

PERSONAL LINES INSURANCE

A CENTURY OF DAMAGE

— PROPERTY LOSSES DUE TO NATURAL PERILS

BY JOHN MCANENEY, RYAN CROMPTON, KEPING CHEN,
ROY LEIGH AND LARAIN HUNTER

Societal changes are driving the costs of natural disasters which the authors, from Macquarie University's Risk Frontiers, believe is in some ways a positive message. How can this be positive? They say that while Australia can have little direct control over the worldwide emission of greenhouse gases, it can, if it chooses, control where and how people live and build. In this article, they review a century of building damage caused by natural perils. This article is an extract from a forthcoming book: *Transitions: Pathways Towards More Sustainable Urban Development in Australia*.



This article reviews a century of building damage caused by natural perils in Australia, 95 per cent of which is due to natural hazards of a meteorological nature – tropical cyclones, floods, thunderstorms (especially hailstorms) and bushfires. It summarises recent work by Risk Frontiers (Macquarie University) in quantifying numbers of addresses by state and territory vulnerable to riverine flooding (~170,000 properties nationally at the 1-in-100 year Annual Recurrence Interval), bushfire (~500,000 addresses within one hundred metres of the bushland-urban interface) and coastal inundation (fifty per cent of Australians living within seven kilometres of the shoreline').

To better understand how losses are changing over time, we examine four decades of insured property losses as a guide for larger economic losses due to natural disasters. These insured losses are indexed for changes in dwelling numbers, the nominal value of dwellings and building codes to estimate the current loss – the insured loss were the original event to impact today's society. Changes in the number and nominal value of dwellings are used as surrogate measures for contemporaneous changes in population, wealth and inflation. Once the losses are indexed in this way, there remains no obvious signal to be explained by other factors such as anthropogenic climate change.

Trends are similarly and conspicuously absent from a frequency-severity index developed for landfalling tropical cyclones and also in statistics of national bushfire losses. The latter have remained remarkably stable over the last century. We conclude that changing societal factors are the principal reasons for the increasing cost of natural disasters in this country.

That societal changes are driving costs of natural disasters is in some ways a positive message. While Australia can have little direct control

over the worldwide emission of greenhouse gases, it can, if it chooses, control where and how people live and build. Improved building codes introduced after the destruction of Darwin in 1974 by Tropical Cyclone Tracy show what can be done where there is a demonstrated need and political will. Social governance of this kind results in immediate improvements in community resilience to both current and future climate and climate variability.

Introduction

We begin by examining Risk Frontiers' database of historical building losses – *PerilAUS* – the most comprehensive record of its kind in Australia. It was compiled by painstaking examination of official records, early newspapers and scientific accounts of nearly 5,000 hazard events from 1900 to 1999 and for major events to 2003. For almost 1,200 events, it is possible to estimate the number of buildings destroyed with damaged buildings (including commercial premises) normalised to *residential house equivalents* (RHE) using relative building costs and floor areas for different types of buildings (Blong 2004). In principle, one RHE could equal one residential home completely destroyed or ten homes each experiencing damage amounting to ten per cent of their replacement value. Outcomes from bushfires tend to be binary in nature with buildings either completely destroyed or surviving relatively unscathed whereas hail generally results in relatively small amounts of damage to individual dwellings spread over a wide area (Shuster et al. 2006). Tropical cyclones have the potential to inflict significant damage to individual dwellings over very large areas.

Figure 1 shows meteorological hazards dominate building losses in Australia's short-recorded history. In terms of the total number of buildings destroyed (insured and uninsured) between 1900 and 2003, tropical cyclones have been most destructive, accounting for almost one third of losses with floods and bushfires each contributing another 20 per cent, as do thunderstorms if hail, gust and tornado are combined. Earthquake only accounts for five per cent, a proportion heavily dependent upon a single event – the 1989 Newcastle earthquake. For long return period events such as damaging earthquakes, the historical record in Australia is an inadequate sample on which to judge the future. The dominance of meteorological hazards suggests that Australia should be more sensitive than many other jurisdictions to changes in global climate. This is an issue we explore in later discussion.

In terms of the geographic spread of losses, New South Wales and Queensland have been most impacted (Figure 2). Tropical cyclones dominate losses in Queensland, Northern Territory and Western Australia, as does bushfire in Victoria, Tasmania and the Australian Capital Territory, floods followed by thunderstorms in New South Wales and earthquake in South Australia. It must be clearly recognized that risk is not just a function of the hazard but the joint outcome of hazards and societal vulnerability to these hazards. This is a feature that has long been recognized by social scientists (e.g. Mileti, 1999) and by the insurance industry (Walker, 1997), but one largely absent from the international debate on global climate change, which has been narrowly focused on the control of greenhouse gas emissions (Pielke and Sarewitz, 2005).

