

The Socio-Economic Impact of Historic Australian Earthquakes

James E. Daniell^{1,2,3}, David Love⁴

¹General Sir John Monash Scholar, The General Sir John Monash Foundation, Level 5, 30 Collins Street, Melbourne, Victoria, Australia 3000.

²Researcher, Center for Disaster Management and Risk Reduction Technology, Hertzstrasse 16a, Karlsruhe, Germany, 76187.

³PhD Student, Geophysical Institute, Karlsruhe Institute of Technology, Hertzstrasse 16a, Karlsruhe, Germany, 76187.

⁴Primary Industries and Resources South Australia, Adelaide, Australia.

Emails: j.e.daniell@gmail.com, david.love@sa.gov.au

Abstract

By using the CATDAT Damaging Earthquakes database, the socio-economic damage data collected for historic Australian earthquakes and rockbursts are presented. Although the total Australian statistics, just under \$6 billion AUD (2010 HNDECI adjusted dollars) and 16 earthquake deaths and 5 rockburst deaths, are dominated by the 1989 Newcastle Earthquake, many other historic earthquakes have recorded significant losses to regional finance and infrastructure and a repeat earthquake could cause significant damage with the now increased exposure.

The effects of over 90 damaging earthquakes have been recorded in Australia since the beginning of its European history. Given the small return period of European Australian history, there exists a large gap in the historical damaging earthquake record compared to some other parts of the world.

Comparatively, on a global scale, Australia has had very few social losses as a result of earthquakes. Only 6 fatal earthquakes and rock-bursts have been recorded on Australian soil; however, 10 more have caused casualties.

This complete list of Australian damaging earthquake socio-economic losses in CATDAT, sourced from many locations, includes estimates, trends and figures of these earthquakes based on historical Australian building type, economy and social data. Details as to damaging earthquake secondary effects are also presented.

This data should help to standardise the differences seen in literature in values of historic Australian damaging earthquakes and will also aid earthquake loss estimation damage-loss conversion ratios.

Keywords: CATDAT, socio-economic analysis, damaging earthquake, Australian earthquakes, Newcastle 1989.

NOTE:-The concepts in this paper are to be submitted to a journal.

Introduction

For earthquake loss estimation analysis, it is important to know the historical socio-economic effects of earthquakes. Changing conditions in the economy, social or environmental status can significantly change the future effects of earthquakes on the population.

The data used in this paper is sourced from the newly built worldwide CATDAT damaging earthquakes and secondary effects (tsunami, fire, landslides, liquefaction and fault rupture) database (Daniell, 2010b). This was developed to validate, remove discrepancies and expand greatly upon existing global earthquake databases; and to better understand the trends in vulnerability, exposure and possible future impacts of historic earthquakes. It presents a significantly increased database on any available global historic earthquake database.

Over 14500 sources of information from around the world have been primarily utilised over the last few years to present data from over 11600 damaging earthquakes in total, of which over 6500 earthquakes since 1900 have been examined and validated before insertion into the database. Each validated earthquake in the database includes seismological information, secondary effects (social, economic and type), building damage (levels, important infrastructure etc.), ranges of social losses to account for varying sources (deaths, injuries, homeless and affected) and ranges of economic losses (direct, indirect, aid contribution and insurance details). The trends and data are then integrated into a global real-time earthquake economic loss estimation program named EQLIPSE (Daniell 2009b).

The Australian component of the CATDAT damaging earthquakes database has been included in this paper in an attempt to standardise existing databases, and to aid the Australian community in knowledge of historic earthquakes. A number of economic and social estimates have been made to fill in the gaps in knowledge, using literature sources. It must be noted that 85 earthquakes are a small number in the scheme of the 246 nations and 11600 earthquakes in the CATDAT damaging earthquakes database. It was seen that the Coates (1996) study of Australian floods and the additional study of Daniell et al. (2010a) for the CATDAT Floods database into Asia-Pacific region, using historical estimates for social losses, showed that floods pose a significantly greater threat; however, given the 1989 Newcastle Earthquake, the economic estimates from these two disaster types are reasonably similar for Australia. In Figure 1, Australia is shown in the context of the Asia-Pacific region for earthquake versus flood impact. The theory shows that every country is different in terms of flood or earthquake domination, and due to the long return period of earthquakes in some regions, this diagram will shift given a big event.

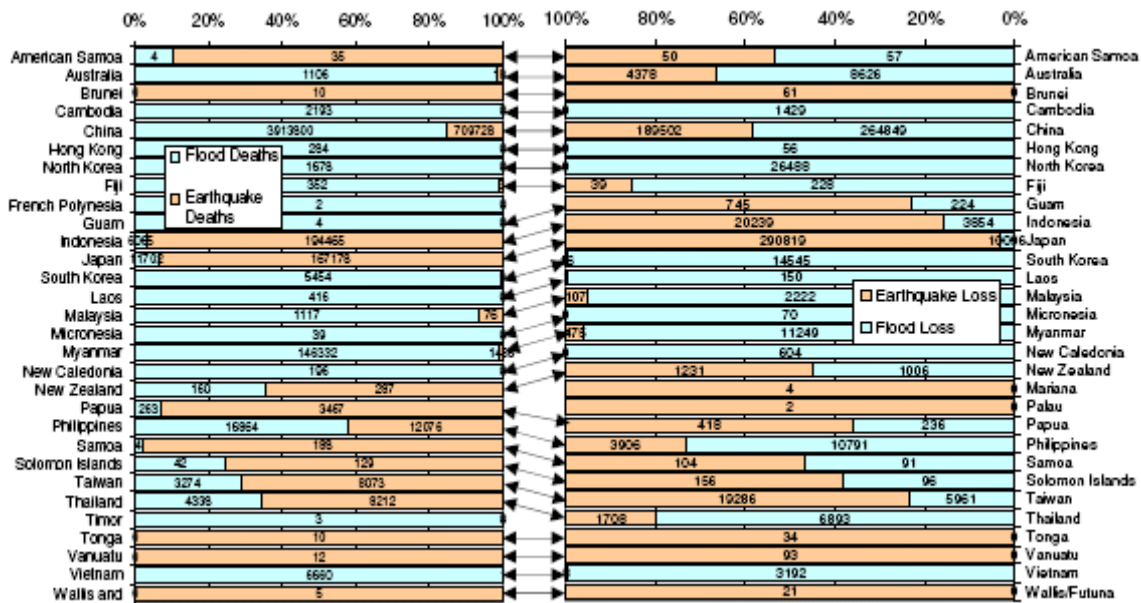


Figure 1 – Relative Flood and Earthquake event deaths (total) (left) and economic losses (in 2010 million USD inflation adjusted) (right) since 1900 in respective Asia-Pacific countries through use of CATDAT (Daniell et al. 2010)

Development of the database for Australia

The following major databases were first consulted in terms of Australian earthquakes to compare the quality and quantity of the data in the CATDAT database – EMA, MunichRe NATHAN, EM-DAT, UTSU, NGDC, PAGER-CAT. These databases rendered a list of 18 damaging earthquakes. A list of corrections for Australian Earthquakes in these databases has been included in this paper in the Appendix.

