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# How much do disasters cost? A comparison of disaster cost estimates in Australia

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ABSTRACT

Extreme weather events in Australia are common and a large proportion of the population are exposed to such events. Therefore, there is great interest as to how these events impact Australia's society and economy, which requires understanding the current and historical impact of disasters. Despite global efforts to record and cost disaster impacts, no standardised method of collecting and recording data retrospectively yet exists. The lack of standardisation in turn results in a range of different estimates of economic impacts. This paper examines five examples of aggregate disaster loss and impacts of natural disasters in Australia, and comparisons between them reveal significant data shortcomings. The reliability of data sources, and the methodology employed to analyse them can have significant impacts on conclusions regarding the overall cost of disasters, the relative costs of different hazards (disaster types), and the distribution of losses across Australian states. We highlight difficulties with time series comparisons, further complicated by the interdependencies of the databases. We reiterate the need for consistent and comparable data collection and analysis, to respond to the increasing frequency and severity of disasters in Australia.

## 1. Introduction

Globally, Australia is among one of the most frequented countries by disasters [1]. Disasters that hit major population centres understandably impact heavily on the economy, and it is a goal of both policy makers and researchers to understand the burden this places on communities. To the question "How much do disasters cost Australia?" there is no single answer. Currently there is a confounding variety of estimates relating to the cost of weather related disasters in Australia. Even a single estimate of a single event allows considerable scope for interpretation, depending on what is included in the overall tally, and whether it is interpreted as a loss or benefit. These confounds also affect aggregate estimates: one recent estimate based on unpublished data suggested annual costs as high as $9 billion for 2015 [2], and projected these to rise to $33 billion a year by 2050. However this estimate did not consider the potential impacts of climate change, nor did they investigate indirect or intangible damages [3]. Taking these impacts into consideration the actual value would be expected to be much higher [4]. To ensure communities are compensated and governments can budget accurately for losses, there is a real and growing need to estimate how much disasters in Australia have cost in the past, and will cost in the future. There have been several attempts to cost natural disasters in Australia utilising different methods and it is the aim of this paper to compare a selection of these approaches.

The 'cost' or 'loss' from a disaster is not a straightforward concept, and this comes through in the breadth of estimates presented here. While there is some debate about the boundaries of different loss/cost categories, for the purpose of this paper we follow the standard set out in BTE [5] but also see [6–8] and described below. We use the term "loss" except when referring to an item which is normally costed, such as the "cost" of a repair, and when it is the term normally employed as in cost-benefit analysis. Cost or loss estimates may be economic or financial. Economic impact assessments look at all costs and benefits to the whole community affected by a disaster, whereas financial analyses estimate the financial impact on an individual or entity [5,9]. Within an economic impact assessment framework, cost items may be divided into costs directly resulting from the event such as damage to residential structures (often insured) or crops (often not insured). Indirect costs may also be counted, such as those resulting from business interruption (sometimes insured), or disruption to transport

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networks (not insured). Benefits to the community, such as increased activity in the building sector, also need to be considered for a full economic analysis [10]. ‘Cost’ can also be more broadly understood to incorporate intangibles – not directly traded in the market place – such as the cost of loss of memorabilia, cultural heritage or ecosystem services. Similarly, benefits can be intangible, such as the community cohesion built during a disaster response [11]. Further, how costs and benefits are defined depends heavily on the geographical and temporal boundaries of the analysis [10].

This paper starts with an examination of five studies that look at the aggregate cost and relative impacts of disasters to Australia. A comparison of these studies reveals some of the ways in which data source and methodology can have significant impacts on conclusions drawn. A number of loss/impact estimates of the 1983 Ash Wednesday bushfires are then examined to reveal how differences in data source and methodology can make estimates, even of the same event, vary substantially. Analyses of estimates also highlight how much of the full economic cost of disasters is excluded in many figures. Finally, the use of such estimates considering uncertainty in projections about the future is considered.

## 2. Cost categories

Economic loss is defined by the Integrated Research on Disaster Risk (IRDR) program as “the amount of damage to property, crops, and livestock and to the flow of goods and services expressed in monetary terms” [pg. 16; 12]. A full economic analysis of the cost of natural disasters would include direct, indirect and intangible losses (both insured and uninsured), as well as any economic benefits created by the disaster [12]. For Australian as much as for global disasters, the major difficulties in providing a full economic analysis stems from a lack of data, poor data quality, lack of precise definition of cost categories, vague or variable temporal and geographical limitations (e.g. defining where and for how long the event occurred), limited loss indicators, irregular frequency of updates and a lack of reliability assessment [1,12]. Further uncertainty is built into any model that attempts to cost a disaster retrospectively, as the information included in disaster reporting often changes with the priorities of the stakeholder gathering the information.

Disaster cost estimates in Australia have been largely drawn from the Insurance Council of Australia's (ICA) [13] Historical Disaster Statistics or insurance data with some augmentation [EM Knowledge Hub disasters database; 14]. A major obstruction to using this data is that as of mid-2015 the ICA database was no longer available online. More critically, insurance data account for insured losses only, and as such represent only a fraction of the total cost of a disaster. Many residential buildings and contents are underinsured in Australia [15,16], and insurance penetration for cover of crops and fences for example (direct costs) and business interruption (an indirect cost) is limited, particularly for small and medium sized businesses [17]. A multitude of indirect and intangible costs are not captured in insurance data, including loss of public services, residential and non-residential clean-up, alternative accommodation, agriculture, disruption to transport networks, disaster response and relief, health effects, environmental damage, and loss of cultural heritage [18]. In addition, as seen in Stephenson [19] and Stephenson, et al. [20], a full economic impact assessment may classify payments from insurance as a benefit, rather than a loss or cost. Despite these limitations, insurance cost data is used because it is often the only standardized proxy available [21].

## 3. Normalisation

Typically, for historical disaster cost data, time-series analysis is utilised [22,23]. For a time-series analysis, the data needs to be adjusted so that comparisons over time are valid. An approach generally termed “normalisation” is typically used to prepare data for comparative analysis over time. Normalisation adjusts losses by removing the influence of socio-economic changes such as inflation, wealth and population [23,24]. Without normalisation, comparisons might be dominated by growth in inflation, wealth and population, rather than any underlying changes in disaster losses [21]. Reflecting the diverse range of views about the dependence of losses upon the variables, the original values derived from each of the studies explored here were estimated using different normalisation methods. The use of different methods emphasising different types of changes over time is a common limitation of normalisation and reflects the complexity of adjusting losses to be comparable over time. The Bureau of Transport Economics (BTE) [5] adjusted total loss estimates for inflation only, to standardise to 1998 dollars. This approach attempts to reflect historic costs in today's dollars, but does not reflect the cost of the event were it to take place today. More comprehensive approaches to normalisation attempt to take this into account by incorporating additional variables in the adjustment of costs, allowing for what Pielke Jr, et al. [22] term “apples for apples” comparison of economic damage. For example, Crompton [25] normalised insurance data for inflation, population and changes in building standards, while Handmer, et al. [26] adjust total loss estimates using what has become a common combination of normalisation variables: inflation, population and wealth.

