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A NATURAL HAZARD BUILDING LOSS PROFILE FOR AUSTRALIA: 1900-2015

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ABSTRACT

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This study examines building damage as recorded in PerilAUS to determine the national profile of natural peril impacts and frequencies. The analysis employs Risk Frontiers' Damage Index based on a House Equivalent (HE) loss metric introduced by Blong (2003); a normalisation correction based on Crompton and McAneney (2008) and Crompton et al. (2010); and a lower bound event threshold of 25 normalised HE. The latter is equivalent to a monetary loss of around \$10m in 2015-16. Normalisation puts historical events on a common footing with losses that would be incurred given 2015 societal and demographic conditions. It answers the question: what would be the building losses if historic events were to recur today?

While more validation and analysis remains to be done, we are confident that the relative importance of the various perils and their spatial distribution across states and territories has been faithfully captured. Broadly we find that there have been on average 5.85 events per year causing losses in excess of 25 normalised HE. This frequency exhibits no statistically significant change since 1900. The mean loss per event is \$118m with a standard deviation of \$430m.

The most costly event in terms of building damage is the 1999 Sydney hailstorm, which was also the most expensive insured loss. The losses broadly follow a Pareto distribution in which 20% of events account for 80% of the aggregated normalised building losses and the top 20 are responsible for 50% of those losses. We can expect natural disaster events as costly as the 1999 Sydney hailstorm to occur about once per century, events like the Brisbane floods once every 30 to 40 years and that of the Hobart Bushfires about once a decade.

Just why most of the extreme losses – the 1974 Brisbane floods and Cyclone Tracy in the same calendar year, the 1999 Sydney hailstorm and the 2011 Queensland and Victorian floods – are clustered post-1970 requires further investigation. We do not believe this to be a reporting bias and know in the case of floods, for example, that Brisbane experienced much higher floods in the early and late 19th century than either the 1974 and 2011 floods. Regardless of the reason, the pattern of losses demonstrates clearly the 'heavy-tailed' character of the distribution of natural peril losses: in other words, there is always the possibility of event losses far in excess of the historical mean. This may be occur because of an event of higher intensity or larger footprint, that footprint impacting an area of higher-valued exposure, or all of these together.

Of all the perils, tropical cyclones have been most destructive and responsible for 30% of the national building damage since 1900. Bushfires, floods and hail have all been similarly costly each accounting for another 18% of building losses, although when hailstorms are combined with other storm events (excluding cyclones), thunderstorms similarly contribute 30% of the losses. Compared with meteorological hazards, geophysical perils have had a minor influence on building damage over the last 116 years with earthquake losses dominated by a single event – the 1989 Newcastle earthquake. However this time period is too short to predict the



frequency of damaging seismic events and in the case of this peril, as with some others, the spatial pattern of losses shown here could be overturned by another extreme loss.

QUESTIONS FOR FURTHER RESEARCH

1. Further validation of the House Equivalent calculations with particular scrutiny on Central Damage Value estimates by peril. The best way to do this is by comparison with the ICA Disaster List once this has been updated and normalised and with output from Risk Frontiers suite of Natural Catastrophe Loss models.
2. Comparison of the pattern of loss of life with the building damage over the common period (1970 to 2015) where both databases are thought to be complete.
3. Scrutiny of the loss data in respect of meteorological indices – ENSO, SAM, IOD, etc.
4. Exploration of what these data mean for the national spend on mitigation – is mitigation making a material difference to the loss profile?
5. How can this data contribute to a national risk assessment?
6. Why are extreme HE losses ‘clustered’ post-1970? Is there a reason for this or is it just a random pattern?
7. What is the significance of the fat-tailed nature of the distribution of losses for emergency management?



BACKGROUND

Estimating the cost of natural disasters in Australia is an important but far from trivial task. Interest in having better definition of this cost and its spatial distribution arises from many parts of government as well as the emergency management sector. The authors of an early effort by the BTE (2001) recognised some of the difficulties and warned readers, “any conclusions drawn [from their report] must be regarded as tentative.” The BTE (2001) analysis of economic losses was heavily based on a corrupted version of the Insurance Council of Australia’s Catastrophe List (ICA Disaster List), which provides insurance sector losses since 1967.

Rather than economic losses, Blong (2005) was focused firmly on direct losses, specifically fatalities and building damage. Like our study here, his data source was Risk Frontiers’ PerilAUS database (Coates 1996; Haynes et al. 2010; Crompton et al. 2010; Coates et al. 2014) using data from 1900 onwards. He employed Risk Frontiers House Equivalent (HE) methodology (Blong 2003). While this metric has the virtue of being inflation-proof, it ignores other societal changes that have taken place since the turn of last century. In other words, the assessment preferentially gives more weight to more recent events, in much the same way as did the BTE (2001) report. This shortcoming can be overcome using adjustments that have become known as loss normalisation (Pielke and Landsea 1998).

Crompton and McAneney (2008) normalised Australian insurance sector losses from a corrected version of the ICA Disaster List and then updated this methodology again in 2011 for a report to the Insurance Council of Australia. Losses were broken down by state and peril beginning with the 1967 Hobart bushfires. This work was further updated again for the Productivity Commission’s (2014) inquiry into the natural disaster funding arrangements. Key findings were that a small number of extreme events were responsible for most of the aggregated normalised insurance losses and that the increase in insured costs over time could be accounted for by increasing exposure and wealth. This view has now been accepted by the IPCC (2012; 2014).

In our present study, we re-examine Australian building losses using a further updated version of PerilAUS. Natural hazards considered comprise bushfire, earthquake, flood, severe storm (gust, hail, lightning, rain and tornado) and tropical cyclones.

The project was completed in two steps: 1) updating the data held within *PerilAUS*, and 2) analysis of building damage from natural hazard events between 1900 and 2015 by peril type and by state and territory. The focus of this report is the second of these.

Other phases of this CRC-funded research programme have dealt with fatalities associated to natural perils and have been reported upon separately (e.g. Coates et al. (2016)). Fatalities will not be further discussed in this report.



METHODOLOGY

PerilAUS contains detailed information on natural hazard events impacting Australia from European settlement (1788) and before, but with good confidence from 1900. The data emphasises natural hazard incidence and consequences such as fatalities, damage to the built environment, insurance losses, economic costs and event physical attributes.

As noted in previous Bushfire and Natural Hazards CRC reports, *PerilAUS* data is based on material collected from news media, government departments and the published literature. In terms of newspaper accounts, while a range of newspapers were examined, *The Sydney Morning Herald* and its forerunner, *The Sydney Gazette*, provide an unbroken record of just over 200 years of disaster reporting, for the first hundred years and more, by correspondents in every tin-pot settlement in the country. While parts of the paper are indexed, much of the run is not and researchers read every natural hazards-related item up to the late 1990s (Blong 2004). The ICA Disaster List, which records insurance sector losses since 1967, has also been consulted to provide a crosscheck on the loss figures in *PerilAUS* and also to ensure key events were not overlooked.

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-five other hazard- and risk-related studies: for example, Coates et al. (1993); Coates (1996); Coates (1999); Blong (2003 and 2005); Haynes et al. (2009); McAneney et al. (2009); Haynes et al. (2010); Crompton et al. (2010); Bianchi et al. (2014) and Coates et al. (2014).

At the time of writing, December 2016, *PerilAUS* contains a total of 15,299 event records from the year 1900. An additional 1163 events were added during the last 12 months of this project. Not all of these events will have caused building losses. In fact there is no easy way of separating events that have caused building losses from those that have impacted in other ways. All that can be said is that each event listed in *PerilAUS* has had an impact on human health and/or the built environment.

The additional events listed since November 2014 include:

- a few year 2013 events
- many year 2014 events
- all year 2015 events and
- any new data in all major (ICA listed) events from 1967-2015.

Many of the new event reports related to the fatality investigations of this project.