The NGDC database includes 10 earthquakes for Australia. MunichRe NATHAN has 2 earthquakes. UTSU counts 15 damaging Australian earthquakes – but has errors with the 1902 Clarendon Earthquake Swarm where they define moderate damage, whereas through historic records these earthquakes can be deemed to have not caused damage. PAGER-CAT has 3 Australian earthquakes with socio-economic damage (Meckering, Cadoux and Newcastle). EM-DAT presents 4 earthquakes. These databases can be shown to underestimate the true effects of historic Australian earthquakes. Even with the cut-off criteria of these databases, many more earthquakes should be included based on their criteria. Thus, there is a major need for an accurate damaging earthquake database.

A damaging earthquake is defined in the CATDAT database by the following criteria:

- Any earthquake causing collapse of structural components.
- Any earthquake causing death, injury or homelessness.
- Any earthquake causing damage or flow-on effects exceeding \$10,000 international dollars (\$9990 AUD as of November 2010), Hybrid Natural Disaster Economic Conversion Index adjusted to 2010.
- Any earthquake causing disruption or a reasonable economic or social impact as deemed appropriate.
- A requirement of validation of the earthquake existence via 2 or more macroseismic recordings and/or seismological information recorded by stations and at least 1 of the 4 definitions above.

For the Australian dataset this rendered 88 earthquakes and rockbursts. These have been gathered from various journals, papers, databases, reports and presentations. In addition, five

earthquakes have been recorded from the Banda and Timor Seas (Indonesia), which have caused damage in northern Australia. Two earthquakes from Chile have caused damage in eastern Australia through tsunamigenic action. The cost of the tsunami warnings in present years has not yet been calculated into the database, but these should be included on the basis of disruption.

Casualty-bearing Earthquakes in Australia

As has been gathered from the CATDAT database, there have been 16 earthquake related deaths in Australia from 3 earthquakes, and 5 rockburst related deaths from 3 events. There have also been 10 additional earthquakes with only people injured and 1 tsunami. This is always contentious, as the degree of injury is always difficult to fathom and some databases do not include rockbursts. Compared with the rest of the world, there seems to be a much smaller effect socially through historic earthquakes, than economically.

The seismological information, full description and other effects are contained within the CATDAT database.

Table 1 – The casualty bearing earthquakes and rockbursts in modern Australian history (1788-) – CATDAT Damaging Earthquakes Database v4.07, J. Daniell, 2010.

Earthquake	State	MI	Deaths	Serious Injuries	Minor Injuries	Cause
07.07.1883 Adelaide	SA	4.9			1	1 Person injured jumping from a window
10.05.1897 Beachport	SA	6.8		5	45	Numerous injuries including several serious at Beachport
19.09.1902 Warooka	SA	6.0	2		1	2 heart attacks related to the earthquake
25.06.1903 Moonta	SA	RB		1	9	Rock fall in mine due to rockburst – 1 seriously injured, with 9 having more minor injuries
27.08.1917 Kalgoorlie	WA	RB	1			1 death due to underground rock fall
02.09.1932 Selwyn Fault	VIC	4.5			3	At least 3 people treated for shock
12.04.1935 Gayndah	QLD	5.5	1			1 railway worker shaken off a railway bridge at Biggenden
28.02.1954 Adelaide	SA	5.4		3		3 serious injuries
22.05.1960 Chile Tsunami	NSW	Tsu			2	1 girl fell in – rescued. Another man was smashed against a wall when attempting to flee the water.
14.10.1968 Meckering	WA	6.8 Ms		5	28	At least 5 serious injuries and over 20 minor injuries
02.12.1977 Balliang	VIC	5.0			1	1 broken arm of a child falling from a bunk
02.06.1979 Cadoux	WA	6.1			1-5	Between 1 and 5 minor injuries.
27.12.1989 Newcastle	NSW	5.4 Mw	13	30	135	Nine people died at the Newcastle Workers Club; three people were killed in Beaumont Street, Hamilton, and one person died of shock. 165 total hospitalised. Refer to Carr et al. (1997) for more information.

06.08.1994 Ellalong	NSW	5.4			5	5 minor injuries
1996-1998 Rockbursts	WA		3			Potkin et al., 2000.
25.04.2006 Beaconsfield	TAS	2.2	1	2		1 died due to rockburst – rock fall, 2 major injuries (14 days underground)
20.04.2010 Kalgoorlie	WA	5.2 Mw			2	A man and woman were hospitalised with minor injuries

It should be repeated that as a concert at the Workers Club in Newcastle was to be held on the night of the 28th December 1989 (local time), hosting 2000 people, the fatality count for Australia could have been much higher had this earthquake not occurred during the day (Carr et al. 1997). It also should be noted, that there is contention whether the Beaconsfield event is defined as a rockburst or earthquake. In this paper, it is defined as a rockburst.

Economic Losses in Australian Earthquakes

Many estimates have been made of economic losses from Australian earthquakes historically, with much conflicting information. There is a natural range from any earthquake of economic estimates as it is always difficult to calculate damage. Insured loss information is often the only descriptor of damage and a total loss estimate has to be calculated as a percentage increase on this insured loss. It has been found in historic earthquakes in Australia, that the further back that economic estimates went in time, the higher they were based on property and quantifiable losses, not taking into account the life cost and flow-on effects. In many cases, some damage estimates that were obvious errors were eliminated from the CATDAT range of economic losses for each Australian earthquake. The CATDAT database includes a full economic range from different sources, as well as a CATDAT preferred lower bound and upper bound value and also a median value for each entered earthquake.

For the 95 earthquakes, many historical newspaper reports (The Advertiser, The Argus, Sydney Morning Herald, Brisbane Courier etc.) and other reports and papers were used to construct the building losses as well as potential economic loss estimates. In many cases, building losses were used with a trended loss estimate based on labour, chimneys, walls, broken windows, ceilings, semi-destroyed, and fully destroyed buildings. These series were created through use of the Australian Bureau of Statistics – Australian Yearbooks from 1908 onwards, and using contemporary sources (Haig 1989, Haig 2001, Forster 1985, Maddison 2003, World Bank 2010 etc.). Lists of the new economic estimates created as part of this study of earthquake loss resulting from earthquakes in Australia are detailed below in the Appendix to the paper. The percentage urbanity of the affected earthquake region was applied in order to better create this index. In the CATDAT database, this has simply been done on a country-by-country basis for the rest of the world.

