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SHAPING FUTURE CATASTROPHIC DISASTERS

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Version	Release history	Date
1.0	Initial release of document	01/08/2018

Publisher:
Bushfire and Natural Hazards CRC

August 2018

Citation: Gissing, A, Eburn, M & McAneney J 2018, *Shaping future catastrophic disasters,* Melbourne, Australia, Bushfire and Natural Hazards CRC

Cover: Lismore flood. Source: iStock

TABLE OF CONTENTS

ABSTRACT

This study explores the influence of political, economic, environmental, social and technological factors on our changing riskscape and how these factors might influence the ability of communities to respond and recover from future catastrophic disasters. These factors are explored through a review of relevant literature and short interviews with emergency management leaders.

While there is wide uncertainty regarding future conditions that may shape disaster events, special consideration should be given to the increased risks posed by urban development in at-risk areas; the impact of climate change on the extreme weather events; system inter-connectedness and contagion risks; cyber-security; societal reliance on new technologies, and ageing infrastructure.

There are, however, opportunities to positively influence future risk profiles through the adoption of improved building codes and risk-informed land-use planning; urban renewal to enhance the resilience of existing development; climate change adaptation, especially in respect to the consequences of increased air temperatures and sea-level rise; by incorporating resilience considerations into infrastructure design; and the adoption of technological advances to better understand and manage risk.

INTRODUCTION

Extreme weather events and natural disasters are among the greatest risks facing communities across the globe (World Economic Forum, 2018). The annual cost of natural disasters in Australia has been projected to attain some $39 billion per year on average by 2050 (in present value terms), even in the absence of significant impacts anticipated to arise from global climate change (Australian Business Roundtable for Disaster Resilience and Safer Communities, 2017). Queensland and New South Wales are expected to remain the most impacted States.

The term 'catastrophic' is in the view of the authors is over used in the context of natural peril events. This is also true of the analogous label 'natural disasters' as in the Insurance Council of Australia's Natural Disaster List (Crompton and McAneney, 2008). In this report we will continue with common usage but make the point that further research is required to explore what might constitute a truly catastrophic event for Australia. The impacts of the 2010-11 earthquake swarm in Christchurch, New Zealand, with an economic cost close to 20% of that country's annual GDP, probably comes closest to a catastrophic event in our region. However, the impacts cannot be viewed in isolation of the nation's ability to respond and recover from such an event: a tropical cyclone, for example, that completely destroys every building in a small rural town, while locally disastrous may not be reflected in the national accounts. Further examination of this issue lies outside of the scope of this report.

Regardless of the fuzziness about the nomenclature adopted, there is no uncertainty about the fact that a major natural catastrophe in Australia is inevitable (Crosweller, 2015). Many plausible disaster scenarios such as extraordinary floods, bushfires, tsunami, cyclones, pandemics, infrastructure failures and heatwaves have annual average probabilities of occurrence of less than 1 in 500 years. Other more far-reaching scenarios with global consequences may arise from solar storms, earthquakes or volcanic mega-eruptions albeit at less frequent or even more uncertain probabilities.

Scenario analyses often consider potential disasters in isolation, but our nation is also susceptible to a series of smaller damaging events whose compounding impacts could lead to a much larger economic loss. Moreover, and while in general terms our nation is well diversified in terms of having well separated major concentrations of population in our capital cities, the possibility of a series of severe weather events across the country which collectively exhaust the response capacity of emergency responders cannot be dismissed.

The severity of future catastrophic disasters will be dictated by the intensity of hazard events in concert with the vulnerability of at-risk societies. It is clear that to date, the rising cost of natural 'disasters' (in the loose sense of the term described above) is mainly dictated by where and how we chose to live (Crompton and McAneney, 2008, McAneney and Crompton, 2014, IPCC, 2014) This being the case, it is important to consider how future catastrophic disasters might be shaped by choices we make as a society to various political, economic and environmental alternatives along with technological advances. Our exploration of these influences here has been captured in a series of short interviews with emergency management leaders and a review of relevant literature. The document seeks to provide some strategic foresight that may assist in the development of strategic plans to minimize the consequences of future catastrophic disaster risks and in accessing capability needs for responding to the inevitability of such events.

VIEWS OF EMERGENCY MANAGEMENT LEADERS

Interviews with 32 emergency management leaders were undertaken to identify factors that may influence the severity of future catastrophic disasters. These leaders comprised representatives of emergency response agencies including the SES (n=9), coordinating emergency management agencies (9), rural fire agencies (3), urban fire agencies (2), police (2) and a selection of organisations including one health department (1) and six private consultants (6). Most had eleven or more years' experience with thirteen of those having more than 31 years. Leaders interviewed were from NSW (n=11), VIC (n=7), SA (n=5), QLD (n=4), WA (n=2), TAS (n=1), NT (n=1) and the Commonwealth (n=1).

When asked how they would define a catastrophic disaster, the most common response was that catastrophic disasters are those that overwhelm capability and capacity to respond and recover (n=21). Nine suggested that this meant exhausting of a state's capability and capacity, two leaders put this in the context of exhausting national capability and capacity and a further two leaders suggesting community capability and capacity. Impacts were described as widespread across political, economic, social, technological, legal and environmental (n=9); extreme (6); and prolonged (4). Four leaders suggested catastrophic events were beyond experience or what might normally occur, with one leader suggesting that they were beyond imagination.