HOUSE EQUIVALENTS

PerilAUS employs the “House Equivalent” (HE) metric to allow easy comparison between peril types, locations and years of record (Blong 2003; Blong 2005). All buildings losses are categorised as an equivalent number of median-sized residential homes so that four residential dwellings suffering 25% damage in an earthquake is equivalent to one dwelling completely destroyed in a bushfire. Damage to other buildings is also measured in terms of numbers of median-sized residential homes using comparisons based on relative floor areas and construction costs per m² – the Replacement Ratio (RR). A median-sized house is given a RR of 1.0 while a median-sized townhouse has a RR of 0.7; an Office and Showroom 23; a General Hospital 410. In short, RR is the multiple required to express the cost of a building in equivalent numbers of median-sized residential houses. Blong (2003) tabulates RR for different categories of construction. Clearly buildings such as hospitals, hotels and shopping centres vary enormously in scale and where better information exists about cost ratios, it should be used.

The amount of damage sustained by each building category is assigned a Central Damage Value (CDV) ranging from 0.02 for Light, 0.10 for Moderate, 0.4 for Heavy, 0.75 for Severe Damage and 1.0 for Total destruction. These values follow from post-event reconnaissance missions undertaken by Risk Frontiers and others. It then follows that the total damage for an individual building *l* can be expressed as:

$$\text{Damage (HE)}_i = \text{RR}_i \times \text{CDV}_i$$

Or more generally, the total event damage

$$\text{Damage (HE)} = \sum_{i,j} \text{RR}_i \times \text{CDV}_i$$

where the summation is across all buildings (*i*) and locations (*j*) impacted.

The Damage Index is concerned only with buildings and ignores damage to motor vehicles, fences, building contents, business interruption, infrastructure, demand surge and other cost elements that may all feature strongly in insurance claims. This distinction is important when considering events like hailstorms, where, for example, a large proportion of the toll in urban areas may come from damage to cars, particularly if the storm occurs during a period of peak traffic flow. In the 1999 Sydney hailstorm about a third of the insured cost was due to damage to motor vehicles.

Clearly the accuracy of the HE calculation is very sensitive to the estimation of CDV and to the number of buildings damaged. Judgement needs to be applied especially where the data on numbers of buildings and the degree of damage is poor as will often be the case in media reports.

Nonetheless there are real benefits of considering building damage in this way. In particular, it enables a good understanding of the components of damage in any particular event. Comparisons can be made between total damage and/or the components of damage of a particular peril type across time and space and on the relative destructiveness of different perils, e.g. flood vis-à-vis bushfire. The index is also inflation-proof. More detail can be found in Appendix 1.

NORMALIZATION OF HOUSING EQUIVALENTS

In order to compare the impacts of historical events with more recent events we employ what has become known as *loss normalisation* (Pielke et al. 1998; Crompton and McAneney 2008; Crompton et al. 2010). Loss normalisation answers the question: what would be the cost today if historical peril events were to impact upon current societal and demographic conditions? Clearly a repeat today of an event that destroyed a handful of homes in 1905 has the potential to inflict much larger losses in areas which now have much higher numbers of homes than was the case at the time of the original event. The normalisation process used here accounts for this by adjusting historical losses for known changes in numbers of dwellings and improvements in building codes and construction in cyclone-prone parts of the country.

To normalize bushfire building damage (HE) records to current societal conditions we follow Crompton et al. (2010) by converting the HE in year i to year 2015 numbers as follows:

$$HE_{2015} = HE_i \times N_{i,j} \quad (1)$$

where $N_{i,j}$ is the *dwelling number factor* defined as the ratio of the number of dwellings in year 2015 in state or territory j to those present in year i . The number of dwellings in each state or territory is reported in the census of population and housing and/or year books, which are available from the Australian Bureau of Statistics (ABS) [<http://www.abs.gov.au>]. A dwelling is defined as a structure intended for human habitation—normally a house, flat, caravan, and so on—but also includes hotels, prisons, hospitals—that were occupied on census night. National censuses were undertaken irregularly until 1961 and at 5-yearly intervals since. Linear interpolation was used to determine the number of dwellings for years between census years. Growth in the number of dwellings is assumed as a proxy for growth in HE.

The HE representation avoids the need for an inflation adjustment. Although Blong (2003) differentiates between small, median, and large houses based on floor area, this level of detail is not often included in the source documents and so, for most building types, numbers of HE were based on a single (median) size of each building type.

We follow Crompton and McAneney (2008) in paying special attention to wind losses caused by tropical cyclones since improved building codes were brought into force following the destruction of Darwin by Tropical Cyclone Tracy in 1974. These mandated improvements in building construction standards came into effect at different times in different areas of the country: here we adopt 1975 for Darwin, 1976 for Townsville and 1981 elsewhere as threshold years for building code regulation of the wind standard and to discriminate between new and improved construction.

We have applied this technique to the tropical cyclones that have produced the most building damage and estimated the adjustment for the remaining events from a curve fit to the results. There is scatter about the curve due to the way in which the adjustment is calculated and it outputs TC Building Code Adjustment Factor as a function of the year the



event occurred. Failure to allow for the wind standard being regulated would be to assume the ratio of pre- to post-19XX buildings is the same in season 2015 as what it was when the event occurred.

The Building Code Adjustment Factor is unique to each tropical cyclone event loss and incorporates the proportion of the loss attributable to wind damaged buildings as opposed to flooding or storm surge, wind damage to cars, etc. and the proportion of pre- and post-19XX dwellings in the impacted Urban Centre and Locality (UCL) both in the season the event occurred and in season 2015. It also accounts for pre- and post-19XX residential building loss ratios (ratios of damage losses to replacement values) that are a function of peak gust speed. This loss ratio also includes damage due to wind-driven rain following wind damage to the envelope of the dwelling. The adjustment assumes the post-19XX buildings were built in line with the wind standard, i.e. no more or less vulnerable than the wind standard prescribes.

Urban Centres and Localities (UCLs) are a geographical unit that statistically describe Australian population centres with populations exceeding 200 persons. They are designed for the release of data from the Census of Population and Housing, and are derived from analysis of the data within Statistical Areas Level 1 (SA1s) from the 2011 Census. UCLs are created from aggregates of SA1s. Centres with a core urban population of 1,000 persons or more are considered to be Urban Centres, whilst smaller centres with populations of 200 persons or more and a core urban population below 1,000 persons are considered to be Localities

([http://www.abs.gov.au/websitedbs/D3310114.nsf/4a256353001af3ed4b2562bb00121564/6b6e07234c98365aca25792d0010d730/\\$FILE/Urban%20Centres%20and%20Localities%20and%20Significant%20Urban%20Areas%20-%20Fact%20Sheet.pdf](http://www.abs.gov.au/websitedbs/D3310114.nsf/4a256353001af3ed4b2562bb00121564/6b6e07234c98365aca25792d0010d730/$FILE/Urban%20Centres%20and%20Localities%20and%20Significant%20Urban%20Areas%20-%20Fact%20Sheet.pdf)).



THE NATIONAL EVENT LOSS PROFILE

TIME SERIES OF LOSS FREQUENCIES AND HOUSING EQUIVALENTS

Figure 1 shows the annual aggregated number of events causing normalised damage in excess of more than 25 HE. This threshold is adopted to overcome a likely bias against very small events that may not have been featured in newspapers or been the subject of official enquiries. On average there are 5.85 such events per year. With an average house price of \$400k, this threshold is equivalent to an event loss of \$10 m due to damaged buildings. Using a threshold HE rather than a dollar loss is more defensible because inflation alone will reduce the significance of a \$10 m loss over time. By way of comparison, the ICA Disaster List employs a notional value of \$10 m but its application has not always been rigorously adhered to.