In addition, the BTE (2001) life costing has been added to the economic loss where the total loss estimate was deemed not to include the flow-on life effects of earthquakes. The economic costs for fatalities, major injuries and minor injuries have been trended through history using proportionate unskilled wage, because the proportion of the losses for fatalities, major injuries and minor injuries comes from lost wages and lost time.

It should be noted at this point that there will be minor changes to the CATDAT database as additional economic trend information studies become available in every country. For Australia, the GDP, unskilled wage and CPI information is reasonable for the entire modern

Australian history (1788 onwards). As a trend, these have been depicted on the following diagram to show the difference between the indices from 1880 onwards.

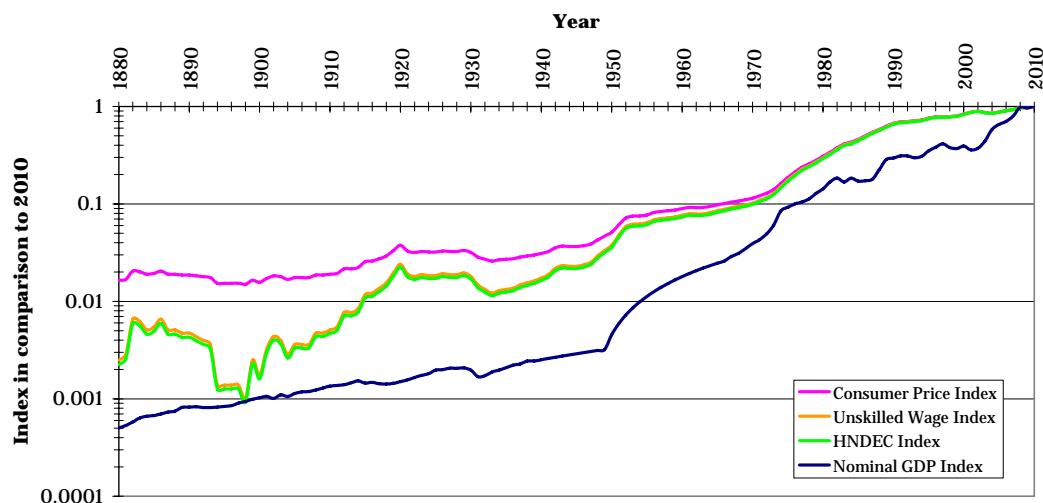


Figure 2 – Australian measuring worth indices including the comparative Australian Average HNDECI (Historical Natural Disaster Economic Conversion Index).

The following Table shows the historical cumulative earthquake economic losses in Australia. It can be seen a large proportion can be attributed to one event – Newcastle 1989. This poses a problem for earthquake loss modellers in Australia in that there are only one major urban centre event of a significant magnitude and destruction (with the exception of the Adelaide 1954 earthquake). The modern history or scientifically recorded history of Australia only dates back to 1788, causing a problem for earthquake records. In addition, during the early years of European settlement, very little of Australia was inhabited by the Europeans.

Shown below in Table 2 are the highest 10 economic losses in Australian history, based on the HNDEC indexing system within the CATDAT database. Table 5 in Appendix A.2 shows the full number of economic loss earthquakes in Australia. The HNDECI is the Hybrid Natural Disaster Economic Conversion Index designed to bring the cost of an event year earthquake into 2010 dollars. A simple CPI/inflation-based series does not account for the cost in 2010 dollars, as shown by Daniell et al. (2010).

For the purposes of simplicity, pre-1966 values have been converted from pounds to dollars by multiplying by 2 as per the 1966 decimal currency conversion rate.

Table 2 – The Top 10 Economic Loss bearing earthquakes in modern Australian history (1788-) – CATDAT Damaging Earthquakes Database v4.07, J. Daniell, 2010.

Location information			Economic Loss in AUD x 10 ⁶ (date of event)			Median HNDECI-adjusted 2010 Economic Loss
Earthquake	State	Ml	Best Estimate	CATDAT Upper	CATDAT Lower	
1989 Newcastle	NSW	5.4 Mw	3246	4000	1650	5313.1
1954 Adelaide	SA	5.4	9.07	9.07	6.2	152.5
1994 Ellalong	NSW	5.4	50.05	50.05	36	70.7
1968 Meckering	WA	6.0	5.23	7	5	57.2
1902 Warooka	SA	6.0	0.048	0.06	0.02	12.1
1979 Cadoux	WA	6.1 Mw	4.08	4.08	3.8	15.5

1897 Beachport	SA	6.8	0.0145	0.015	0.01	11.5
1918 Bundaberg	QLD	5.4	0.12	0.12	0.12	8.3
2006 Beaconsfield	TAS	2.2	6.49	12	4	7.2
1961 Robertstown	NSW	5.0	0.5	0.5	0.5	6.6

*Over 14000 sources of information have been used in the production of the entire CATDAT database, so it has not been possible to reference all used sources in the trend indices and historical earthquakes.

Figure 3 shows the cumulative Australian economic loss due to earthquakes through time. The ‘CATDAT best estimate’ value is the median within the CATDAT database, or chosen as the most likely single value for the economic loss incurred within that earthquake. The ‘Literature Upper Value’ is the highest value found in the literature (where obvious errors were removed). The ‘Literature Lower Value’ is similarly the lowest value found in the literature. The ‘CATDAT Upper Value’ and ‘CATDAT Lower Value’ are the highest and lowest plausible estimates, given the data through numerous sources. This is subjective to some extent as it uses expert judgement. The Newcastle Earthquake dominates cumulative economic losses – accounting for some 90% of historical economic losses. The CATDAT Lower value accepts the \$1.5bn estimate of Walker (2009) as a possible estimate for the total economic loss and also accepts the upper estimate quoted by sources of \$4bn. The preferred estimate however is \$3.246bn.

