



2019/2020 Australian bushfire season

The 2019/2020 Australian bushfire season is far from over but has already been unprecedented in its destruction. Since August multiple concurrent and sequential bushfires across many states have resulted in loss of life and destruction of homes, businesses, farms, infrastructure and the environment. By the end of January over 9.8 million hectares has been burnt with over 3048 homes destroyed (AFAC). Unlike other major seasons where destruction has occurred in one day, the damage toll has been the contribution of numerous major fires across the season.

Infrastructure damage has resulted in widespread blackouts and telecommunications failures, with those at risk unable to obtain bushfire warnings. Road closures resulted in isolation, concerns for food security and forced medical evacuations.

The threat of bushfires saw local tourist economies damaged and warnings to international tourists to avoid travel to Australia; bushfire smoke caused public health issues and business disruption; and burning of vegetation in water catchments reduced water quality and contributed to fish kills.

Environmental damage has been severe, with an estimated one billion wild animals killed (UNEP) and threats to those that have survived due to habitat destruction. Smoke from bushfires affected New Zealand and travelled to South America.

Bushfires have occurred at the time of severe drought, when heatwaves, severe storms, floods and cyclones have also threatened Australian communities. Losses from recent hailstorms in NSW, VIC and the ACT are reported as half a billion dollars and rising.

An immense effort has been launched by all tiers of Government including contributions by international defence and firefighting agencies. Businesses, not-for-profit and community service organisations have provided immense support. In recent weeks the strain on resources has been compounded by the emergence of the 2019-nCoV outbreak.

The events have provided an illustration of a compound event with its component events made up of multiple cascading consequences which have caused complex resourcing, coordination and recovery challenges.

Australia has been experiencing more frequent fire weather, and fire seasons are longer. This trend is expected to continue under the influence of climate change.

In our 25th anniversary edition we provide a brief overview of Risk Frontiers' bushfire research to date as well other key analysis related to natural hazards.



The Gold Rush Colony, Mogo



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Northern NSW bushfire impact research

Steven George, Salome Hussein, Jacob Evans, Risk Frontiers

Risk Frontiers deployed a damage survey team in early December. The team travelled to bushfire-affected communities in northern NSW to make observations and report on impacted areas. The two fires concerned behaved differently and were influenced by weather conditions and terrain. The role of wind conditions and embers in the Busbys Flat Fire were significant factors in the location and distribution of destroyed buildings and their proximity to bushland. Industries/Infrastructure affected: Sawmill, pine plantations, railway.

Long Gully Fire (Drake Fire)

A survey of Long Gully Road from the Bruxner Highway confirmed the area had dense vegetation, which was severely burnt during the Long Gully Fire (LGF). The southern end of Long Gully Road (close to the fire ignition point) is remote and steep, which would likely have limited initial fire control efforts. Losses from early stages (September) of the LGF appear to be limited to private holdings and farms, with no evidence of any commercial or industrial enterprises being impacted. The team located 15 buildings (and one vehicle) impacted by the fire along Long Gully Road - most were totally destroyed or damaged enough to require demolition. The buildings were a combination of residences (of varying size and construction) and out-buildings. Destroyed properties varied in distance from the road from 10-15 metres to 1.9 km and were on either side of the road. Visible debris revealed no consistency to the construction materials of destroyed buildings, with corrugated sheeting, brickwork, timber and fibro (or similar) sheeting evident and several examples of water tanks remaining. There was minimal variation in distance to adjacent bushland. Most destroyed structures were no more than 20 metres from significant bush. At several locations, only a concrete slab remained after debris was removed. Over 7.5 weeks, the LGF burnt more than 74,000 hectares of bush and

farmland. Conditions on Tuesday 8 October caused the LGF to reintensify and join with other local fires (including the Busbys Flat Fire). Together, the new combined fire was responsible for extensive damage to Rappville and two fatalities.

The Busbys Flat Fire (BFF), Rappville and wider area

An act of arson on Friday 4th October in the Busbys Flat area is the suspected cause of the Busbys Flat Fire (BFF). High temperatures and ferocious winds on Tuesday 8th October caused the BFF to intensify and merge with other major fires burning in the area, including the still active Long Gully Fire. This combined fire destroyed an estimated 30 homes and commercial properties as it travelled from its ignition point east toward Rappville (population 170). A noteworthy aspect of this fire, as reported by witnesses and volunteers, was the quantity of embers it generated, which were then carried by strong wind over large distances. Within the town, 16 buildings, mainly dwellings, were burnt. Where debris had not been cleared, the most common construction materials were evidently timber and fibro, with corrugated sheeting and brickwork. At least eight of the 16 destroyed building sites had “asbestos” warning signs posted and were secured by fences. There was an apparently random distribution of destroyed buildings, and the lack of substantial bushland within the village demonstrated how embers in high winds can propagate fires over long distances. The fire that impacted Rappville and surrounding areas was responsible for significant commercial losses, consisting of 200 claims costing an estimated \$25 million. Significant infrastructure damage included a large sawmill located on Old Tenterfield Road, distorted steel tracks and destroyed hardwood sleepers of the Rappville Rail Bridge, and extensive fire damage to numerous large pine plantations.