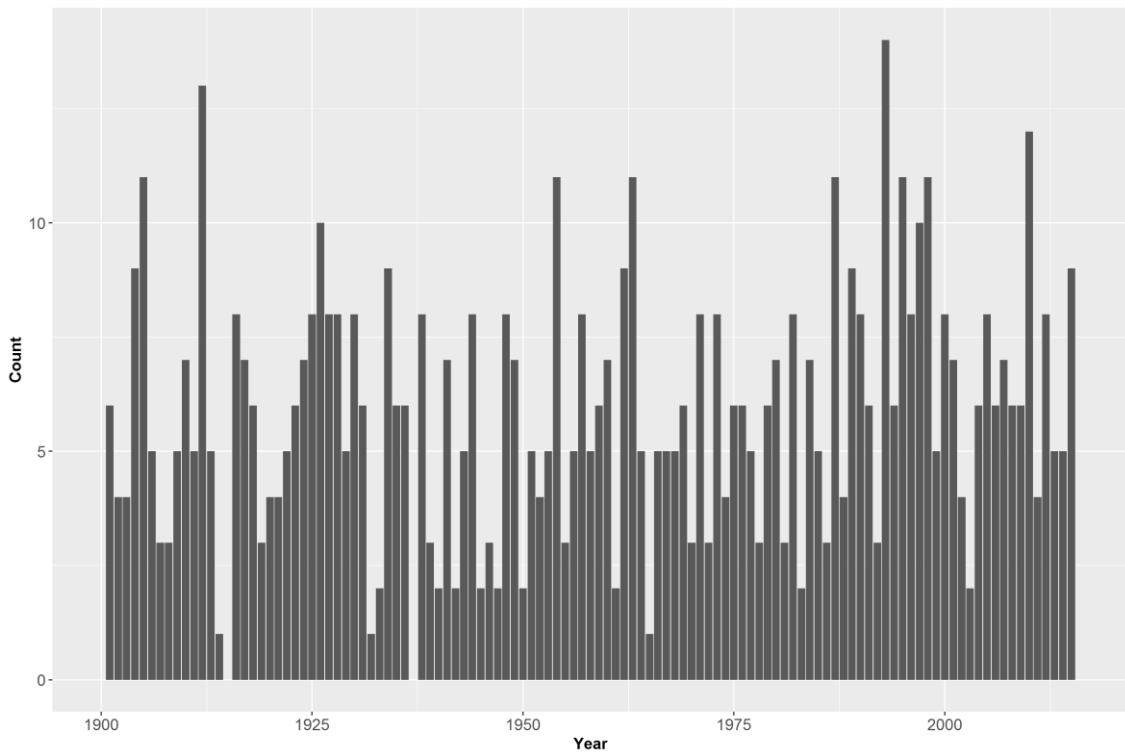


Figure 1. The annual number of damaging events per year since 1900 with normalised HE losses > 25. Year 1900 refers to the 12-month financial year beginning July 1: this is done to separate successive summer periods, when many but not all natural disasters occur.

Figure 2 shows the aggregated but non-normalised HE losses by year since 1900. It shows losses in what is equivalent to ‘the dollars of the day’. This is an ‘apples-with-oranges’ comparison as it ignores large social and demographic changes that have occurred over the 116 years. For consistency with Figures 1 and Figure 3 (see later), Figure 2 also excludes events with normalised HE losses <25.



The normalised losses in Figure 3 show the normalisation adjustment is successful in cancelling out the escalating trend obvious in Figure 2 and point to increasing concentrations of population and wealth in at-risk locations being the primary cause of increasing building damage. This result is in line with other scholarship across different perils and jurisdictions (Pielke et al. 2008; Crompton and McAneney 2008; Bouwer (2011); McAneney et al. (2017) and references therein.) This conclusion has also been accepted by the IPCC (2012, 2014).

The average event loss over the 116 years is \$118m with a standard deviation is \$430m. In four years, financial years 1973, 1974, 1998 and 2010, losses exceed 10,000 HEs. Key events responsible for these extreme losses are the Brisbane floods in 1974, Cyclone Tracy (1974), Sydney hailstorm (1999) and the Queensland and Victorian floods (2011). Just why these large losses appear 'clustered' post-1970 is unclear and warrants further research. We do not believe it to be a reporting bias. In the case of the Brisbane floods for example there were floods in the early and late 19th century than were larger than either the 1974 or 2011 events (van den Honert and McAneney 2011). Globally we have seen apparent time clustering of large earthquakes, but proving these occurrences to be statistically different from a random pattern is very difficult (Dimer de Oliveira 2012).

Table 1 shows the top 20 normalised HE totals, which are responsible for 50% of the aggregated normalised losses. This list includes five different perils and reinforces the fact that the Australian riskscape is not dominated by one single peril. Figure 4 also shows these data to conform to a Pareto distribution (Vose 1996) with 20% of events responsible for 80% of the aggregated normalised HE losses.

Table 1 also lists the Average Annual Recurrence Interval of losses calculated as:

$$ARI = (116+1)/Rank \quad (2)$$

It shows that natural disaster losses of the order of those inflicted by the 1999 Sydney hailstorm can be expected about once per century and those similar to the 1967 Hobart bushfires once every decade. The fat-tailed nature of the distribution means that losses well in excess of the historical mean are always possible.

Table 2 lists the top 10 normalised insurance losses to 2015 societal conditions and shows a slightly different view of risk (McAneney et al. 2016). Nonetheless it is gratifying to see that the ranking of the top events in Table 1 is more or less preserved in the ICA Disaster List. Differences between the two tables arise from the following:

- The shorter record of the ICA Disaster List which begins in 1967
- The ICA Disaster List misses many smaller events
- Until the 2011 Queensland and Victorian floods, flood damage to residential homes was not uniformly insured
- Insured claims cover many other elements of damage than just building losses, including business interruption losses and vehicles. Both were significant contributors to the insured cost of the 2007 Pasha Bulker storm, for example, in which 4000 motor vehicles were destroyed.
- The ICA Disaster List contains errors: for example, neither PerilAUS nor the BoM attribute any losses to Tropical Cyclone Madge (1973).

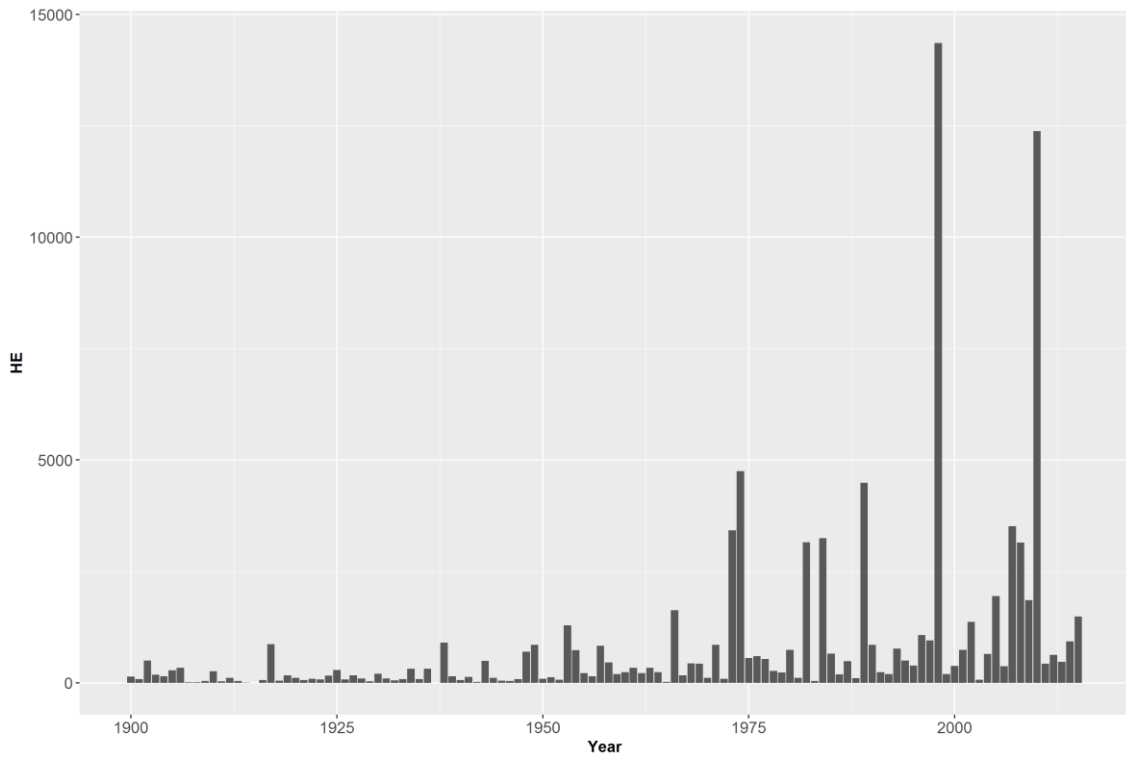


Figure 2: Non-normalised HE losses aggregated by financial year since 1900.