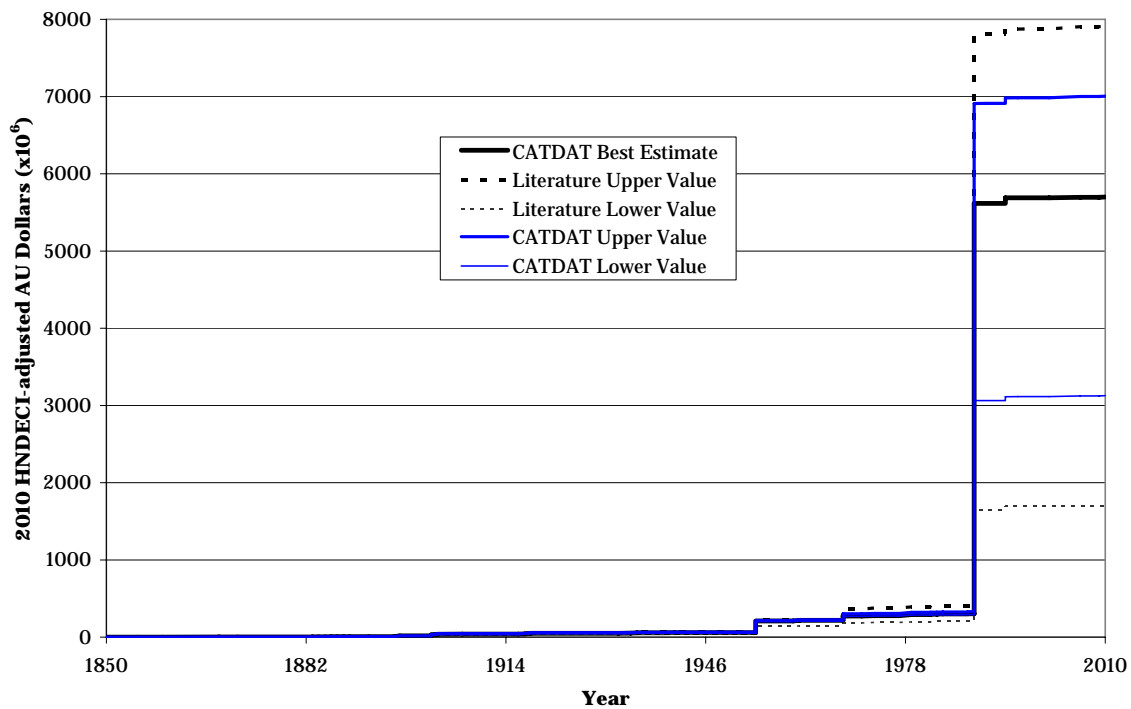


Figure 3 – Cumulative Australian economic loss in 2010 dollars AU as a result of earthquakes from 1850 onwards.

Figure 4 removes the Newcastle 1989 earthquake, showing the relative economic loss due to all other earthquakes in Australia. It can be seen that there has been an increasing trend as Australia has become increasingly populated. This trend does not follow losses in a global sense (Daniell, Wenzel and Khazai, 2010).

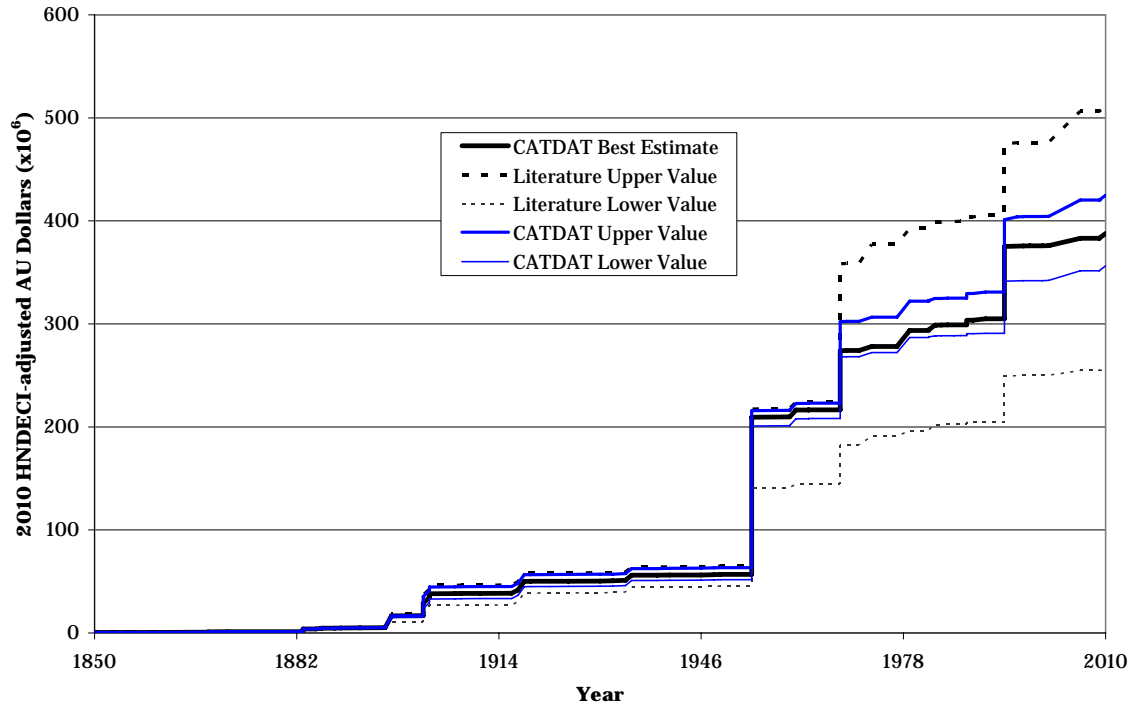


Figure 4 – Cumulative Australian economic loss in AUD as a result of earthquakes from 1850 onwards, with the removal of the Newcastle 1989 earthquake.

The following diagram shows the location and relative economic loss of damaging earthquakes in Australia since 1788 in 2010 HNDECI-adjusted dollars for each earthquake. It can be seen that South Australia and New South Wales dominate losses. It can also be seen that the economic losses have been incurred from earthquakes around settled areas. The estimates for each earthquake can be viewed in the Appendix.