Driven by the underlying assumptions driving the normalisation [22], the procedure applied influences results of trend analysis considerably. Particularly in countries like Australia, with rising populations and expanding economies, the compounding impact of inflation, population and wealth growth dramatically exacerbates the estimation of losses toward the beginning of the period of analysis. If population and wealth growth are held to be connected with disaster losses and therefore *not* independent – an assumption that might be more plausibly maintained at smaller sub-national geographic and economic scales – their removal from loss estimates will reduce the value today of historic losses.

The process of normalisation further assumes historical records of both damage cost estimates and the corrective variables applied are accurate [27]. In the case of Australia, which has a well-recognised bureau of statistics, the recorded series of inflation, wealth and population figures are likely to be robust. As we discuss in Section 3 below, the damage cost estimates used as the basis for normalisation show considerable variation depending on the sources used.

## 4. Comparison of aggregate analyses and cost databases

The economic loss of weather related disasters in Australia was evaluated from four domestic reports – Bureau of Transport Economics [5]; Handmer, et al. [26]; Blong [28] and Crompton [25]. As a comparison from an international perspective, we selected a fifth report by Guha-Sapir, et al. [1]. This provides a long-term analysis of economic and human losses for Australia, and is one of the few international reports that has disaggregated information for countries. Other databases, such as Munich Re, must be purchased for specific purposes and therefore cannot be compared in this context. Each report, along with its data sources and conclusions, are discussed below. This is followed by a comparative discussion. To make comparisons clearer between each of the estimates, in our discussion data are further adjusted to 2013 dollars using the Reserve Bank of Australia (RBA) [29] inflation calculator.

The reports differ in ways too significant to allow for their results to be directly measured against each other at the level of individual events. However, a cautious comparison highlights the way in which data and methodology can influence conclusions drawn. We find that one of the most significant factors influencing conclusions is the cost categories captured in the data used in the various analyses. As described below, insurance industry data – which accounts for a subset of direct costs only - underlies several of the analyses. We emphasize that all models are abstractions by definition; in loss assessment the model chosen will generally reflect the precise purpose of the exercise (e.g. use by insurers, vs trend analysis for changes in hazards vs analysis of national economic impacts) and data availability.

### *4.1. Crompton 2011 – Normalising the Insurance Council of Australia Natural Disaster Event List: 1967–2011*

Using ICA data for events from 1966 to 2011 in Australia, this study normalises the losses to estimate what they would be under 2011 conditions. The normalisation procedure controls for changes in number and value of dwellings, as well as building regulations. However, the study is limited by relying on household insurance data, as hazards that are not covered by insurance, people that are not insured or are under-insured, and assets and impacts that are not covered by insurance are all omitted from loss estimates. Despite this limitation, the study finds no observable trends in disaster losses over time, once building number, value and standards have been accounted for. The report found that the average Australian annual weather-related (normalised) insured losses to be $1.22 billion (2013AUD) (and just the last 10 years $1.52 billion). Differing from the previous report by Crompton and McAneney [21], the 1999 Sydney hailstorm is now reported as the most costly disaster for insured losses (overtaking Cyclone Tracy and the Newcastle earthquake which were previously reported to have the highest insured losses). The last 10 years of the analysis (of the 45-year dataset) accounts for 25% of the overall losses, providing additional evidence that, according to their assumptions, the average annual insurance cost of disasters is not increasing over time.

#### *4.1.1. Insurance council of Australia Natural Disaster Event* List

Before being removed mid-2015, the ICA database was the most internally consistent and reliable estimate of insured losses to Australian households from natural disasters. While thresholds for inclusion into the database have changed over time, most exceed AUD $10 million (in the dollars of the day). The largest limitation of this database is that it only includes household insured losses, which represent a subset of direct and tangible costs only. Furthermore, some events, such as floods, are often not insured for in Australia, and this can have significant impacts on the analysis [5,30]. No losses from government, from industry or from life and injury are taken into consideration in this database. Therefore, it can only be considered as a limited proxy indicator of the potential total economic losses from natural disasters in Australia.

### *4.2. Bureau of Transport Economics (BTE) 2001 – Economic Costs of Natural Disasters in Australia*

BTE [5] drew its data from the Emergency Management Australia (EMA) database (now EM Knowledge Hub) and is one of the most widely cited sources for the cost of disasters in Australia. The report is now out of date and an update has been generated [26], which is discussed below. BTE adjusted their data for inflation, but not for changes in wealth or population, prior to analysis. All disasters included in the original EMA database include estimates of insured loss, 'estimated total loss' and the value of loss of life and injury were included where known.

The BTE report found that the average annual cost of disasters to Australia between 1967 and 1999 was $1.75 billion (2013AUD) (Table 1). However, this annual cost estimate was heavily influenced by three large scale disasters – Cyclone Tracy (1974), the Newcastle earthquake (1989) and the Sydney hailstorm (1999). If these three events are removed from the analysis the average annual cost declines to $1.32 billion (2013AUD). According to BTE [5], the most costly disaster type in Australia is floods (28.9%), followed by severe storms (26.2%) and cyclones (24.5%). Despite only accounting for 7.1% of the total cost of disasters in Australia, bushfires had the largest impact on human life with 223 (39.5%) deaths and over 4,000 injuries (57.4%)

**Table 1**
Summary of five reports and their key findings.

| Analysis name | Data source and analysis time frame | Key Australian findings | Distinguishing factors | Loss indicators |
|---|---|---|---|---|
| Normalised Australian insured losses from meteorological hazards: 1967–2011 – Crompton 2011 | Insurance Council of Australia Natural Disaster Event List. Meteorological disasters only. 1967–2011 | Australian average annual weather-related (normalised) damage. 1967 –2006: $1.22 billion (2013AUD) | Normalises damage estimates to 2011 conditions by adjusting for population, wealth, inflation and building standards | Insurance losses only |
| Economic Costs of Natural Disasters in Australia – BTE 2001 | EMA database (insured losses from Insurance Council of Australia, plus broader loss estimates, newspaper reports). Excludes heatwaves. 1967–1999 | Average annual cost of disasters to Australia 1967–1999: $1.75 billion (2013AUD) | Most comprehensive and frequently cited Australian analysis | Insurance loss; direct loss; human loss |
| Losses from Natural Disasters in Australia: 1967–2013 – Handmer, Ladds and Magee 2015 | AUS-DIS (losses derived from reports, journals, databases and media). Includes heatwaves and earthquakes. 1967–2013 | Average annual loss from disasters between 1967 and 2013 was $3.26 billion (2013AUD) | Dataset created from a wide array of sources and rated for their reliability – less reliant on media sources and normalises data for population and wealth | Insurance loss; direct loss; human loss |
| Natural Hazards Risk assessment: An Australian Perspective – Blong 2004 | Risk Frontiers database (scientific and government reports, other databases, BoM, Geoscience Australia newspaper reports). Meteorological hazards only. 1788–2003 | 1788 – 2003: tropical cyclones and floods account for 70%+ fatalities. 1900 –2003: tropical cyclones, floods thunderstorms and bushfires caused 93.6% of building damage | Looks at deaths and building damage, rather than dollar value economic loss estimates | Human loss and economic loss (focussed on building damages) |
| Thirty years of natural disasters 1974–2003: The numbers - Guha-Sapir, Hargitt and Hoyois (2004) | EM-DAT database (insurance, world meteorological, UN agencies, NGO's, research institutions). 1974–2003 | Australia is Among top 10 countries globally for number of disasters; top 10 for most expensive bushfire globally; annual average loss of $1.65 billion (2013AUD) | Compares disaster statistics in a global context | Economic and human loss |

from 1967 until 1999.