The remainder of this article is structured as follows. First, we present new information based on work undertaken by Risk Frontiers on the vulnerability of property to riverine flooding, bushfire and coastal

inundation. We will then consider the results of a recent indexation of the Insurance Council of Australia's (ICA) database of insured losses. Our interest is to see whether any observable signal remains once we have adjusted the original losses for changes in dwelling numbers, values and building codes in tropical cyclone-prone locations (Crompton and McAneney, 2007). Any trend remaining after this indexation might then be reasonably ascribed to other factors including anthropogenic climate change. In an attempt to probe more deeply, we then examine two particular hazards: tropical cyclones and bushfires, in order to see if the threat to properties is increasing in concert with rising global air and sea surface temperatures. We conclude with some brief policy implications especially the importance of adaptation measures to reduce community vulnerability to natural hazards.

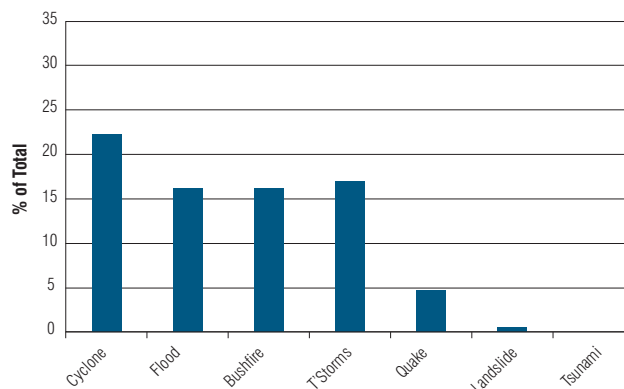


Figure 1: Percentage of the accumulated building damage between 1900 and 2003 attributed to different perils. T'storms refers to the combined losses from thunderstorms – hail, gust and tornadoes. (Source: PerilAUS database, Risk Frontiers.)

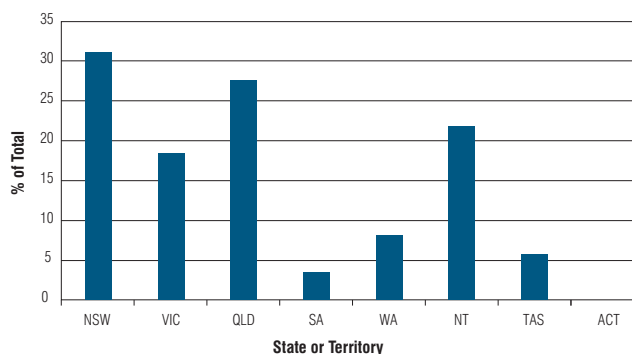


Figure 2: Percentage of the accumulated building damage between 1900 and 1999 by state or territory. (Source: PerilAUS database, Risk Frontiers.)

National distribution of addresses vulnerable to riverine flooding

Work undertaken by Risk Frontiers has estimated the national flood risk to residential homes (Leigh, 2006). These efforts reviewed 300 flood areas and suggest there are approximately 170,000 residential properties susceptible to mainstream flooding by an event with an average recurrence interval (ARI) of one hundred years. This estimate is based primarily on the number of residential buildings liable to over-ground inundation; although the nature of the data available sometimes meant that alternative measures, such as the number of buildings susceptible to over-floor flooding, were also used. Only residential properties in urban settlements prone to mainstream riverine flooding are included.

Storm water flooding from overflowing drainage systems and coastal inundation from tsunami and storm surge were excluded (except for storm surge coincident with river flood). All major flood-prone settlements were considered within areas containing approximately 75 per cent of Australia's population.

Over ninety per cent of residential properties expected to be flooded by a 100-year ARI event are located in Queensland, New South Wales and Victoria (Table 1). The 100 year ARI is a commonly used but arbitrary risk metric that tells us nothing about the distribution of addresses either above or below this threshold. On the other hand, it is adequate to identify regions and cities most at risk. About 22 per cent of these flood-prone properties are located in Brisbane city, Ipswich and the Gold Coast. The ten most flood-prone areas account for 45 per cent of the total number of identified flood-prone properties (Table 2). The evident corollary of this is that 55 per cent of flood prone properties lie outside of these ten areas.

Table 1: Number of residential properties susceptible to mainstream riverine flooding by an event with a 100-year ARI.