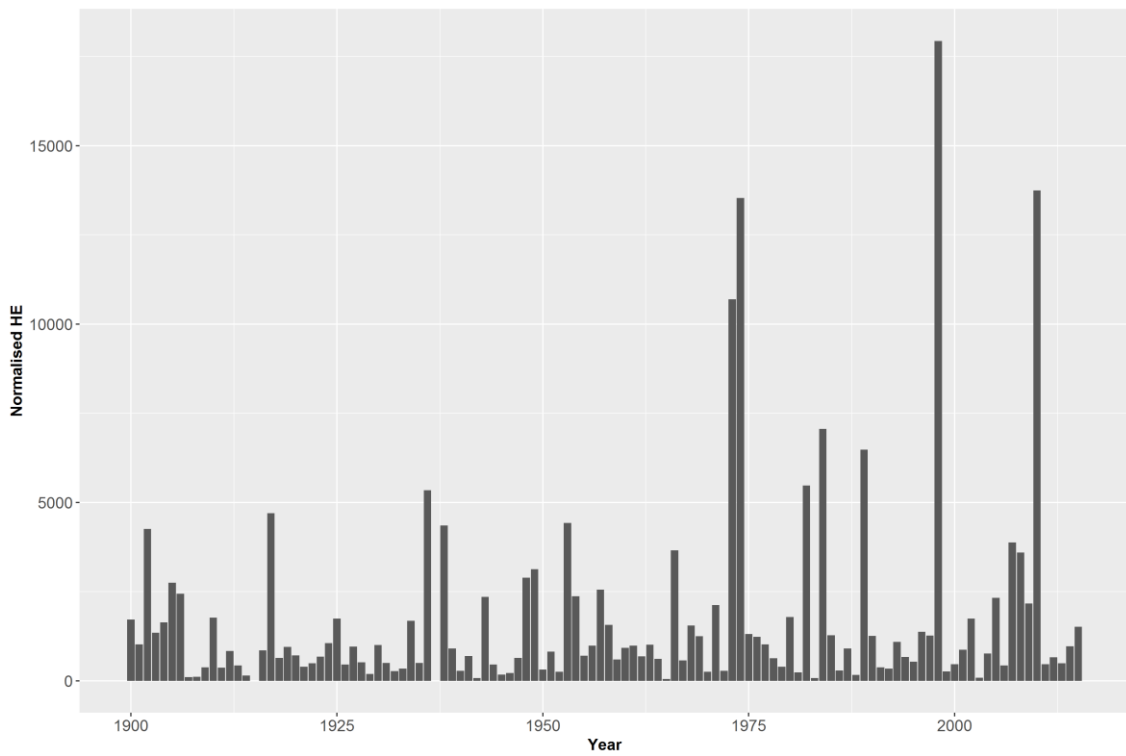


Figure 3. As per Figure 2 but showing normalised aggregated HE by year.



Table 1. Events ranked by normalised building damage in HE (1900 – 2015) and Annual Average Return Interval (ARI). Losses have been estimated assuming the value of a median-sized building in 2016 is \$400k.

Rank	Year	Event	Estimated Loss (\$millions)	ARI (years)
1	1999	Sydney hailstorm	5754	116
2	1974	TC Tracy	5334	58
3	2011	Brisbane floods	4763	39
4	1974	TC Wanda floods	3654	29
5	1985	Brisbane hailstorm	2323	23
6	1983	Ash Wednesday fires	1991	19
7	1937	Unnamed TC	1990	17
8	1989	Newcastle earthquake	1952	15
9	1939	Black Saturday bushfires	1673	13
10	1903	TC Leonta	1556	12
11	1967	Hobart bushfires	1394	11
12	2007	Western Sydney hailstorm	1219	10
13	1954	Unnamed TC	1108	9
14	1918	Unnamed TC	1017	8
15	2009	Black Saturday bushfires	995	8
16	1907	Unnamed TC	874	7
17	1998	Brisbane and region hailstorm	778	7
18	2010	Perth hailstorm	742	6
19	1918	Unnamed TC	604	6
20	2003	Canberra bushfires	603	6

Table 2. Top 10 Australian normalised (2014–2015) insurance sector natural disaster loss events (McAneney et al. 2016).

Rank	Year	Event	Cost (Millions AUD)
1	1999	Sydney Hailstorm	4475
2	1974	Tropical Cyclone Tracy	4178
3	1989	Newcastle Earthquake	3834
4	1974	Brisbane Floods	2701
5	2011	Queensland and Victorian Floods	2506
6	1983	Ash Wednesday Bushfires (Wildfires)	2371
7	1985	Brisbane Hailstorm	2046
8	2007	Pasha Bulker East Coast Low Storm	1966
9	1973	Tropical Cyclone Madge	1520
10	1990	Sydney Hailstorm	1433

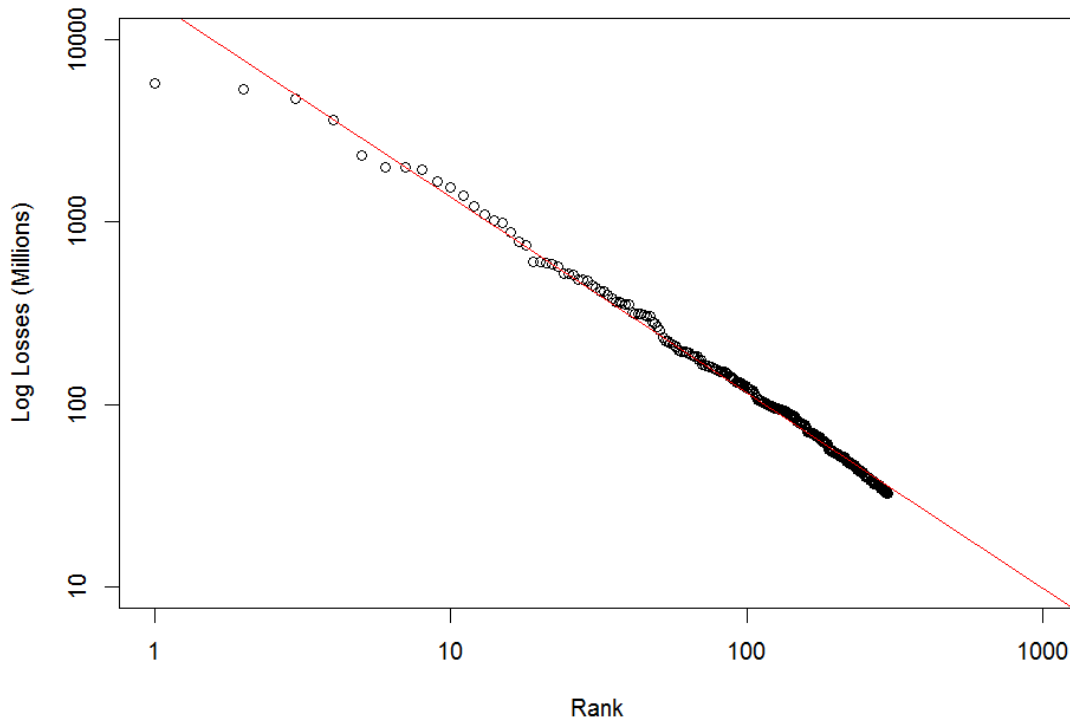


Figure 4. The top 300 normalised losses as listed in Table 2 against rank. The straight line shows a Pareto (power law) distribution.