Interviewees were then presented with a series of factors identified from the literature and asked to score each factor on a Likert scale of 1 to 5, where 1 is *not influential* and 5 *very influential*. Participants were asked to score the influence of factors on possible catastrophic disasters for both the current day and at year 2030. The factors scored included economic and geo-political elements; domestic politics; growth in urban density; increasing urban growth in at-risk areas; rising population; community expectations; community preparedness; social cohesion; ageing population; increasing ethnic diversity; system interconnectedness; ageing infrastructure; terrorism; climate change; technology; cyber security; and artificial intelligence.

Survey results identified that emergency management leaders viewed climate change, systems interconnectedness, community preparedness and increasing growth in at-risk areas as the most influential factors shaping possible current day catastrophic disasters. The weighted-average score for each factor is presented in Figure 1.

The most influential factors for 2030 were similar but included some additional factors. Overall the most influential factors by 2030 were seen to be climate change, rising urban density, increasing urban growth in at-risk areas, ageing infrastructure and technology (including cyber-security). The weighted-average scores for each factor is presented in Figure 2.

Factors that experienced the most significant change in their perceived influence between the current day and 2030 included artificial intelligence, geo-political environment, technology and ageing infrastructure. Factors viewed as most likely to remain similar in their influence were social media, community preparedness, domestic politics and community expectations. The weighted-average score for each factor is presented in Figure 3.