State	Number of residential properties	Proportion of total
Queensland	62,130	36%
New South Wales	55,677	33%
Victoria	42,376	25%
Western Australia	1,142	1%
South Australia	6,582	4%
Northern Territory	990	1%
Tasmania	723	<0.5%
Australian Capital Territory	0	0%
TOTAL	169,620	100%

Table 2: Ten most flood-prone regions in Australia based on a 100-year ARI flood.

Region or City	State	Number of flood-prone residential properties	Proportion of national total
Gold Coast	QLD	20,128	12%
Brisbane & Ipswich	QLD	18,010	10%
Shepparton	VIC	6,572	4%
Melbourne	VIC	6,000	3%
Mackay	QLD	5,924	3%
Brown Hill & Keswick Creeks (Adelaide)	SA	5,000	3%
Hawkesbury-Nepean floodplain (Sydney)	NSW	4,862	3%
Wyong & Tuggerah Lake	NSW	4,651	3%
Grafton	NSW	4,167	2%
Benalla	VIC	3,641	2%

Bushfire-prone addresses

Distance from bushland is not the only variable determining bushfire vulnerability, but it is demonstrably the most important (Chen and McAneney, 2004). It is also easily quantifiable. For this reason, Chen and McAneney (2005) calculated separation distances between addresses and adjacent bushland for all addresses in and around major capital cities with the exception of Darwin (Northern Territory), which, despite a history of grassfires, has experienced few building losses.

In order to identify addresses, we employed the Geocoded National Address File (G-NAF) street address database. It contains about 10.9 million addresses with known locations including up to 12 per cent potential duplicates in its earlier versions. For the time being, it is Australia's most authoritative geo-located address database.

For bushland maps, we first sourced government agencies and publicly available land cover databases. Many are now quite dated and at a coarse spatial resolution. High-resolution imagery is preferable but more affordable are medium-resolution Landsat 7 ETM+ images and we used these to classify bushfire-prone vegetation. We focused on identifying large areas of continuous bushland, i.e. areas greater than 0.5km² where large fires could develop and, on occasions, get out of control; small, scattered and discontinuous areas of vegetation were ignored. More recently, we have updated the analysis using the Geodata Topo database (Geoscience Australia, 2006).

Given the locations of all addresses and bushland, the calculation of shortest distance between them is straightforward. Five distance ranges were categorised. Group 1 are addresses within one hundred metres of bushland and so comprise the most at-risk addresses. Another four categories are given in intervals out to 700 metres, the maximum extent to which we have seen damage (Chen and McAneney 2004).

All major capital cities and surrounding areas
(N = 8,161,680)

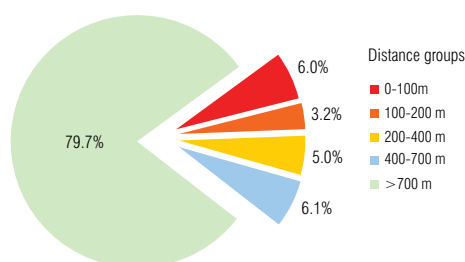


Figure 3: Breakdown of properties by distance category from large areas of bushland. Total number of unique addresses (9.6 million).

For the 8,161,680 addresses analysed, about 6.0 per cent of addresses fall into Group 1 as very exposed to bushfire risks, being either immediately adjacent or very close to extensive bushland and about 80 per cent of all addresses are located beyond 700 metres (Figure 3) with negligible exposure to bushfire.

Coastal vulnerability

Another concern is coastal flooding due to a range of ocean-related phenomena such as storm surge, tsunami and significant sea level rise associated with global warming. Using the most recent, fine resolution global and national databases, Chen and McAneney (2006) quantify

the number of addresses in Australia located within three kilometres of the coast and having an elevation less than six metres above mean sea level. These thresholds were adopted as national benchmarks for a variety of reasons. When uninterrupted by topography, the 2004 Boxing Day tsunami penetrated coastal regions of Sumatra some three to four kilometres inland and we can assume that this is potentially possible in Australia as well. The six metres elevation arose from reasons of technical accuracy, because storm surges of this magnitude are possible in some areas prone to tropical cyclones and as a plausible upper bound on sea level rise in the next one hundred or more years (Solomon, 2007).

Nationally, 7.4 per cent (about 700,000) of national addresses fall within these thresholds and about fifty per cent of national addresses are located within seven kilometres of the shoreline (Chen and McAneney, 2006). The proportion of coastal addresses varies significantly by state and territory (Figure 4): in Tasmania more than forty per cent of addresses are located within one kilometre of the coast and eighty per cent are within four kilometres, while in Victoria the corresponding proportions are only about nine per cent and 23 per cent. The statistics for other states lie within these extremes. The majority of coastal vulnerable addresses are located on the eastern seaboard – Queensland and New South Wales (Figure 5).