Damaged paddocks in the Northern Tablelands

Statistical dependence of bushfire risk on distance to bush and the influence of ember attack

Proximity to bushland is a significant factor in determining a building's vulnerability. Figure 1 depicts bushfire damage based on aggregated data from recent major bushfires and shows the percentile of destroyed buildings in relation to nearby bushland (i.e: an ignition source). However, the Rappville (2019) and Duffy (2003) examples suggest that in cases where ember attack is a major element of a fire's behaviour, this dependence may be less important. At Rappville ~55% destroyed structures occurred between 9 - 100 metres of bushland with the remaining ~45% occurring outside 100 metres. These distances were significantly greater at Duffy. Notably, weather conditions prior to both fires were starkly similar. At Duffy, the Bushfire CRC reported that "unusual severity of the fire was generated by extreme weather conditions" (a combination of particularly strong wind, temperatures near 40°C and drought conditions) and that "most houses were ignited by either ember attack or house-to-house ignition."¹

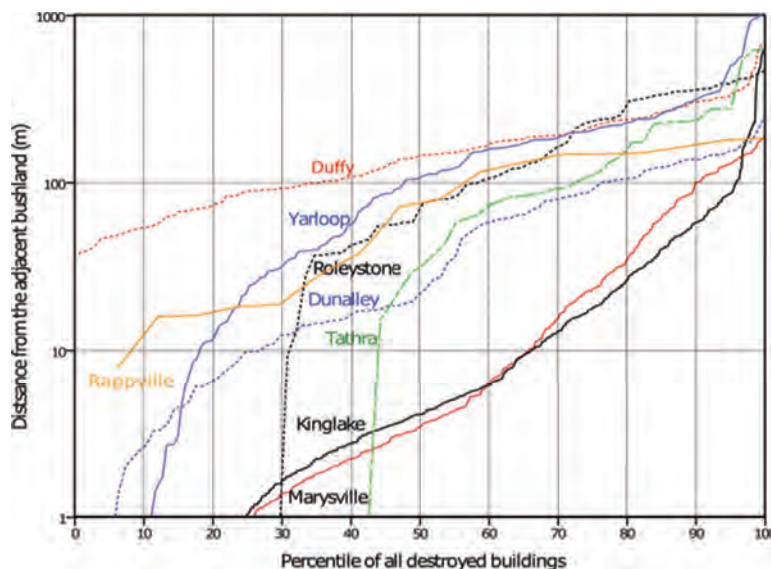


Figure 1: Cumulative distribution of buildings destroyed in major bushfires in Australia in relation to distance from nearby bushland. For reference, approximately 42% of homes destroyed in Tathra were within 1m of bushland while 25% of homes destroyed in Marysville and Kinglake were within 1m of bushland. At Rappville, the closest building to bushland was approximately 9m with about 50% of destroyed buildings located between 10 - 100 m from bushland.

¹Bushfire CRC Report - INVESTIGATION OF BUSHFIRE ATTACK MECHANISMS RESULTING IN HOUSE LOSS IN THE ACT BUSHFIRE 2003 (2005). http://www.bushfirecrc.com/sites/default/files/downloads/act_bushfire_crc_report.pdf

Bushfire deaths in Australia, 2010-2020

Lucinda Coates, Risk Frontiers

Targeting policy interventions to enhance public safety is critical. Here we interrogate PerilAUS, Risk Frontiers database of natural hazard occurrences in Australia, to analyze bushfire deaths occurring since those of the 2009 Black Saturday fires.

This data was based mainly on articles from the news media - a rich source of details and circumstances around such fatalities - and represents lower bound estimates. The financial year is utilised for bushfire season totals. Increases in population have been normalised utilising fatality rates, which look at the overall number of deaths for a given group of people (say, males, or persons aged 30-34) against the population of that group. We have measured this in terms of deaths per 100,000 (background) population.

At least 65 deaths due to bushfires have occurred in Australia from FY 2010 to FY 2020 (Table 1). Just over half of the deaths (n=35; 54%) occurred during FY 2020 (note: the current fire season is far from over, especially for the southern states of Australia).

The most common age range of those killed in bushfires was 60-64 years (n=12; 18%), followed by 65-69 years (n=8; 12%). No deaths occurred below the age range of 15-19. The normalised age ranges shows the 60-64 to 75-79

age groups being overrepresented. Again, the 60-64 age group showed the highest value (death rate 0.94 deaths per 100,000 population), followed by age groups 75-79 (0.81), 65-69 (0.73) and 70-74 (0.60).

Table 1: Deaths from bushfires in Australia, FY 2010-2020 as at 29/1/2020

Financial Year	Deaths	Percentage
2010	3	5%
2011	1	2%
2013	6	9%
2014	4	6%
2015	2	3%
2016	10	15%
2017	2	3%
2019	2	3%
2020	35	54%
Total	65	100%

Of the 65 total deaths, 54 (83%) were male and 11 (17%) female. This relates to death rates of 0.46 deaths per 100,000 population for males and 0.09 for females.

New South Wales is the Australian jurisdiction where most of the deaths (n=33; 51%) occurred. This is followed by Victoria (n=9; 14%) and Western Australia (n=9; 14%) then South Australia (n=8; 12%). Over longer time periods, however, Victoria has had the highest proportion of deaths.

Twelve (18% of) deaths occurred inside a house or other building and 53 (82%) outside. Of those outside, 26 (49%) were in a land vehicle, 22 (42%) were on foot and five (9%) were in an aircraft. Vehicles were related to 33 (45%) of deaths; eight (11% of) deaths were treefall-related. Four deaths were related both to vehicles and to treefall.