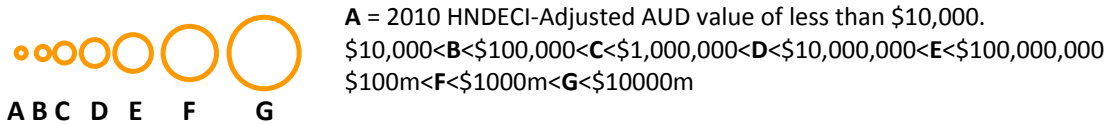
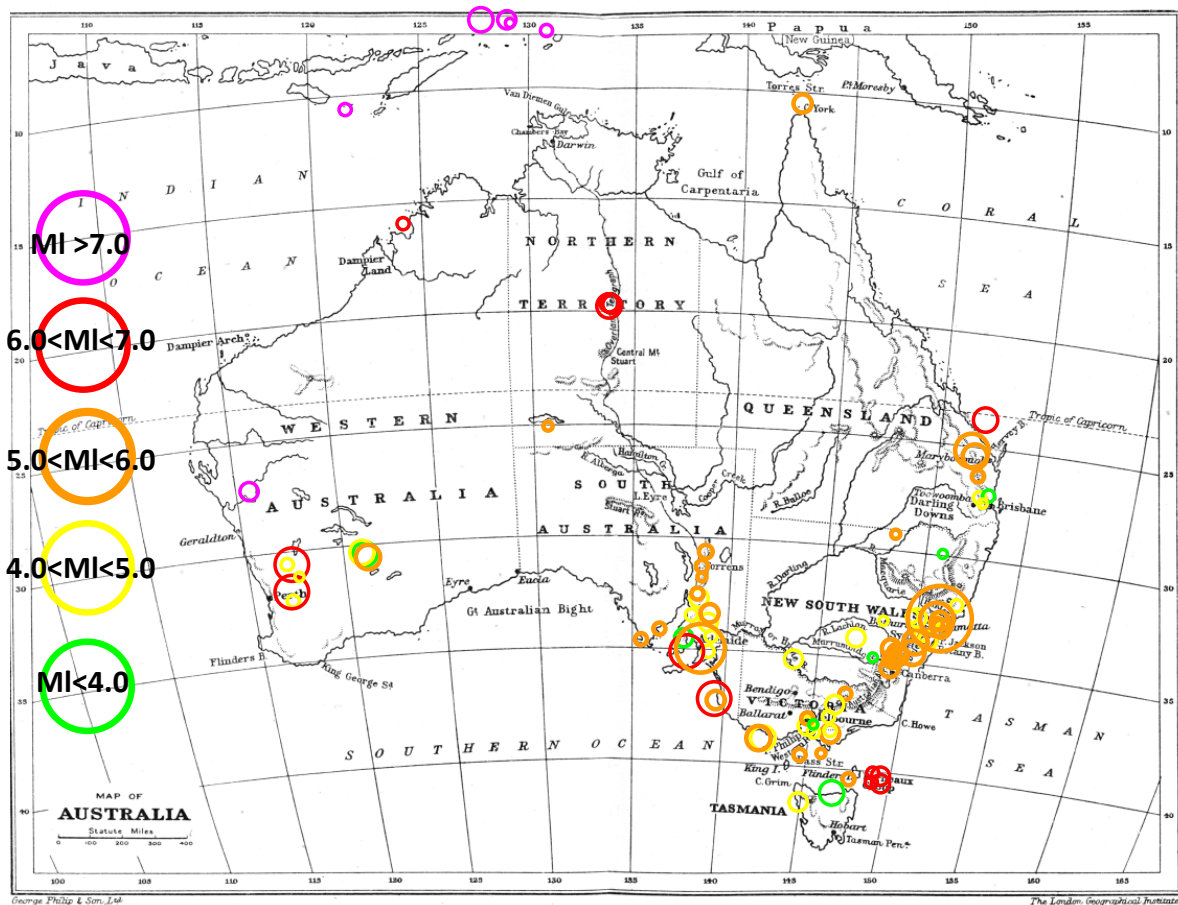


Figure 5 – A representation of the economic loss from each Australian damaging earthquake in 2010 HNDECI-adjusted dollars

Normalised Earthquake Losses

The Australian damaging earthquakes will be reanalysed for current population and infrastructure using earthquake loss software developed as part of the OPAL project (Daniell 2009) and also using the EQRM software package for comparison. However, a first-order loss estimate can be created using the HNDEC indexed values and the current population versus historical population in the area, and also an index of the level of vulnerability of the building stock to the historical building stock.

A similar approach to that of Crompton and McAveney (2008) for meteorological hazards has been used to normalise historic Australian earthquakes. Other approaches have been applied by Vranes et al. (2009) for normalising US earthquake damages. The appropriate documentation for indexing the Insurance Council of Australia database of Crompton et al. (2005) has not been able to be sourced; however, a similar method is likely to have been employed to the meteorological hazards. The following method is used to normalise CATDAT earthquakes for worldwide locations to the economic conditions of 2010, if the earthquake were to occur today. Where regional data is available this is also incorporated into

the calculation. The normalised 2010 damage for a certain location ($NormD_{2010,loc}$) is characterised by the following equation:-

$$NormD_{2010,loc} = D_{2010,loc} \times PD_{y,loc} \times V_{y,loc} \times CW_{y,loc}$$

2010 Event Adjusted Damage

The 2010 HNDECI adjusted damage ($D_{2010,loc}$) is used as the initial input of the normalised damage calculation. The HNDEC Index converts the event year-dollar earthquake damage to 2010-dollars through time via a hybrid index of GDP, wage and CPI as per Daniell, Wenzel and Khazai (2010).

Population-Dwelling Factor

The first factor used in the normalisation is the population-dwelling factor ($PD_{y,loc}$). It is assumed that the number of people in each dwelling has remained constant through time, or that the proportion of construction cost is constant per population (in countries where the former are not available). This assumption will be modified further with increased data in subsequent analysis. In the area most affected in terms of damage, the population has been calculated in the region of the earthquake at the time of event, and in 2010 to indicate the relative difference in exposure. This difference is determined as a multiplier:-

$$PD_{y,loc} = Pop_{2010, location} / Pop_{year\ of\ event, location}$$

Building Vulnerability Factor

The second factor is the change in vulnerability based on building code changes on a state-wide basis and the change in building types used in terms of earthquake resistance in an attempt to evaluate the difference in damage to infrastructure as a result of the same earthquake occurring in the present year (2010). A building code will not lead to all damage from infrastructure being prevented, and is only there to reduce damage. Thus, if a building code is totally effective this multiplier would still be most likely 0.5 or more. In some cases where construction materials of buildings have moved from timber to masonry, the vulnerability of these buildings to earthquakes could actually increase over time. A slight link to risk perception has also been included in this part of the index, based on the time since the last major historic earthquake occurred in that region.

The first building code in Australia to include earthquake loading was introduced in 1979 – AS2121-1979. However, this did not have much impact on seismic design in urban centres, with the exception of Adelaide from 1983 onwards. A second earthquake resistant building code was introduced in 1993 after the Newcastle earthquake – AS1170.4-1993. The third earthquake resistant building code came into effect in 2007 – AS1170.4-2007. Each of these code changes usually bring about an improvement in the building resistance against earthquakes, depending on the hazard zonation of the historic earthquake location. The vulnerability factor is:-

$$V_{y,loc} = 1 + 0.05*(No.\ of\ years\ since\ last\ damaging\ EQ/222) - 0.5*(Pop_{(1979\ or\ post-1979\ y),loc}) / (Pop_{2010,loc} - Pop_{(1979\ or\ post-1979\ y),loc}) * (BCQV_{(1979\ or\ post-1979\ y)-2010, location})$$

Where BCQV = Building Code Quality of buildings in the region from 1979 or the year of the event as compared to 2010. This is also undertaken for 1993 and 2007, in terms of quality of BC. This is subjective.

Community Wealth Factor

This factor shows the difference in community output between the year of the event and 2010. This is the change which comes about as GDP and wealth increases faster than population increases in a region, hence it accounts for the increase through time of transportation, utilities and production per head of population. This will be further modified through further research as a regional analysis is needed for each historic earthquake, as certain locations can reduce production through time due to closed mining or other industry pursuits, or a large population

migration to other locations. Currently, this factor takes into account state based changes in wealth and output through the difference between the historic GDP with the removal of inflation and a reduction factor. The community wealth factor is as follows:-

$$CW_{y,loc} = (GDP_{2010,loc}/GDP_{y,loc})/(CPI_{2010,loc}/CPI_{y,loc}) \times 0.1 + 1$$

Table 3 is the summary of normalised economic losses if the top 10 Australian historic earthquakes occurred with today's population, wealth and infrastructure vulnerability types.