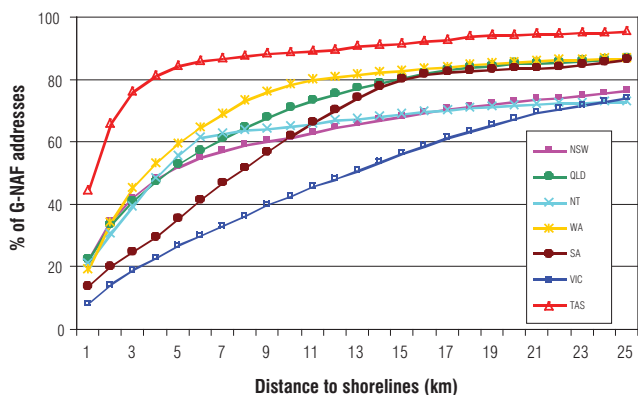


Figure 4: Percentage of coastal addresses by state / territory and distance to shoreline.

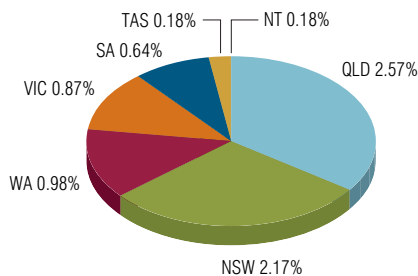


Figure 5: Percentage of coastal vulnerable addresses (distance less than 3km from the shore and elevation less than 6m above the mean sea level) by state and territory. Proportions refer to the total number of national addresses (9.6 million).

Insured losses – what would they cost today?

The ICA Disaster List is a record of natural hazard events in Australia that have caused significant insured losses since 1967. It contains details of each event including date; areas affected; and total insured (industry) cost in “original” dollars. Although the threshold loss for inclusion in the database has varied over time, most events had losses in excess of AUD\$10 million. Crompton et al. (2005) developed an indexation methodology to account for changes in population, wealth and inflation so as to estimate the likely impact of past events on today’s society

– a current (2006) loss. It uses the increase in the number of dwelling numbers and the nominal (inflation adjusted) dwelling value as surrogates for population, wealth and inflation. This methodology produces very comparable adjustments to that of Pielke and Landsea (1998) (Crompton et al. 2005).

We have already established the importance of tropical cyclones on Australian building losses (Figure 1) and so for this reason, Crompton and McAneney (2007) introduced a further adjustment to account for improved building standards in tropical cyclone-prone areas. These code changes were introduced after Tropical Cyclone Althea devastated Townsville in 1971 and Tropical Cyclone Tracy destroyed Darwin in 1974. For details of this correction, the reader is referred to Crompton and McAneney (2007).

Figure 6a presents the original losses in the Disaster List with the five geological events – four earthquakes and one tsunami – excluded. Annual losses have been calculated for 12-month periods beginning July 1 to take account of the southern hemisphere seasonality of the meteorological hazards. The analysis begins at the 1966 season (1966/67) and ends in 2005.

When correctly indexed (Figure 6b), the time series of insured losses exhibits no obvious trend (increase or decrease) over the last four decades. The conclusion that any trend in the unadjusted losses is largely attributable to changes in the number and value of dwellings, as well as building standards in tropical cyclone-prone regions, is an important result. Contrary to widespread belief, it shows no clear signal that global changes in climate are significantly impacting building losses in Australia to the present time. A similar conclusion was reached by Pielke and Landsea (1998) in relation to hurricane losses in the US.

Table 3 ranks the top ten insurance event current losses (all perils now, not just meteorological) with the Newcastle earthquake and Tropical Cyclone Tracy topping the list with indexed losses of around AUD\$4 billion. Total direct losses (insured plus uninsured) will often be roughly twice these figures. The top ten indexed losses comprise five distinct perils.

Figures 7a and 7b show the breakdown of insured losses by frequency and meteorological hazard category. Twenty-one per cent of loss events (ignoring earthquakes) are tropical cyclones that have been responsible for 32 per cent of losses, a figure very similar to Figure 1. Hailstorms comprise 19 per cent of loss events and have been responsible for 36 per cent of losses. Floods are less prominent than in Figure 1 but are probably under-represented in Figures 6 and 7 because this peril has not been uniformly insured.

Figure 7c shows the contribution of the various states and territories to the average annual current (2006) loss of AUD\$890 million. New South Wales produced half of the combined weather-related and geological losses. This representation is a crude measure of the national distribution of risk – a true metric should also take into consideration the standard deviation or volatility of these losses (McAneney 2005). It is nonetheless reflective of the multi-hazard threats facing New South Wales and Queensland as well as population density and property values.