The most common causal factor of death was being burnt whilst in vehicles (n=15; 23%). Of these, ten were due to late evacuation and five were due to firefighting (including en route). Thirteen (20%) were burnt in (or near) their home: nine were in the house, undertaking no/ little action or being too late to evacuate and four were firefighting. Eleven deaths (17%) were due to a cardiac event and of those ten known, all were firefighting: five saving their own properties, two professional firefighters, two informal volunteers (i.e., with RFS or CFA) and one member of the public (i.e., not a brigade member but helping out on someone else's property). Two of the three fatalities caused by a medical condition exacerbated by the fires were due to asthma caused by bushfire smoke, at some distance from the active fire zone.

In relation to the activity of the decedents immediately prior to death, 30 (46%) were involved in firefighting efforts and another nine (14%) were en route to fight fires. Thirteen (20%) were attempting to evacuate: nine were

late evacuations, three were saving their own property and then attempting to evacuate and one, a formal volunteer, was warning neighbours to evacuate. Ten (15%) of the decedents were undertaking no or little activity but were in/ near their home.

The most common reason behind the activity being carried out by the decedent was saving their own property, belongings or animals (n=14; 22%) – either firefighting or evacuating late from firefighting. Eleven (17%) were evacuating late or did not attempt to evacuate – either in car or in house. Thirteen (20%) were formal volunteers involved in firefighting, eleven (17%) were professional firefighters and five were members of the public involved in firefighting.

Figure 1 shows the death rate per 100,000 population for bushfires that have affected Australia since 1900, from PerilAUS. This 110-year record shows no particular trend over time but, rather, episodic severe bushfire seasons against a background of relatively low death rates.

The total of 35 deaths for the 2019/20 fire season, whilst relatively low, is still 35 too many: however, compared to the severity and the widespread extent of the fires, the death toll could have been higher. The PerilAUS record over the last decade shows that particular focus should be given to:

- professional and volunteer firefighters
- males aged 60+ trying to save own property, especially those with cardiac conditions
- males aged 55+ attempting a late evacuation or not leaving home in time
- males and females aged 55+ and remaining in their house.

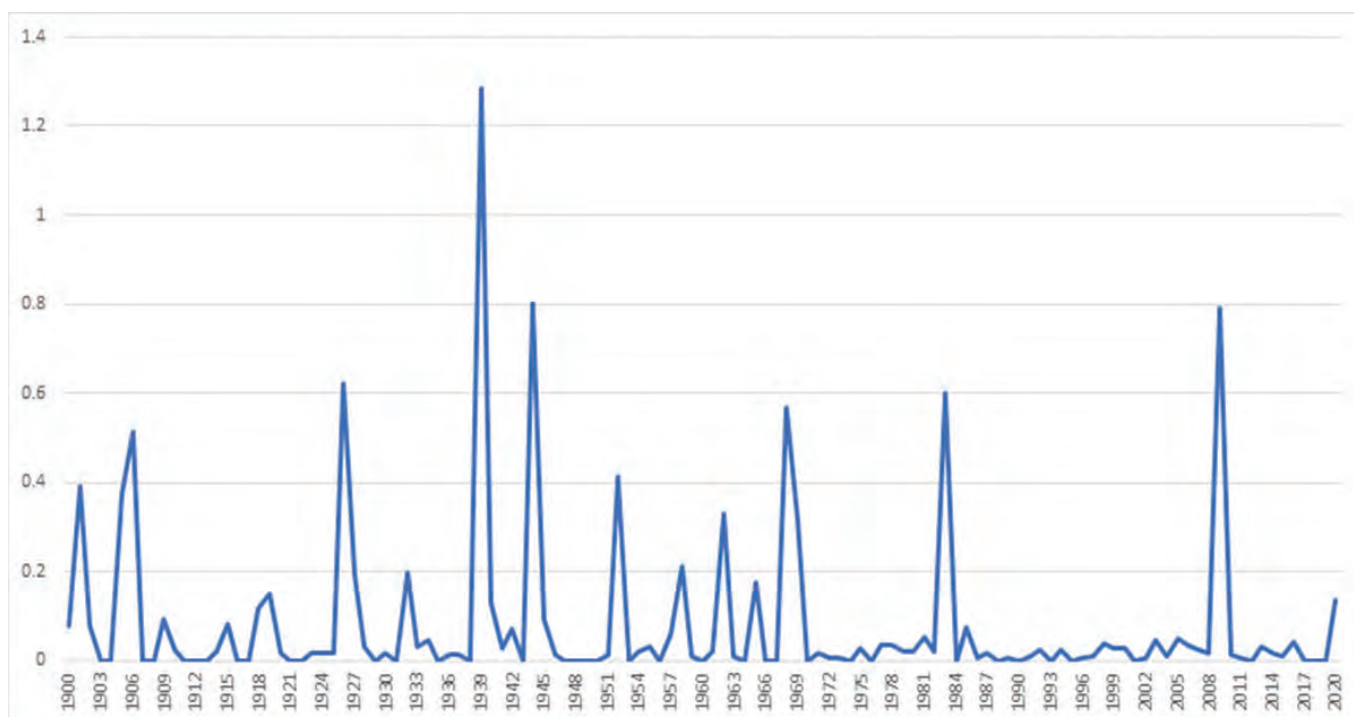


Figure 1: Death rates per 100,000 population from bushfires in Australia, FY 1900-2020

Risk Frontiers turns 25!

by Russell Blong

Last year Risk Frontiers turned 25 demonstrating the success of what may be Australia's longest-running insurance industry research collaboration. In this, our 73rd newsletter, Professor Russell Blong, the founder of Risk Frontiers, shares his memories of the early years.