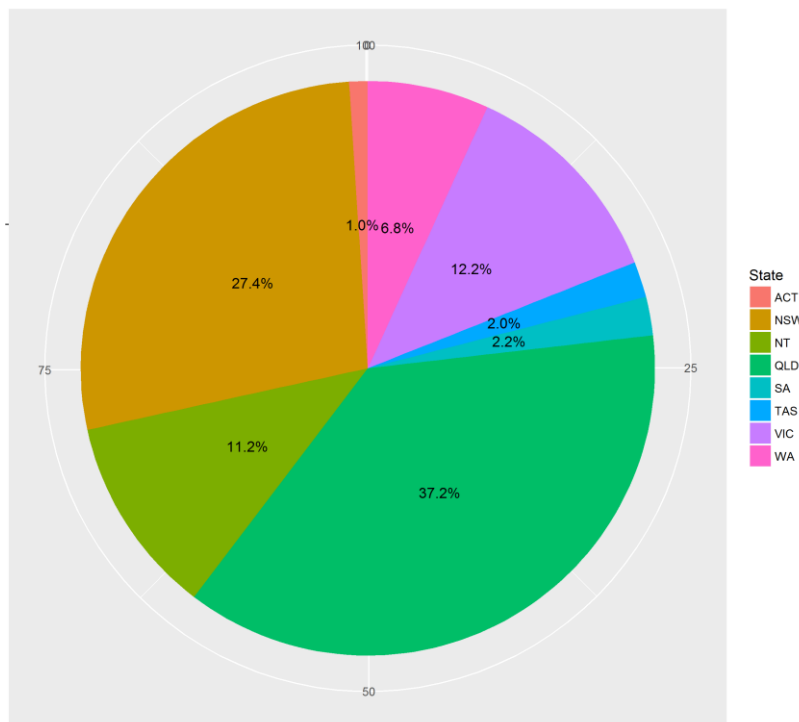


Figure 5. Breakdown of normalised HE losses by State since 1900.



BREAKDOWN OF TOTAL LOSSES BY STATE

Figure 5 shows a pie chart representation of normalised HE damages by State since 1900. Queensland tops the list with 37% of the national total followed by NSW at 28% and Victoria 12%. Collectively NSW and Queensland account for 75% of total building losses incurred over the last 116 years.

BREAKDOWN OF LOSSES BY PERIL

Figure 6 displays a breakdown of the national event count and normalised HE losses since 1900 by peril. We note that whereas bushfires and floods cause losses comparable to their frequency, tropical cyclones, hail and earthquakes are much more destructive than their frequency might imply. “Others” include storms other than hail and tropical cyclones, landslides, tornadoes and lightning strikes. Storms occur frequently but are relatively non-destructive compared with the major perils identified individually.

Of all the perils, tropical cyclones have been the most destructive accounting for 30% of the losses with hail, flood and bushfire each contributing another ~18% each. Earthquake losses are mostly attributable to a single event – the 1989 Newcastle earthquake.

In Figure 7 we examine the same data but in this case group all normalised HE losses due to hail with strong wind gusts, tornadoes, lightning and heavy rainfall into a Thunderstorm category (TS). Collectively thunderstorms are as destructive as tropical cyclones in accounting for 30% of the damage.

The breakdown of losses by peril in Figures 5 and 6 are broadly in line with those of Crompton and McAneney (2008) determined from an analysis of the ICA Disaster List but differ in detail due to:

- the importance of more recent extreme events – the 2009 Victoria bushfires, the 2011 Queensland and Victorian floods and Tropical Cyclone Yasi also in 2011 amongst others;
- a longer dataset, and
- consideration of a wider range of perils.

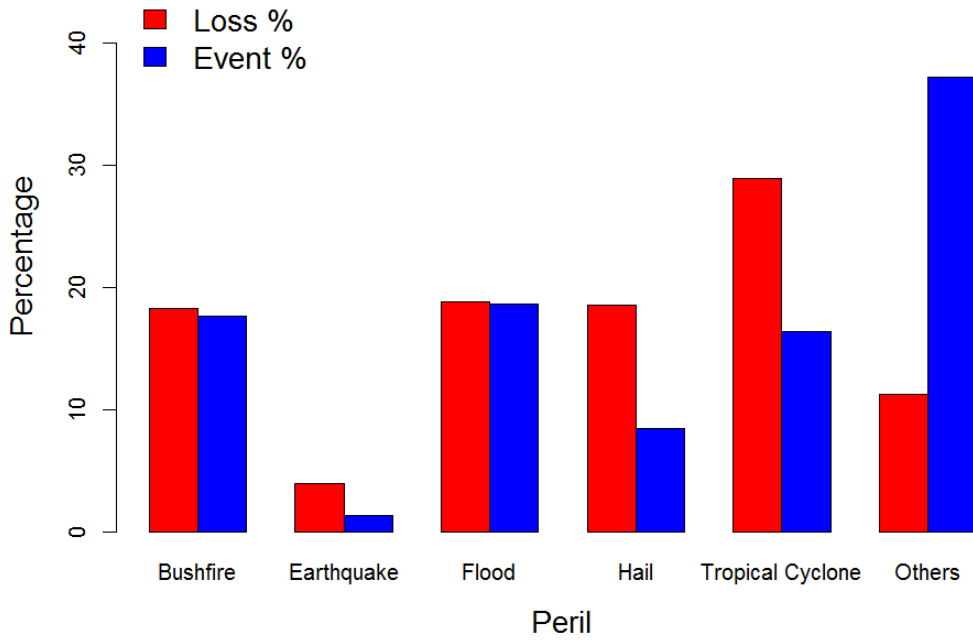


Figure 6. National event frequencies and normalised HE losses by peril type.

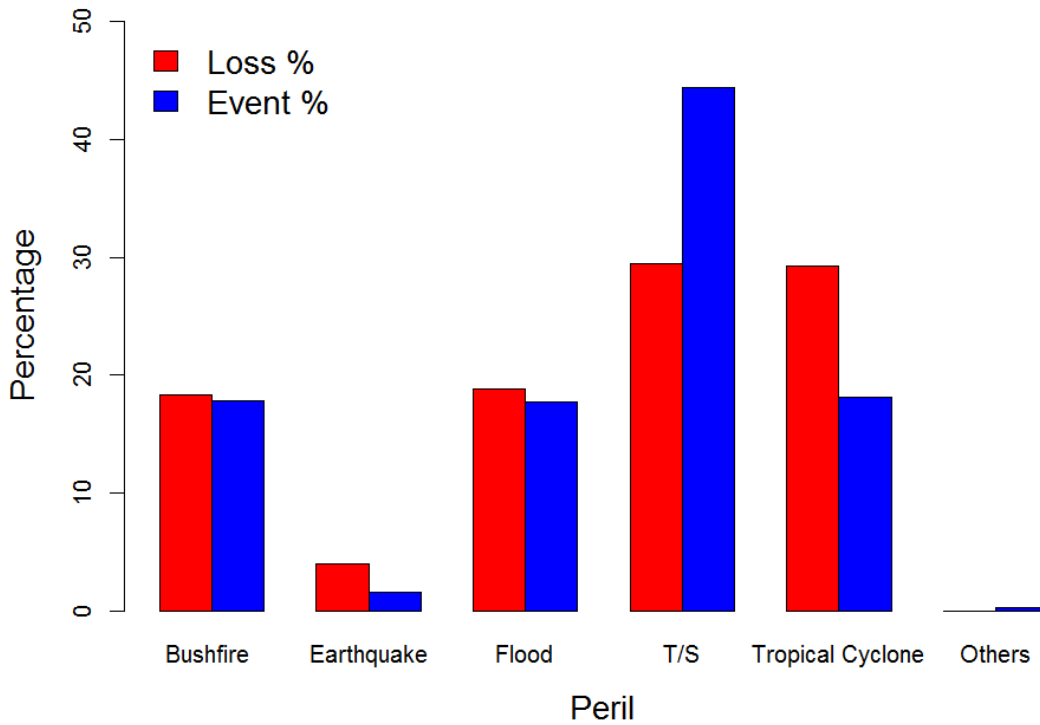


Figure 7. As for Figure 5 but with losses due to hailstorms, gust, tornado, heavy rainfall and lightning events grouped under Thunderstorms. “Others” now refers only to landslides.