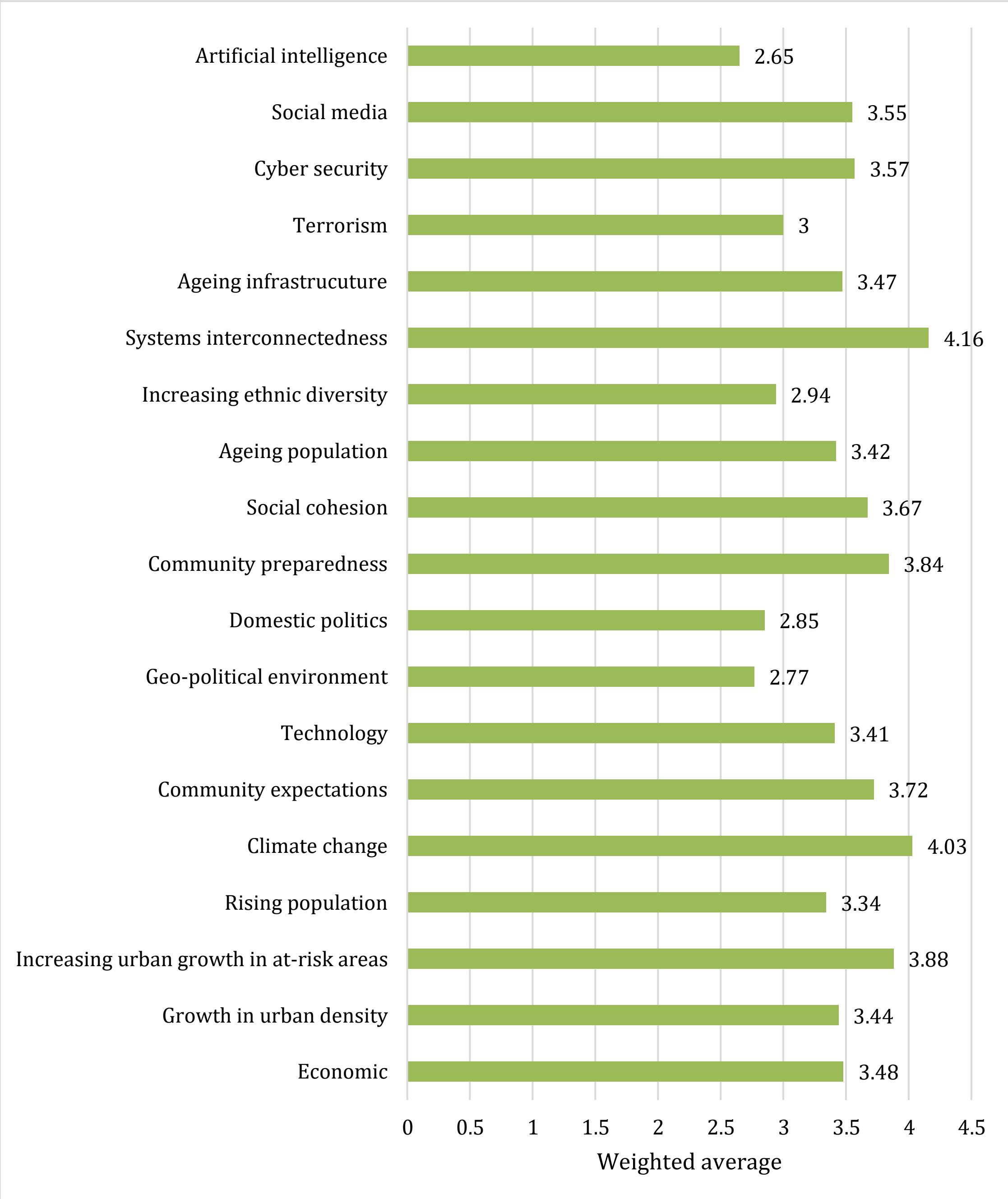

Figure 1: Current influence of factors on possible catastrophic disasters

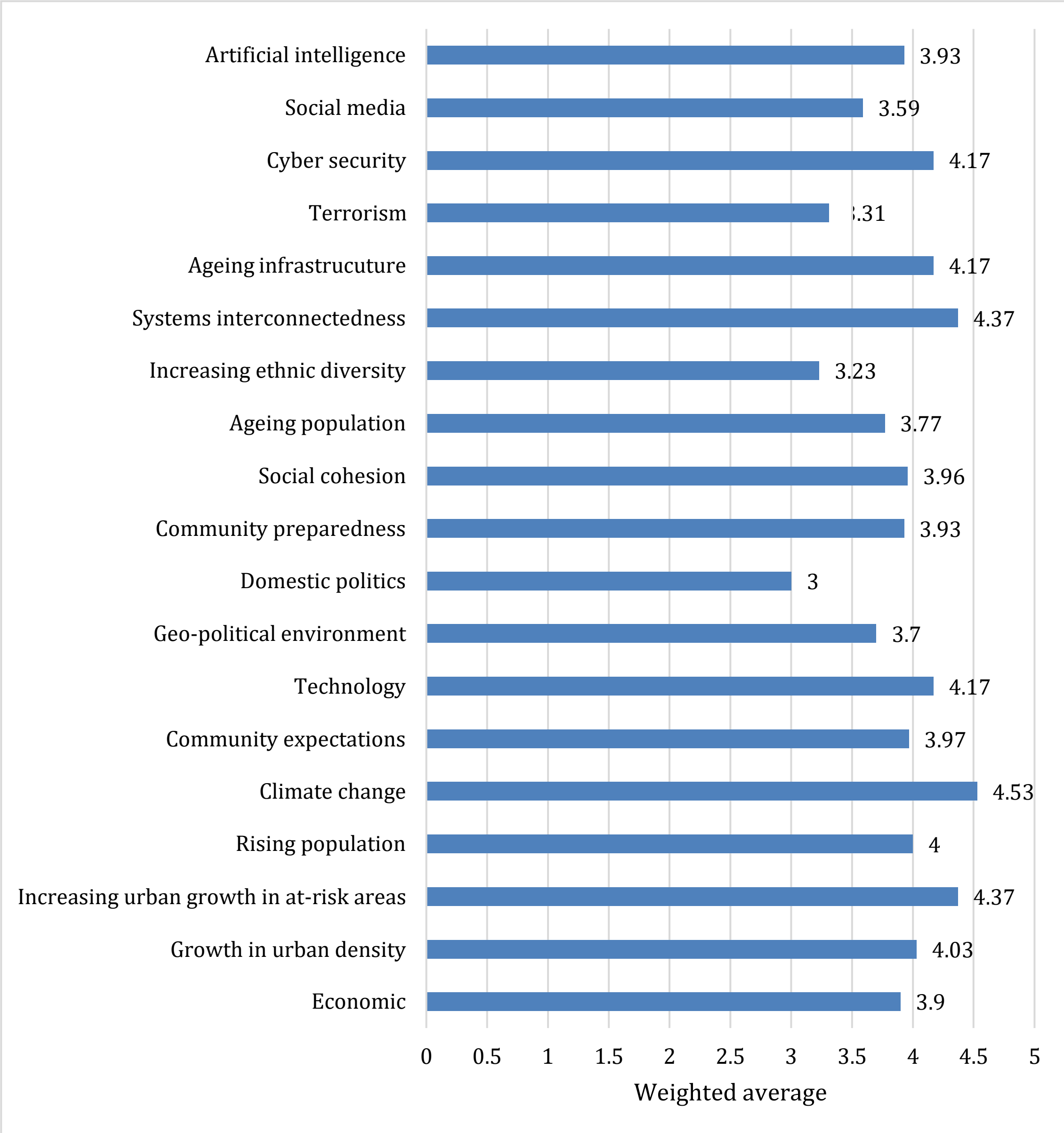

Figure 2: Influence of factors on possible catastrophic disasters by 2030

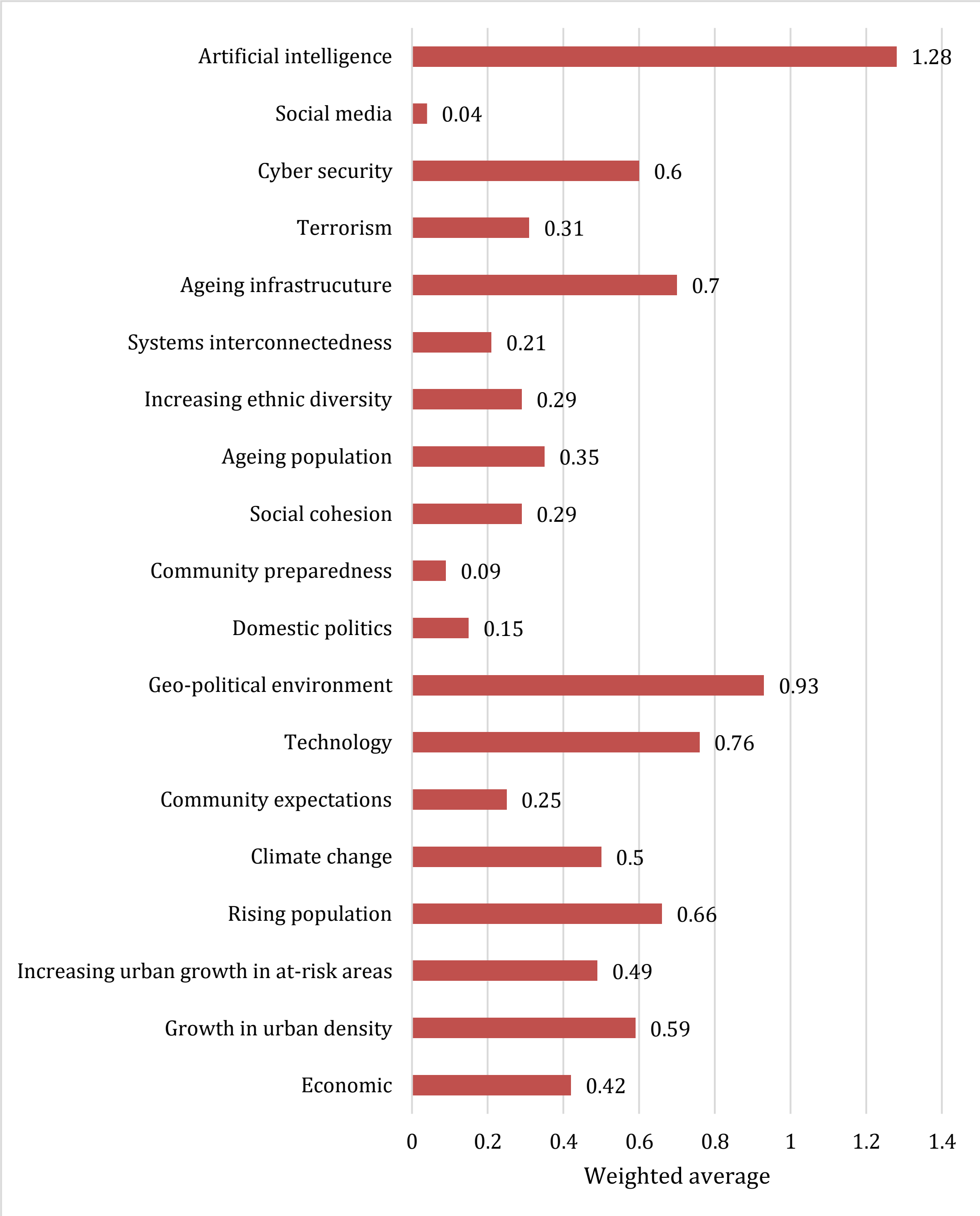

Figure 3: Change in perceived influence of factors between current day and 2030.

In what follows, we now examine in more detail the key themes of demographic and urban change; climate change; economic and geopolitical forces and technological change.

DEMOGRAPHIC AND URBAN CHANGE

Australia's population is projected to rise from 24.4 million in 2016 (Australian Bureau of Statistics, 2017c) to between some 36.8 and 48.3 million people by 2061 (Australian Bureau of Statistics, 2013). The number of Australian households by 2036 is projected to have increased by 50% (Australian Institute of Family Studies, 2016).

Increased population will necessitate a commensurate growth in building stock to ensure an adequate stock of housing at affordable levels. Some 160,000 new dwellings per annum will be required up to 2023 and 155,000 per annum between 2023-38. Most of this growth will be needed in South-East Queensland, Melbourne, Sydney and Perth (McDonald and Temple, 2011). Such increased urban growth occurs in the existing context of rising disaster losses driven by growing urban development and wealth (McAneney and Crompton, 2014, Handmer et al., 2018).

Increased development pressures will also place pressure on Governments to allow development in at-risk areas. In some areas the projected exposure to natural catastrophes is expected to grow. In the Hawkesbury Nepean Valley the number of people requiring evacuation during a flood of 1867 proportions is estimated to rise