrous	105 (54.7%)
Record/ highest known/ unprecedented	18 (9.4%)
	192 (100.0%)

Table 4.15 Tropical Cyclone: Severity vs death toll

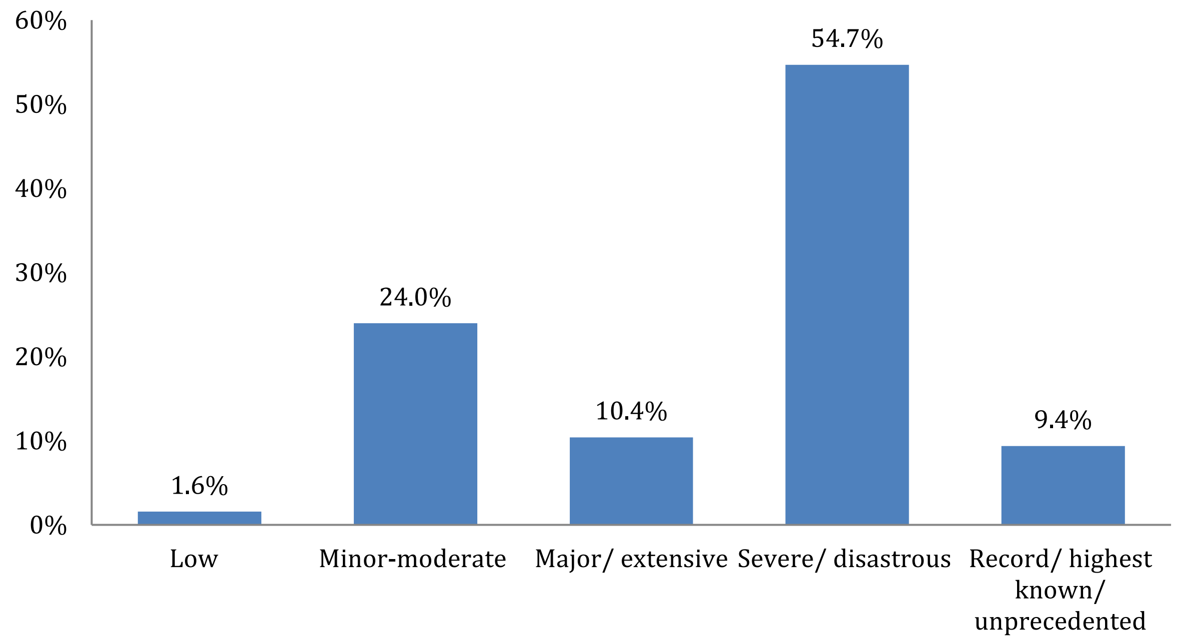

Figure 4.4 Tropical Cyclone: Fatality vs severity of hazard

	Count
Surge	0 (0.0%)
Wind	58 (30.2%)
Rain	1 (0.5%)
High seas	127 (66.2%)
Unknown	6 (3.1%)
Total	**192 (100.0%)**

Table 4.16 Tropical Cyclone: Deaths by hazard type

	Males	Females	Unknown	Count
Surge	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Wind	37 (23.0%)	21 (80.8%)	0 (0.0%)	58 (30.2%)
Rain	1 (0.6%)	0 (0.0%)	0 (0.0%)	1 (0.5%)
High seas	119 (73.9%)	4 (15.4%)	4 (80.0%)	127 (66.2%)
Unknown	4 (2.5%)	1 (3.9%)	1 (20.0%)	6 (3.1%)
Total	**161 (100.0%)**	**26 (100.0%)**	**5 (100.0%)**	**192 (100.0%)**

Table 4.17 Tropical Cyclone: Deaths by hazard type and gender

	Low	Minor/ moderate	Major/ extensive	Severe/ disastrous	Record/ highest known/ unprecedented	Count
Surge						0 (0.0%)
Wind			4 (20.0%)	50 (47.6%)	4 (22.2%)	58 (30.2%)
Rain			1 (5.0%)			1 (0.5%)
High seas	2 (66.7%)	45 (97.8%)	15 (75.0%)	51 (48.6%)	14 (77.8%)	127 (66.2%)
Unknown	1 (33.3%	1 (2.2%)		4 (3.8%)		6 (3.1%)
Total	**3 (100.0%)**	**46 (100.0%)**	**20 (100.0%)**	**105 (100.0%)**	**18 (100.0%)**	**192 (100.0%)**

Table 4.18 Tropical Cyclone: Deaths by hazard type and severity

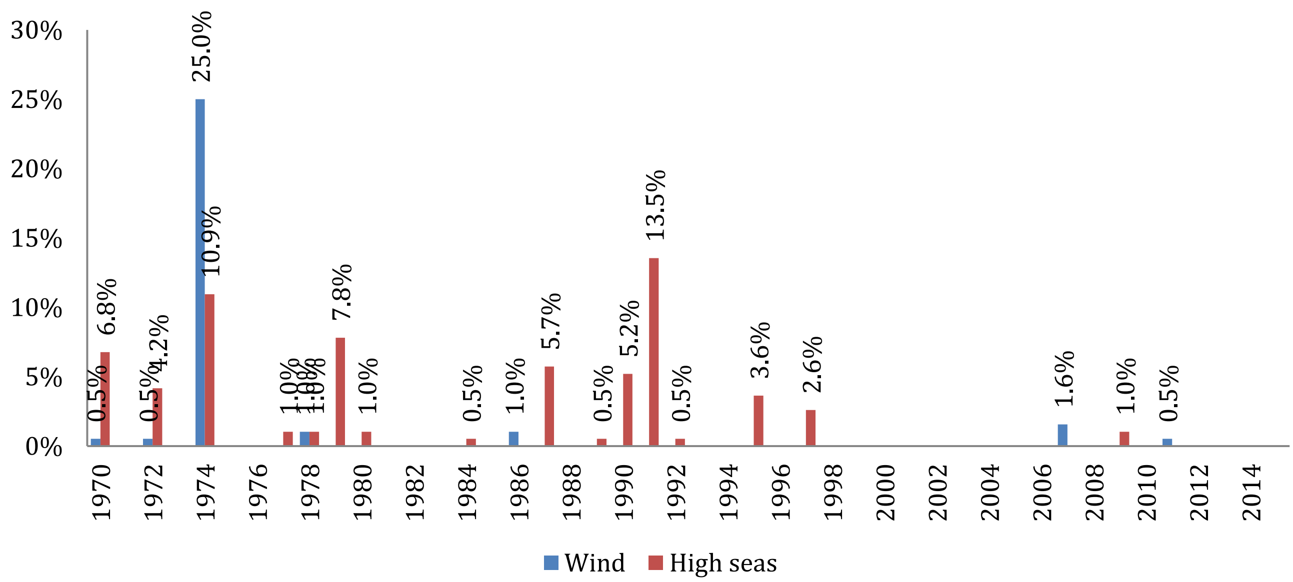

Figure 4.5 Tropical Cyclone: Deaths by hazard type over time

EARTHQUAKE

The 1989 Newcastle earthquake was a relatively deep "thrust fault" earthquake felt as far as Bateman's Bay to the south, Dubbo to the west and Armidale to the north. The size of the earthquake, as measured by its Magnitude, was 5.6, and the largest ground shaking level, as measured by maximum intensity, was assessed as VIII on the Modified Mercalli Scale (MMI). An aftershock was recorded on 29 December and possibly one other aftershock – a remarkable lack of aftershock activity. The earthquake was felt at intensity MMI IV to V in Sydney and was clearly felt in Canberra, especially in tall buildings. The effects of the earthquake were amplified in Newcastle due to its CBD having been built on a thin layer of alluvial soil constituting a former course of the Hunter River where it flowed into the sea and on landfilled areas. The *PerilAUS* record indicates that Newcastle previously suffered damaging earthquakes in 1842, 1868 and 1925.

Modern structures in the epicentral region and downtown Newcastle suffered considerable damage including the Newcastle Workers Club (NWC), which was being renovated and partially collapsed and where ten people died. Some 300 people, mostly elderly, were in the NWC at the time of the earthquake (10:27 am), when it was not particularly crowded. Many buildings and structures were damaged, due largely to the poor quality of their initial construction and long-term structural deterioration. Three were killed in Beaumont Street, Hamilton, where a number of old buildings suffered damage, and one person died of earthquake-induced shock (the following day). Some 179 persons were injured. [All data from the *PerilAUS* database, obtained in turn from a variety of sources.]

Demographics

A total of 14 people were killed due to the Newcastle Earthquake of 1989. An equal gender split of fatalities occurred with very similar age profiles. The highest proportion of those killed were 60 or older (Table 4.19, Figure 4.5).

	Male	Female	Total
0-9	0 (0.0%)	0 (0.0%)	0 (0.0%)
10-19	0 (0.0%)	0 (0.0%)	0 (0.0%)
20-29	0 (0.0%)	0 (0.0%)	0 (0.0%)
30-39	1 (14.3%)	0 (0.0%)	1 (7.1%)
40-49	0 (0.0%)	1 (14.3%)	1 (7.1%)
50-59	1 (14.3%)	1 (14.3%)	2 (14.3%)
60-69	3 (42.9%)	3 (42.9%)	6 (42.9%)
70 or older	1 (14.3%)	2 (28.6%)	3 (21.4%)
Unknown	1 (14.3%)	0 (0.0%)	1 (7.1%)
Total	**7 (100.0%)**	**7 (100%)**	**14 (100.0%)**

Table 4.19 Newcastle Earthquake: Age and Gender

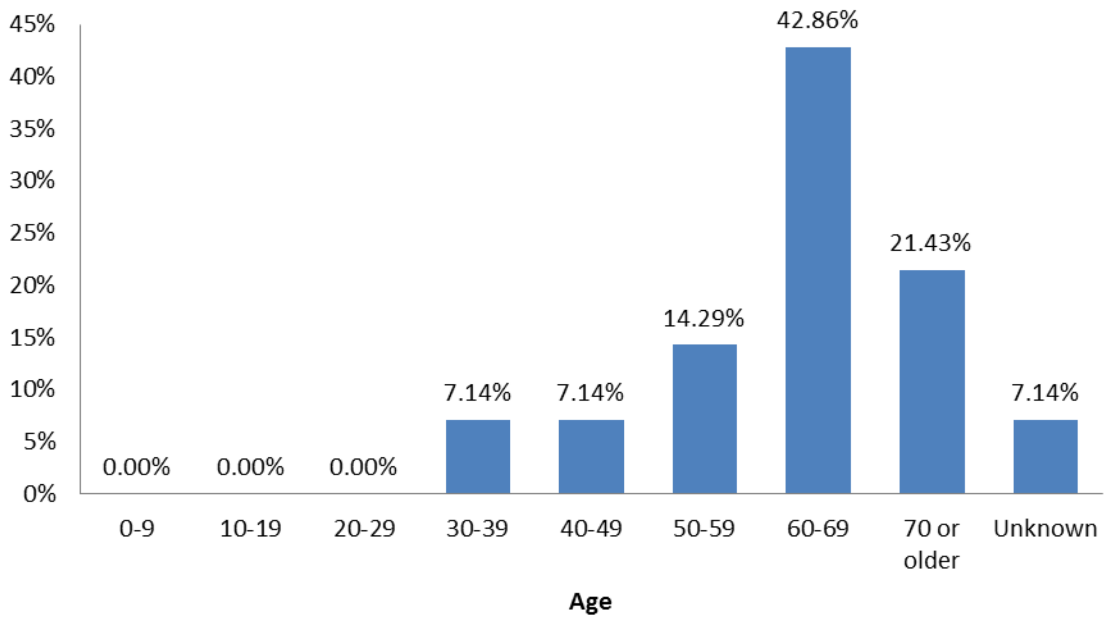

Figure 4.5 Newcastle Earthquake: 10-year age groups

Cause of death

The majority of people died from injuries received from the collapse of buildings: however, one died the next day of a brain hemorrhage (a fatal stroke) brought on by the stress of the earthquake (attributed by the NSW State Coroner) (Table 4.20).