In 1988 I was awarded an Australian Research Council Grant to investigate natural hazards in Australia. I thought we could leverage insurance industry involvement to expand the scope of the project, but it soon became clear that the industry really wasn't interested. I chatted to Gerhard Berz, global head of Geohazards at Munich Re, who agreed the industry should be engaged and urged me to persist.

I decided to spend the first half of 1989 at Munich Re in Sydney. A few days before I was due to start the Newcastle Earthquake (26th December 1989) occurred (see article by Paul Somerville in this issue) making natural hazards research in Australia much more interesting for the insurance industry.

The ARCG team at Macquarie University – Kylie Andrews, Clare Byrnes, De Radford and Lucinda Coates – had already begun work on a natural perils database (now PerilAUS) spanning the period since 1900, when a severe hailstorm on 18th March 1990 caused damage in 130 postcodes in Sydney. Overnight, the Australian insurance industry, which at the time really had no hazards research capacity at all, became interested in academic research. We examined hundreds of residential claims from the 1990 hailstorm and prepared a database of Sydney hailstorms back to 1788 – analyses that years later would become important components of HailAUS.

We also built a scenario-based Sydney residential property earthquake model in a spreadsheet for NRMA. While crude by today's standards, this was the first Australian earthquake loss model that wasn't based entirely on hand waving and selective heuristics (i.e., guessing).

In early 1992 I came across a copy of a letter written to all Australian universities by Ray Carless and Rob de Souza from Greig Fester, reinsurance brokers, seeking expressions of interest in developing an earthquake loss model for Australian capital cities. Although the deadline for responses had long passed, I rang up and we eventually produced earthquake loss models for insured residential property in Sydney and Melbourne. This study was published by Greig Fester, with most of the modelling work, including the switch from spreadsheet to Fortran, undertaken by Laraine Hunter.

The NHRC moved to a demountable classroom on the edge of the Macquarie campus (a site now occupied by Macquarie Hospital). We did some research work for our insurance supporters on a range of topics, for Geoscience Australia on landslide and tsunami databases,

for Department of Foreign Affairs and Trade on natural disasters in the Solomon Islands, on crop hail damage, on lightning fatalities, the volcanic eruption in Rabaul in 1994, integrated natural peril hazard assessments in Vanuatu and Fiji, and an evaluation of the Australian International Decade for Natural Disaster Reduction program.

While we had been confident that the NHRC would be self-funding by the time the three years were up, all too soon we were talking to our industry partners about another three years, and then another ... Meanwhile our insurance industry engagement grew and with it the number of industry sponsors, eventually reaching 10 by 2001 – QBE, Benfield Greig, Swiss Re, Guy Carpenter, NRMA, Aon Re, Employers Re, CGU Insurance, Gerling Global Group, and Royal Sun Alliance – a superb cross-section of the Australian and global insurance industry.

In the early years it would be fair to say the university administration was cautious and could have been more supportive of the NHRC and there was some internal opposition to it being a separate research centre. This, no doubt, stemmed from the uniqueness of the NHRC business model within a university, with perhaps few, if any, similar models in place around the world at the time. We were helped through all of this by Peter Curson, then Head of the School of Earth Sciences. Eventually we were able to show the university administration that NHRC was a profit centre rather than a cost centre, as we were bringing in substantial funds external to the university system in addition to engaging industry.



An image in the Natural Hazards Observer (University of Colorado) announcing the start of the NHRC.

We also moved out of the 'tin shed' and back to the main Earth Sciences building at the University. Luckily this failed to put a dent in the number of lunches and other special occasions we celebrated.

In 1996 NHRC commenced work on flood vulnerability. This work took more years than we intended and even more years to reach valuable agreements with the industry. In the meantime, we commenced a range of flood-related research and evaluation for the NSW Department of Land and Water Conservation and undertook a major effort to understand flood damage to residential and other buildings – all of this at a time when flood insurance in Australia was rare. At the same time, we began the development of HailAUS with additional financial support from Benfield Greig and Hannover Re.

Graduate students including Heather McMaster, Stephen Yeo, Keping Chen, Christina Magill, Sandra Schuster, Andrew Gissing and Ben Miliauskas completed theses on hail damage to crops, flooding in Fiji, geospatial approaches to natural hazards and risk assessment, volcanic risk in Auckland, hail identification and losses in

Sydney, commercial flood damage and micro tremors in Newcastle.

In 2001, at the suggestion of Ian Watson, a colleague who had been on the staff of Physical Geography at Macquarie University, the Natural Hazards Research Centre changed its name to Risk Frontiers and a new era began. The insurance industry had changed from an almost entirely analyst-free zone in the early 1990s to workplaces where researchers, analysts and actuaries were thinking about catastrophic events and insurance implications. John McAneney joined Risk Frontiers as Deputy Director and in 2003, shortly after Risk Frontiers-NHRC's ninth birthday. Russell Blong, worn down by endless strategising and long lunches, called it a day and John took over as Director.

Now, 25 years on, Risk Frontiers is Australia's leading catastrophe loss modelling and research company, demonstrating the success and impact of industry collaboration. We have swapped spreadsheets for Machine Learning and now provide services globally to a diverse range of clients.

To be continued.



Happy birthday everyone and all the best
in the new year!