#### 4.2.1. EM Knowledge Hub (formerly EMA disaster database)

The EM Knowledge Hub is utilised by many researchers, and was utilised by BTE [5], because it is freely available and contains a large depository of statistics on Australian disasters. It also includes more costs than insurance data only, and it is updated regularly, with the opportunity for the public to provide submissions of additional data. Where they are known, statistics on human losses (death, injury, evacuated and homeless) and tangible losses (buildings, transport vehicles, infrastructure, crops and livestock) are included. Events are included in the database if they induced any of the following impacts: at least three deaths, at least 20 injuries or illnesses, or at least $10 million in total estimated cost of damage.

Limitations of the original database identified by BTE included a heavy reliance on insurance data and media reports - which likely resulted in small events not being recorded (as insurance data was only recorded for losses greater than $10 million) and some cost estimates being unverified [5; pg. xiv]. Estimates of total cost are calculated by using a multiplier of insurance costs. These multipliers were “provided by the ICA and are subjective impressions based on experience rather than empirical analysis” [31]. Although the multipliers vary by type of hazard, the resulting total costs are derived from insured costs exclusively, and are therefore likely conservative. Despite the fact that EM Knowledge Hub data estimates attempt to include costs other than insured losses, estimates are not based on economic principles of disaster loss assessment as described by BTE [5; Chapter 4] or Handmer, et al. [8]. Furthermore, EM Knowledge Hub does not classify heat waves as disasters, even though they often meet the death or injury or economic cost criteria outlined by the group.

### 4.3. Handmer, Ladds and Magee 2015 –Losses from natural disasters in Australia: 1967–2013 (the BTE update)

This report draws on the newly established database, AUS-DIS, prepared for the examination of economic costs of natural disasters in Australia from 1967 until 2013. This report serves as an update to the BTE [5] report with notable differences. The costing framework is similar to BTE in that the cost categories are: insured loss, estimated total loss and the value of loss of life and injury. However, the normalisation procedure, as discussed in 2.1 above, has been updated. The database also includes a reliability analysis of the data sources. While still far from being a full economic analysis, it is currently the most comprehensive and up-to-date assessment of total economic loss from disasters in Australia. The report found that the average annual costs of disasters between 1967 and 2013 was $3.26 billion (2013AUD). Similar to the BTE [5] this value is heavily influenced by large disasters occurring throughout the period, where the 10 largest events accounted for about a third of the cost. Instead of adjusting the cost by the removal of large events, the authors argue that these costs be kept in the analysis to accurately reflect the cost of disasters in Australia because of the regularity with which these very large events occur (on average, more than one every five years).

State-wide analysis reveals that Queensland ($1.01 billion annually) and New South Wales ($0.96 billion annually) make up 58.5% of the total costs of disasters in Australia. Victoria is a close third with an average annual cost of $0.74 billion and these three states account for 80.5% of the total costs of disasters in Australia. Since 2000, these three states account for 90% of disaster losses in Australia. Severe storms ($1.04 billion annually) and floods ($1.04 billion annually) are identified as the most costly types of disaster. Following this, cyclones and bushfires have relatively similar yearly costs ($608 and $554 million respectively). Differing from the BTE report, this update included the costs of heatwaves; these came to a total of $1.07 billion for the entire reporting period and accounted for 50% of all deaths recorded in the analysis. The authors suggest that the true cost of heatwaves in Australia has been significantly underestimated in previous estimates, and that emphasis needs to be placed on costing such disasters as they are expected to occur more frequently into the future [32,33].

#### 4.3.1. AUS-DIS database

This database was created with the intention of addressing some of the limitations identified by the BTE (2001) report. Where possible it includes full economic cost of natural disasters from 1967 until 2013, including direct, indirect and intangible losses. For an event to be included in the database it must have cost more than $10 million when normalised to 2013 dollars or have three or more lives lost. In addition, the database contains a reliability measure where for an event to be included a reference other than media report must be available. Events were originally sourced from EM Knowledge Hub, and then each recorded event was independently investigated and verified by a source other than media. Additional disasters that were not in EM Knowledge Hub found through this investigation were added when verified from at least two sources. Rankings were given to the quality of the information sources and disaster events were not included if they did not meet the ranking threshold. While media reports were still utilised to create the database, they were not relied upon for making disaster loss estimates.

Costs were normalised for GDP, population growth and inflation, and where total costs were not available, insurance losses were multiplied by an empirically-derived factor for each disaster type to estimate total economic cost. This factor was calculated from the averaged differences between insured and total costs, for those events where the total costs *were* available. AUS-DIS has some limitations that affect the accuracy of most disaster databases. Very few events have undergone a full economic analysis and some large events might not have been included, stemming from a lack of metadata. There are still many events without full identification and assessment of indirect and intangible losses.

### 4.4. Blong 2004 – Natural hazards risk assessment: an Australian perspective

Blong [34] utilises the Risk Frontiers database but does not enumerate the cost of disasters to Australia in dollars. This analysis is more concerned with looking at where and by which hazard building and human disaster losses occur. Instead of looking at insured loss or total loss, Blong [34] discusses impacts in terms of house equivalents (HE), which expresses the value of an average house. This approach takes all building damage and makes it equivalent to a house loss through comparisons of floor areas and per m$^2$ constructions costs. This alternative approach leads to different conclusions which highlight some salient points about the complexities of disaster impact assessment.

Blong's [34] national assessment found that across Australia between 1788 and 2003, tropical cyclones and floods account for more than 70% of fatalities. Since 1900, building damage could almost be entirely accounted for by meteorological hazards (floods, cyclones, bushfires, storms), as opposed to geological (earthquakes). Heatwave deaths are not included in the analysis, despite a recent report from Risk Frontiers reporting that it is responsible for more deaths than all other natural hazards combined from 1844 to 2010 [32]. Between 1900 and 2003 it was found that tropical cyclones alone accounted for one third of building damage.