	Total
Injury – building/structure collapse	13 (92.9%)
Heart attack, stroke, overexertion, shock, collapse	1 (7.1%)
Total	**14 (100.0%)**

Table 4.20 Newcastle Earthquake: Cause of death

Form of transport and location

Ten of the victims were inside the Newcastle Worker's Club while three were on foot but close to structures (Table 4.21 and Table 4.22).

	Total
In a house or building – i.e. no transport	10 (71.4%)
On foot	3 (21.4%)
On a horse	0 (0.0%)
In a vehicle - car or truck	0 (0.0%)
In the water - swimming or boating	0 (0.0%)
On a motorbike	0 (0.0%)
Other	0 (0.0%)
Unknown	1 (7.1%)
Total	**14 (100.0%)**

Figure 4.21 Newcastle Earthquake: Transport

	Total
Outside – open ground (open park, paddock, sheep yard)	0 (0.0%)
Outside – near house/ structure	3 (21.4%)
Outside – adjacent to house/ structure (in doorway or on roof)	0 (0.0%)
In a house/ structure – destroyed	10 (71.4%)
Unknown	1 (7.1%)
	14 (100.0%)

Figure 4.22 Newcastle Earthquake: Location

Capacity and awareness

All those that died were believed to have been capable of independent action (Table 4.23), although it is believed that at least some of those who were killed in the Newcastle Worker's Club are likely to have consumed alcohol. However, it is unlikely that this contributed to their death: the event occurred suddenly with no warning and all the victims were taken by surprise.

	Total
Capable of independent action	14 (100.0%)
Physically disabled or incapable and reliant on power source	0 (0.0%)
Following decisions of others	0 (0.0%)
Child or children on their own, under 11 years old	0 (0.0%)
Total	**14 (100.0%)**

Table 4.23 Newcastle Earthquake: Capacity

Actions taken

The fatalities were coded in relation to the actions taken prior to the onset of the hazard (top row in Table 4.24) and also the actions taken once the hazard became apparent (first column in Table 4.24). The highest proportion were recreating prior to the onset of the hazard (36%, n5). All of the victims were unable to take any action when the earthquake struck and were taken by surprise.

	Recreating	Carrying out everyday non work-related activities	Carrying out everyday work-related activities	Sheltering	En route	Other	Unknown	Total
Attempting vertical evacuation	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
Taken by surprise - No attempt at evacuation/ Very late evacuation	5 (100.0%)	1 (100.0%)	2 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	5 (83.3%)	**13 (92.9%)**
Being rescued/evacuated	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
Refused to be rescued	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
Sheltering	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (33.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
En route to home	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
Unknown	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (16.7%)	**1 (7.1%)**
Total	**5 (100.0%)**	**1 (100.0%)**	**2 (100.0%)**	**0 (100.0%)**	**0 (100.0%)**	**0 (100.0%)**	**6 (100.0%)**	**14 (100.0%)**

Table 4.24 Earthquake: Actions taken prior to the onset of the hazard (top row) vs actions taken once hazard became apparent (first column)

SEVERE STORM

Gust

Demographics

At least 142 fatalities due to gusts were identified over the period of study. Figures 4.6 & 4.7 & Table 4.25 show these deaths over time since 1990 and Figure 4.8 shows death rates over time. A regression calculated from the death rate data (Figure 4.8) showed a slightly increasing trend in fatalities across time. However, due to the variation in the data this trend is not statistically significant ($F_{1,24}$=0.088, p>0.75). The raw numbers and death rates show a consistent trend with years of higher death totals interspersed more or less regularly with a "background" number of deaths. Figure 4.6 shows that, if anything, more gust deaths have occurred in the latter half of the record. However, it must be remembered that the *PerilAUS* record was enriched with NCIS data from 2000/2001 and so it is conceivable that gust fatalities have been missed prior to then.

Deaths in any one year range from zero up to 13. The worst years have been 2005, 1990, 1998, 2001 and 2014. The annual death rate has varied from zero to 0.70 deaths per million population (1990); the death rate averaged over each decade is 0.25 deaths per million population in the 1990s, 0.30 in the 2000s and 0.29 from 2010-2015.

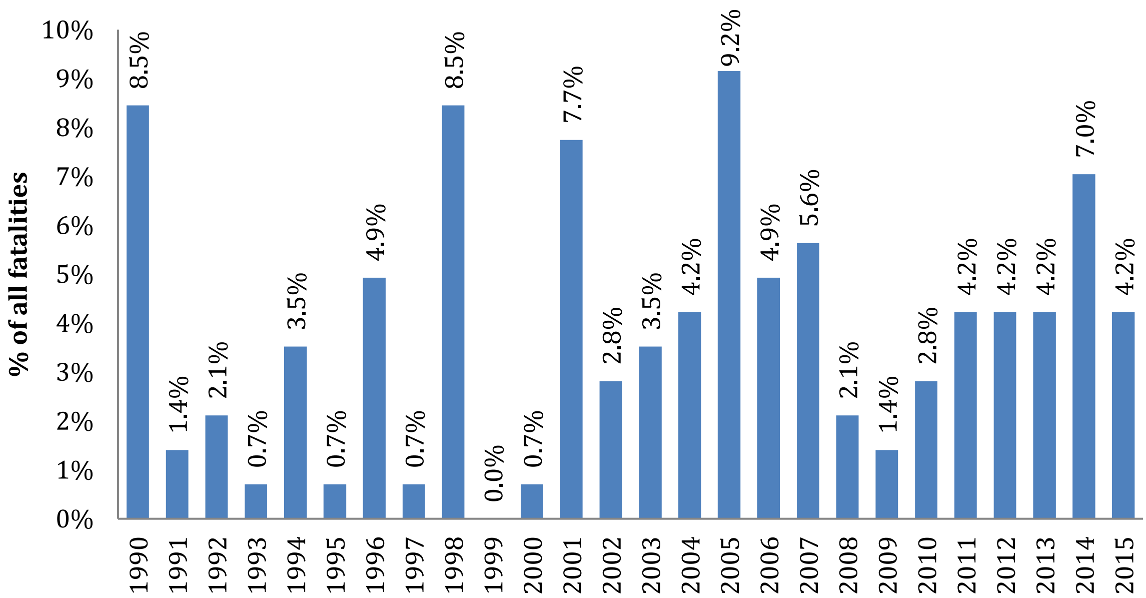

Figure 4.6 Gusts: Percentage of fatalities over time (by year, 1990-2015)

	Total
1990-1994	23 (16.2%)
1995-1999	21 (14.8%)
2000-2004	27 (19.0%)
2005-2009	33 (23.2%)
2010-2014	32 (22.5%)
2015	6 (4.2%)
	142 (100.0%)

Table 4.25 Gusts: Fatalities over time (5-year periods, 1990-2015)

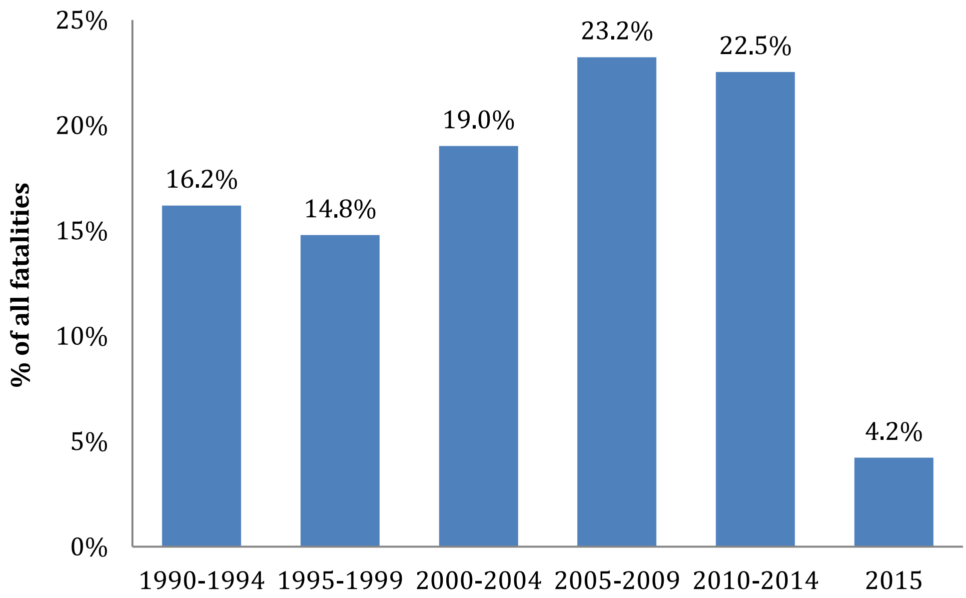

Figure 4.7 Gusts: % Fatalities over time (5-year periods, 1990-2015)

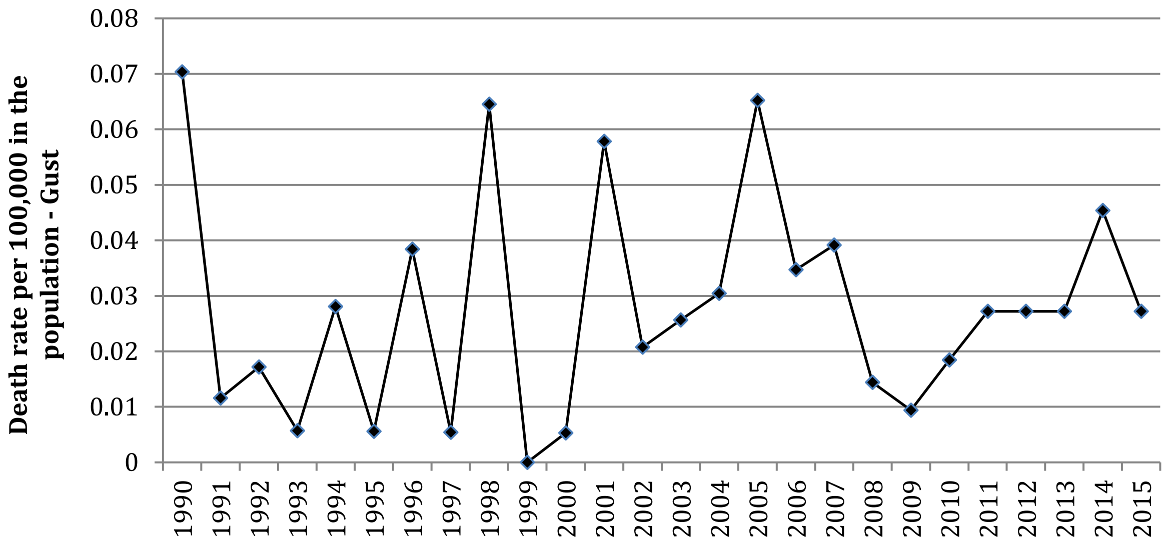

Figure 4.8 Gusts: Death rate over time

Tables 4.26 & 4.27 show the majority of the fatalities are male 75% (n106), with the highest proportion of the fatalities amongst males who are 30-39 and 40-49 (19% each of male fatalities) and females aged 10-19 (21% of female fatalities) – although the distribution was more even amongst females.