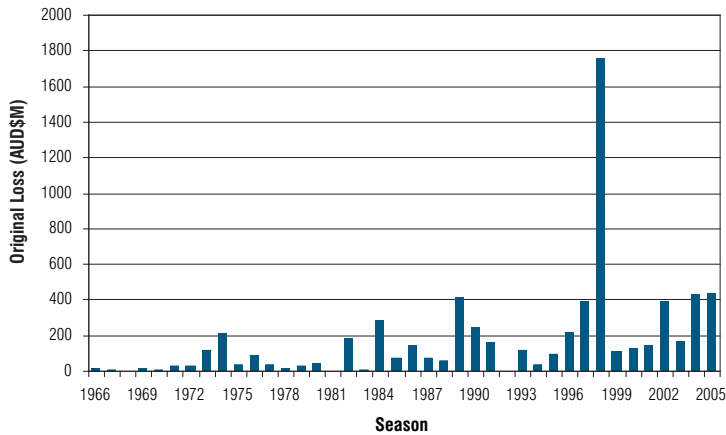


Figure 6a: Original annual aggregate insured losses (AUD\$M) for weather-related events in the ICA Disaster List for 12-month periods beginning 1 July.

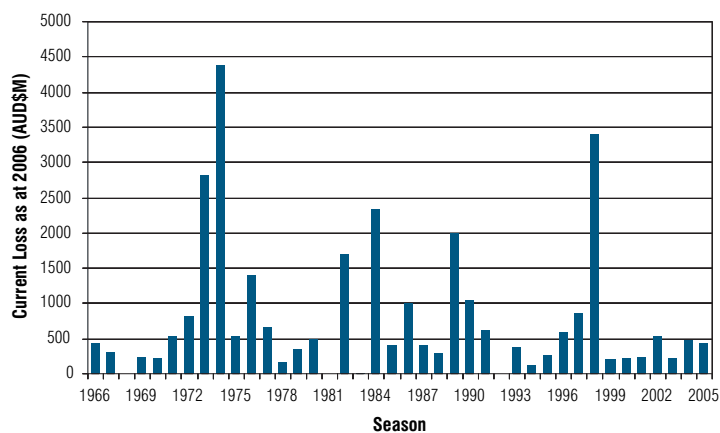


Figure 6b: As for (a) above but losses have been indexed to 2006 dollars. Tropical cyclone-related losses have been reduced to account for post-1980 improvements in building codes in tropical cyclone-prone areas following Crompton and McAnaney (2007).

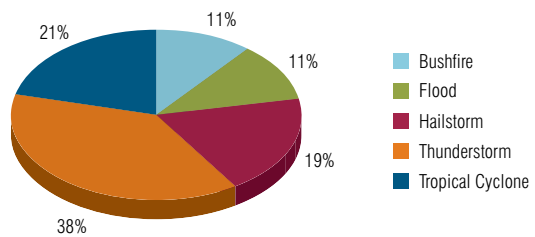


Figure 7a: Percentage of the number of weather-related events classified by hazard type in the ICA Disaster List. Here event losses from hailstorms have been separated from other forms of severe storms – tornados and high winds.

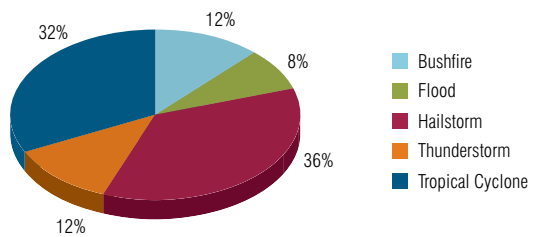


Figure 7b: Percentage of the total accumulated current losses as at 2006 (AUD\$M) of weather-related events in the Disaster List classified by hazard type.

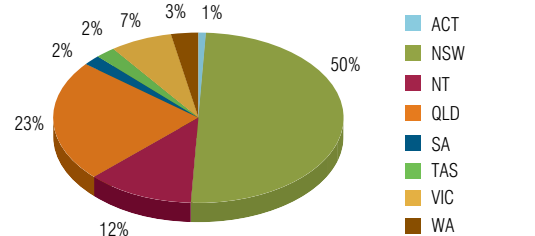


Figure 7c: Break-up by State and Territory of the national annual average current insured losses. Losses due to geological hazards have been included.