Farewell to the 'tin shed' – from left Russell Blong, Laraine Hunter, De Radford, Carol Robertson, Frank Siciliano, Roy Leigh, Ivan Kuhnel, Stephen Yeo, and Keping Chen. Lucinda Coates – the one person to have survived the whole 25 years of NHRC-Risk Frontiers (and even she failed to turn up for some years) – took the photo in 1999. Sadly, both Laraine and Roy have left this earth – visit <https://riskfrontiers.com/people/tributes/> to learn just how important they were to the early years of NHRC-Risk Frontiers and how much we valued them.

Officials acquitted of professional negligence in the Fukushima nuclear disaster

Paul Somerville, Risk Frontiers

Onset of a catastrophe

I was watching the news on NHK TV (Japan's public broadcaster) on September 11, 2011 when the broadcast was abruptly interrupted by a news flash that a JMA (the Japan Meteorological Agency) magnitude 7.9 earthquake had occurred off the Tohoku coast of northern Japan (Risk Frontiers Briefing Note 217, 2011). It was night in Japan and at first there was not much to see as no reports of extensive shaking damage were shown. As JMA continued to update its estimate of the magnitude from 7.9 to 8.4 and then 8.7, I received an email from my colleague Dr Thio in California estimating the magnitude at 9.0 about 20 minutes after the event began, confirmed by JMA five minutes later. Soon the first arrivals of tsunamis at ports along the Tohoku coast began to appear on the screen, followed by dramatic images of waves and inundation never seen before on TV. The tsunami killed more than 18,000 people along Japan's north-east coast, including Fukushima. Initially there was little mention of the Fukushima Nuclear Power Plant, operated by Tokyo Electric Power Company (TEPCO), and it took weeks before the dire condition of the five units became clear, as graphically chronicled by Australian journalist Mark Willacy (2013).

Reactors 1 to 3 at the plant suffered nuclear fuel meltdowns, while hydrogen explosions damaged the buildings housing units 1, 3 and 4 (Figure 1). The nuclear meltdowns sent plumes of radiation into the atmosphere and forced the evacuation of 160,000 people living near the plant, 31,000 of whom are still unable to return to their homes. TEPCO has said it will take 40 years to locate and remove the melted fuel from the reactor cores, although some experts believe decommissioning could take longer. The government has estimated that the total cost of dismantling the plant, decontaminating surrounding areas and compensating victims at about \$US200bn. TEPCO this week announced that its preferred method of disposing of more than a million tonnes of contaminated water stored at the site is to discharge it into the Pacific ocean, which is strongly opposed by local fishermen who have spent the last eight years rebuilding their industry.

Acquittal of TEPCO executives

On 19 September 2019, three former top executives of TEPCO were acquitted of professional negligence resulting in death and injury related to the 2011 Fukushima nuclear accident. The trial started in June 2017 after a judicial review panel comprising ordinary citizens ruled that the former executives should be indicted. Initially, prosecutors twice declined to proceed with the case, citing insufficient evidence and a slim chance of conviction. A total of 37 hearings were held for the trial, during which more than 20 witnesses, including current and former TEPCO officials as well as earthquake and tsunami experts, were questioned.



Figure 1. From top: The 15.5 metre high tsunami overtopping the tsunami sea walls on March 11, 2011; The tsunami inundating the reactors; An explosion on March 15 ruptured the reactor components of Reactor no. 2 and breached the main containment; Smoke rising from damaged Reactor No. 3 Source: TEPCO

While no one is officially recorded as having died as a direct result of the meltdowns, the former executives were indicted for negligence that allegedly resulted in the deaths of 44 people, including patients who were forced to evacuate from a nearby hospital, as well as injuries suffered by 13 people as a result of the hydrogen explosions.

In concluding the two-year trial, the Tokyo District Court ruled that it was not realistic for the former executives to have predicted all possible tsunami scenarios. The defendants, who were the only people facing prosecution in relation to the nuclear disaster, had all pleaded not guilty to charges of professional negligence resulting in death, arguing that the data available to them before the disaster was unreliable, that the tsunami was unforeseeable and that the meltdowns would have occurred even if they had implemented preventive measures. Prosecutors had sought five-year prison terms for them.

The Fukushima nuclear accident, and what TEPCO knew

In planning the design of the Fukushima plant in 1967, TEPCO decided to reduce the natural 35-metre cliff at the site to just ten metres in height. The 15.5 metre high tsunami generated by the earthquake overtopped the plant's 5.7-metre tsunami seawall (Figure 2), flooding the basements of the power plant's turbine buildings and disabling both the main power supply and the emergency diesel generators used for cooling the reactor cores to avoid meltdown. Installation of the emergency diesel generators just ten metres higher may have prevented the meltdowns from occurring.

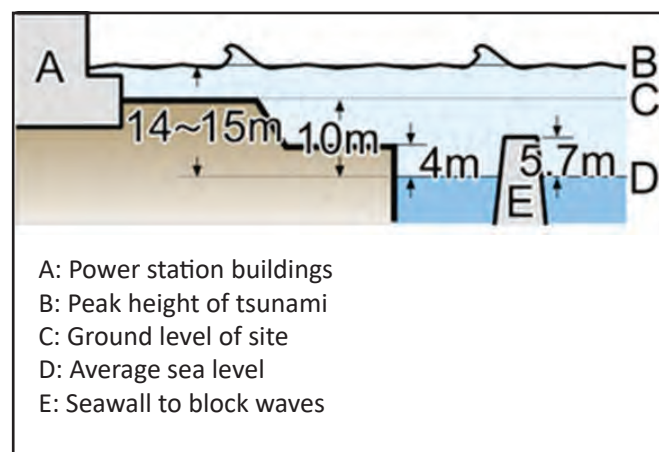


Figure 2. The height of the tsunami that inundated the power station buildings.