BREAKDOWN OF LOSSES BY PERIL AND BY STATE

Figures 8 to 12 show the proportional breakdown of the total losses attributable to various perils across States and Territories. Over the last century, bushfires have been most destructive in Victoria where they have been responsible for over 50% of the national building loss caused by this peril. Nonetheless bushfires also pose a serious risk in all other states and territories with the exception of Queensland where losses are minor compared with floods and cyclones.

Figure 9 shows that earthquake losses are dominated by the 1989 Newcastle event. However, 116 years of data is too short a time period to dismiss the seismic risk posed to buildings and even another modest event in a major metropolitan area such as Adelaide or Melbourne, for example, could turn this graph on its head. Poor construction practices in respect to seismic ground motions and high property costs mean that earthquake risk tends to drive the top end of reinsurance programmes covering Australian natural hazard risks.

Figure 10 shows hail to have been a problem especially in NSW followed by Queensland. Large and costly storms experienced in Perth (March 2010) and Melbourne (Christmas Day 2011) serve as a reminder that hail is not just an issue for NSW and Queensland.

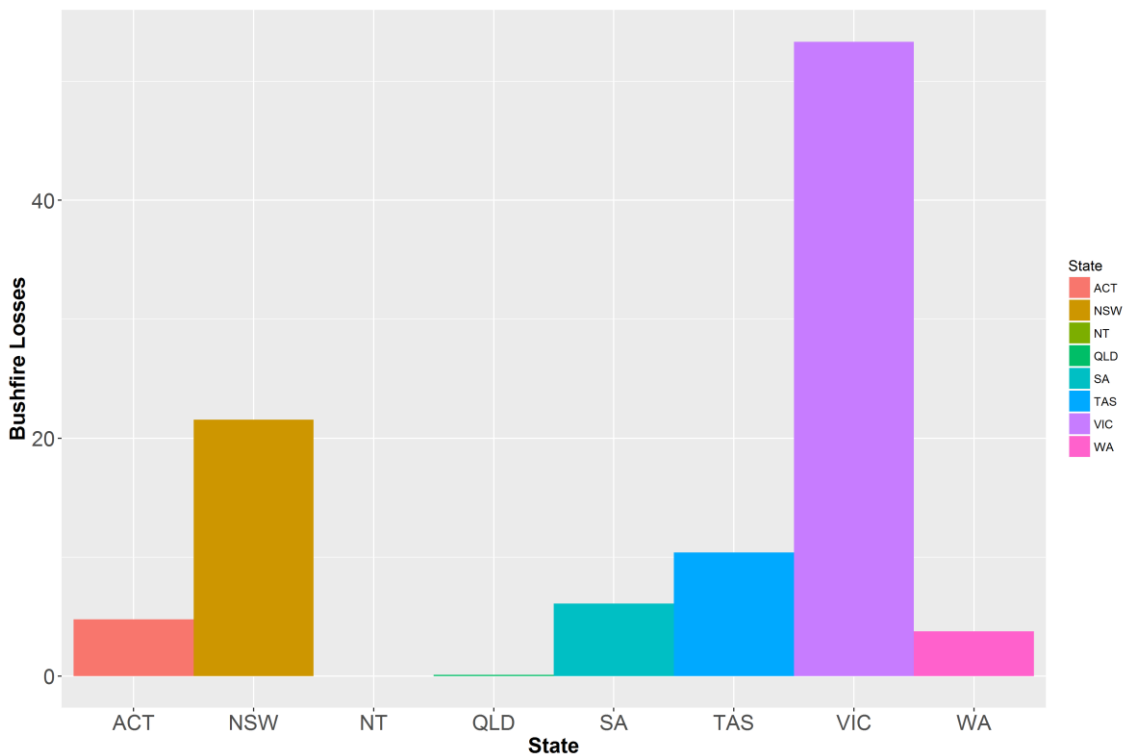


Figure 8. Percentage of the aggregated normalised HE losses caused by bushfires in different States and Territories.

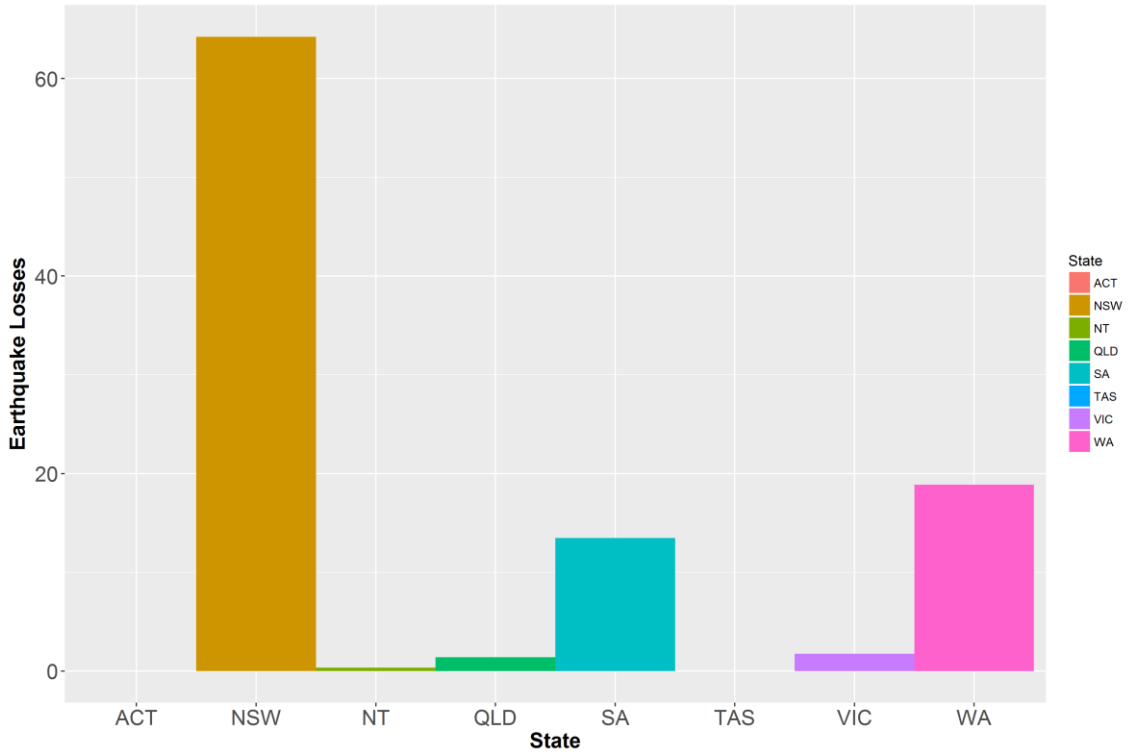


Figure 9. Percentage of the national aggregated normalised HE losses caused by earthquakes across different States and Territories.