Rank	Year	Peril	Location	Original Loss (AUD\$M)	Current Loss (2006) (AUD\$M)
1	1989	Earthquake	Newcastle	862	4300
2	1974	Tropical Cyclone	Darwin	200	4070
3	1999	Hailstorm	Sydney	1700	3300
4	1974	Tropical Cyclone/ Flood	Brisbane	68	1790
5	1983	Bushfire	Multiple	176	1610
6	1990	Hailstorm	Sydney	319	1480
7	1985	Hailstorm	Brisbane	180	1430
8	1973	Tropical Cyclone	Multiple	30	820
9	1976	Hailstorm	Sydney	40	740
10	1986	Hailstorm	Sydney	104	710

Table 3: Ranking of indexed insured current (2006) event losses.

Frequency and severity of tropical cyclones that made landfall on the Australian east coast

Previous discussion has examined aggregate losses. In this section, we focus upon land falling tropical cyclones using data derived from the Bureau of Meteorology (www.bom.gov.au). We further restrict the analysis to those crossing the east coast of Australia during the last 45 years and having a central pressure less than or equal to 995hPa.

Tropical cyclone activity in the South-Western Pacific region is strongly related to the El Niño – Southern Oscillation (ENSO). Cooler ocean temperatures exist in the Western Pacific and Coral Sea during El Niño episodes and ocean temperatures near the Queensland coast are typically above average during La Niña phases. Consequently, tropical cyclone activity tends to shift further away from the east coast of Queensland and further north resulting in fewer than average numbers of landfalling tropical cyclones during the El Niño phase than the La Niña phase.

Figure 8 shows successive five-season period frequencies of tropical cyclones that have crossed the east coast since the 1961 season (1961/62). Within each of the five-season periods there are different numbers of El Niño, La Niña, and neutral events. With the exception of 1971-75, there have been between two and four tropical cyclones for each period. It comes as no surprise that La Niña episodes dominated the 1971-75 period.

‘There is no indication that tropical cyclones are becoming more frequent or more dangerous’

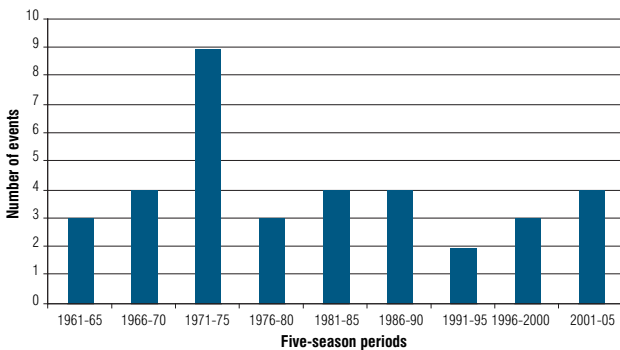


Figure 8: Number of tropical cyclones to cross the east coast during five-year periods.

Figure 8 only tells part of the story. Of more interest is the combination of frequency and intensity. According to Gray (2003), when normalised for coastal population, inflation, and wealth per capita, tropical cyclone-spawned damage in the US rises by a factor of four for each successive increase in Saffir-Simpson intensity category. Thus a landfalling Category-3 hurricane typically causes about four times the normalised damage of a Category-2 hurricane and so forth. Figure 9 takes this weighting into account: Category-5 and -4 events have each been assigned an equal weighting of 1/4; Category-3 a weighting of 1/16; Category-2 a value of 1/64 and Category-1 events 1/256. The weighted frequency by intensity is then summed for each 5-year period to obtain a potential destructiveness index assuming that the same damage relativities between categories hold true under Australian conditions.

By concentrating on the damage potential of the hazard alone, Figure 9 allows for Australia’s low population density and the large physical separation distances between population centres. Actual damage arising from individual tropical cyclones will vary widely as a result of the tropical cyclone track in relation to centres of population, terrain and topography, proportions of building construction conforming to improved wind loading codes, wealth per capita as well as attributes of the cyclone such as forward speed, storm surge and rainfall.

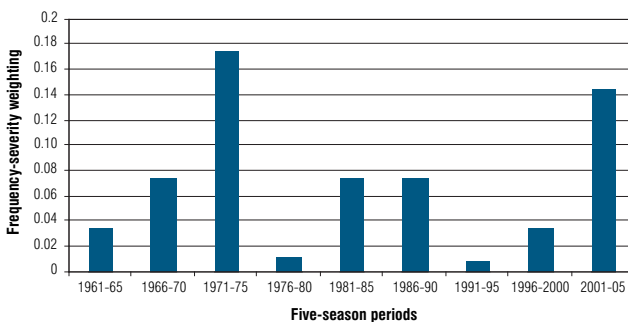


Figure 9: Potential destructiveness index of tropical cyclones that have crossed the east coast of Australia during five-year periods.