#### 4.4.1. Risk Frontiers database

The Risk Frontiers database spans the longest time scale of any Australian disaster database, from 1788 to now. It is the most comprehensive for fatalities and damage to buildings. With more than 20-person years of data collection, the database is built from a range of sources of information regarding the loss of life and property from Australian disasters. Unfortunately, it is not available to the public and the authors are unable to locate any comprehensive disaster cost estimates derived from the database.

The database has several limitations, highlighted by Risk Frontiers. These include a partial reliance on newspaper reports, underestimation of building damage and incomplete records – particularly for earlier disasters. The building damage index developed for the database, which also reduces building damage to housing equivalents (HE), is novel and the conclusions drawn are illuminating, particularly when compared with more traditional measures of loss from disasters. However, the focus on structural assets means that many of the cost items outlined above (Section 2) would not be included in the analysis.

### 4.5. Guha-Sapir, Hargitt and Hoyois (2004) – Thirty years of natural disasters 1974–2003: the numbers

This report summarises the impacts of disasters globally over 30 years including all natural disasters (earthquake, extreme temperature, storms, floods, landslides, drought and bushfires) with a focus on human losses, but also includes economic losses. It is one of few international reports that provides disaggregated information for countries. It aims to highlight regions that are most vulnerable to disasters, calculated as total economic cost and cost as a proportion of GDP, as well as reporting number of deaths and people affected. The report does not explain how total losses were calculated, only that they were "adjusted" to US 2003 dollars. Australia ranks highly in frequency of disaster along with Mexico, the US, India, China and parts of South-East Asia (Indonesia, Philippines and Bangladesh). Australia also has some of the most expensive bushfires, ranking in the top 10 of total cost of bushfires globally. The total number of natural disasters for Australia reported for the time period investigated was 158 (which included 36 drought events) and only 110 had economic damages reported. The average annual economic reported losses for Australia were $1.65 billion (2013AUD). The total number of people killed and affected by natural disasters was 15,812,396 (including 7,080,000 affected by drought).

#### 4.5.1. EM-DAT disaster database

The freely available EM-DAT disaster database is the most frequently referenced international database. EM-DAT forms the basis of the Global Assessment Reports (GAR) for the UNISDR [35], and is used for most global reports on natural disaster trends. It contains records of economic and human losses from global disasters from 1900 and is updated daily. The thresholds for inclusion in the database are that an event must have caused any of the following: 10 deaths, 100 people to be affected, a state of emergency to be declared, or a call for national assistance to be made. Sources of information are varied and include (but are not limited to) UN agencies, NGO research institutions, insurance agencies, and the press. EM-DAT relies heavily on national reporting, and as such the quality of the data varies considerably depending upon national and institutional data collection approaches.

### 4.6. Disaster cost reports summary

Table 1 summarises the reports and their key findings. Each data source used by the respective reports generate estimates with a variety of strengths and weaknesses. The EM Knowledge Hub used by BTE [5] is widely used, freely available and includes more than insured costs; but suffers from acknowledged limitations. The AUS-DIS database employed by Handmer, et al. [26] builds upon these strengths, and seeks to overcome many of these limitations. However, it has only recently been published, and has not been widely used or reviewed. The Risk Frontiers database used by Blong [34] is the longest running and most comprehensive dataset, but it is not freely available. The ICA event list used by Crompton is the most reliable record of insured losses and is likely the most standardized, but does not include non-insured losses. Finally, the EM-DAT database used by Guha-Sapir, et al. [1] is international and actively maintained, with normalised loss estimates, but lacks the detail included in the AUS-DIS and Risk Frontiers databases. We consider these differences in more detail in Section 5 below.

## 5. Discussion of aggregate loss estimates

Before losses from the studies are compared, it is critical to note that simply due to the way that the data was collected, several differences exist. Three of the reports discussed here [5,25,26] refer to an average annual cost of weather related events in Australia all beginning in 1967. The year 1967 was chosen by all studies as it is when disaster loss recording in Australia was made a priority and the ICA database began recording historical data losses. All the reports provide a time series analysis of losses in Australia from disasters. BTE [5] and Handmer, et al. [26] further the discussion to analysis of losses by state and disaster type. They also provide an analysis of human loss. Blong [28] is unable to be compared in this context as there are no economic cost estimates in the report. Comparisons with the Blong report in this paper are limited to disaster location, type and fatalities (Sections 5.3–5.5).

### 5.1. Number of disasters

The decisions that are made about which data to include in a database or report automatically affect the number of disasters that are included in the respective study. Knowing the number of disasters that have occurred (particularly ones that have significant costs) has implications for trends over time. If the number of disasters occurrences cannot be agreed upon, then there is very little chance that any resulting trend analysis across all sources can be reliable. Fig. 1 demonstrates just how significant these differences can be.

For three of the four decades that the BTE [5] covered, it reports more disasters than any other database. AUS-DIS recorded higher numbers of disasters than other sources (except BTE [5]) in most decades, while EM-DAT [36] consistently had the fewest disasters recorded. The difference in the numbers is likely due to the aims of the databases and criteria for inclusion [12]. AUS-DIS and EM Knowledge Hub focus on economic damages, seeking to identify every disaster that occurred in Australia since 1967 that resulted in more than $10 million in damages. EM-DAT is more concerned with human losses, aiming to identify disasters that cause loss of life or displacement of people. AUS-DIS has more disasters reported than the current day EM Knowledge Hub, in part because the EM Knowledge Hub has had a series of reductions in the number of disasters it includes online, including the removal of some historical entries [37].

BTE utilised EM Knowledge Hub before disasters had begun to be removed. However, this still does not explain why they have more disasters recorded than any other database. It is likely that the BTE recorded events that occurred in multiple states as an event for each of those states, effectively counting each cross-state event twice for Australia, making state figures correct but overestimating national figures. In contrast AUS-DIS instead counted single events and gave a proportion of the total cost to each state that was affected. This means that the number of disasters that occur in each state is likely to be underestimated by AUS-DIS, though the economic loss from that disaster is accounted for.

The significantly fewer number of disasters reported by ICA in comparison to EM Knowledge Hub and AUS-DIS may be attributed to the fact that it focuses on insured disasters only, and many disasters in Australia are underinsured or not insured at all. Even when reports of insurance payments do exist, they rarely approach the full costs of disasters to a community [2,31,38]. Consequently, when examining trends of disasters over time, it is unlikely that these types of databases will give a realistic view of frequency or severity of disaster impacts.