from 90,000 at present to between 158,000 to 171,000 by 2041 (Infrastructure NSW, 2017); exposure to coastal inundation across Queensland is forecast to nearly double by 2030 (Australian Government Productivity Commission, 2014); and in Melbourne increases in urban density is occurring without equivalent increases in evacuation capacity (Foster et al., 2013b). Given these examples, risk-reflective land-use planning will remain key to ensuring existing risks are not significantly exacerbated.

The continued improvement of building-codes will have further benefits as older building stock is replaced by new development built to more risk-reflective construction codes. When replacing existing structures in hazardous locations there are opportunities to increase the resilience of new structures and improve the safety of those living in them, as well as those in surrounding buildings. However, this must be balanced against placing additional populations at-risk if increases in housing density are proposed.

More people today are living in apartments, a 78% increase since 1991 (Australian Bureau of Statistics, 2017b). To support the anticipated growth in population the density of development will continue to change with more high-density apartment living around key city nodes. Since 2009, apartment building approvals have more than tripled with the majority of this growth occurring in Sydney, Melbourne and Brisbane (Reserve Bank of Australia, 2016). Much of the growth has been in high rise apartments with around 38% of households living in apartments being in structures of four or more floors (Australian Bureau of Statistics, 2017b). Concentrated high population density means that more people will be exposed to harm if hazards impact such areas.