	Total
Males	106 (74.7%)
Females	33 (23.2%)
Unknown	3 (2.1%)
	142 (100.0%)

Table 4.26 Gusts: Age

	Male	**Female**	**Unknown**	**Total**
0-9	4 (3.8%)	3 (9.1%)	0 (0.0%)	7 (4.9%)
10-19	6 (5.7%)	7 (21.2)	0 (0.0%)	13 (9.2%)
20-29	10 (9.4%)	3 (9.1%)	0 (0.0%)	13 (9.2%)
30-39	19 (17.9%)	3 (9.1%)	0 (0.0%)	22 (15.5%)
40-49	19 (17.9%)	5 (15.2%)	1 (33.3%)	25 (17.6%)
50-59	15 (14.2%)	3 (9.1%)	0 (0.0%)	18 (12.7%)
60-69	11 (10.4%)	3 (9.1%)	0 (0.0%)	14 (9.9%)
70 or older	3 (2.8%)	1 (3.0%)	0 (0.0%)	4 (2.8%)
Unknown	19 (17.9%)	5 (15.2%)	2 (66.7%)	26 (18.3%)
Total	**106 (100.0%)**	**33 (100%)**	**3 (100.0%)**	**142 (100.0%)**

Table 4.27 Gusts: Age vs gender

Cause of death

The highest proportion of those killed from gusts died due to drowning/ injury/ exposure, (30%, n42): however, this is followed closely by those who died from injuries received in a vehicle accident (25%, n35) and those killed from a tree or limb fall (25%, n35) (Table 4.8).

	Total
Asphyxiation – Drowning	2 (1.4%)
Drowning/injury/exposure	42 (29.6%)
Injury – from fall	4 (2.8%)
Injury – building/structure collapse	3 (2.1%)
Injury – hit: by debris or projectiles etc	8 (5.6%)
Injury – Vehicle accident	36 (25.4%)
Injury – Tree-/ tree limb fall	35 (24.7%)
Heart attack, stroke, overexertion, shock, collapse	1 (0.7%)
Electrocution (fallen power lines etc)	8 (5.6%)
Missing presumed dead	2 (1.4%)
Unknown	1 (0.7%)
Total	**142 (100.0%)**

Table 4.28 Gusts: Cause of death

Spatial distribution, location, transport, seasonality and time of day

The state with the highest proportion of fatalities (Table 4.29) is NSW with 40% (n57), followed by Victoria and Queensland with 22% (n31) and 20% (n29) respectively. Table 4.30 and Figure 4.9 show the fatalities by state and month. The highest numbers of fatalities occurred in December (18%, n25) – mainly from NSW (one-third of its fatalities, n19), followed by April (13%, n18) – mainly from Tasmania (55%, n6). Almost as many deaths in April occurred in Victoria (16%, n5) and Queensland (14%, n4). Most deaths in Queensland occurred in May (41%, n12). Deaths in Victoria and WA were dispersed more or less evenly throughout the year. There were hardly any deaths from gusts in SA, NT or ACT (Table 4.29).

State	
NSW	57 (40.1%)
Victoria	31 (21.8%)
South Australia	2 (1.4%)
Western Australia	10 (7.0%)
Northern Territory	1 (0.7%)
Queensland	29 (20.4%)
Tasmania	11 (7.8%)
ACT	1 (0.7%)
Total	**142 (100.0%)**

Table 4.30 Gusts: State

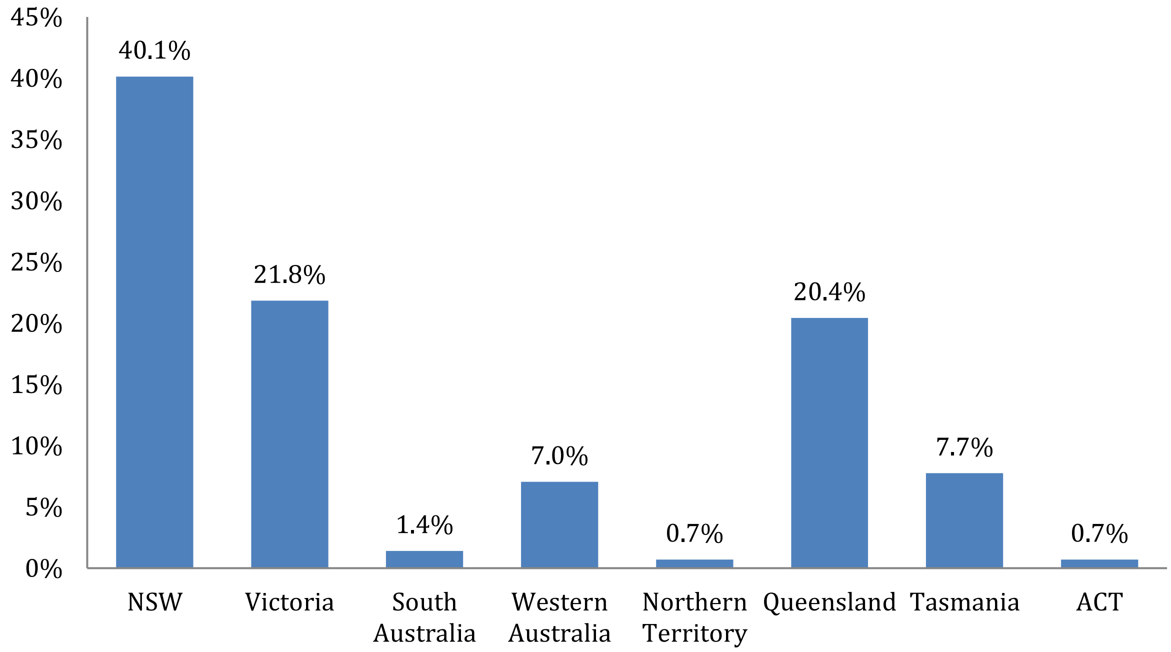

Figure 4.9 Gusts: State

	NSW	Vic	SA	WA	NT	QLD	Tas	ACT	Total
Jan	3 (5.3%)	5 (16.1%)		1 (10.0%)		3 (10.4%)			12 (8.5%)
Feb	7 (12.3%)						1 (9.1%)		8 (5.6%)
Mar	1 (1.8%)	5 (16.1%)				2 (6.9%)	1 (9.1%)		9 (6.3%)
April		5 (16.1%)	2 (100.0%)	1 (10.0%)		4 (13.8%)	6 (54.5%)		18 (12.7%)
May	2 (3.5%)					12 (41.4%)			14 (9.9%)
June	3 (5.3%)	7 (22.6%)		1 (10.0%)			1 (9.1%)		12 (8.5%)
July	6 (10.5%)						1 (9.1%)		7 (4.9%)
Aug	6 (10.5%)	3 (9.7%)				1 (3.4%)			10 (7.0%)
Sep	1 (1.8%)	1 (3.2%)		1 (10.0%)		2 (6.9%)			5 (3.5%)
Oct	2 (3.5%)			3 (30.0%)	1 (100.0%)	1 (3.4%)			7 (4.9%)
Nov	7 (12.3%)	5 (16.1%)		2 (20.0%)		1 (3.4%)			15 (10.6%)
Dec	19 (33.3%)			1 (10.0%)		3 (10.4%)	1 (9.1%)	1 (100.0%)	25 (17.6%)
	57 (100.0%)	**31 (100.0%)**	**2 (100.0%)**	**10 (100.0%)**	**1 (100.0%)**	**29 (100.0%)**	**11 (100.0%)**	**1 (100.0%)**	**142 (100.0%)**

Table 4.30 Gusts: Percentage of fatalities by state and month

Over half of the known fatalities died during the day (Table 4.31). The majority (28%, n40) of people died outside on or in the water, followed by 18% (n26) of people who were on the road (Table 4.32). In terms of transport, the majority (30%, n43) were on foot or in a boat on the water (25%, n36), followed by in an aircraft (17%, n24) or a vehicle (13%, n18) and 8% (n11) of fatalities were in a house (Table 4.33).

Time of day	
Daylight	78 (54.9%)
Darkness	35 (24.7%)
Indeterminate	29 (20.4%)
Total	**142 (100.0%)**

Table 4.31 Gusts: Time of day

	Total
Outside – open ground (open park, paddock, sheep yard)	11 (7.8%)
Outside – near watercourse	1 (0.7%)
Outside – on or in the water (sea or river)	40 (28.2%)
Outside – adjacent to the ocean – rock platform, beach or shore	4 (2.8%)
Outside – near house/ structure (e.g. in the garden or yard – hanging washing)	13 (9.2%)
Outside – adjacent to house/ structure (in doorway or on roof)	6 (4.2%)
Outside – on road	26 (18.3%)
Outside - natural shelter (tree or cave)	3 (2.1%)
In a house/ structure – destroyed	9 (6.3%)
In a house/ structure – not destroyed	1 (0.7%)
Other	25 (17.6%)
Unknown	3 (2.1%)
	142 (100.0%)

Table 4.32 Gusts: Location of fatality

	Total
In a house – i.e. no transport involved	11 (7.8%)
On foot	43 (30.3%)
On a horse	0 (0.0%)
Carried by other(s)	2 (1.4%)
In a vehicle – car, ute, 4WD or truck	18 (12.7%)
On the water – in a boat (private or working)	36 (25.4%)
On a motorbike	3 (2.1%)
In an aircraft	24 (16.9%)
Other	1 (0.7%)
Unknown	4 (2.8%)
Total	**142 (100.0%)**

Table 4.33 Gusts: Form of transport at the time of death

Capacity and awareness

In terms of capacity, the majority (55%, n78) were considered to be capable of independent action, although 25% (n36) were following the decisions of others (Table 4.34). Of this latter group, 15 were involved in four separate aircraft accidents (one incident killing ten people), 14 were in ten separate boating incidents and 4 were students following the instructions of leaders in an outdoors exercise (in three separate incidents).

	Total
Capable of independent action	78 (54.9%)
Following decisions of others	36 (25.4%)
A child or group of children on their own, age < 11	7 (4.9%)
Encumbered with clothing, possessions or equipment	1 (0.7%)
Looking after dependents which affected ability to save themselves	1 (0.7%)
Unknown or not applicable	19 (13.4%)
Total	**142 (100.0%)**

Table 4.34 Gusts: Capacity to act

Awareness of the hazard is shown in Table 4.35. From this it is seen that the majority of fatalities were unaware of the hazard and taken by surprise (41%, n58) or knew there was a hazard but did not expect it to be so strong (29%, n41). In most cases (57%, n81), there were obvious signs of the hazard (Table 4.36).