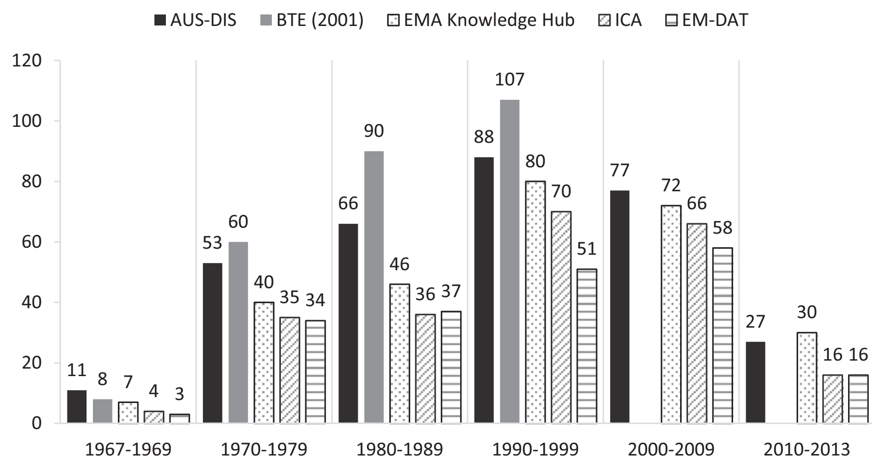


**Fig. 1.** Comparison of number of disasters in the databases of AUS-DIS, the BTE report and its source EMA Knowledge Hub (counts are from July 2013), ICA and EM-DAT.

All of the studies list limitations with data collection, and no database claims to have captured every disaster that meets their inclusion criteria. The range of estimates observed here is not unique to Australian disasters. In an analysis of five countries disaster events, La-Red and OSSO [39] demonstrated that the likelihood of an event occurring in EM-DAT that was recorded in DesInventar (a semi-global disasters database) was a little above chance (58% overlap), while the converse was true only 6% of the time.

This reflects a common problem that occurs in national and international databases and furthers the call for streamlining of disaster recording globally in order to make them comparable [12]. While the number of disasters recorded for Australia had significantly more overlap that the La Red and OSSO analysis, across the studies investigated, there were still discrepancies from the studies as to whether the frequency of disasters is increasing. BTE [5], with Handmer et al., [26] concluded that there was an increasing trend in the number of natural disasters per year over time. *Monetary loss estimates.*

The average annual total cost of natural disasters (without including monetary estimates for deaths and injuries) from BTE [5] is $1.75 billion and from Handmer, et al. [26] it is more than double at $3.65 billion. The Guha-Sapir, et al. [1] reported value lies between these values at $2.10 billion which includes an average of $0.64 billion in losses from drought (removing drought results in a total loss of $1.46 billion). Handmer, et al. [26] and Crompton [25] concluded that there was no obvious trend in disaster losses over the recorded periods of both databases once costs had been normalised. This same result has been found by studies internationally where comparing databases at a national level produces similar trends, but at a regional level discrepancies become larger and may not be useful for estimates at that level [40–42]. The differences in these values stem from a number of sources. The initial discrepancy is outlines in the previous section – number of disasters included in the economic analysis.

Second, the source of information for the values used for the estimate vary between reports [43]. A primary source of costs for all reports is the ICA, which, as discussed below, significantly underestimates the total economic cost of disasters in Australia. Following this the strategy for collecting estimates differs significantly between the reports. BTE's data source – EMA – relied heavily on media reports for loss estimates. Media reports have both reliability and validity issues as the estimates reported are often during or immediately following the disaster [44]. At this point in time the full cost of the disaster cannot be known, and the media often exaggerate the reported losses from the event [44]. Handmer, et al. [26] try to validate their information sources, only including disasters that could be verified by two independent sources. However, this built inconsistency into the estimates, as some sources were full economic analyses of disasters, while others were from media and reports. Guha-Sapir, et al. [1] primary sources of information have changed over the 30 years of statistics reported. While humanitarian and disaster agencies were the primary source of information in the 1970's and 80's, insurance companies reported more disasters in the 1990's, and more recently specialised agencies have become the primary source of information. Each of these organisations have different objectives for collecting disaster loss information, therefore, are likely to have different estimates for different disasters. This highlights the difficulty in establishing internal consistency due to the varying sources of information [45].

In preparing the BTE [5] and Handmer et al. [26] reports, some of the disasters recorded only had insurance data available therefore the authors sought to estimate the full economic costs using a multiplier. This was another source of difference between these two reports as the BTE multiplier was based on estimates from Joy [31], while Handmer et al., [26] attempted to empirically derive the multipliers for each disaster type from disasters with known insurance and reported costs available. These two different approaches resulted in very different multipliers for each of the disaster types, thus very different reported losses. This approach is limited as the likelihood that the multiplier captures the true economic loss of an event is small.

Looking at insured losses only, Crompton [25] annual loss estimate converts to $1.22 billion and for Handmer, et al. [26] is $1.34 billion. BTE's [5] estimate was one-third of the other reports at $439 million which can be explained from their method only partially normalising the data - they adjust for inflation only, ignoring the very significant influence of Australia's population and real GDP growth over this period. The difference between Crompton [25] and Handmer, et al. [26] estimates is the normalisation procedure used. Crompton [25] normalises for the size, location and number of new dwellings in an area and for population and GDP. Handmer, et al. [26] is normalised with respect to CPI, population growth and real GDP growth. Despite these difference the overall yearly estimates differ by only $12 million, a relatively small amount with respect to disaster losses – and likely well within the uncertainties surrounding these estimates. A more significant problem of reported insurance losses in Australia is that they focus solely on residential losses. Therefore, these estimates fail to account for government and industry losses which can be significant.

It is also often desirable to include monetary valuation of death and injury in disaster cost estimates. In Australia, normal practice is increasingly to utilise statistical value of life figures provided by the Office of Best Practice Regulation [46]. Loss estimates from BTE [5] with monetary valuation of death (where BTE used a Human Capital approach) and injury included increases to $2.72 billion (2013AUD) per year, while Handmer, et al. [26] value increases to $3.98 billion (2013AUD). Averaging this across the years means that when fatalities

**Table 2**
Comparison of top ten loss events as reported by different metrics of three reports. Shown are the ten highest ranked normalised insured losses (2013AUD million) from Crompton and Handmer et al. [rank for normalised losses] and ten highest ranked normalised total losses (2013AUD million) from Handmer et al. and ten highest ranked house equivalents losses from Blong. Reported insured losses for Crompton and reported total losses for Handmer et al. are in dollars of the day.