The prosecution claimed that the TEPCO top executives should be held responsible because they could have predicted tsunamis of the height that inundated the Fukushima plant. They claimed that the executives were present at meetings where experts warned of massive tsunamis that could inundate the Fukushima coast. The findings were reported to TEPCO executives, according to a written statement from former TEPCO executive Kazuhiko Yamashita, who said the three executives had approved plans to carry out tsunami safety measures in March 2008. However, in July the same year, according to Yamashita, the trio shelved the plans, saying it would be



Figure 3. Stone marker indicating historical tsunami inundation limits, with road descending the slope to a narrow coastal plain. One such marker dates back to the 869 Jogan tsunami.

difficult to convince the government and local residents of the power plant's safety and that the move could prompt calls for halting operations, implying that the executives had recognized the necessity for such measures.

What was known of the hazard?

The Japanese government's Headquarters for Earthquake Research Promotion (HERP) released its long-term evaluation in 2002 predicting that a very large tsunami could occur off Tohoku including the area off Fukushima. It was known that a very large tsunami-generating earthquake, the Jogan earthquake, had occurred in the Tohoku region on 9 July 869, about one thousand years earlier. The extent of flooding of the Sendai plain caused by the Jogan tsunami, which had been mapped using dated deposits of sand, extended at least 4 kilometres inland. Its inundated areas closely matched those of the 2011 Tohoku tsunami in Sendai, suggesting that it may have also had a magnitude of 9.0 (Minoura et al., 2001). The Tohoku coast is dotted with markers like the one shown in Figure 2 indicating inundation limits in past earthquakes and warning people not to build at lower levels, an admonition difficult for fishermen to heed.

Dr Kunuhiko Shimazaki, who was a member of HERP's earthquake research panel in 2002 (and my host when I was a Visiting Research Fellow at Tokyo University's Earthquake Research Institute in earlier years), told the court that the Cabinet Office pressured the panel shortly before the announcement of the HERP long-term evaluation to state that the assessment was unreliable. The headquarters reported in its introduction to the HERP long-term evaluation that there were problems with the assessment's reliability and accuracy. In his testimony, Shimazaki pointed out that the Central Disaster Prevention Council's decision not to adopt the long-term evaluation led to inappropriate tsunami countermeasures, and he stated that many lives would have been saved if the countermeasures based on the HERP long-term evaluation had been in place (Mainichi Newspaper, 2018a).

Failure of regulatory authority

A former safety screening division official of the Ministry of Economy, Trade and Industry's Nuclear and Industrial

Safety Agency (NISA) reported that TEPCO did not accept the agency's request to assess the tsunami hazard after the release of the HERP report in 2002 (Mainichi Newspaper, 2018b). The official held a hearing on TEPCO the following month as to whether the report would affect safety measures at the Fukushima No. 1 plant. NISA told the utility to calculate a possible earthquake-tsunami disaster off the coast from Fukushima to Ibaraki prefectures. In response, TEPCO representatives showed reluctance, saying that the calculation would "take time and cost money" and that there was no reliable scientific basis in the assessment report. In the end, the agency accepted the utility's decision to shelve the earthquake-tsunami estimate. In 2006, NISA again requested TEPCO to prepare its nuclear plants for massive tsunamis exceeding envisioned levels, but the company did not comply until finally conducting a calculation in 2008.

Tsunami hazard analysis ignored

Annaka et al. (2007) and Thio et al. (2007) were the first to develop probabilistic methods for tsunami hazard analysis. Dr Annaka worked at Tokyo Electric Power Services Co. (TEPSCO), a subsidiary of TEPCO, and I saw his presentation at a conference in Japan (JNES, 2010) in which he estimated that the return period of a 5.7 metre high tsunami at Fukushima was as little as a few hundred years. In 2007 and 2008, TEPSCO estimated that tsunamis up to 15.7 meters high could inundate the nuclear plant based on the HERP analysis. The TEPSCO witness told the court that he briefed TEPCO headquarters of the outcome of TEPSCO's estimate of possible tsunami heights in March 2008. An employee at TEPCO headquarters subsequently asked the witness whether the estimated scale of possible tsunami could be lowered by changing the calculation method. He found that it could not, and eventually his prediction was not accepted as TEPCO's estimate of the height of a possible tsunami (Mainichi Newspaper, 2018c).

The prosecution stated that, although TEPCO headquarters initially considered measures to protect the Fukushima No. 1 nuclear complex from tsunami after being briefed of the outcome of TEPSCO's tsunami estimate, those who were on the company's board at the time postponed drawing up tsunami countermeasures, instead commissioning the Japan Society of Civil Engineers to look into the matter. Consequently, TEPCO failed to reflect the 15.7 metre prediction in its tsunami countermeasures at the power station. The Prime Minister's Cabinet Office's Central Disaster Prevention Council also did not adopt the long-term evaluation in developing its disaster prevention plan.