Table 3 – Normalised 2010 Economic Losses from Australian Earthquakes – CATDAT Damaging Earthquakes Database v4.07, J. Daniell, 2010.

Earthquake	State	Historic Pop.	2010 Pop.	PD	V	CW	D ₂₀₁₀	NormD ₂₀₁₀ w/o CW	Norm D ₂₀₁₀
1989 Newcastle	NSW	130000Cd 432865Sd	147000Cd 540000Sd	1.17	0.77	1.12	5313.1	5228.8	5361
1954 Adelaide	SA	483500	1190000	2.46	0.81	1.66	152.5	303.9	504.4
1994 Ellalong	NSW	470 43500 (C)	1015 51600 (C)	2.0	0.94	1.14	70.7	132.9	151.5
1968 Meckering	WA	240 (606000)	116 (1700000)	2.0	0.85	1.24	57.2	97.2	120.6
1979 Cadoux	WA	stable (36)	stable	1.2	0.82	1.12	15.5	15.3	17.1
1897 Beachport	SA	655* (154000)	2880 (1190000)	6.6	0.9	2.60	11.5	68.3	177.6
1902 Warooka	SA	187** (163000)	1122 (1190000)	6.3	0.89	2.72	10.4	58.6	159.2
1918 Bundaberg	QLD	23178***	145000	6.3	0.95	2.96	8.3	49.7	147.0
1961 Robertstown	NSW	5000°	12000	2.4	0.8	1.38	7.2	13.8	19.1
1903 Warrnambool	VIC	6450°°	30000	4.65	0.92	2.53	5.5	23.5	59.5

*Robe and Kingston SE population, ° Bowral population, **Ardrossan and Warooka, °°In 1903 Warrnambool had 1260 inhabited dwellings, ***Bundaberg (8727) and Rockhampton (15451), Cd – city district, Sd – state district, C - Cessnock

This view of 2010 normalised losses demonstrates that the 1897 Beachport, 1902 Warooka, 1918 Bundaberg, 1968 Meckering and 1994 Ellalong earthquakes all would cause about the same amount of economic damage as they did were they to reoccur today. A similar method can be used to normalise fatalities and injuries; however, owing to the small nature of casualties in previous Australian earthquakes, this has not been presented in this paper. As more earthquakes occur in Australia, increased work on collecting socio-economic loss information should be undertaken to aid future risk assessment.

Conclusion

It can be seen from the CATDAT damaging earthquakes database that many more damaging earthquakes have occurred in Australia than indicated by other global earthquake databases. Over 90 Australian earthquakes have been entered into the database but this is still a work in progress. Currently, in 2010 HNDECI-adjusted AUD, just under \$6 billion damage has occurred to Australian infrastructure through history. 21 deaths, over 275 people injured and over 1500 homeless have also been recorded.

Earthquakes have not yet caused a large amount of damage in Australia. However, given the lack of major urban-centred earthquakes (with the exception of Newcastle and Adelaide)

since 1788, it must be said that the socio-economic trends lack a significant sampling. When further earthquakes occur, the hazard map of Australia will change significantly.

As the earthquake record in Australia is so short (220 years), it is extremely important to characterise the socio-economic impacts of these earthquakes in an attempt to learn as much as possible about physical and community vulnerability combined with the increasing exposure. There is much uncertainty in historic earthquakes; yet, by recreating and studying each individual earthquake, much insight can be gathered.

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Appendix

A.1 Corrections to existing databases based on historical values

PAGER-CAT presents 3 damaging earthquakes in Australia – Meckering 1968, Cadoux 1979 and Newcastle 1989 but these are presented correctly. This database is a combination of the PDE-USGS, HTD, GLIDE, EM-DAT, NGDC, UTSU and other sources.

NGDC (The Significant Earthquake Database) presents 10 damaging earthquakes in Australia and 24 significant earthquakes in total (Mw7.5 or greater, or damage). Although the criteria states that the following criteria are needed, it seems as though any damaging earthquake is included. 2225 events have occurred since 1900 with some form of damage.

‘The Significant Earthquake Database contains information on 3820 destructive earthquakes from 2150 B.C. to the present that meet at least one of the following criteria: Moderate damage (approximately \$1 million or more), 10 or more deaths, Magnitude 7.5 or greater, Modified Mercalli Intensity X or greater, or earthquake generated a tsunami’ (NGDC, 2010).

EM-DAT presents 4 Australian events with a total 12 deaths and total \$1,009,675,000 US damage. Their criteria for inclusion in the database: *Ten (10) or more people reported killed, Hundred (100) or more people reported affected, declaration of a state of emergency or a call for international assistance* (EM-DAT v12.07, 2010).

MunichRe NATHAN is another database which includes earthquakes effects as part of its NatCat service with the following criteria:- *Any disaster which causes casualties, economic damage or disruption*. It mentions 2 Australian earthquakes - Newcastle 1989 and Adelaide 1954 (for which there is no data).

The Emergency Management Australia database presents some socio-economic data for 38 Australian earthquakes. However, there are many gaps. Their criteria is as follows; however, it technically allows any damaging earthquake to be included:- *Greater than 3 or more dead, 20 injured or ill, and/or significant damage to property, infrastructure, agriculture or environment, or disruption to essential services, commerce, industry, or trauma or dislocation of the community at an estimated total cost of A\$10,000,000 or more”* (EMA Database, 2010).

The Insurance Council of Australia database shows the effects of 4 Australian earthquakes in terms of insured losses. It is also trends this data through to 2007 normalisation. No errors were found in the dataset for earthquakes.

Table 4 – Errors and Discussion Points in existing databases for Australian earthquakes.