At present damages to infrastructure are over-represented in Australian disaster loss statistics (Australian Business Roundtable for Disaster Resilience and Safer Communities, 2016). The need to repair assets and increase their resilience in the context of a possible increase in extreme weather events in the future will place added pressure on the budgets of infrastructure operators (Infrastructure Australia, 2015).

Ageing infrastructure and underinvestment in maintenance may also impact upon the reliability of services. Local road, regional rail and regional water infrastructure are of most concern. In many cases these assets are maintained by local government who have limited and declining budgets to service and maintain infrastructure (Infrastructure Australia, 2015).

Australian infrastructure has struggled to keep pace with demand (Infrastructure Australia, 2015) a situation that will be made worse as population increases. By way of example, the Hawkesbury Nepean Flood Strategy action is underway to improve adequate evacuation capacity on local roads (Infrastructure NSW, 2017). This example is an illustration of the need to ensure that urban and infrastructure planning are integrated and considered in the context of improving resilience against natural hazards (Infrastructure NSW, 2018, Infrastructure Australia, 2015).

The Australian Energy Market Operator (2018) has identified changing climate is likely to increase energy demand, increase stress on energy infrastructure, increase the risk of disruption and generally provide more uncertainty around energy needs. The 2017/18 summer provided an example of this when the Australian Energy Market Operator had to resort to emergency powers in order to avoid blackouts on two occasions during extreme heat events. The Australian energy market will be transformed into a more distributed network of power generation (Australian Energy Market Operator, 2018); the evolution of micro-grids may assist to build resilience and reduce the scale of cascading energy failures (Roberts and Chang, 2018).

As infrastructure networks increase in complexity and interdependence, and the *internet-of-things* grows, unexpected risks will likely grow, including possible cascading impacts of failure (Boin and t Hart, 2010). For example, future automation in the healthcare industry could expose vulnerable people to life threatening impacts if the infrastructure that new technologies rely upon is disrupted. A broader systems approach is called for rather than such risks being allowed to occur in isolation by individual operators. Greater reliance on technologies and their interdependencies also increases vulnerability to threats such as solar storms and cyber-attacks.

Whilst our cities grow, some rural centres are likely to continue their decline with decreasing and more elderly populations. Such trends have been associated with lower levels of community volunteering that may in turn reduce emergency service capacity in these areas and increase the need for multi-agency responses (Foster et al., 2013a).

Our population is living longer and now 1 in 6 people are above the age of 65 (Australian Bureau of Statistics, 2017c). This proportion is projected to grow to some 22% of the population or some 8.7 million people by 2056 (Australian Institute of Health and Welfare, 2017). Elderly people tend to be more vulnerable to the impacts of natural hazards and can be socially isolated and are particularly at-risk during heatwaves (Coates et al., 2014). A greater proportion of elderly people may mean that less of the population is able to volunteer with emergency management organisations. Growing demands on the national health budget to service the needs of an ageing population may increase pressures on budgets to manage disaster risks.

The number of people living alone is projected to increase by up to 65% by 2036 to between 3.3 and 3.4 million households. Older woman are more inclined to live alone than other people (Australian Bureau of Statistics, 2015). Increasing social isolation may act to reduce resilience.

Household tenure appears to be relatively stable overtime. There has been a slight increase in the number of households renting from 28.1% in 2006 to 30.9% in 2016 (Australian Bureau of Statistics, 2017a). There is some evidence to suggest that those that rent are less likely to take out insurance and are harder for emergency managers to engage with (Foster et al., 2013b).

Housing affordability has decreased in our major cities forcing the movement of essential workers out of some suburbs (Gurran and Phibbs, 2018). This may in turn impact on community's capacity to respond locally to disaster events. Housing affordability also increases the need to grow housing supply placing added pressure on developing land that maybe at-risk from various hazards.

Community apathy towards natural disasters will likely continue to be an issue. Few longitudinal studies have been completed on this subject but existing research shows that traditional community engagement methodologies have delivered little change (Webber et al., 2017).

Social cohesion is suspected to diminish as a consequence of increasing geographical concentration of immigrants in our cities; increasing negative views towards Muslims; weakening levels of trust in national government and the increased appeal of populist politics (Markus, 2017). Reductions in social cohesion may lead to lower levels of social capital and resilience.

CHANGING NATURE OF HAZARDS

Australia has a long history of climate variability and this is forecast to continue into the future (Australian Government Productivity Commission, 2014). Beyond climate variability we are now living in the warmest period of modern civilization (CSIRO and Bureau of Meteorology, 2016). Global annual average temperatures have risen by more than 0.7 C for the period 1986-2016 relative to 1901-1960 (U.S Global Change Program, 2017). Australian average surface temperatures have increased by 0.9 C since 1910 (CSIRO and Bureau of Meteorology, 2015), with the duration, frequency and intensity of extreme heat events also increasing (CSIRO and Bureau of Meteorology, 2016).