Again we see no obvious change (increase or decrease) in the potential destructiveness over the past forty-five years. Figures 8 and 9 focus on the east coast because this is where most building assets are located; however, very similar results hold for the western and north coasts of Australia or for the entire coastline. While we acknowledge that the small number of tropical cyclones per five-year time interval makes it difficult to draw robust conclusions, there is no indication that tropical cyclones are becoming more frequent or more dangerous.

Annual probability of bushfire losses

Many studies on bushfire risk in Australia have concluded that this hazard will increase under high greenhouse gas emission scenarios (e.g. Pitman et al., 2006). With this in mind, it is interesting to look at the statistics of event losses over the last century. Table 4, drawn from the *PerilAUS* database, lists three relevant statistics between given start years and 2003. The second and third rows list the average annual frequency of having more than 25 and 100 homes destroyed within a single week, in other words, the annual probability of having significant individual event losses. The seven day period has some relevance for reinsurance treaties.

Table 4: National bushfire building loss probabilities calculated between the start year and 2003. The first row gives the frequency of any (non-zero) loss while the second and third include only events that have resulted in more than 25 or 100 homes destroyed within a single week. 1926, 1939, 1967 and 1983 were each years with significant losses (> 500 homes destroyed) (McAnaney et al. 2007).

Start Year	1900	1926	1939	1967	1983	1990
Annual probability of a non-zero loss	56%	53%	48%	57%	57%	57%
Annual probability of losing >25 homes in 1 week	39%	40%	42%	41%	38%	36%
Annual probability of losing >100 homes in 1 week	18%	19%	22%	19%	19%	21%

The stability of probabilities over time evident in Table 4 is startling. At least some home destruction can be expected in approximately 55 per cent of years and the likelihood of losing more than 25 and one hundred homes has remained steady at around forty per cent and twenty per cent respectively since the turn of the last century. At current average asset values (AUD\$375,000 for average home and contents), an event loss of 25 homes would come close to AUD\$10 million, the lower limit for consideration in the ICA Disaster List.

That the probability of building destruction has remained so stable in the face of significant demographic changes and improvements in fire fighting capacity over the last century is curious. To invoke global climate change and argue that increases in temperature and an increasingly lengthy urban-forest interface have been exactly compensated by improved fire management techniques stretches credulity. The result seems better explained by infrequent mega-fires that have occurred about five times in the last 75 years and have been responsible for the majority of building losses. Fires such as these will exhaust the resources of even the most professional fire services. Although we concede that bushfire losses are the result of a complicated mix of social and climatic phenomena, one inference is again clear: there is no evidence to suggest that losses are increasing due to human-induced climate change.

Policy implications

The collective evidence reviewed above suggests that social factors – dwelling numbers and values – are the predominant reasons for increasing building losses due to natural disasters in Australia. The role of anthropogenic climate change is not detectable at this time. This being the case, it seems logical approach that in addition to reducing greenhouse gas emissions, equivalent investments be made to reduce society's vulnerability to current and future climate and climate variability.

We are aware of few policies explicitly developed to help Australian communities adapt to future climate change (Leigh et al., 1998). One positive example is improved wind loading codes introduced in the 1980s as part of a *National Building Code of Australia*. These codes have been mentioned already and were introduced for all new housing construction following the destruction of Darwin by Tropical Cyclone Tracy in 1974. As a result, dramatic reductions in wind-induced losses were observed following Tropical Cyclones Winifred (1986) and Aivu (1989) (Walker, 1999) and most recently, Larry (2006) (Guy Carpenter, 2006). While these measures were introduced in response to the immediate threat from current climatic events, the benefits will hold true under any future.

An increased threat from bushfires under global climate change is often assumed. However, our analyses suggest that while the prevalence of conditions leading to bushfires is likely to increase, the impact is unlikely to be as dramatic as the combined changes of all of the other factors that have so far failed to materially affect the likelihood of bushfires losses over the last century. This is not to ignore the threat posed by global climate change, but, at least in the case of fire in Australia, the main menace will continue to be the extreme fires. The threat to the most at-risk homes on the bushland-urban interface can only be diminished by improved planning regulations that restrict where and how people build with respect to distance from the forest. Again these are political choices. ■

1 Chen, K. and K.J. McAneney. 2006. High-resolution estimates of Australian coastal population: with validations of global data on population, shoreline and elevation. *Geophysical Research Letters*, 33, L16601.