Reconciling acquittal with the conclusions of the Nuclear Accident Independent Investigation

At first it seems difficult to reconcile the acquittal with the Message from the Chairman of the Nuclear Accident Independent Investigation Commission (National Diet of Japan, 2012):

"The .. accident at the Fukushima Daiichi Nuclear Power Plant cannot be regarded as a natural disaster. It was a profoundly manmade disaster – that could and should

have been foreseen and prevented. And its effects could have been mitigated by a more effective human response.... What must be admitted – very painfully – is that this was a disaster "Made in Japan." Its fundamental causes are to be found in the ingrained conventions of Japanese culture: our reflexive obedience; our reluctance to question authority; our devotion to 'sticking with the program'; our groupism; and our insularity. [The nuclear power industry's] regulation was entrusted to the same government bureaucracy responsible for its promotion. This... was reinforced by the collective mindset of Japanese bureaucracy, by which the first duty of any individual bureaucrat is to defend the interests of his organization. Carried to an extreme, this led bureaucrats to put organizational interests ahead of their paramount duty to protect public safety.'

Perhaps his statements that *"This report singles out numerous individuals and organizations for harsh criticism, but the goal is not—and should not be—to lay blame,"* and *"Had other Japanese been in the shoes of those who bear responsibility for this accident, the result may well have been the same"* may have contributed to the acquittal.

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Earthquake risk in Australia 30 years after the 1989 Newcastle Earthquake

Paul Somerville, Risk Frontiers



Newcastle Workers Club. Source: livinghistories.newcastle.edu.au

The 1989 Newcastle Earthquake and its Impact

The Newcastle earthquake occurred at 10:27am local time on December 28, 1989. It had a magnitude M_w of 5.42 (Allen et al., 2018), the epicentre was approximately 15 km SW of the Newcastle CBD (near Boolaroo) and it occurred at a depth of about 11 km.

The earthquake claimed 13 lives: nine people died at the Newcastle Workers Club (pictured above), three people were killed along Beaumont Street in Hamilton and one person died of shock in Broadmeadow. Melchers (2012) showed that collapse of the Newcastle Workers Club would have been unlikely if there had not been significant deficiencies in the structure as built. The number of people in the city on the day of the earthquake was lower than usual, due to a strike by local bus drivers. It is estimated that about 500 people may have died on a normal day.

The earthquake caused damage to over 35,000 homes, 147 schools and 3,000 commercial and other buildings, with significant damage (over \$1,000) to 10,000 homes and structural damage to 42 schools within the immediate Newcastle area. About 300 buildings were demolished. Approximately 300,000 people were affected by the earthquake and 1,000 made homeless. 160 people required hospitalisation but the Royal Newcastle Hospital was rendered inoperable by the earthquake. Insured

losses are estimated to be \$4.25 billion normalised to 2017 values (McAneney et al., 2019).

The effects of the earthquake were felt over an area of about 200,000 sq. km, with isolated reports of shaking felt up to 800 km from Newcastle. Damage to buildings and facilities occurred over a 9000 km² region. The damage was most severe on soft sediments from the Hunter River, with shaking intensity of MMI VIII observed at many locations.

Lessons learned

As pointed out by Woodside and McCue (2017), the Newcastle earthquake demonstrated that all the basic principles of earthquake engineering design that have been learned abroad also apply to Australia. Specifically, the damage was due to:

- Failure of unreinforced masonry, especially the failure of galvanised brick ties due to corrosion from the lime mortar
- The failure of non-structural elements such as ceilings and chimneys
- The effects of eccentricity and soft stories on the performance of buildings
- Inadequate seismic design including tying together of the structure.

As described by Brunsdon and Bull (2019), the involvement by New Zealand engineers in the Newcastle earthquake response and recovery prompted a closer look at New Zealand's earthquake preparedness, particularly through the professional engineering lens. In conjunction with the preceding Loma Prieta earthquake and subsequent Northridge and Kobe earthquakes, the Newcastle earthquake strongly influenced subsequent work in New Zealand, notably the development of capabilities in post-earthquake assessment and placarding and urban search and rescue. As a result, New Zealand was much better prepared to deal with the many challenges presented by the Canterbury Earthquake Sequence of 2010/11, and significant post-earthquake support of urban search and rescue in Christchurch was provided by Australian engineers who had been trained by their New Zealand counterparts.

Contribution to the development of seismic provisions in the Australian Building Code

Prompted initially by the Mw 6.68 Meckering earthquake of 1968 and further by the three Mw 6.3 to 6.6 Tennant Creek earthquakes of 1988, Standards Australia in 1988 decided to revise the Australian Building Code standard AS 2121. The appointed subcommittee first met on 12 December 1989 in Adelaide, about two weeks before the Newcastle earthquake on 28 December 1989 (Woodside and McCue, 2011). The Newcastle earthquake provided impetus to this task, and the revised code was introduced as AS1170.4 in draft form in 1991 and published in 1993. The performance objective was and still is for life safety or better in a rare event, currently defined as one whose ground motion has an annual probability of exceedance (AEP) of 1:500 (return period of 500 years). The code peak accelerations, up to about 0.1g in some cities, are exceeded close to earthquakes having magnitudes above about Mw 4.5.

In many locations in Australia, wind forces, rather than earthquake forces, govern code-based structural design, and so many practicing engineers here do not develop a full understanding of the nature of the forces presented by earthquakes. It is one thing to design a structure to resist the steady force of the wind on the side of a building, and quite another to design it to resist the forces that result from an earthquake, which are equivalent to having the rug you are standing on pulled sideways from under you. Unless the building is strong enough that its roof can follow the abrupt horizontal movement of its foundation within a separation of a few percent of its height as the ground moves back and forth, it will collapse. This requires the careful detailing of connections between columns, beams, floors and walls so that even if the building is damaged in a strong earthquake it does not collapse. In contrast, buildings can easily be designed to withstand the strongest winds even without structural damage let alone collapse.