	Total
Knew there was a hazard or imminent risk of a hazard but did not expect to encounter it	13 (9.2%)
Knew there was a hazard or imminent risk of a hazard but did not expect it to be as strong/damaging	41 (28.9%)
Unaware and taken by surprise/ too little time to enact survival strategy	58 (40.9%)
Child under 11 years old	6 (4.2%)
Unknown	24 (16.9%)
Total	**142 (100.0%)**

Table 4.35 Gusts: Awareness

	Total
Obvious signs of hazard	81 (57.0%)
No obvious signs of hazard or none until too late	21 (14.8%)
Unknown	40 (28.2%)
Total	**142 (100.0%)**

Table 4.36 Gusts: Visible signs

Actions taken

It is of interest to compare the deceaseds' actions prior to and at the onset of the hazard (Table 4.37). Most of the deceased were taken by surprise, with no attempt at, or very late, evacuation undertaken (42%, n59). Of these, 38% (n23) of fatalities occurred whilst the deceased was recreating, 20% (n12) whilst working, 18% (n11) whilst *en route* to a destination and 13% (n8) whilst carrying out everyday activities. All eight people carrying out everyday activities were taken by surprise. Of those people who were *en route* to a destination prior to the onset of a hazard, 27% (n11) were taken by surprise (as indicated above) and 20% (n8), who may have had an opportunity to avoid the hazard, kept on going. It is perhaps of note here to point out that of those persons killed who had been recreating prior to onset of the hazard, 47% (n23) were taken by surprise (as indicated above), 16% (n8) were attempting to evacuate and 6% (n3) were awaiting evacuation but another 6% (n3) had actually sought some shelter from the storm.

Table 4.38 shows the action being carried out prior to onset of hazard against the gender of the deceased. The majority of both males (34%, n36) and females (36%, n12) were recreating, followed by being *en route* to a destination (29%, n31 and 30%, n10 respectively). In addition, 15% (n16) of males were working. A percentage of females (9%, n3) were carrying out repairs/ maintenance due to damage from previous hazard impacts prior to the onset of the hazard.

Table 4.39 shows the action being carried out prior to onset of hazard against the age of the deceased. The majority of people were recreating (35%, n49), followed by being *en route* to a destination (30%, n41). Of those recreating, the majority (20%, n10) were aged 40-49, followed by those aged 10-19 (16%, n8). Of those *en route*, 24% (n10) were aged 30-39 and 12% (n5) were aged 20-29 and 40-49. Focussing on those aged 20-29, most (39%, n5) were *en route* to a destination, 23% (n3) were working and 15% (2) recreating. Of the 30-39 age group, the majority (46%, n10) were *en route* and 27% (n6) were recreating. Most of the 40-49 year-olds (40%, n10) were recreating; 20% (n5) were *en route* and 16% (n4) were working.

Regardless of gender or age (Tables 4.40 and 4.41), the majority of people (42%, n59) were taken by surprise. Slightly more males (6%, n6) were attempting to evacuate than (still) being *en r*oute to a destination (5%, n5); more females (15%, n5) were *en route* than were attempting to evacuate (9%, n3). Focusing on the age groups, the two deceased who had been working were in the 20-39 year age group and eight of the ten *en route* to a destination were in the 20-49 year age group.

	Recreating	**Carrying out everyday non work-related activities**	**Carrying out everyday work-related activities**	**Preparing property - livelihood**	**Sheltering from storm**	**Carrying out repairs / maintenance due to damage from previous hazard**	**En route**	**Collecting children**	**Other**	**Unknown**	**Total**
Attempting to evacuate	8 (16.3%)								1 (25.0%)		**9 (6.3%)**
Taken by surprise - No attempt at evacuation/ Very late evacuation	23 (46.9%)	8 (100%)	12 (75.0%)		1 (100.0%)	3 (50.0%)	11 (26.8%)	1 (100.0%)	1 (25.0%)		**60 (41.6%)**
Awaiting a planned rescue/ evacuation	3 (6.1%)										**3 (2.1%)**
Refused to be evacuated										2 (13.3%)	**2 (1.4%)**
Sheltering from storm	3 (6.1%)		1 (6.3%)								**4 (2.8%)**
Collecting / securing items due to impending rain & wind										1 (6.7%)	**1 (0.7%)**
Working			2 (12.5%)								**2 (1.4%)**
En route							8 (19.5%)			2 (13.3%)	**10 (7.0%)**
Carrying out repairs / maintenance due to hazard damage etc						1 (16.7%)	2 (4.9%)			1 (6.7%)	**4 (2.8%)**
Attempting to rescue people						1 (16.7%)	1 (2.4%)		1 (25.0%)		**3 (2.1%)**
Attempting to rescue/ retrieve property – household/car or livelihood	1 (2.0%)			1 (100.0%)							**2 (1.4%)**
Other						1 (16.7%)	1 (2.4%)				**3 (2.1%)**
Unknown	11 (22.4%)		1 (6.3%)				18 (43.9%)		1 (25.0%)	9 (60.0%)	**40 (28.2%)**
Total	**49 (100.0%)**	**8 (100.0%)**	**16 (100.0%)**	**1 (100.0%)**	**1 (100.0%)**	**6 (100.0%)**	**41 (100.0%)**	**1 (100.0%)**	**4 (100.0%)**	**15 (100.0%)**	**142 (100.0%)**

Table 4.37 Gusts: Actions taken once the hazard became apparent vs action prior to onset of hazard

	Male	Female	Unknown	Total
Recreating	36 (34.0%)	12 (36.4%)	1 (33.3%)	**49 (34.5%)**
Carrying out everyday non work-related activities	3 (2.8%)	5 (15.2%)	0 (0.0%)	**8 (5.6%)**
Carrying out everyday work-related activities	16 (15.1%)	0 (0.0%)	(0.0%)	**16 (11.3%)**
Preparing property - livelihood	1 (0.9%)	0 (0.0%)	(0.0%)	**1 (0.7%)**
Sheltering from storm	1 (0.9%)	0 (0.0%)	(0.0%)	**1 (0.7%)**
Carrying out repairs / maintenance due to damage from previous hazard impacts	3 (2.8%)	3 (9.1%)	(0.0%)	**6 (4.2%)**
En route	31 (29.3%)	10 (30.3%)	(0.0%)	**41 (28.9%)**
Collecting children	0 (0.0%)	1 (3.0%)	(0.0%)	**1 (0.7%)**
Other	3 (2.8%)	1 (3.0%)	(0.0%)	**4 (2.8%)**
Unknown	12 (11.3%)	1 (3.0%)	2 (66.7%)	**15 (10.6%)**
Total	**106 (100.0%)**	**33 (100.0%)**	**3 (100.0%)**	**142 (100.0%)**

Table 4.38 Gusts: Action prior to onset of hazard vs Gender

	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70 or older	Unknown	Total
Recreating	4 (57.1%)	8 (61.5%)	2 (15.4%)	6 (27.3%)	10 (40.0%)	7 (38.9%)	4 (28.6%)	2 (50.0%)	6 (23.1%)	**49 (34.5%)**
Carrying out everyday non work-related activities		2 (15.4%)			2 (8.0%)	1 (5.6%)	2 (14.3%)	1 (25.0%)		**8 (5.6%)**
Carrying out everyday work-related activities			3 (23.1%)	2 (9.1%)	4 (16.0%)	4 (22.2%)	1 (7.1%)		2 (7.7%)	**16 (11.3%)**
Preparing property - livelihood				1 (4.6%)						**1 (0.7%)**
Sheltering from storm					1 (4.0%)					**1 (0.7%)**
Carrying out repairs / maintenance due to damage from previous hazard impacts	1 (14.3%)		1 (7.7%)	2 (9.1%)			2 (14.3%)			**6 (4.2%)**
En route		3 (9.1%)	5 (38.5%)	10 (45.5%)	5 (20.0%)	3 (16.7%)	2 (14.3%)		13 (50.0%)	**41 (28.9%)**
Collecting children					1 (4.0%)					**1 (0.7%)**
Other	2 (28.6%)				2 (8.0%)					**4 (2.8%)**
Unknown			2 (15.4%)	1 (4.6%)		3 (16.7%)	3 (21.4%)	1 (25.0%)	5 (19.2%)	**15 (10.6%)**
Total	**7 (100.0%)**	**13 (100.0%)**	**13 (100.0%)**	**22 (100.0%)**	**25 (100.0%)**	**18 (100.0%)**	**14 (100.0%)**	**4 (100.0%)**	**26 (100.0%)**	**142 (100.0%)**

Table 4.39 Gusts: Action prior to onset of hazard vs Age

	Male	Female	Unknown	Total
Attempting to evacuate	6 (5.7%)	3 (9.1%)	0 (0.0%)	9 (6.3%)
Taken by surprise - No attempt at evacuation/ Very late evacuation	42 (39.6%)	16 (48.5%)	1 (33.3%)	59 (41.6%)
Awaiting a planned rescue/ evacuation	3 (2.8%)	0 (0.0%)	0 (0.0%)	3 (2.1%)
Refused to be evacuated	2 (1.9%)	0 (0.0%)	0 (0.0%)	2 (1.4%)
Sheltering from storm	2 (1.9%)	2 (6.1%)	0 (0.0%)	4 (2.8%)
Collecting / securing items due to impending rain and wind	1 (0.9%)	0 (0.0%)	0 (0.0%)	1 (0.7%)
Working	2 (1.9%)	0 (0.0%)	0 (0.0%)	2 (1.4%)
En route	5 (4.7%)	5 (15.2%)	0 (0.0%)	10 (7.0%)
Carrying out repairs / maintenance due to hazard damage etc	4 (3.8%)	0 (0.0%)	0 (0.0%)	4 (2.8%)
Attempting to rescue people	3 (2.8%)	0 (0.0%)	0 (0.0%)	3 (2.1%)
Attempting to rescue/ retrieve property – household/car or livelihood	2 (1.9%)	0 (0.0%)	0 (0.0%)	2 (1.4%)
Other	3 (2.8%)	0 (0.0%)	0 (0.0%)	3 (2.1%)
Unknown	31 (29.3%)	7 (21.2%)	2 (66.7%)	40 (28.2%)
Total	**106 (100.0%)**	**33 (100.0%)**	**3 (100.0%)**	**142 (100.0%)**

Table 4.40 Gusts: Actions taken once the hazard became apparent vs Gender

	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70 or older	Unknown	Total
Attempting to evacuate	1 (14.3%)			1 (4.6%)	3 (12.0%)	2 (11.1%)	1 (7.1%)	1 (25.0%)		9 (6.3%)
Taken by surprise - No attempt at evacuation/ Very late	4 (57.1%)	9 (69.2%)	5 (38.5%)	8 (36.4%)	17 (68.0%)	8 (44.4%)	4 (28.6%)	1 (25.0%)	3 (11.5%)	59 (41.6%)
Awaiting a planned rescue/ evacuation		1 (7.7%)	1 (7.7%)		1 (4.0%)					3 (2.1%)
Refused to be evacuated						2 (11.1%)				2 (1.4%)
Sheltering from storm		1 (7.7%)		1 (4.6%)					2 (7.7%)	4 (2.8%)
Collecting / securing items due to impending rain and								1 (25.0%)		1 (0.7%)
Working			1 (7.7%)	1 (4.6%)						2 (1.4%)
En route			3 (23.1%)	3 (13.6%)	2 (8.0%)		2 (14.3%)			10 (7.0%)
Carrying out repairs / maintenance due to hazard damage etc						1 (5.6%)	1 (7.1%)		2 (7.7%)	4 (2.8%)
Attempting to rescue people		1 (7.7%)		1 (4.6%)	1 (4.0%)					3 (2.1%)
Attempting to rescue/ retrieve property – household/car or livelihood				1 (4.6%)			1 (7.1%)			2 (1.4%)
Other				1 (4.6%)	1 (4.0%)		1 (7.1%)			3 (2.1%)
Unknown	2 (28.6%)	1 (7.7%)	3 (23.1%)	5 (22.7%)		5 (27.8%)	4 (28.6%)	1 (25.0%)	19 (73.1%)	40 (28.2%)
Total	**7 (100.0%)**	**13 (100.0%)**	**13 (100.0%)**	**22 (100.0%)**	**25 (100.0%)**	**18 (100.0%)**	**14 (100.0%)**	**4 (100.0%)**	**26 (100.0%)**	**142 (100.0%)**

Table 4.41 Gusts: Actions taken once the hazard became apparent vs Age

Hail

The *PerilAUS* record holds no fatalities from hail for the period 1990 to 2015. However, death by hail has occurred at least twice in Australia prior to 1990, according to *PerilAUS*. The record gives two instances of indirect deaths: one from falling off a roof while clearing hail; the other possibly due to a horse bolting due to hail. There is also one unsubstantiated death but with no details (the only reference found being the BoM Severe Weather archive).