Database	Earthquake	Error and Correction
NGDC	Newcastle 1989	Quoted 12 deaths and 1.1 million dollars loss but should be 1100 million dollars US damage. This value is quite low – equivalent to 1397 million AUD.
NGDC	Meckering 1968	2.2 million dollars loss – when looking at the loss sources, this value is too small. Is essentially insured loss.
NGDC	Cadoux 1979	1.5 million loss – also too small – insured loss value.
NGDC	Macquarie Island 1989	Damage of less than \$1 million – no damage can be found in the literature apart from a 0.1m tsunami in Sydney Harbour, Tasmania and Jervis Bay.
NGDC	Adelaide 1954	Estimate of between 1 and 5 million USD damage. The value in 1954 was

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		close to \$10 million USD damage.
EM-DAT	Cadoux 1979	\$7.075 million USD = \$6.332 million AUD. This value seems too high!
EM-DAT	Meckering 1968	\$2.6 million USD = \$2.33 million AUD, 16 injuries. Underestimate of injuries and damage.
EM-DAT	Newcastle 1989	12 deaths, 115 injured, 0 homeless (ERROR!), \$1000 million US damage = 1270 million AUD. This value is very low!
EM-DAT	Ellalong 1994	5 injuries, but does not include any economic damage!
Utsu	Newcastle 1989	1 st estimate = 9 deaths, 107 injuries. 2 nd estimate = 11 deaths, 120 injuries. Underestimate of deaths and injuries.
Utsu	Beachport 1897	No estimate of damage
Utsu	Clarendon, November 1902	Clarendon Swarm – some damage. However, this is not true as no damage was reported from Clarendon as per the Advertiser, 1902. It was also mostly in October.
Utsu	Warrnambool, 1903	Queensland. This is not correct as Warrnambool is in Victoria.
Utsu	W. Australia, 1906	Bottles fell off shelves in Carnarvon, 500 kilometres (311 mi) away, but this does not constitute a damaging earthquake!
Utsu	Winton, 16.10.1907	Some damage. This earthquake can not be found to exist! This could be confused with the 28.10.1907 Goode Island earthquake in QLD.
Utsu	Newcastle, 16.01.1908	Some damage. This earthquake does not exist as per Hunter, 1991. This could be reports of coal mining subsidence.
Utsu	Meckering 1968 and Cadoux 1979	Limited damage. There was more than limited damage!
Utsu	Ellalong 1994	Insignificant/slight damage. This is not correct!
Utsu	Beaconsfield 2006	1 death, 0 injured. – 2 people were trapped for 14 days. This has a lasting impact and should be counted as injuries, given bruises, suffering etc.
EMA	Total Damage	16 dead, 249 injured, 1450 homeless, 1.28597 billion dollars AU – the economic damage is underestimating the true extent, attempting to incorrectly bring forward damage estimates via CPI.
EMA	Year Date Errors	Berridale – Date is not 01.01.1959. Damage Unknown. Date = 18.05.1959. No notable damage with the exception of slight non-structural damage in Berridale and near Eucumbene. Boolaroo – Date is not 01.01.1925. The date is 18.12.1925. Darwin – Date is not 01.11.1983. The date is 26.11.1983. Dunning – Date is not 01.01.1949. The date is 10.03.1949. Goode Island – Date is not 01.01.1907. The date is 28.10.1907. Launceston – Date is not 01.01.1946. The date is 14.09.1946. Lithgow – Wrong date 01.01.1985. The date was 13.02.1985. Maitland – Date is not 01.01.1868. The date is 18.06.1868. Mornington Peninsula – Date is not 01.01.1932. The date is 02.09.1932. Newcastle – Date is not 01.01.1837. The date was 02.08.1837 but there was no notable damage. Picton – Date is not 01.01.1973. The date is 09.03.1973. Robertson – Date is not 01.01.1961. The date is 21.05.1961. Robe – Date is not 01.01.1948. The date is 06.08.1948. Warrnambool – Date is not 01.01.1903. The date is 06.04.1903 or 14.07.1903 depending on which they are referring to. Wilpena – Date is not 01.01.1972. The date is 18.04.1972.
EMA	Warrnambool 1903	\$450,000 AU damage CPI adjusted. This is only equivalent to 4000 AU pounds in 1903. The estimated cost exceeded 2180 pounds (McCue, 1978) and is most likely several thousand pounds for the 2 earthquakes. It is my estimate that the Warrnambool earthquakes were seen to cause more damage than this value. Using CPI, my estimates are \$1.16 million 2010 CPI-Adjusted AU for the April 1903 earthquake and \$0.69 million AUD (2010 CPI-adjusted) for the July 1903 earthquake. The McCue estimates are also included in CATDAT
EMA	Banda Sea 01.04.1994	Banda Sea NT Earthquake – magnitude 6.8 causing damage in Darwin. This earthquake cannot be found in the seismicity records.
EMA	Multiple earthquakes	Maitland 1868, Gayndah 1883 and 1935, Launceston 1892 and 1946, Beachport 1897, Warooka 1902, Kalgoorlie 1917, Bundaberg 1918, Boolaroo 1925, Selwyn 1932, Meeberrie 1941, Robe 1948, Gunning 1949, Berridale 1959, Wilpena 1972, Proserpine 1985, Gatton 1988, Eugowra

		1994, Baw Baw 1996, Alice Springs 1997, Kimberley 1997. No economic estimate.
MunichRe	Adelaide 1954	Unknown damage.

A.2 Estimates created using damage reports for existing earthquakes.

Full details of the following economic loss estimates for Australian earthquakes will be included in subsequent papers and may change slightly as additional damage details are found. However, they are reasonable to an order of magnitude.

In the CATDAT estimates shown below of event year losses, the values of actual loss pre-1966 in column 8 are in AU Pounds, and post-1966 in Australian Dollars.

Column 9 values are all in 2010 HNDECI-adjusted AUD. The following is a small subset of the full database.

Table 5 – Estimates of economic loss for Australian Earthquakes mostly previously undetermined. This was undertaken using damage reports and trends in reconstruction and building materials.

Date	Lat.	Long.	MI	States Affected	Damaged Buildings or Infrastruct. (Levels not included)	Actual Loss ('000s)	2010 HNDECI Adjusted AUD ('000s)
12.2.1801	-33.80	150.90	(5.0)	NSW	5	0.05	128
17.5.1823	-33.60	150.80	(4.5)	NSW	bridge	0.3	236
27.1.1841	-32.80	151.60	4.9	NSW	minor	0.01	5
28.10.1842	-32.60	151.60	5.3	NSW	minor	0.05	24
16.9.1855	-39.5	145	(5.5)	VIC	1	0.07	7
21.11.1859	-40.70	145.00	5.4	TAS	4	0.2	35
18.6.1868	-32.80	151.60	5.3	NSW	1 moderate, 40 slight	1	385
13.8.1868	-18.50	-71.00	8.5	NSW, TAS, WA	3 boats	0.5	192
8.6.1871	-35.37	148.13	5.3	NSW	5 slight	0.3	208
7.7.1883	-35.10	138.70	4.7	SA	1	0.1	36
28.8.1883	-25.50	151.70	5.9	QLD	350	7	2502
13.7.1884	-40.50	148.50	6.2	TAS	minor	0.2	87
12.5.1885	-39.90	148.90	6.65	TAS	2	0.15	61
29.11.1886	-34.75	148.80	5.5	NSW	30	2	673
16.4.1887	-34.30	135.80	5.7	SA	5	0.1	43
5.7.1888	-34.80	149.10	5.3	NSW, ACT	1	0.1	43
12.2.1889	-34.00	139.00	4.9	SA	1	0.1	47
27.1.1892	-40.40	149.50	6.9	TAS	5 moderate, 20 slight	0.26	144
22.8.1896	-33.69	138.91	4.3	SA	4	0.1	158
10.5.1897	-37.30	139.70	6.5	SA	15 destroyed, 1000, powerlines	7.29	9954-11537
7.5.1902	-32.75	138.50	4.8	SA	50	0.4	201
19.9.1902	-35.00	138.00	6	SA	Walls destroyed, 100s, powerlines	24.22	8638-18868 (12148)
6.4.1903	-38.40	142.50	4.3	VIC	100s	10	5478
25.6.1903	-34.08	137.61	Mining	SA	mining	0.5	274
14.7.1903	-38.43	142.53	5.3	VIC	100s	6.2	3396
27.10.1907	-10.58	142.50		QLD	1	0.2	120
4.5.1908	-42.00	145.40	4.9	TAS	1	0.27	124
26.10.1911	-33.92	136.73	5.5	SA	75	0.225	89