Motivated by the relatively small (Mw 6.2) Christchurch earthquake of February 22, 2011, which caused major damage and rendered the CBD unusable for a long

period of time because it occurred directly underneath the city, Goldsworthy and Somerville (2012) argued for the adoption of a lower probability event (1:2,500 AEP or 2,500 year return period instead of 1:500 AEP or 500 years return period) in Australia in conformance with developments in building codes in Canada, New Zealand and the United States. Unlike the mainly empirical approach to code development based primarily on the past performance of structures in earthquakes, this new generation of codes uses the framework of performance-based design to quantitatively estimate the capacity of buildings to withstand strong ground motion.

Recent developments in seismic provisions in the Australian Building Code

Major improvements were made in the national seismic hazard map of Australia by Geoscience Australia (NSHA18; Allen et al., 2019). Revision of the magnitudes of historical Australian earthquakes led to the conclusion that for a given magnitude, earthquakes are about half as frequent in Australia as had been previously thought. However, the NSHA18 hazard map was not adopted in the most recent revision of AS1170.4 on August 15, 2019 (Standards Australia, 2019), which contains a minimum peak ground motion level of 0.08g for design. The large reductions in probabilistic seismic hazard estimates in NSHA18 mean that the ground motion levels embodied in AS1170.4 – 2019 are roughly equivalent to an AEP of 1:2,500 (return period of 2,500 years) in most of the capital cities, as shown by Allen et al. (2019), thus largely fulfilling the objective proposed by Goldsworthy and Somerville (2012).

Development of catastrophe loss modeling for the insurance industry

Catastrophe loss modeling for the insurance industry was in its infancy when the Newcastle earthquake occurred. Through the founding of Risk Frontiers in 1994, enabled by the sponsorship of the insurance industry in Australia, the Newcastle earthquake spurred the development in Australia of quantitative methods of estimating catastrophic losses from natural disasters based on validation against comprehensive catalogues of historical losses. Risk Frontiers now has a complete set of catastrophe loss models for all perils in Australia as well as several others in the Asia Pacific region.

Cautionary notes

The beneficial outcome of NSHA18 described above is offset by the fact that in Australia, due to the lack of attention given to seismic design, the performance of some buildings is likely to be poor even in a small event. In Australia, material codes such as the Steel Structures code (Standards Australia, 1998) and the Concrete Structures code (Standards Australia, 2009) do not require designers to use capacity design principles in their design. The implementation of these design principles in New Zealand since the 1980s, in line with the performance requirement for "near collapse" or better under a 2,500

year return period event, is what probably saved many lives in the Christchurch earthquake. Australian building codes do not address single story dwellings.

To further deter complacency, note that there have been 30 known earthquakes with magnitudes larger than the 1989 Newcastle earthquake since 1840, nine of which had magnitudes of Mw 6.2 (the size of the 2011 Christchurch earthquake) or larger. Several Australian capital cities, including Adelaide, Canberra and Melbourne, have known faults in their vicinity that are capable of generating damaging earthquakes. Australian earthquakes have sometimes occurred in clusters; the three Mw 6.3 to 6.6 earthquakes occurred in one day in the 1988 Tennant Creek sequence. Australian earthquakes have also been followed by long aftershock sequences like that of the Canterbury sequence; one occurred off the east coast of Tasmania near Flinders Island from 1884 to 1886 with magnitudes as large as Mw 6.4.

The 1989 Newcastle earthquake, with a revised Mw of 5.42, caused a loss equivalent to \$4.25 billion if it were to recur today (McAneney et al., 2019). This is the largest earthquake loss among all of the Australian natural disaster losses spanning 1967 to the present listed by these authors. Although weather related disasters have historically caused larger losses than the 1989 Newcastle earthquake, larger earthquakes could cause larger losses than those of any weather-related disaster.

Challenges for the way forward

The 1989 Newcastle earthquake and the 2011 Christchurch earthquake present challenges for improving the outcomes of future earthquakes in Australia. We need ongoing training of emergency responders in search and rescue, and of engineers in assessing the safety and placarding of buildings in the immediate aftermath of the earthquake. Extending beyond prescriptive code formulas, we need to foster among practicing structural engineers a better understanding of the principles that underly earthquake resistant design. Given the high level of vulnerability of Australian cities to earthquakes, building design and construction need to consider not only the integrity of individual buildings and infrastructure and the life safety of their occupants, but also the role that they play in providing the functionality and viability of whole communities, with advanced focus on recovery. It took several years for Newcastle to recover from its relatively small magnitude earthquake. Almost ten years on, Christchurch is still struggling to regain the functionality that its residents took for granted before the 2011 earthquake. We must do what we can to avoid that fate.

A good way to advance preparedness and mitigation activities is to develop plans for response to and recovery from significant scenario earthquakes in major cities. These plans need to involve emergency responders, structural engineers, architects, city planners, community

organisations, and the members of relevant government departments (such as building officials) and elected representatives of the affected cities, states and nation. Members of the public at large also need to be aware of what to do if they experience an earthquake. The message to “drop, cover and hold on” is promoted and practiced in annual “ShakeOut” exercises around the globe.

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