Rain

PerilAUS listed few rain-related deaths for 1990-2015. Three can be ascribed to rain-caused water-logged soils, two of which resulted in treefalls, and two are ambiguous as to causal effect. A few concern rain-related traffic accidents. Whilst investigating NCIS records, inquests relating to further rain-related traffic accidents were found. The difficulty in trying to ascertain the influence that rain had in causing such traffic accidents was considered to outweigh any benefit this information could provide to the emergency response and emergency management sectors. Due to the small number of records in *PerilAUS*, no analysis was done. Ethics considerations preclude reporting in any detail.

Tornado

Only three tornado fatalities have been recorded in Australia from 1990-2015. Due to the small number, no analysis was done. Ethics considerations preclude reporting in detail. The actions taken by a parent in the first incident, 2002, were sensible – sheltering from lightning in a house. However, a tornado associated with the electrical storm caused part of the house to collapse, which killed one of the family. The two deaths in the second incident, 2014, may be termed indirect as the tornado caused a power failure, which resulted in asphyxiation.

Gusts and Tornado – Distance between home and location of fatality

The NCIS system contained the latitude and longitude for the home and also the location of the fatality for 93 of the gust and tornado fatalities. An analysis of the distance from home for these fatalities (Table 4.42) demonstrates that the greatest proportions of these fatalities were close to home (0-5 km = 39%, n36) or very far from home (more than 100 km = 28%, n26).

	Count
0 km	8 (8.6%)
>0 km to 2 km	15 (16.1%)
>2 km to 5 km	13 (14.0%)
>5 km to 10 km	7 (7.5%)
>10 km to 20 km	8 (8.6%)
>20 km to 50 km	9 (9.7%)
>50 km to 100 km	7 (7.5%)
>100 km	26 (28.0%)
Total	**93 (100.0%)**

Table 4.42 Gust & Tornado: Familiarity of death location

LIGHTNING

Demographics

A total of 48 fatalities from lightning strikes were identified from 1990-2015. A regression taken of the death rate data in Figure 4.10 showed a slightly decreasing trend in fatalities across time. However, due to the variation in the data, this trend is not statistically significant ($F_{1,24}$=0.613, p>0.4). Therefore the data is better described as an even distribution over time in terms of both raw numbers and death rates (Figures 4.11 & 4.12). Average annual death tolls have ranged from 1 to 3 throughout the period of study with the notable exception of 2015, when 5 people were killed by lightning. The annual toll averaged over a decade was 1.8 for the 1990s, 1.7 for the 2000s and 2.0 for the period 2010-2015. Death rates show a slightly better picture but no definite downward trend is apparent, with an average death rate over the 1990s of 0.11 deaths per million population compared with 0.08 for the 2000s and 0.09 for the period 2010-2015 (Figure 4.12).

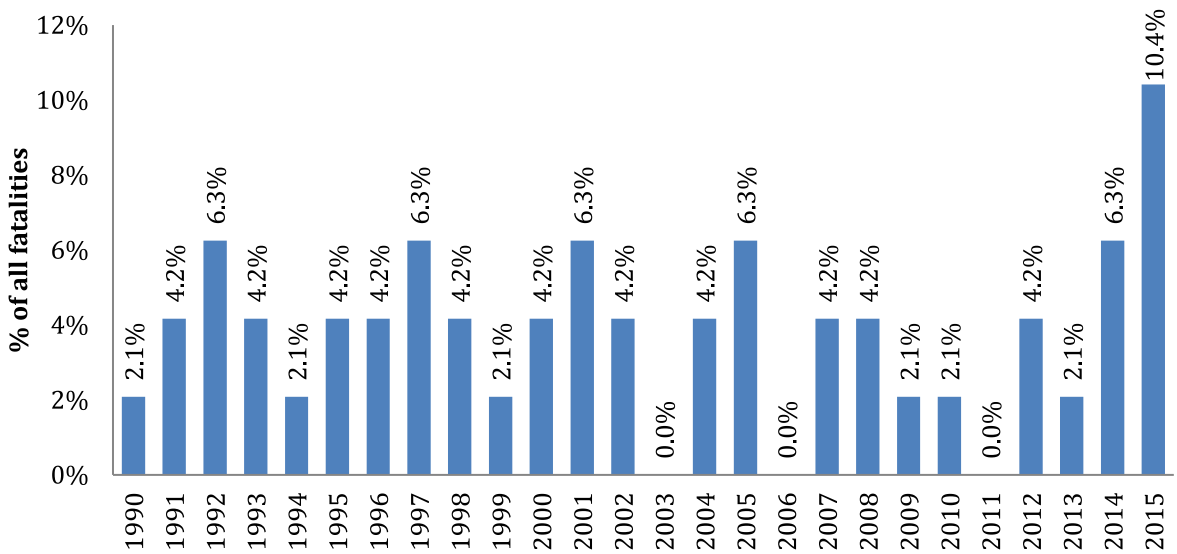

Figure 4.10: Lightning fatalities 1990-2015 (every year)

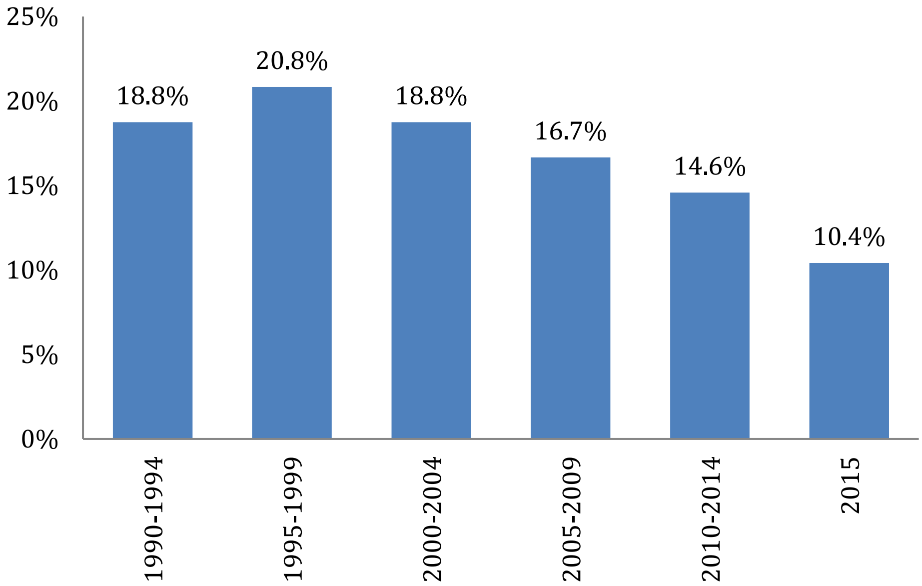

Figure 4.11: Lightning fatalities 1990-2015 (in 5 year time periods)

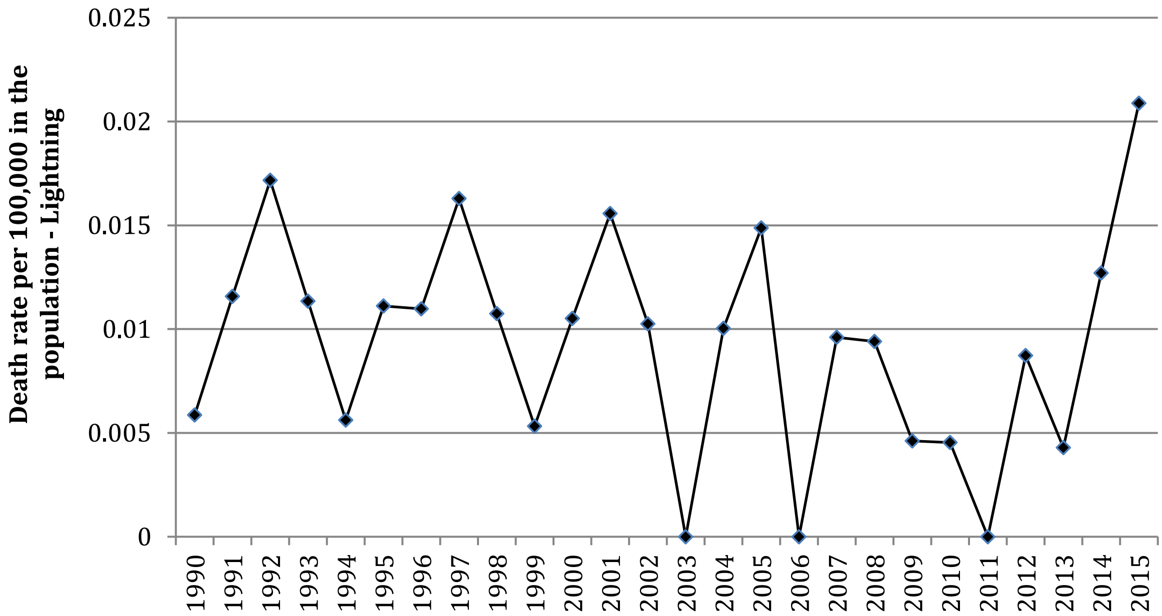

Figure 4.12: Lightning fatalities death rates over time

The majority of the fatalities are male, accounting for 79% of the total number (n39) (Table 4.43). The age ranges with the highest proportions, each with approximately a quarter of the total fatalities, are those in the 10-19 age range (21%, n10), 30-39 age range, (27%, n13) and the 40-49 age range, (25%, n12) (Table 4.44).

	Total
Males	38 (79.2%)
Females	10 (20.8%)
	48 (100.0%)

Table 4.43 Lightning: Gender

	Male	Female	Total
0-9	1 (2.6%)	0 (0.0%)	1 (2.1%)
10-19	7 (18.4%)	3 (30.0%)	10 (20.8%)
20-29	2 (5.3%)	2 (20.0%)	4 (8.3%)
30-39	10 (26.3%)	3 (30.0%)	13 (27.1%)
40-49	11 (28.9%)	1 (10.0%)	12 (25.0%)
50-59	3 (8.0%)	0 (0.0%)	3 (6.3%)
60-69	1 (2.6%)	1 (10.0%)	2 (4.2%)
70 or older	2 (5.3%)	0 (0.0%)	2 (4.2%)
Unknown	1 (2.6%)	0 (0.0%)	1 (2.1%)
Total	**38 (100.0%)**	**10 (100%)**	**48 (100.0%)**

Table 4.44 Lightning: Age vs gender

Cause of death

The majority of victims have been killed directly through a lightning strike (Table 4.45), although the exact mechanism of lightning injury differs. As this can be difficult to ascertain, this aspect was not focused upon for this study.