| Report | Handmer, Ladds and Magee (1967–2013) | | | | | Crompton (1967–2013) | | | | Blong (1967–2003) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Event | Year | Reported total loss | Normalised insured loss | Normalised total loss | Event | Year | Reported insured loss | Normalised insured loss | Event | Year |
| 1 | Tropical Cyclone Tracy | 1974 | 1,504 | 11,460 [1] | 16,396 | Sydney Hailstorm | 1999 | 1,700 | 4,479 | Tropical Cyclone Tracy | 1974 |
| 2 | Melbourne Severe Storm | 2011 | 7,725 | 7,722 [2] | 15,446 | Tropical Cyclone Tracy | 1974 | 200 | 4,264 | Ash Wednesday Bushfire | 1983 |
| 3 | Queensland Flood | 2010/ 2011 | 6,218 | 7,552 [3] | 14,038 | Newcastle Earthquake | 1989 | 862 | 3,378 | Sydney Hailstorm | 1999 |
| 4 | Sydney Hailstorm | 1999 | 2,300 | 6,444 [6] | 12,082 | Brisbane Flood | 1974 | 68 | 2,645 | Newcastle Earthquake | 1989 |
| 5 | Black Saturday Bushfire | 2009 | 4,836 | 6,565 [5] | 11,847 | Queensland Flood | 2010/ 2011 | 2,400 | 2,758 | Katherine Flood | 1998 |
| 6 | Ash Wednesday Bushfire | 1983 | 1,480 | 7,176 [4] | 11,223 | Brisbane Hailstorm | 1985 | 180 | 2,151 | Black Tuesday Bushfires | 1967 |
| 7 | Brisbane Flood | 1974 | 1,355 | 5,676 [7] | 10,162 | Ash Wednesday Bushfire | 1983 | 176 | 1,872 | Brisbane Flood | 1974 |
| 8 | Newcastle Earthquake | 1989 | 2,016 | 4,214 [9] | 8,425 | New South Wales Severe Storm | 2007 | 1,480 | 1,816 | Victoria Flood | 1993 |
| 9 | Tropical Cyclone Yasi | 2011 | 3,927 | 4,098 [10] | 8,197 | Tropical Cyclone Madge | 1973 | 30 | 1,556 | Cyclone Althea | 1971 |
| 10 | Canberra Bushfire | 2003 | 2,324 | 3,373 [12] | 6,747 | Tropical Cyclone Yasi | 2011 | 1,300 | 1,410 | Canberra Bushfires | 2003 |

are included disasters cost and additional $0.97 and $0.33 billion respectively each year. The major differences in the values discussed stem from the original data used to create the values, as well as whether the data is partially or fully normalised. These vastly different estimates highlight just how much data methodology and sources influence loss estimates.

### 5.2. The most expensive disasters

Table 2 shows the most damaging events for normalised insured losses from Crompton (2011), total normalised losses (insured and reported) from Handmer, et al. [26] and House Equivalent (HE) losses from Blong (2004). The most expensive disasters that appear in all lists occurring before 2004 are: Cyclone Tracy (1974), the Sydney hailstorm (1999), Newcastle earthquake (1989), Queensland floods (1974), and the Ash Wednesday bushfires (1983; discussed in detail in Section 6). These disasters are well known within the Australian community for the severe damages they caused, but the magnitude of cost to the community differs with different methods of analysis and restrictions on inclusion.

Some disasters are so large they may be identified as outliers [5]. Within Australia, each of the past four decades is represented by between one and four or five large scale, economically costly disasters. While Handmer, et al. [26] show no obvious trend in disaster loss over the 1967–2013 period, they do indicate that the number of large disasters may be increasing, and that there appears to be more disasters occurring in the last decade. This may be an artefact of the better reporting of some types of disaster losses and improved knowledge of what is to be included when calculating total loss. For example, the Black Saturday bushfire was costed through a report that investigated all losses from micro- to macro-level with a high degree of precision, and that included intangible and indirect loss [20]. These inclusions are likely to increase the overall cost of a disaster, and thus its overall ranking in the list of most expensive disasters. By comparison, earlier disasters that lack this level of comprehensive analysis are likely to appear less costly.

### 5.3. Disaster type

When looking at types of disasters that have had the most impacts, the source of the data plays a significant role. A comparison of values that do not include monetary estimates of death and injury finds that every data set examined had a different ordering of the top three most costly disaster types (Table 3). Although across the five datasets there is agreement of which disaster types are in the top three: severe storms, floods and tropical cyclones. Looking at insurance data alone, severe storms are most costly, likely due both to the number of events that occur and their impact on dense residential areas and automobiles. This is in agreement with total economic losses estimated by Handmer, et al. [26]. Tropical cyclones come in second from insurance costs, followed by floods. Floods have not been uniformly insured in Australia, therefore are likely under-represented in the analysis [30,47]. BTE [5] list floods as the most expensive disaster in Australia, while floods come in second for total economic costs from Handmer, et al. [26], and third from house damages as assessed with the HE analysis [34].

While there is little agreement in the order of most expensive disaster types, four of the five databases list (in order) bushfires, earthquakes and landslides as the least expensive disasters in Australia over the time period. Major landslides are rare in Australia, and are usually included in the databases due to loss of life rather than economic losses. The economic cost of earthquakes predominantly comes through via a single event, the 1999 Newcastle earthquake. Earthquakes since have not occurred near population centres. Despite some incredibly large losses to bushfires in the last decade (i.e. Black Saturday), bushfires remain the fourth most expensive disaster type

**Table 3**
Percentage of loss from different hazards (excluding heatwaves) by database.

| Database | EMA | AUS-DIS | | PerilAus | ICA | | EM-DAT | |
|---|---|---|---|---|---|---|---|---|
| **Event type** | 1967–1999 | 1967–1999 | 1967–2013 | 1788–2003 | 1967–1999 | 1967–2013 | 1967–1999 | 1974–2003 |
| **Severe storm** | 26% | 28% | 31% | 23% | 43% | 43% | 12% | 28% |
| **Flood** | 29% | 28% | 27% | 21% | 27% | 14% | 36% | 21% |
| **Tropical cyclone** | 24% | 23% | 21% | 30% | 14% | 27% | 36% | 28% |
| **Bushfire** | 8% | 16% | 19% | 19% | 10% | 10% | 7% | 9% |
| **Earthquake** | 13% | 5% | 3% | 6% | 6% | 6% | 10% | 3% |
| **Landslide** | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% |

across all databases.

### 5.4. Fatalities

Over 50% of deaths between 1967 and 2013 were caused by heatwaves, according to Handmer, et al. [26]. The only other database that included heatwaves in their analysis was EM-DAT, which estimated worldwide heatwave fatalities at 4% of total deaths from disasters, though this was not reported in the associated publication. In a separate analysis from Risk Frontiers (not included in Blong [34]), it was found that there were 4,555 deaths from heatwaves between 1900 and 2011 – more than from the total combined deaths from all other hazards [32]. The large discrepancies in the numbers likely extend from definition of a heat wave, a previous lack of understanding of how a heatwave causes death [32], and the underreporting of heatwave deaths because of difficulties in attribution. Despite their impact, none of the other reports include heatwaves in their analysis, and we have therefore excluded them from further comparison. This is a severe limitation of all the databases apart from AUS-DIS.