By John McAneney, Ryan Crompton,
Keping Chen, Roy Leigh and Laraine Hunter
(Risk Frontiers, Macquarie University,
NSW, Australia)

This article is an extract from a forthcoming book: *Transitions: Pathways Towards More Sustainable Urban Development in Australia*, edited by Professor Peter Newton of Swinburne University and Published by CSIRO Publishing Melbourne, due out late 2007.

Risk Frontiers is an independent research centre devoted to helping insurers better understand and price natural catastrophe risks in the Asia Pacific Region. By performing research into the likelihood and costs of natural disasters, Risk Frontiers aims to assist the insurance industry in setting realistic premiums; build safer communities; and encourage the responsible management of natural hazard risks. It is sponsored by Aon Re, the Australian Reinsurance Pool Corporation, Benfield Australia, Guy Carpenter, IAG Insurance, QBE, Suncorp-Metway, Swiss Re and Promina.

References

- Blong, R. 2004. Residential building damage and natural perils: Australian examples and issues. *Building Research & Information* 32 (5), 379-390.
- Chen, K. and K.J. McAneney. 2004. Quantifying bushfire penetration into urban areas in Australia. *Geophysical Research Letters*, 31, L12212.
- Chen, K. and K.J. McAneney. 2005. The bushfire threat in urban areas. *Australasian Science*, 26(1): 14-16.
- Chen, K. and K.J. McAneney. 2006. High-resolution estimates of Australian coastal population: with validations of global data on population, shoreline and elevation. *Geophysical Research Letters*, 33, L16601.
- Crompton, R.P., K.J. McAneney, and R Leigh. 2005. *Indexing the Insurance Council of Australia Natural Disaster Event List*. Report prepared for the Insurance Council of Australia, Risk Frontiers.
- Crompton, R.P. and K.J. McAneney. 2007. Trends in Australian insured losses due to natural hazards 1967 -2006. *Environ. Science & Policy* (submitted for publication).
- Gray, W.M. 2003. Twentieth century challenges and milestones. In *Hurricane! Coping with Disaster* Ed. Robert Simpson, American Geophysical Union, Washington DC 2003.
- Geoscience Australia, 2006. *Geodata Topo 250k Series 3*. Geocat # 64059. Commonwealth of Australia.
- Guy Carpenter. 2006. *Tropical Cyclone Larry Review*. Guy Carpenter, Inc.
- Leigh, R.J., Taplin, R. and G.R. Walker. 1998. Adaptation of the insurance industry to climate change, and consequent implications. *Australian Journal of Environmental Management*, 5(2), pp.81-96.
- Leigh, R. 2006. *An estimate of the number of residential properties in Australia liable to inundation by an ARI 100-year flood*. Report prepared for the Insurance Council of Australia, Risk Frontiers.
- McAneney, K.J. 2005. Australian bushfire: Quantifying and pricing the risk to residential properties, pp. 13-22. In R. J Morrison, S. Quin and E.A. Bryant [eds.] *Proceedings of the Symposium on Planning for Natural Hazards – How Can We Mitigate the Impacts?* 2-5 February 2005, University of Wollongong.
- McAneney, K.J., Chen, K., Crompton, R. and A. Pitman. 2007. Australian Bushfire Losses: Past, Present and Future. In *Proceedings of 4th International Conference on Wildfire*, May 13-17, Seville, Spain.
- Mileti, D. 1999. *Disasters by design*. Joseph Henry Press. Pp. 351.
- Pielke Jr, R.A. and C.W. Landsea. 1998. Normalized hurricane damages in the United States: 1925-95. *Weather & Forecasting*, 621-631.
- Pielke Jr, R.A. and D. Sarewitz. 2005. Bringing society back into the climate debate. *Population and Environment* 26: 255-268.
- Pitman, A. J., Narisma, G.T. and K.J. McAneney. 2006. The impact of climate change on Australian bushfire risk. *Climatic Change* (in press).
- Schuster, S. S., Blong, R.J. and K.J. McAneney. 2006. Relationship between radar-derived hail kinetic energy and damage to insured buildings for severe hailstorms in Eastern Australia. *Atmospheric Research* 81, 215-235.
- Solomon, S. (ed.), 2007. *Climate Change 2007: The Scientific Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, New York.
- Walker, G.R. 1997. Current developments in catastrophe modelling. Pp. 17-36. In *Proceedings of Aon Group Australia Conference: Financial Risk Management for Natural Catastrophes*. Griffith University Press, QLD, Australia.
- Walker, G.R. 1999. Designing future disasters: An Australian perspective. Pp. 17-24. In *Proceedings of Aon Group Australia Conference: The Changing Risk Landscape: Implications for Insurance Risk Management*, Southwood Press, Sydney, Australia.