	Total
Drowning/injury/exposure	1 (2.1%)
Injury – Tree-/ tree limb fall	2 (4.2%)
Asphyxiation – other (failure of breathing apparatus due to power outage, mud, CO2 poisoning)	1 (2.1%)
Lightning strike	44 (91.7%)
Total	**48 (100.0%)**

Table 4.45 Lightning: Cause of death

Spatial distribution, location, transport, seasonality and time of day

The state with the highest proportion of lightning fatalities (Table 4.46) is NSW, accounting for 40% (n19) of the deaths, followed by Queensland with 21% (n10) and Victoria and WA jointly with 17% (n8). No lightning deaths are recorded for Tasmania and the ACT over this time-period. The highest numbers of fatalities occurred in November, December and January (Table 4.47) and during daylight hours (75%, n36) (Table 4.48). In terms of their location (Table 4.49), the highest proportion (25%, n12) were on open ground, such as an open park or paddock, followed by those who had sought natural shelter such as a tree under which to take cover (19%, n9). The third highest proportions were those who were located next to or on the water (13%, n6 and 10%, n5 respectively). The vast majority of fatalities were on foot when they were killed (65%, n31) (Table 4.50).

State	
NSW	19 (39.6%)
Victoria	8 (16.7%)
South Australia	1 (2.1%)
Western Australia	8 (16.7%)
Northern Territory	2 (4.2%)
Queensland	10 (20.8%)
Tasmania	0 (0.0%)
ACT	0 (0.0%)
Total	**48 (100.0%)**

Table 4.46 Lightning: State

	Total
January	11 (22.9%)
February	3 (6.3%)
March	5 (10.4%)
April	4 (8.3%)
May	0 (0.0%)
June	1 (2.1%)
July	1 (2.1%)
August	0 (0.0%)
September	1 (2.1%)
October	1 (2.1%)
November	13 (27.1%)
December	8 (16.7%)
	48 (100.0%)

Table 4.47 Lightning: Seasonality

Time of day	
Daylight	36 (75.0%)
Darkness	10 (20.8%)
Unknown	2 (4.2%)
Total	**48 (100.0%)**

Table 4.48 Lightning: time of day

	Total
Outside – open ground (open park, paddock, sheep yard)	12 (25.0%)
Outside – near watercourse	1 (2.1%)
Outside – on or in the water (sea or river)	5 (10.4%)
Outside – adjacent to the ocean – beach or shore	6 (12.5%)
Outside – near house/ structure (e.g. in the garden or yard – hanging washing)	2 (4.2%)
Outside – adjacent to house/ structure (in doorway or on roof)	3 (6.3%)
Outside – on the road	2 (4.2%)
Outside – natural shelter (tree or cave)	9 (18.8%)
Outside – open manmade structure (picnic shelter, bus stop)	3 (6.3%)
In a house/ structure – not destroyed	2 (4.2%)
Other	3 (6.3%)
Unknown	0 (0.0%)
	48 (100.0%)

Table 4.49 Lightning: Location

	Total
In a house – i.e. no transport involved	3 (6.3%)
On foot	31 (64.6%)
On a horse	1 (2.1%)
In a vehicle - car or truck	2 (4.2%)
In the water - swimming or boating	5 (10.4%)
On a motorbike	3 (6.3%)
Other	1 (2.1%)
Unknown	2 (4.2%)
Total	**48 (100.0%)**

Table 4.50 Lightning: Transport

Capacity and awareness

The vast majority of the deceased were capable of independent action (92%, n44): only 2 people were following the decision making of others (Table 4.51). For those cases known, almost equal numbers of the deceased had been unaware and taken by surprise (48%, n15) and aware that there was a hazard or imminent risk of a hazard but did not expect to encounter it (45%, n14) (Table 4.52). For those cases where information was available, equal numbers of the deceased had witnessed obvious signs of the hazard (50%, n13) as those that did not (50%, n13) (Table 4.53).

	Total
Capable of independent action	44 (91.7%)
Physically disabled or incapable and reliant on power source	1 (2.1%)
Following decisions of others	2 (4.2%)
Child or children on their own, under 11 years old	1 (2.1%)
Total	**48 (100.0%)**

Table 4.51 Lightning: Capacity to act

	Total
Knew there was a hazard or imminent risk of a hazard but did not expect to encounter it	14 (29.2%)
Knew there was a hazard or imminent risk of a hazard but did not expect it to be as strong/damaging	1 (2.1%)
Unaware and taken by surprise/ too little time to enact survival strategy	15 (31.3%)
Child under 11 years old	1 (2.1%)
Unknown	17 (35.4%)
Total	**48 (100.0%)**

Table 4.52 Lightning: Awareness

	Total
Obvious signs of hazard	13 (27.1%)
No obvious signs of hazard or none until too late	13 (27.1%)
Unknown	22 (45.8%)
Total	**48 (100.0%)**

Table 4.53 Lightning: Visible signs of the hazard

Actions taken

The fatalities were coded in relation to the actions taken prior to the onset of the hazard (top row in Table 4.54) and also the actions taken once the hazard became apparent (first column in Table 4.54). The highest proportion were recreating prior to the onset of the hazard (46%, n22) with the majority of those people unable to take an action, or an effective action, when the hazard became apparent as they were taken by surprise (82%, n18). When the actions taken when the hazard became apparent are considered in isolation, those taken by surprise are in the majority (75%, n36)

	Recreating	Carrying out non work-related activities	Carrying out work-related activities	Sheltering from storm	En route	Unknown	Total
Attempting vertical evacuation	1 (4.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**1 (2.1%)**
Taken by surprise - No attempt at evacuation/ Very late evacuation	18 (81.8%)	5 (83.3%)	9 (100.0%)	1 (33.3%)	3 (75.0%)	0 (0.0%)	**36 (75.0%)**
Being rescued/evacuated	1 (4.5%)	0 (0.0%)	0 (0.0%)	1 (33.3%)	0 (0.0%)	0 (0.0%)	**2 (4.2%)**
Refused to be rescued	0 (0.0%)	1 (16.7%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**1 (2.1%)**
Sheltering from storm	1 (4.5%)	0 (0.0%)	0 (0.0%)	1 (33.3%)	0 (0.0%)	0 (0.0%)	**2 (4.2%)**
En route to home	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**1 (2.1%)**
Unknown	1 (4.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (25.0%)	3 (100.0%)	**5 (10.4%)**
Total	**22 (100.0%)**	**6 (100.0%)**	**9 (100.0%)**	**3 (100.0%)**	**4 (100.0%)**	**3 (100.0%)**	**48 (100.0%)**

INCLUDES 1 'OTHER' IN THE ACTIONS TAKEN PRIOR TO ONSET OF HAZARD

Table 4.54 Lightning: Actions taken prior to the onset of the hazard (top row) vs actions taken once hazard became apparent (first column)

When the actions taken prior to the onset of the hazard are considered by gender we see that while the highest proportion of both men and women were recreating at the time of their death, a proportion of men were also carrying out everyday work and non-work related activities (Table 4.55).

	Male	Female	Total
Recreating	17 (44.7%)	5 (50.0%)	**22 (45.8%)**
Carrying out everyday non-work-related activities	5 (13.2%)	1 (10.0%)	**6 (12.5%)**
Carrying out everyday work-related activities	8 (21.1%)	1 (10.0%)	**9 (18.8%)**
Sheltering from storm	2 (5.3%)	1 (10.0%)	**3 (6.3%)**
En route	2 (5.3%)	2 (20.0%)	**4 (8.3%)**
Other	1 (2.6%)	0 (0.0%)	**1 (2.1%)**
Unknown	3 (7.9%)	0 (0.0%)	**3 (6.3%)**
Total	**38 (100.0%)**	**10 (100.0%)**	**48 (100.0%)**

Table 4.55 Lightning: Action taken prior to onset of hazard vs Gender

OVERVIEW AND POLICY RECOMMENDATIONS

Key Results

- At least 406 deaths have occurred in Australia due to tropical cyclones, earthquakes and severe storms (gust, hail, lightning, rain and tornado) across the periods of study.
- From 1990-2015, over three-quarters of the 254 deaths identified have been due to severe storms and, of those deaths, over half were due to gusts.
- Of those hazard types with large numbers of fatalities (over 20), the majority of deaths have been amongst males (tropical cyclone 84%, gust 75% and lightning 79%).
- In the majority of natural hazards studied (cyclone, gust, hail, lightning, rain, tornado), the importance of (early) shelter in a sturdy building was noted.

Recommendations:

- Many of the trends resulting from our analysis of the data support current practices and recommendations of emergency management (EM) groups and the government such as land-use planning and marine safety. Future work should directly evaluate existing EM recommendations in the context of the hazards analysed in order to investigate their effectiveness, and/ or how these measures are communicated to the public.
- Community engagement/ education campaigns for the high-fatality hazards of tropical cyclone, gust and lightning should target males.

TROPICAL CYCLONE

Tropical cyclones have killed at least 192 people in Australia from 1970-2015. Numbers and death rates have decreased over time: the death rate has fallen from a maximum 0.87 per million population in 1974 (influenced by TC Tracy) to <0.01 now. Annual death rates, averaged over the respective decades, are 0.87 for the 1970s, 1.15 for the 1980s, 0.27 for the 1990s, 0.02 for the 2000s and 0.01 for the 2010s. There are now many fewer deaths at sea than earlier in the record. Deaths on land through the action of wind have been reduced through the legislation and enforcement of building codes put into effect following the devastation of Cyclone Tracy in 1974 (Mason *et al*., 2013). However, this is also due to a measure of luck: in recent years, not many large population centres such as, for example, the Gold Coast, Cairns or Townsville have suffered a direct hit from a severe tropical cyclone at landfall with the wind speeds that were seen in Cyclone Tracy, therefore these safety recommendations have not really been tested in an area with significant exposure. The severity of the hazard at the location of impact can be non-severe yet be fatal: category 2 (at incident location) cyclones killed 26% of the total while severe (category 4 at incident location) cyclones killed 55%.

Travel by sea, whether for work or pleasure, has historically been the riskiest activity to carry out during a cyclone and this continues to be the case. Australia's most notorious cyclone, Mahina (aka the Bathurst Bay Hurricane), remains the costliest natural disaster (excepting disease pandemics) in terms of human life in Australia's history. Of the approximately 410 lives lost on 4 March

1899 recorded in *PerilAUS*, some 300 were at sea (the pearling fleet). Since the advent of radar and better communications this maritime toll has decreased but only in the last decade and a half is it approaching zero. Since 1970, *PerilAUS* records show that (apart from TC Tracy) any large death tolls from tropical cyclones have been due to deaths at sea:

- In the 1970s: 14 in TC Ada, 8 in TC Emily, 21 in TC Tracy (and 49 on land), 15 in TC Hazel and 4 in two other events
- In the 1980s: 11 in TC Kay and 4 in three other events
- In the 1990s: 10 in TC Alex, 26 in TC Fifi, 7 in TC Bobby, 5 in TC Justin
- Since 2000: a much lower death toll – 2 lives lost at sea in TC Hamish.