BTE [5] and Handmer, et al. [26] identify bushfires as the most hazardous disaster type to human life (after heatwaves), accounting for 39% and 47% of natural disaster fatalities in Australia respectively (Fig. 2). In comparison, Blong [34; pg. 6] found that bushfires account for only 12% of Australian fatalities due to natural hazards between 1788 and 2003, which corresponds to Guha-Sapir, et al. [1] estimate of 19% of deaths were from bushfires between 1974 and 2003. The reasons for this striking difference could be related to the different time periods analysed; as Blong [34] points out, death rates from all natural hazards have been steadily declining since the late 1700 s, possibly due to better disaster management, and this could impact the results. Conversely there were high death tolls in the 2000 s not covered by Blong [34] or Guha-Sapir, et al. [1], primarily due to bushfires, and in particular the Victorian bushfires of February 2009 (Black Saturday). This does not affect the ordering of which disasters are most deadly, but instead impacts the proportion of lives lost to bushfires in comparison to tropical cyclones. Before the extraordinary toll of bushfires took hold, floods and tropical cyclones accounted for the largest loss of life, when heatwaves are excluded.

### 5.5. Where do disasters occur?

Understanding where disasters occur is complicated and depends on what metric is used to measure their impact. When considering exclusively the number of disasters, the different databases are in agreement of where the most disasters occur across Australian states (see Fig. 3). The total costs of disasters across states tend to agree as well, with New South Wales and Queensland bearing their brunt. However, when looking at house equivalent damage estimates as in Blong [34], then the Northern Territory becomes the most hazardous state on a per capital basis, and when evaluated by land mass, the Australian Capital Territory is the most hazardous. When the 2000 decade is included in the total costs of disasters, Victoria overtakes the Northern Territory [26]. As expected, the more southern states are more affected by severe storms and bushfires, while the northern states are more affected by tropical cyclones.

## 6. Individual event loss assessment

The 1983 Ash Wednesday bushfires resulted in one of the most devastating disasters in Australia's history. Below we compare six assessments of this event, looking at loss (and in some cases net impact) estimates. Three estimates come from the ICA database [13], EM Knowledge Hub [14] and the BTE report [5], which are discussed above. While not contained within the larger datasets, a further three estimates of the impact of the Ash Wednesday bushfires are included to enrich the comparison. The comparison highlights how data and methodology can lead to profoundly different estimates of the loss associated with the same event. The six estimates are as follows.

1. The ICA database estimates losses, in both Victoria and South Australia, from the Ash Wednesday bushfires. This estimate represents insured losses only.
2. A Legislative Assembly Ministerial Statement [48] estimate has been cited numerous times. This estimate relates only to State agency asset loss, other public sector losses, lost assets to the private sector (majority of the total) and State agency operating costs.
3. Stephenson [19] utilizes several economic assessment frameworks to estimate net losses to Victoria. This estimate should be considered differently to the others because it includes monetized benefits as well as costs (hence it is net, not gross loss), across a full suite of economic, social and environmental impacts. The estimate includes ecosystem service loss as well as agricultural business interruption, which are significant but rarely included in assessments. Importantly, and according to the economic theory applied, payments by government, donations and insurance are counted as economic benefits of the fires.
4. Munich Re [49] presents both insured losses (taken directly from the ICA), as well as overall losses for Victoria and South Australia. Insured losses account for 52% of overall losses, however what is included in overall losses that is not included in insured losses is not reported.
5. The EM Knowledge Hub [14] estimate includes an insured losses figure (which differs from ICA estimate), as well as a 'total estimated cost' figure. It is unclear where this higher figure came from, although we speculate it may have been from media reporting.
6. BTE [5] applied the principles espoused in their report to the Ash Wednesday 1983 bushfires to conduct an economic analysis of the impact of the fires. While acknowledging data limitations, the estimate includes both direct and indirect costs, and monetized loss estimates from injuries and fatalities. Similar to Stephenson [19], this BTE [5] analysis should be understood differently from the other estimates because it is an attempt at an analysis from the perspective of the whole economy.

Table 4 summaries the Ash Wednesday loss/impact estimates, converted to 2013 Australian dollars.

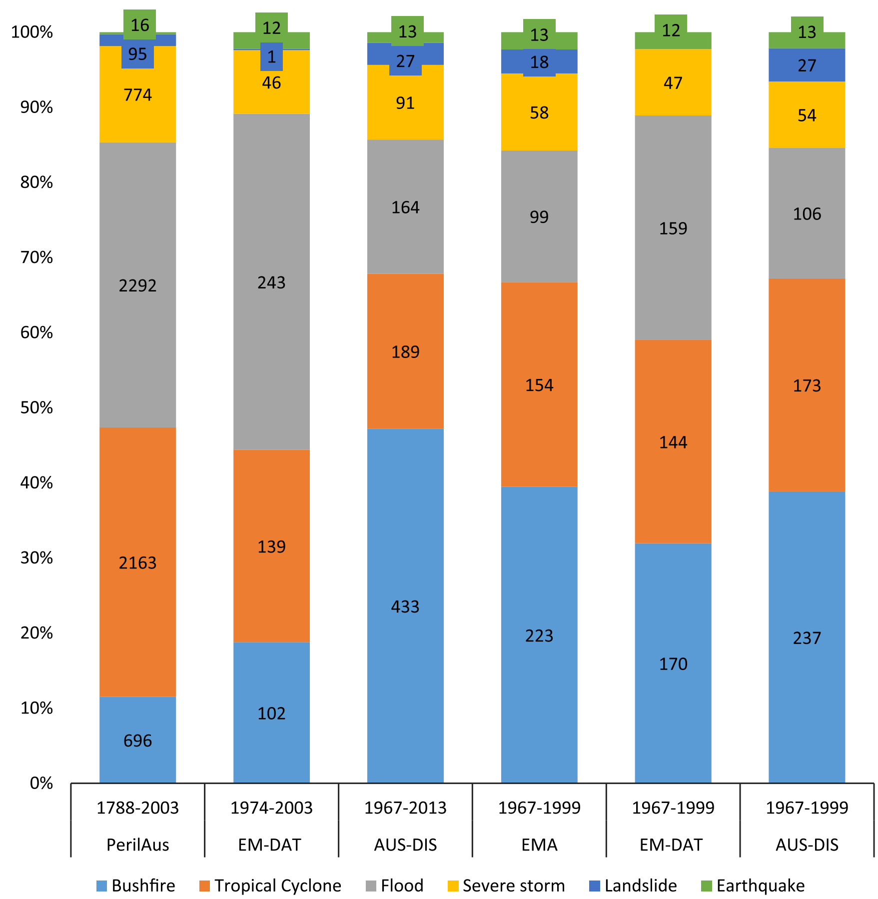


**Fig. 2.** Comparison of total fatalities (excluding heatwaves) reported by each of the databases.

The estimates of the cost of the Ash Wednesday bushfires listed above range from $556 - $1,872 million (2013AUD). This variation is due to the data sources and methodologies used to determine cost estimates. We see that insurance data is a conservative estimate of some losses: the estimate of insured losses from the ICA database is the small estimate, likely because insured losses represent only a fraction of overall losses. Full economic impact assessments – such as Stephenson (2010) and BTE (2001) result in much higher estimates. Yet even these analyses lack many potential loss items, likely due to lack of available data.