Mean sea level has risen between 20-23 centimetres since 1880 (U.S Global Change Program, 2017). The rise since 1993 has averaged 3.2mm per year (Figure 1) (NASA, 2018). Chen and McAneney (2006) showed that 50% of Australians live within 7 km of the coast. Proximity to the coast is likely also true of most infrastructure and where sea level rise presents a significant risk.

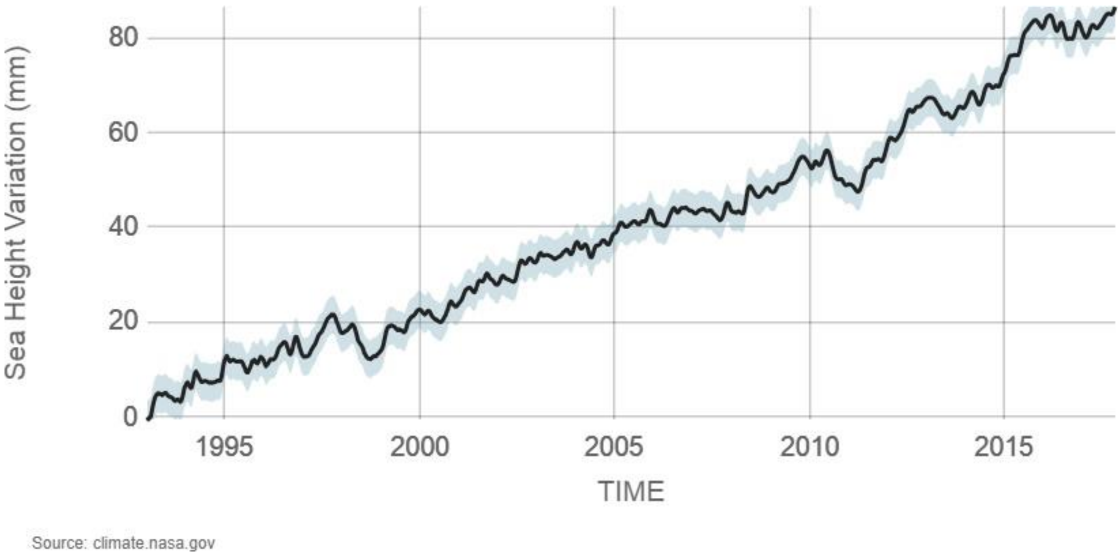

Figure 4: Historical sea height variation

Future climate projections with at-least *high confidence* include: that average temperatures will continue to increase across all seasons, with more hot days and warm spells; increased intensity of extreme rainfall for much of Australia; further sea level rises and poorer fire weather (CSIRO and Bureau of Meteorology, 2015).

Specifically, global mean temperatures are projected to rise from 0.3-1.7 degrees Celsius under low greenhouse emissions scenarios to 2.6-4.8 degrees Celsius under high emissions scenarios (IPCC, 2014). As illustrated in Figure 4 even a small rise in the mean temperature will likely equate to a large shift in temperature extremes. This naïve sideways shift of the air temperature distribution assumes that the variance remains unchanged and this is unlikely to be the case for many other climate-related extreme weather events such as the incidence of bushfires, wind and hailstorms, tropical cyclones and floods. The future event probability of such events under a warmer climate remains a research endeavour because the relationship between local extremes and global average air temperature is complex and likely different by both hazard and region.

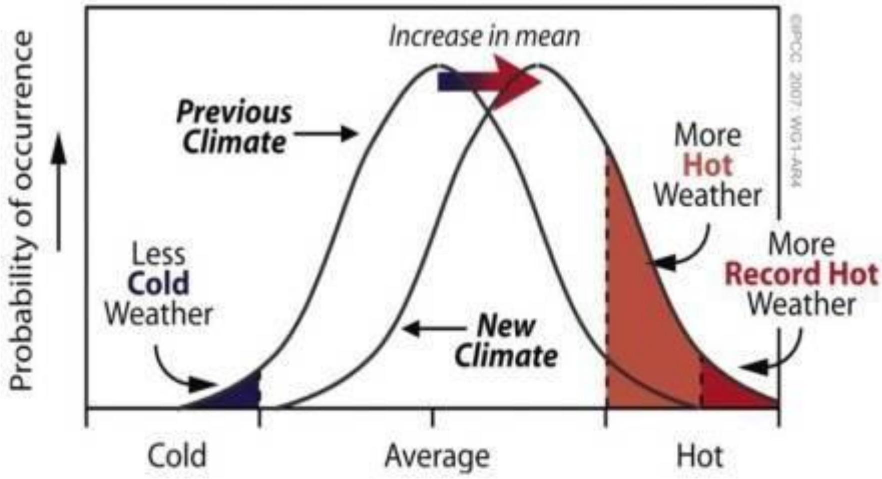

Figure 5: Distribution of climate phenomena (Source: IPCC 2007)

Global mean sea level rise is projected to increase from between 26-55 cm under low emissions scenarios to 45-86 cm under high emissions scenarios by 2080-2100 relative to 1986-2005. Past 2100, sea levels will continue to rise, and could increase by between 1 to 3 meters, depending on future global emission levels (IPCC, 2014).