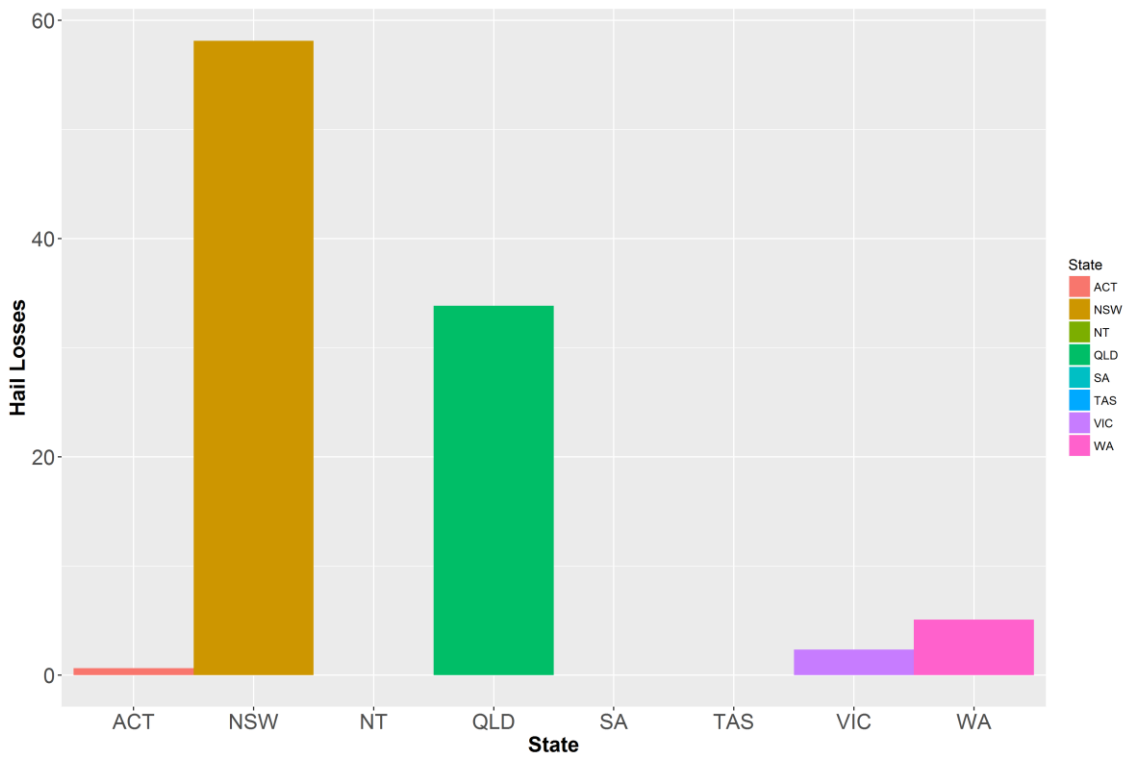


Figure 10. Percentage of the aggregated normalised HE loss caused by hail across different States and Territories.

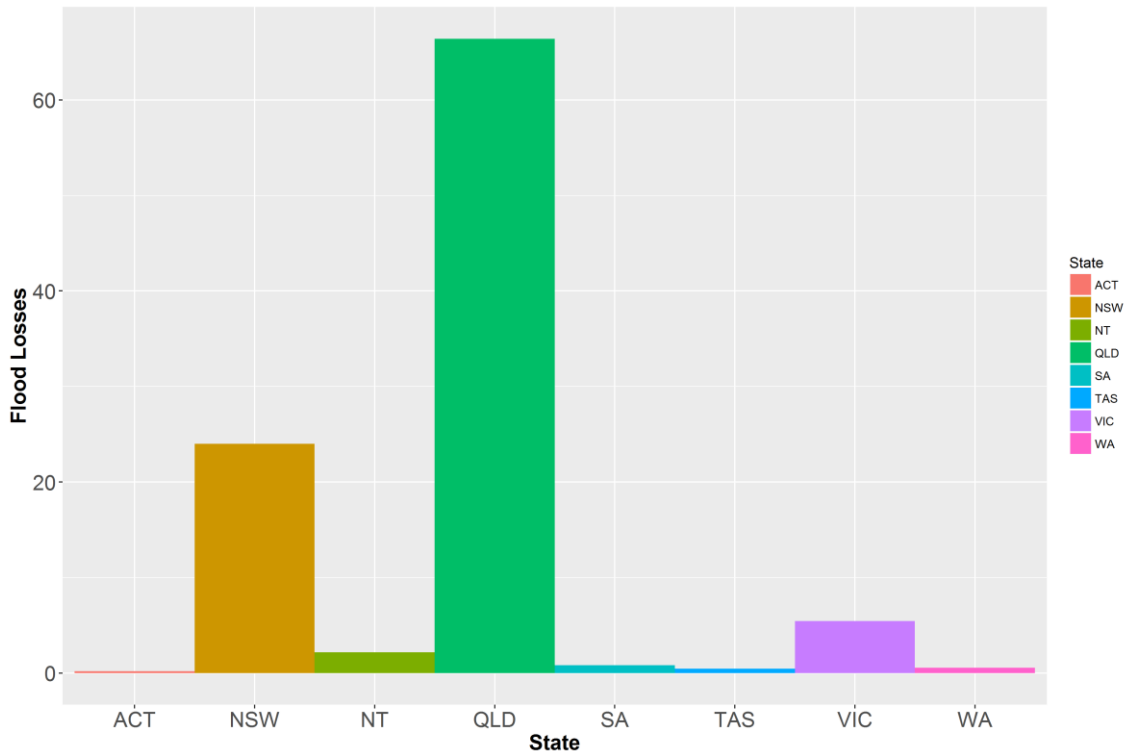


Figure 11. Percentage of the aggregated normalised HE loss caused by flood across different States and Territories.

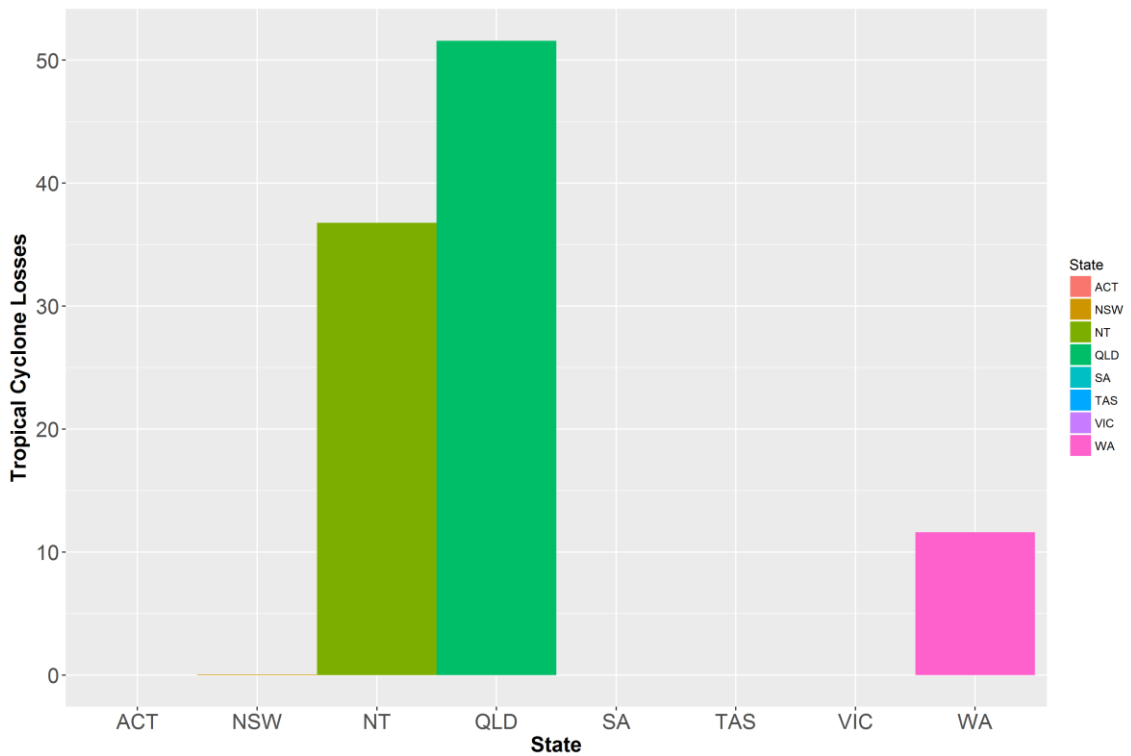


Figure 12. Percentage of the aggregated normalised HE loss caused by tropical cyclones across States and Territories.



Figure 11 shows that flood losses have been particularly destructive in Queensland with 65% of the national toll experienced in that state. The 1974 and 2011 floods were particularly damaging, although even larger floods were witnessed in Brisbane in the early and late 19th century (van den Honert and McAneney (2013)). NSW follows next after Queensland with 25% of the national total. NSW has probably invested more in flood mitigation than have other states.

Lastly, in the case of Tropical cyclones over 50% of the aggregated HE losses by tropical cyclones have occurred in Queensland with another 37% in the Northern Territory, notably the destruction of Darwin in 1974. Cyclone Tracy is yet another reminder of how sensitive these statistics can be to a single event (Figure 12).