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10.6.1916	-32.25	152.50	4.6	NSW	2	0.45	80
27.8.1917	-30.66	121.36	Mining	WA	mining	20	3164
6.6.1918	-23.50	152.50	6	QLD	3000 approx. with some damage	60	8348
15.8.1919	-33.50	150.70	4.6	NSW	3	0.5	55
10.4.1922	-39.30	144.30	5.6	VIC	minor	0.5	59
18.12.1925	-33.00	151.60	5.3	NSW	3	1	116
27.10.1930	-34.40	148.80	5.2	NSW, ACT	22	1.5	177
2.9.1932	-38.30	145.00	4.5	VIC	minor	1	161
18.11.1934	-34.80	149.20	5.6	NSW, ACT	5 moderate, 100 slight	3.5	577
12.4.1935	-25.50	151.67	5.5	QLD	100s	30	4807
26.3.1939	-31.10	138.30	5.8	SA	2	0.15	20
28.4.1941	-26.90	115.80	7.2	WA	3	2	225
14.9.1946	-39.97	149.35	6.1	TAS, VIC	30	1.5	134
6.8.1948	-37.36	139.68	5.6	SA	100	4	288
10.3.1949	-34.74	149.20	5.5	NSW, ACT	100s	3	189
2.11.1950	-6.50	129.50	8.1	NT	1	0.1	6
28.2.1954	-34.90	138.70	5.4	SA	3	4538	149170-152530
19.9.1954	-28.50	148.60	5.3	QLD, NSW	minor, water tanks	0.1	3
22.5.1960	-38.29	-73.05	9.5 Mw	QLD, NSW, VIC, TAS	20 boats	11.06	300
7.10.1960	-7.40	130.70	7.3	NT	minor	3	81
17.11.1960	-27.33	152.85	4.4	QLD	minor	2	54
21.5.1961	-34.55	150.50	5.8	NSW	landslides, 2000 homes affected	250	6558
18.1.1963	-32.25	117.17	4.9	WA	2	0.5	13
4.11.1963	-6.80	129.60	8.2	NT	Electricity supply and telephone services at Darwin.	9.32	244
28.8.1965	-32.23	138.30	5	SA	minor	0.75	18
8.4.1968	-30.80	117.10	4.4	WA	minor	1	11
14.10.1968	-31.52	116.98	6.8 Ms	WA	59 destroyed, 2000, railway lines, roads, pipelines	5227	59689-79092
20.6.1969	-38.47	146.30	5.3	VIC	100	30	317
6.1.1971	-33.46	138.56	4.6	SA	10	1.5	14
6.7.1971	-38.42	145.11	4.9 Ms	VIC	4	2	19
18.4.1972	-31.58	138.62	5.3	SA	minor	1	9
9.3.1973	-34.13	150.27	5.5	NSW	minor	500	4004
2.12.1977	-37.86	144.26	5	VIC	5	4.1	19
2.6.1979	-30.82	117.11	6.1 Mw	WA	25 severe, 75 slight, roads, water pipes, power, railway lines	4089	14501-15527
7.2.1980	-54.16	158.89	6.4 Ms	TAS	1	1	3
4.3.1982	-29.82	151.20	3.7	NSW	1	1	3
21.11.1982	-37.15	146.76	5.4	NSW	1	10	28
26.11.1982	-33.94	147.25	4.6	NSW	25	200	557
24.11.1983	-7.57	128.19	7.1 Ms	NT, WA	Electric power and telephone services	500	1259

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29.12.1983	-30.79	138.40	4.8	SA	5	10	25
30.10.1984	-26.31	151.96	4.7	QLD	10	20	48
13.2.1985	-33.49	150.18	4.3	NSW	100	65	112-225
8.1.1986	-27.15	152.50	3.2	QLD	1	5	10
24.6.1987	-33.44	150.15	4.3	NSW	50	50	95
6.1.1988	-31.20	117.50	4.3	WA	3	5	9
22.1.1988	-19.85	133.80	6.3	NT	included below	500	353-882
22.1.1988	-19.80	133.91	6.6 Ms	NT	included below	500	529-882
22.1.1988	-19.83	133.88	6.7	NT	100, SA Darwin Pipeline	1500	1058-2646
14.8.1988	-27.56	152.33	4	QLD	3	5	9
28.5.1989	-25.28	130.67	5.7	NT	minor	1	2
27.12.1989	-33.02	151.60	5.4 Mw	NSW	300 destroyed, 10000 moderate, 40000 slight. Much other damage to utilities, transportation and services.	3.247m	2.73m - 6.58m (5.313m)
9.3.1991	-30.78	121.50	4.2	WA	10 slight, minor mining interruptions	1000	294-1472
2.6.1994	-10.41	112.94	7.8 Mw	WA	petrol pipe, carpark fence	10	14
21.8.1994	-33.42	148.36	4	NSW	slight damage to 100 homes.	5	7
6.8.1994	-33.00	151.20	5.4	NSW	1050	50050	50476-70078
25.9.1996	-37.37	146.01	4.5 Mw	VIC	30	250	287-2875 (325)
9.3.1997	-33.82	138.97	5.1	SA	minor	200	259
10.8.1997	-16.10	124.38	6.3 Mw	WA	1 slight	15	19
22.5.1998	-34.60	147.90	3.8	NSW	minor	2.5	3
29.8.2000	-38.40	146.20	4.6	VIC	minor	15	18
27.10.2001	-35.36	143.69	4.8	VIC, NSW	5 slight, 30 SAIDA minutes disruption.	180	208
25.4.2006	-41.16	146.86	2.2	TAS	Caused many interruptions. Mines. TV. Radio.	6494	6899-15762 (7165)
6.3.2009	-38.42	145.87	4.6	VIC	Minor	10	10
22.9.2009	-38.28	145.25	3.1	VIC	5 slight	30	31
20.4.2010	-30.80	121.49	5.2 Mw	WA	80, interruptions to power.	4628	4628