There is more uncertainty about changes regarding tropical cyclones. Present research shows a declining number of historical tropical cyclones in the Australian region, though this is based on a short period of data (CSIRO and Bureau of Meteorology, 2016). In the future cyclones may change in their intensity, but decline in their frequency and possibly expand their occurrence further south, though there is only *low confidence* in this projection (CSIRO and Bureau of Meteorology, 2016). Similar projections have been made for East Coast Lows.

There is high uncertainty on the impacts of climate change on the incidence of hailstorms. One of the few studies available has suggested that Sydney may see an increased frequency of hailstorms (Walsh et al., 2016), but again these storms are complex and more work is required to understand the influence of warming climate on their dynamics and occurrence..

A warmer climate will mean that the atmosphere can hold more water vapor, likely resulting in more intense rainfall events (Climate Council, 2017). However, uncertainty exists about impacts on riverine flooding given that the relationships with other conditions such as antecedent catchment wetness are not well known (Do et al., 2017). Certainly, in the US, the National Academy of Sciences reports increasing intensities of rainfall but no increase in floods. In Fiji, in a region with demonstrable increases in air temperature, flood levels on the Ba River catchment showed no changes in frequency or flood heights over the 122 year record (McAneney et al., 2017).

Much debate has occurred about the impacts of current changes in climate on existing disaster losses. Analysis of historical insurance losses once normalised for changing societal factors, show no increase over time, (McAneney and

Crompton, 2014, Australian Government Productivity Commission, 2014), though some impact maybe observed in future decades. The IPCC concluded:

> *Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters (high confidence). Long-term trends in economic disaster losses adjusted for wealth and population increases have not been attributed to climate change, but a role for climate change has not been excluded (high agreement, medium evidence) (IPCC, 2014).*

Beyond climate-related hazards, our understanding of Australian earthquake risk is also evolving after a recent re-evaluation of Australia's historical earthquake catalogue by GeoScience Australia. This review found probabilities of damaging earthquakes to have been significantly overestimated. Revised earthquake event probabilities will be released mid-2018 and imply a lowering of the nation's earthquake risk. Nonetheless large event losses are still possible, and current building codes and practices address much lower ground shaking levels than those that occur close to large earthquakes.

IMPACTS

Changes in the nature of natural hazards are likely to impact emergency management organisations and communities in the following ways over coming decades:

- The combination of more intense heatwave conditions, rising demands on energy infrastructure and an aging population will increase the risk of more severe consequences related to future heatwaves and place additional demands on emergency services and health resources.

- There is considerable uncertainty regarding the impacts of climate change on bushfire risk (Clarke, 2015). Fire losses show no change over the previous century(Crompton et al., 2010), but weather conducive for bushfires may start earlier and end later, with more frequent intense fire weather conditions anticipated (Bushfire CRC, 2008, CSIRO and Bureau of Meteorology, 2016). These conclusions of increased hazard are particularly relevant to temperate forests, as opposed to more arid grassland where climate change may act to reduce fuel levels and hence hazard levels (Clarke, 2015). In the event of increasing bushfire hazard, this may result in greater demands on firefighting and supporting resources; reduced ability to suppress fires; and increased resource fatigue (AFAC, 2009).

- Increased temperatures are likely to make it more difficult for forest management agencies to maintain existing planned burning strategies although latest science has questioned the benefits and highlighted externalities associated with planned burning (Broome et al., 2016).

- Increased sea levels will increase the risks associated with flooding in coastal and estuarine areas. Erosion of beaches will threaten nearby building stock, infrastructure and reduce economic value. There are likely to be increased pressures by communities for coastal protection works to reduce the threats to properties. Pressures may also be applied to insurers to cover damages related to actions by the sea that are excluded in most present day policies. However, the more certain the risk of rising sea levels become the less relevant insurance solutions become: insurance is about risk transfer and not an alternative to better land use planning and prudent risk management (McAneney et al., 2015). The increased frequency of flooding events in estuary areas will place further demands on emergency service resources.

- Increased precipitation combined with enhanced coverage of impervious surfaces, particularly in our cities will increase the risk of storm water and flash flooding within small urban catchments placing greater demands on emergency services.

- More frequent disaster events may increase fatigue suffered by emergency service workers and reduce their capacity to cope when faced with a truly catastrophic event.

- Reduced probabilities of large earthquakes will reduce the risk of a seismic catastrophe event, however, there are significant benefits in maintaining existing earthquake mitigation measures at the same level of effort.

ECONOMIC AND GEOPOLITICAL FORCES

The future growth of Australia's national economy is uncertain. Australian Government Treasury (2015) projections are for the economy to slow, with annual growth in real GDP falling from 3.1 percent to 2.8 percent over the next 40 years. This modeled decline is anticipated on the basis of a forecast slowing in population growth and a decline in workforce participation (Australian Government Treasury, 2015). Slowing growth in the resources sector combined with a competitive global economy will pose additional challenges. In short if economic growth is to be maintained, this will require innovation to grow new opportunities and markets. The confidence in these long-term projections is uncertain but is certainly low.

Given the increases in demand for resources from the world's growing population, there will be further pressures to utilise scarce resources more efficiently (CSIRO, 2016). Australia's connectivity to the global economy as a trading nation makes it vulnerable to economic shocks, as was the case with the Global Financial Crisis in 2008. Risks may be triggered by geo-political strains, trade wars or financial system crisis.