BIASES AND DATA LIMITATIONS OF PERIL AUS

Newspaper articles, while containing valuable narrative detail, can contain inaccuracies and bias towards newsworthy events. The *Peril AUS* record from the early 1900s 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 1990s. The inclusion of government, scientific, historical and other reports helps balance this bias.

News media has been searched in recent years via Trove - National Library of Australia - and Factiva – an online search tool and current international news database. However, Trove cover is sparse to non-existent beyond the 1960s and Factiva covers only from the mid-1980s (for the *Sydney Morning Herald*) or the early- to mid-1990s (for the main newspaper from other states and territories), with cover very good from about the mid-1990s onwards (including the more local news media).

Importantly, the inclusion of all those events within the Insurance Council of Australia (ICA) list (from 1967 to 2015) assigned a Catastrophe number has ensured that the most damaging natural hazard events that have impacted Australia since 1967 have all been accounted for.

Some possible big events that did not impact populated areas in the early part of last century may not have warranted mention in local newspapers and *Peril AUS* will not contain records of such events.

The main limitation to *Peril AUS* (and any other historical database) in respect to our current task is that there is often no one source of precise data to support the HE calculations for many events. Quite often the reports available are: “Many buildings were damaged.” It is difficult to extrapolate the number and type of buildings and the percentage of damaged caused to them from a statement like this. In the case of large events, where a CDV is estimated for a very large number of buildings, the resulting HE value needs to be treated with caution, as a small change in CDV or RR can translate into a potentially large change in HE.

It is impossible to assert that *Peril AUS* has captured every detail of building damage and/or fatalities caused by natural hazards. It is true, however, that it represents the best collection of such data in Australia since 1900.



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APPENDIX 1

A BUILDING DAMAGE INDEX (adapted from Blong (2004))

Since damage other than to buildings is difficult to get a grip on, we have focused on what is probably the most important component of losses. But even focusing on building damage alone still presents some problems. How for example do you compare severe damage to a dozen houses with the destruction of the local pub, or police station? Or hospital? We approached this issue by developing a purpose built damage index that we hope will have wide applicability. The Risk Frontiers Damage Index reduces building damage to House Equivalents (HE): for example, two houses half-destroyed is equivalent to one house totally destroyed. Buildings other than houses are made equivalent to houses using relative floor areas and construction costs per m². Much of the necessary data can be found in construction handbooks (e.g. Rawlinsons, 1999).

By way of example, if we set the cost of building an average Australian house at AUD\$800/m² (in 1999 dollars) and the cost of building a supermarket at AUD\$1,130/m², the construction cost of a supermarket is about 1.4 times that of an average house. Then, if the floor area of an “average” Australian house was 180m² and that of the supermarket 2,000m², then the Replacement Cost Ratio (RR) for the supermarket is about 16.0:

$$[(\$1130 \times 2000 \text{m}^2) / (\$800 \times 180 \text{m}^2)] = 15.7$$

In other words, the cost of replacing the supermarket is roughly 16 times that of replacing an average residential house (RR=16).

Consider now a tornado that takes out 10 houses, the supermarket, the local pub, and half-destroys six more houses. With a cost ratio of 1.9 and a floor area of 1,000m², the RR for the pub = 11. Thus, the tornado damage amounts to 10+16+11+(0.5x6) = 40 HE.

The Damage Index is concerned only with building damage and, as currently constructed, ignores damage to motor vehicles, parking areas, swimming pools, gazebos, fences, barbecues and other important elements of Australian life. It also ignores building contents, though all of the elements named above (plus aeroplanes, power pylons, gas pipes and fire engines) could be readily turned into HE values given sufficient time and desire. Obviously, the HE index also ignores the social value or utility of the buildings as is evident from the relative replacement ratios for the supermarket and the pub.

In the tornado example above six houses were described as “half-destroyed”. Often we will want to be more sophisticated than that. Table 2 outlines a scheme relating ten Damage Classes to Central Damage Values (CDV) and ranges in these values for each class.

**Table A1.** Central Damage Values (CDV)

Damage Class	CDV	Range
Light	0.02	0.1 – 0.05
Moderate	0.10	0.05 – 0.20
Heavy	0.40	0.20 – 0.60
Severe	0.75	0.06 – 0.90
Collapse	1.00	0.9 – 1.00

Table A1 shows that Heavy Damage implies damage equivalent to about 40% of the replacement value of a building. Thus for our supermarket, Heavy damage implies 40% of the Replacement Ratio (0.4×16) = 6.4 House Equivalents.

The single-word Damage Class descriptors in Table A1 conveys only limited information. Table A2 provides more detailed information for tropical cyclone and landslide damage – those familiar with the literature will note our indebtedness to Leicester and Reardon (1976) and Alexander (1989). Details for tornado, hail, earthquake, bushfire, flood and tsunami can be found in Blong (2003).

We can now express damage as:

$$\text{Damage (HE)} = \text{No of Buildings} \times \text{RR} \times \text{CDV}$$

Consider now a tropical cyclone that struck the town of Endsleigh in 1998, where 40 houses suffered Moderate wind damage, 60 houses Severe damage, a grandstand (RR=10) totally Collapsed, and a Motel suffered Heavy damage. Thus:

$$\begin{aligned} \text{Damage (HE)} &= [40 \times 1.0 \times 0.1] + [60 \times 1.0 \times 0.75] + [1 \times 10.0 \times 1.0] + [1 \times 7.0 \times 0.4] \\ &= 4 + 45 + 10 + 2.8 \\ &= 61.8 \text{ House Equivalents} \end{aligned}$$

The same tropical cyclone caused landsliding in the suburb of Slippery Slope, destroying 12 houses, while a debris flow entered a single-storey office block (RR=6, CDV=0.3):

$$\begin{aligned} \text{Damage (HE)} &= [12 \times 1.0 \times 1.0] + [1 \times 6.0 \times 0.3] \\ &= 13.8 \text{ HE} \end{aligned}$$



Table A2: Damage descriptions for specified Central Damage Values

Peril	CDV				
	0.02 Light	0.10 Moderate	0.40 Heavy	0.75 Severe	1.00 Collapse
Tropical cyclone	Negligible – missile damage to cladding or windows	Loss of half roof sheeting	Loss of roof structure + some damage to walls	Loss of all walls	Loss of walls, floor and some support piers on elevated houses
Landslide	Hairline cracks (<0.1mm) in walls or structural members	Minor settlement of foundations	Walls out of perpendicular by several degrees; floors inclined; or heaved; open cracks in walls	Structure grossly distorted; partition walls and brick infill at least partly collapsed; footings lose bearing; service pipes disrupted	Partial/total collapse

The same tropical cyclone produced flooding in Gurgle, another Endsleigh suburb, with water entering 180 houses (CDV=0.1), floating debris severely damaging a 1000m² warehouse (RR=4.2), producing Heavy damage to a suburban police station (RR=2.1) and destroying five adjacent small retail outlets (RR=0.5):

$$\begin{aligned} \text{Damage (HE)} &= [180 \times 1.0 \times 0.1] + [1 \times 4.2 \times 0.75] + [1 \times 2.1 \times 0.4] + [5 \times 0.5 \times 1.0] \\ &= 24.5 \text{ HE} \end{aligned}$$

Thus the total damage produced in Endsleigh by the cyclone is 100.1 HE and allowing the House Equivalents shown in Table A3 to also serve as percentages, we can note that more than 60% of the total building damage was produced by the cyclonic winds and that nearly 80% of the total damage was to residential buildings.

Table A3 characterises some of the real benefits of considering building damage in this way. We now have a good understanding of the components of damage in the Endsleigh cyclone. We can compare total damage and the components with earlier cyclones that struck



Endsnigh and with the consequences of cyclones that have struck other parts of Australia. We can also compare the consequences of cyclones with the consequences (for buildings) of other natural perils. Now we have the basis for a reasonably rational natural hazards risk assessment.

Table A3. 1998 Endsigh tropical cyclone damage summary – House Equivalents

	Wind	Landslide	Flood	Total
Residential	49.0	12.0	18.0	79.0
Commercial	2.8	1.8	5.65	10.3
Govt./Public	10	-	0.9	10.9
Total	61.8	13.8	24.5	100.1