The Legislative Assembly Ministerial Statement estimate is lost assets to the private sector – we presume this was taken from the ICA – with the addition of some State government losses and disaster-related expenditures. Similarly, Munich Re augments the ICA estimate, however their process or estimate sources are unclear. BTE reports to have also augmented the ICA estimate, however their reported insured

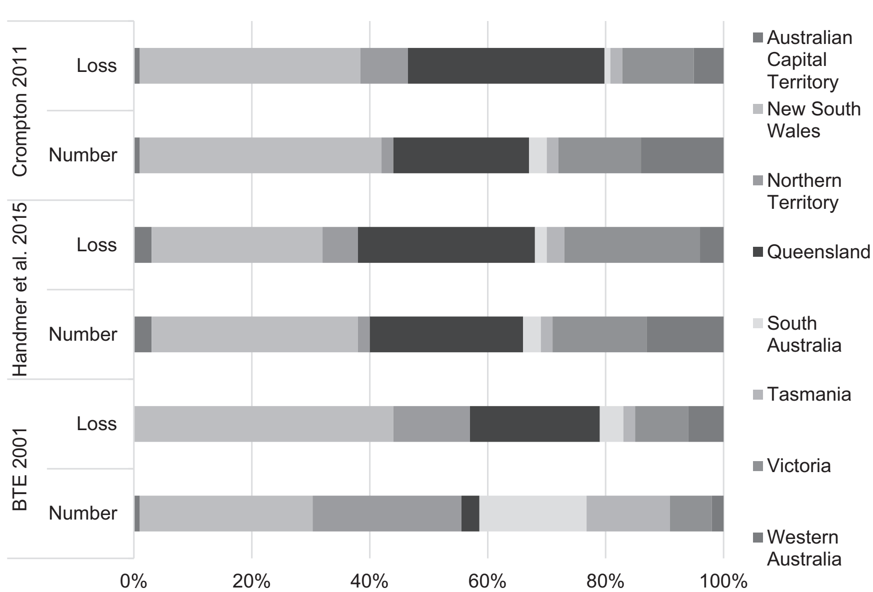


**Fig. 3.** Percentage loss and percentage number of disasters attributed to each state by report.

**Table 4**
Six reported estimates of the cost of the 1983 Ash Wednesday bushfires converted to $2013AUD*.

| Source and coverage | Cost estimate (2013AUD) | Loss categories included in estimate |
|---|---|---|
| ICA database [13] (VIC & SA) | $1,872,435,155 | ICA database. Insurance claims only – direct property damage costs. Original insurance loss reported at $A176 million in 1983. |
| Legislative Assembly Ministerial Statement [48] [cited in VBRC [50] Appendix C] (VIC only) | $556,294,201 | State agency asset loss, other public sector losses, lost assets to the private sector (majority of the estimate) and State agency operating costs. |
| Stephenson [19] (VIC only) | $900,196,185 (net) | Economic analysis from various sources. Contains direct, indirect and intangible, as well as losses and benefits – insurance is a benefit. |
| Munich Re [49] (VIC & SA) | $980,834,512 | Insured losses estimate from ICA (52% of total), which is multiplied or augmented to give an 'overall' loss estimate. Original loss reported at $A335 million in 1983. |
| EM Knowledge Hub database [14] (VIC & SA) | $1,474,789,916 | Insured losses estimate (different to ICA), augmented with media reports to estimate a 'total economic' loss. |
| BTE [5; pg. 109] (VIC & SA) | $1,462,689,075 | Economic analysis from various sources. Includes some indirect and intangible costs including fatalities. |

* Values are adjusted for inflation only using http://www.rba.gov.au/calculator/ and are not normalised in any other way, therefore these are crude estimates for comparison only.

losses is not consistent with ICA; BTE's sources for the wider estimate is also unclear but may include media reports.

## 7. Conclusions

The breadth of estimates on the costs of disasters to Australia presented here are wide. This stems from ongoing limitations of economic estimates of disaster costs both in Australia and globally. It has frequently been noted that this type of data suffers from a lack of availability or reporting; poor data quality of what *is* reported; temporal and geographical limitations; lack of regularity of updating and maintenance; and little or no reliability analysis [51]. As a result, insurance data is often used as a proxy for estimating costs despite it representing only a portion of total losses. Further, when estimates are made, using either insurance data, total loss data or both, some form of normalisation is generally used to make the loss estimates comparable over time, and the methods used have considerable impact on the final loss estimate. This last point is demonstrated in this review, as each report utilises different data and normalisation methods, and accordingly comes to different conclusions.

The reports reviewed here could not even agree on the number of fatalities that had occurred when looking at the same time period and disaster types. The same conclusion was reached when looking at numbers of disasters. Insured losses and total losses were very different as expected, however when using these for trend analysis Handmer, et al. [26] and Crompton [25] came to the same conclusion: that disaster costs were not increasing over time, while Handmer, et al. [26] and BTE [5] report that the number of disasters tend to be increasing over time. The reports were aligned in regards to the most expensive disasters. Unsurprisingly, the most frequently cited disasters also appeared often in the top 10 most damaging disasters, despite their being measured on different scales as per the different aims of the reports. Cyclone Tracy (1974), Ash Wednesday bushfire (1983), Newcastle earthquake (1989), Sydney hailstorm (1999) and the Brisbane flood (1974) appeared in all three reports' list of top 10 mostly costly disasters. The reports were also aligned in regards to where disasters occurred. New South Wales and Queensland had the highest costs and number of disasters of Australian states.

Projecting into the medium-term, recent estimates from insurance data by Deloitte Access Economics [3] put the total annual insured costs of disasters in 2050 at $23 billion. Their follow-up report showed that when also incorporating social losses this estimate is inflated dramatically to $33 billion a year. The magnitudes of the relative impacts of these factors on the final estimate numbers and their relative size are not known. However, they do highlight important points about how the differing data sources and methodologies may impact the outcome.

Currently in Australia there are no clear estimates on the total amount spent on disaster risk reduction. A recent enquiry by the Australian Productivity Commission called for an additional $200 million to be spent annually on disaster mitigation [52]. A group of businesses, including the insurance sector, have supported this most recently in early 2017 [53]. Late last year the Australian Prime Minister (3 Oct 2016), stated that:

"...we have not spent enough money in Australia on disaster mitigation," he said on Monday. "We need to spend more in advance so that we have to spend less after the rainfall events or the bushfire events that occur so it's important to invest in mitigation, in advance" [54].

We expect to see increased focus on this area.

Despite the variety in cost estimates, the case for continued and expanded investment in disaster risk reduction is firmly established by all approaches. With increasing wealth, population and density, improvements in disaster risk reduction are a "no-regrets" policy option for Australia, because they are economically warranted regardless of whether climate change is acknowledged as increasing the cost of disasters or not [47,55]. In an era when climate change is understood to play a greater role in the prevalence and severity of natural disasters, such cost estimates can be seen as a conservative "first pass" at establishing a small part of the wider cost. Key essential improvements are the inclusion of heatwaves, and the identification, inclusion and valuation of indirect and intangible losses.

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