Further on deaths at sea, when the record is divided into three fifteen-year periods, there have been decreases in the numbers of:

- Recreational boaters from 14 (1970-84), 6 (1985-99) to 0 (2000-15)
- Australian fishers from 29 (1970-84), 7 (1985-99) to 2 (2000-15) and
- International fishers from 39 (1970-84), 65 (1985-99) to 0 (2000-15).

Recommendations:

- Emergency organisations should target, in their education/ outreach campaigns:
    - Males, especially 20-29yo; females 0-9 and 20-29yo
- In warnings given out, consideration should be given to alerting the public to the dangers of <u>any</u> strength of cyclone, no matter whether classed as severe or not.
-

EARTHQUAKE

Earthquakes have killed very few people in Australia's history but the Newcastle earthquake of 1989 provides an example of the vulnerability of Australian cities and towns to earthquakes. The first seismic provisions in Australian building codes (AS1170.4) were introduced in 1990, following the Newcastle earthquake.

This magnitude 5.6 earthquake was responsible for the deaths of 14 people. Because there has only been that one instance of fatalities in earthquakes since 1970 (or even since 1950), there is not much sense in assigning a death rate over a long period of time, although one could say, for the decade of the 1980s, the average annual earthquake death rate was 0.74 per one million population. Further,

- Most people died from the collapse of buildings and structures not built to withstand earthquake.
- Most people died from the collapse of just one building (the Newcastle Workers' Club).
- Non-ductile concrete buildings and unreinforced masonry buildings have weak earthquake resistance (pers. comm., Paul Somerville).

Many buildings and structures were damaged in Newcastle and the surrounding areas, due largely to the weak earthquake resistance of their initial construction (especially in the use of unreinforced masonry (URM) - brick and stone buildings) and long-term structural deterioration. The collapse of the Newcastle Workers' Club building is thought to have been due to steel reinforcing in a concrete column that was inadequate for the purpose of earthquake resistance (the steel provides ductility that allows the column – beam connections to deform but not break in a brittle manner).

All buildings older than 1990 in Australia were designed without consideration for resisting earthquake induced forces. The buildings that are most vulnerable include non-ductile concrete (NDC) buildings (like the Newcastle Workers' Club building) and unreinforced masonry (URM) buildings. The vulnerability of these categories of buildings have been also demonstrated in New Zealand, most recently in the 2010 – 2011 Christchurch earthquakes.

Recommendations:

- Emergency service organizations should encourage members of the public and employers to find out (from their builder or an engineer) whether they live/ work in a building prone to earthquake damage and
- Future research should examine those buildings/ areas which may pose a greater risk of dying in an earthquake: for example, buildings of mass gathering and/ or essential infrastructure facilities which do not meet current earthquake building regulations, such as older hospitals, clubs or shopping malls.

SEVERE STORM

Gust

Gusts from severe storm events have killed at least 142 people in Australia over the period 1990-2015. Numbers and death rates show a very slight upward trend although this is not statistically significant. The annual death toll varies from 0 to 13 with the death rate varying from 0 to 0.70 per million population. Annual death rates, averaged over the respective decades, are 0.25 per million population for the 1990s, 0.30 for the 2000s and 0.29 for the 2010s. The main causes of death were at sea (30%), treefall (25%) and in vehicle (25%).

Treefall is an issue as saturated soils are weaker and root systems less likely to hold in high wind situations. Treefall can be just as fatal as house collapse but trees have a much lower threshold with respect to wind speed. Thus, even in an event where severity is not high, there is still a risk of being killed by a tree – whether in a house or a car, walking or sheltering.

Further,

- 75% of the fatalities (1990-2015) were males.
- The fatality record shows that people have heeded tropical cyclone warnings but do not treat strong wind with the same level of respect, often continuing with their intended activities.
- 36 (25% of) deaths were boating related.

Recommendations:

- Emergency organisations should target, in their education/ outreach campaigns:
  - Males, especially 30-49yo; females 10-19
    - 20-29yo tend to be *en route*, working, or recreating
    - 30-39yo tend to be *en route* or recreating
    - 40-49yo tend to be recreating or, like the 20-29 group, *en route* or working
  - people on/in water, on road or in aircraft
- The fatality record shows that people have heeded the warnings with respect to tropical cyclones but that they do not treat strong wind associated with thunderstorms, squalls and mid-latitude weather systems (such as cold fronts, or east coast lows) with the same level of respect and often continue with their intended activities. Emergency service organisations should focus on the most effective means of engaging with the community in order to emphasize the dangers of "just" storms.
- Existing approaches to community engagement for thunderstorm have focused largely on land based communities. More attention should be paid by emergency service organisations to working collaboratively with marine risk groups, such as recreational boaters, and marine safety and rescue authorities to communicate key safety messages. Attention should be spread across both coastal and inland waterways. Further efforts are required to map the most effective means of communicating with boaters based upon how they access information.

Hail

Although *PerilAUS* holds no fatalities from hail from 1990 to 2015, death by hail has occurred in Australia prior to 1990, and extreme hail sizes – for example, 6-7cm (tennis or baseball size) or greater in diameter – are possible in Australia (e.g. Yeo *et al*, 1999). The largest officially-accepted diameter mentioned in the *PerilAUS* archive is 16cm, although unsubstantiated accounts of diameters 20cm and above exist.

For example, *PerilAUS* records that the 15-minute Sydney hailstorm of April 1999 – the costliest natural disaster in Australian insurance history, and generally remembered for its huge damage toll – injured about 50 people, one of whom was hospitalized after a hailstone fractured his skull. A piece of flying glass also severed an artery. The hailstones were noted as ranging from the size of a 10c coin up to cricket and football sizes, with winds being recorded as up to 200km/hr. One person was killed by lightning during this severe supercell (*PerilAUS*).

Rain

PerilAUS lists few rain-related deaths (for example, drowning in a rain-filled excavation as distinct from a water course) for the period 1990-2015. Rain-related traffic accidents due to, for example, impeded visibility or slippery road conditions are more common, and may deserve further investigation, but are problematic in the assignation of causal effect. The difficulty in trying to ascertain the influence that rain (or fog, etc) had in causing such traffic accidents was considered to outweigh any benefit this information could provide to the emergency response and emergency management sectors, although it is believed that many such fatalities have occurred.

However, investigations for this report and a previous one (Haynes *et al*, 2016) found that people may be overtaken by another severe storm peril type whilst sheltering from rain.

Tornado

Only three tornado fatalities were recorded in Australia within *PerilAUS* from 1990-2015. The lessons to be learnt again relate to the fact that people may be overtaken by one severe storm peril type whilst sheltering from another, and that natural hazards may act indirectly yet still with fatal consequences.

Recommendations:

-
- Further research into improved tornado warning systems should be carried out.

LIGHTNING

Lightning from severe and other storm events has killed at least 48 people in Australia over the period 1990-2015. There is an even distribution of numbers of deaths over this period. The annual death toll varies from zero to three with the exception of 2015 – five deaths. The annual death toll averaged over the respective decades is 1.8 for the 1990s, 1.7 for the 2000s and 2.0 for the 2010s. The annual death rate shows no definite downward trend. Annual death rates, averaged over the respective decades, are 0.11 per million population for the 1990s, 0.08 for the 2000s and 0.09 for the 2010s.

Further, the current study found that:

- 79% of the fatalities were males.
- The annual average decadal death rate has stayed fairly constant
- About 15% of fatalities occurred whilst the deceased was recreating at a beach (near the water's edge; in the water; in the act of leaving the beach) and just over 10% took refuge under a tree.
- About 20% of fatalities occurred amongst outdoor workers (eg farmyard, training camp, building site, race course, near parked vehicle).
- Just under 10% of fatalities occurred whilst the deceased was recreating at a sportsfield, golf course or similar, and a similar number were in a small fishing vessel.

The mechanisms of lightning (Cooper & Holle, 2010) injury include:

- Direct strike (the lightning strike continues unimpeded from the cloud to the deceased)
- Side flash (the current "jumps" from a tree, a washing line, a roof of an unenclosed shelter, a fence, a wired telephone…)
- Contact potential (where the deceased was touching the object struck, e.g., leaning against a tree or holding an umbrella or a golf club)
- Step voltage/ potential or ground current (lightning strikes the ground, the current radiates out and different distances from the strike point bear differing potentials)

- Upward leader (the deceased serves as the conduit for one of the upward leaders ({ground-to-cloud} induced by a downward stepped leader {cloud-to-ground})
- Indirect e.g., blunt force trauma (from tree or tree limb fall, or an exploded tree (from superheated sap)

Cooper & Holle (2010) concluded that step voltage and side flash cause the most deaths – not direct strike. Near trees, the primary mechanism is step voltage then side flash, blunt trauma and then contact potential (Holle, 2012, in an investigation involving both US & non-US fatalities).

Recommendations:

- Emergency organisations should target, in their education/ outreach campaigns:
  - Males, especially aged 30-49yo & 10-19
  - Those adjacent to/ on water, on open ground (open park or paddock) or sheltering under a tree or open picnic shed
- Emergency service organisations already communicate key safety messages such as those formulated by BoM, found at http://www.bom.gov.au/info/thunder/#protection. The following points should be emphasized:
  - the best action to take is to head to the nearest enclosed building or, second-best, an enclosed vehicle, rather than adopting a low profile outdoors
  - If already *en route* in a vehicle, consider pulling over somewhere safe (e.g. not near trees) or slowing down (but with regard to other road traffic).
- Ensure storm safety signage is displayed in prominent locations in large public spaces.
- Ensure that workplaces with outdoor workers (e.g. racecourses etc.), in their work health and safety practices, consider lightning and severe weather, e.g., such as the restrictions placed on when airport baggage handlers may work
- Ensure that sporting bodies have policies for severe weather which have the principle aim of ensuring player welfare, such as that of the Sydney Cricket Association
- Recreational parks such as golf courses should consider building bunkers or lightning-protected enclosed shelters for players to shelter in if they are far from other buildings. Having a dual purpose for these shelters – for example, a storage shed for green-keeping equipment or an alternative meeting venue – might encourage such an undertaking.

FURTHER RESEARCH NEEDED

CORONIAL REPORTS

Coronial reports (especially those held by NCIS) have been of invaluable use in this project. Continued access would enable the adoption of any new policies and procedures around natural hazard risk reduction to be tested. In addition, having the resources to consult the State/ Territory archives and Coroners' offices for records prior to 2001 would enable a better longitudinal analysis of all natural hazard types.

It would be of great benefit to have access to coronial records for:

- Heatwave fatalities, 1900-2015
- All natural hazard fatalities from WA, prior to 2001
- Severe storms, cyclones, earthquakes, bushfires prior to 2001
- The remaining flood and cyclone cases from NT
- Landslides/ rockbursts, 1900-2015

FACTIVA AND TROVE FOR NEWS MEDIA

Similarly, the descriptive reports found in news media have been of great use in this project. Continued funding would enable the types of research and analysis carried out for those areas able to be covered in the current project to be extended to all natural hazards and time periods of interest.

Such research could include:

- Factiva and Trove searches on:
    - Bushfire fatalities, 2014-2015
    - Heatwave fatalities, 1900-2015
    - Landslides/ rockburst fatalities, 2014-2015
    - Severe storm, cyclone and earthquake fatalities prior to 1990
- Trove/ Factiva searches and coronial archive searches (especially NCIS) on:
    - Rain-related traffic fatalities
    - Washed off rocks and other high-wave and/ or high-sea level fatalities

INJURY DATASETS

Unfortunately, the resources at our disposal for this project did not allow investigating the Australian Institute of Health & Welfare (AIHW) injury datasets. If interest (and therefore funding) were existent, much valuable data could be made available.

REFERENCES

1. Agoris, D., Pyrgioto, E., Vasileiou, D. and Dragoumis, S., 2002, Analysis of lightning death statistics in Greece. 26th International Conference on Lightning Protection, Cracow, Poland, 654-657.
2. Ashley, W.S., Black, A.W., 2008, Fatalities associated with non-convective high-wind events in the United States. J. Appl. Meteorol. Climatol. 47: 717-725. Doi: 10.1175/2007JAMG1689.1
3. Baker, T., 1984, Lightning deaths in Great Britain and Ireland, *Weather* 39, 232-234.
4. Blanchi, R., Leonard, J., Haynes, K., Opie, K., James, M. & Dimer de Oliveira, F., 2014, Environmental circumstances surrounding bushfire fatalities in Australia 1901-2011. *Environmental Science and Policy*. Vol 37, p 192-203.
5. Blong, R.J., 2005, Natural hazards Risk Assessment: An Australian Perspective. Benfield Hazard Research Centre *Issues in Risk Science* 4, London: University College, London, 29 pp.
6. BoM, 2016a, About severe thunderstorms. http://www.bom.gov.au/nsw/sevwx/about.shtml, Bureau of Meteorology. Accessed 29 July 2016.
7. BoM, 2016b, About tropical cyclones. http://www.bom.gov.au/cyclone/about/, http://www.bom.gov.au/cyclone/faq/Bureau of Meteorology. Accessed 29 July 2016.
8. BoM, 2016c, Frequently asked questions. http://www.bom.gov.au/cyclone/faq/, Bureau of Meteorology. Accessed 29 July 2016.
9. BoM, 2016d, Storm spotters' handbook. http://www.bom.gov.au/storm_spotters/handbook/tornadoes_and_other_funnels.shtml, Bureau of Meteorology. Accessed 29 July 2016.
10. Buckley, B.W., Sullivan, W., Chan, P., Leplastrier, M., 2010, Two record breaking Australian hail storms: storm environments, damage characteristics and rarity. 25th Conference on Severe Local Storms. American Met. Soc., Denver, Colorado.
11. Cardoso, I., Pinto O. Jr., Pinto I. R. C.A., Holle R.L., 2014, Lightning casualty demographics in Brazil and their implications for safety rules, *Atmos. Res*., 135-136, 374-379.
12. Coates, L., 1996, An overview of fatalities from some natural hazards. Proceedings, *NDR '96: Conference on Natural Disaster Reduction*, Institution of Engineers Australia, 29 September-2 October 1996, Surfers Paradise, Queensland. R.L. Heathcote, C. Cuttler and J. Koetz (Eds), 49-54.
13. Coates, L., 1999, Flood fatalities in Australia, 1788-1996. *Australian Geographer,* 30(3), 391-408.
14. Coates L., Blong R.J., Siciliano F., 1993, Lightning fatalities in Australia, 1824-1991, *Natural Hazards*, 8, 217-233 http://link.springer.com/article/10.1007%2FBF00690909
15. 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. *Environmental Science and Policy,* 42, 33-44. DOI: 10.1016/j.envsci.2014.05.003.
16. Cooper M.A., Holle R.L., 2010, Mechanisms of lightning injury should affect lightning safety messages. 3rd International Lightning Meteorology Conference, Orlando, Florida; 2010
17. 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, Climate and Society*, 2, 300-310.
18. Crompton, R.P., McAneney K.J., 2008, The cost of natural disasters in Australia: the case for disaster risk reduction. *Australian J. of Emergency Management*, 23:43-46.

19. Curran, E.B., Holle R.L., Lopez R.E., 2000, Lightning casualties and damages in the United States from 1959 to 1994, *Journal of Climate*, 13:3448-3464.
20. Daniell, J.E., Love, D., 2010, The socio-economic impact of historic Australian earthquakes. Australian Earthquake Engineering Society Conference, 2010, Perth, Western Australia.
21. Eliot, J., 1899, Hailstorms in India. *Indian Meteorological memoirs*, 6 (6): 237-316, Calcutta, 1899, referenced in Talman, C. F., 1919, Fatalities during hailstorms, *Popular Astronomy*, 27: 405.
22. Elsom, D.M., 2001, Deaths and injuries caused by lightning in the United Kingdom: Analyses of two databases, *Atmospheric Research,* 56:325-334.
23. Elsom, D.M., Webb, J.D.C., 2014, Deaths and injuries from lightning in the United Kingdom, 1988-2012, *Weather,* 69:221-226.
24. Guha-Sapir, D., Vos, F., 2011, Earthquakes, an epidemiological perspective on patterns and trends. Ch. 2 in: R. Spence *et al*. (eds.), Human casualties in earthquakes, Advances in Natural and Technological hazards Research 29, DOI 10.1007/978-90-481-9455-1_2, ©Springer Science+Business Media B.V. 2011
25. Hanstrum, B.B, Mills, G.A., Watson, A., Monteverdi, J.P., Doswell III, C.A., 2002, The cool-season tornadoes of California and Southern Australia. *Am. Meteorol. Society*, 17: 705-722
26. Harper, B., Granger, K., Hall, S, 2000, Severe thunderstorm risks. Natural hazards and the risks they pose to south-east Queensland. Australian Geological Survey Organisation, p.11.
27. Haynes, K., Coates, L., Dimer de Oliveira, F., Gissing, A., Bird, D., Radford, D., D'Arcy, R, Smith, C., 2016, An analysis of human fatalities from floods in Australia 1900-2015. Report for the Bushfire and Natural Hazard Cooperative Research Centre.
28. 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. *Environmental Hazards,* 8, 291-303.
29. 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. *Environmental Science and Policy,* 13(3), 185-194.
30. Holcombe, G., Moynihan, G., 1978, An investigation of the Brisbane tornado of 4 November 1973. Bureau of Met. Australia *Met. Note* 97.
31. Holle, R.L., 2008, Annual rates of lightning fatalities by country. 20th International Lightning Detection conference, 21-23 April, Tucson, Arizona, USA & 2nd International Lightning Meteorology Conference, 24-25 April, Tucson, Arizona, USA. 14p.
32. Holle, R.L., 2016, A summary of recent national-scale lightning fatality studies, *Weather, Climate and Society*, 8: 35-42.
33. Holle, R.L., Lopez R.E., Navarro B.C., 2005, Deaths, injuries, and damages from lightning in the United States in the 1890s in comparison with the 1990s, *Journal of Applied Meteorology*, 44: 1563-1573.
34. Hughes, P., Wood, R., 1993, Hail: the white, *Weatherwise*, 46:2: 16-21, DOI: 10.1080/00431672.1993.9930228.
35. King, D., Anderson-Berry, L., 2010, Societal impacts of tropical cyclones. Seventh International Workshop on Tropical cyclones, (IWTC-VII), 15-20 November 2010, La Réunion, France.
36. Lopez, R.E., and R.L. Holle, 1998, Changes in the number of lightning deaths in the United States during the Twentieth Century, *Journal of Climate*, 11: 2070-2077.
37. Lourensz, R.S., 1981, Tropical cyclones in the Australian Region July 1909 to June 1980, Bureau of Meteorology, Melbourne, Australia, 94 pp.
38. Mason, M., Haynes, K., Walker, G., 2013, Cyclone Tracy and the road to improved wind resistant design. In: *Natural disasters and adaptation to climate change*. Eds. Palutikof, J., Karoly, D., Boulter, S. Cambridge University Press.

39. McMaster, H., 1999, The potential impact of global warming on hail losses to winter cereal crops in New South Wales. *Clim. Chang.* 43: 455-476.
40. McMaster, H., 2001, Hailstorm risk assessment in rural New South Wales. *Nat. Hazards* 24: 187-196.
41. Mills, B., Unrau, D., Parkinson, C., Jones, B., Yessis, J., Spring, K., 2006, *Striking Back: An Assessment of Lightning-related Fatalities and Injuries in Canada.* Final Technical Report, Env. Canada
42. Mills, G., Colquhoun, J., 1998, Objective prediction of severe thunderstorm environments: preliminary results linking a decision tree with an operational regional NWP model. *Weather Forecast*., 13 (1998), pp. 1078–1092
43. Minor, J.E., Peterson, R.E., Lourensz, R., 1980, Characteristics of Australian tornadoes. *Aust. Meteorol. Mag.* 28: 57-77.
44. Murty, O P., Kian, C.K., Ari Husin, M.H., a/l Nanta Kumar, R.K., Mohammed Yusuf, W.Y.W., 2009, Fatal lightning strikes in Malaysia: a review of 27 fatalities, *American Journal of Forensic Medicine & Pathology*, 30:246-251. doi: 10.1097/PAF.0b013e31819d20a4
45. Navarrete-Aldana, N., Cooper, M.A., Holle, R.L., 2014, Lightning fatalities in Colombia from 2000 to 2009, *Nat Hazards* (2014) 74: 1349. doi:10.1007/s11069-014-1254-9
46. Pakiam, J. E., Chao, T. C., and Chia, J., 1981, Lightning fatalities in Singapore, *Meteorological Magazine* 110(1308), 175-187.
47. Phillips, E., 1965, The Nurmurkah tornado of August 1964. *Aust. Meteorol. Mag.* 48: 37-45.
48. Plukss, A., 1979, The tornadoes of 13 November 1976 in Victoria with particular reference to the Sandon area. Bureau of Met. Australia *Met. Note* 101 (16pp.)
49. Prentice, S. A., 1972, Lightning fatalities in Australia, *Inst. Eng. Aust., Electr. Eng. Trans.* 27(4-5), 99-108.
50. Rappaport, E.N., 2000, Loss of life in the United States associated with recent Atlantic tropical cyclones. *Bull. Am. Soc.* 81:2065-2073. Doi: 10.1175/1520-0477(2000)081M<2065:LOLITU>2.3.CO;2
51. Rappaport, E.N., 2014, Fatalities in the United States from Atlantic tropical cyclones: new data and interpretation. *Bull. Am. Soc.* 81:2065-2073. Doi: 10.1175/1520-0477(2000)081M<2065:LOLITU>2.3.CO;2
52. Ryan, C., 1993, costs and benefits of tropical cyclones, severe thunderstorms and bushfires in Australia. Climatic Change 25: 353-367.
53. Schmidlin, T.W., 2009, Human fatalities from wind-related tree failures in the United States, 1995-2007, *Nat. Hazards*, 50: 13-25.
54. Somerville, P., 2016, Personal communication. [Prof. Somerville is an engineering seismologist.]
55. ten Duis, H.J., 1998, Lightning strikes: danger overhead, *British Journal of Sports Medicine*, 32(9): 279-278.
56. Yeo, S., Leigh, R., Kuhnel, I., 1999, the April 1999 Sydney hailstorm. *Aust. J. Emerg. Manag.* 5: 23-25.
57. Zhang W, Meng Q, Ma M, Zhang Y., 2010, Lightning casualties and damages in China from 1997 to 2009. *Nat Hazards*. doi:10.1007/s11069-010-9628-0