Natural disasters may influence economic output in the short term (Australian Government Treasury, 2015). The realization of projected climate change forecasts may also have adverse economic impacts (Australian Government Treasury, 2015).

Income inequality has been rising in Australia (OECD, 2017). Excessive income inequality in the future could impact the resilience of communities as people have an unequal ability to participate in economic and social opportunities, and this may undermine social cohesion (Australian Council of Social Service, 2017).

Globalisation has meant that Australia is now highly dependent upon global supply chains. More integrated and complex global networks come with a growing interdependence (United Nations, 2017). Examples include the disruption to the worldwide supply of automobiles as a result of floods in Thailand and the earthquake and tsunami in Japan in 2011. Most recently the United States suffered a shortage of sterile salt water as a result of the impacts of Hurricane Maria in 2017 in Puerto Rico (McKenna, 2018).

With a significant proportion of Australia's trade passing through SE Asia, concerns have been raised regarding possible disruptions if conflict in this region were to occur. This would be a particular concern for Australia's energy resilience, with ninety percent of its liquid fuel products being imported and no stockholding policies. By 2030 this dependence could be close to one hundred percent (Blackburn, 2014). Disruption to this supply chain could result in cascading failures within the Australian economy.

Globalisation also means greater vulnerability to human disease and bio-security risks introduced by movement of people, animals and goods through our borders.

Global geopolitics have evolved over the last decade after relative peace and stability of the post-cold war era. The situation is now more uncertain with a resurgent Russia, the rise of China, global terrorism, a nuclear-armed North Korea and the emergence of state-centred politics. Such uncertainty is driving new tensions. The evolution of such tensions may result in the re-emergence a cold-war or in conflict itself. Some experts estimate the chances of war between the United States and North Korea at 15 to 50 percent (Kristof, 29/11/2017).

Future conflict could see increased threats to Australia and the need to reactivate civil defence mechanisms that have been neglected for decades, and in turn the depletion of defence resources available to assist with catastrophic events domestically.

TECHNOLOGICAL CHANGE

Technological change has enormous opportunities to shape future catastrophes from both consequence and management perspectives. For example the growth in communication networks across the globe has enabled improved communication of early warnings to citizens.

Some relevant technological changes include.

1. The increasing speed of computing and ability to store large amounts of data is creating opportunities to better understand natural disasters and community vulnerability; to forecast their impacts in real-time at higher resolutions and with improved understanding of uncertainties. There is large potential to modernize the use of data through data sharing; improvements in data quality; and new technologies (Australian Government Treasury, 2015). Over the next decade further advancement in quantum computing if successful will expand data analysis capabilities even further.

2. The widespread adoption of artificial intelligence (AI) across the economy and emergency management sector will likely find new ways to make sense of data, improving decisions and enhancing productivity. AI coupled with impact forecasts might be used to deploy autonomous resources; triage emergency calls; and automate the drafting of warning messages.

3. Next generation communications technology 5G will enable the further evolution and adoption of the *internet-of-things* with dramatically increasing internet delivery speeds. By 2020 it is predicted that some 20.8 billion devices will be connected to the internet globally (Gartner, 2015). Greater connectedness will see significant rises in data being collected by devices and the possibility of this data being accessible to individuals and organisations.

   Our ability to also collect vast amounts of observational data about natural hazards and their impacts has grown and will continue to do so through remote sensing, drones and social media. AI will assist in the detection of perils; forecast their intensity; and impacts. Such improved situational awareness will enhance decision-making and improve the efficiency of resource deployments.

4. Autonomous vehicle technology including drones may revolutionise many aspects of disaster management. Drones are already being used to collect intelligence and inform search and rescue operations. Driverless cars may be able to make safer decisions than their occupants and work together to optimise mass evacuations by vehicles. Networks of firefighting drones may be able to detect and extinguish fires on hot days before they spread and becoming uncontainable. Logistics may be enhanced by driverless vehicles and drones transporting relief supplies into impacted areas reducing demands for human resources and even transporting the injured. Aerial drones may also act to provide

contingency communications. As drones become smaller and more affordable they are likely to become a standard piece of equipment to assist emergency responders.

Figure 6: Conceptual image of the use of drones in firefighting (Source: The Australian)

5. Social media platforms have changed the way the public communicates and have empowered society via additional information to make decisions and to collaborate. It is likely we will see further communication advances and social media applications. Given their vulnerabilities to disruption, however, it will be essential for communities to be prepared to utilize alternate methods of communication.

   Social media's capacity to collect vast amounts of personalised data has been identified as useful in providing incident intelligence. During Hurricane Harvey the recently released snap map (a map of snap chats) was able to provide geo-located mapping of impacts utilising posts from users. Users were able to identify the activity of residents and literally watch the rise and fall of floodwaters through the eyes of Snap Chat users (Epstein, 2017).

   Since 2016 Facebook has deployed its safety check feature, which enables people to register they are safe when an event occurs. Similarly, Google has developed its Person Finder application. Such technologies not only enable people to tell loved ones they are ok, but may assist in notifying others of hazardous areas and freeing up communication networks (Karsten and West, 2016).

6. The deployment of 3D printing technologies to areas impacted by disasters should provide opportunities to fast track repairs of essential infrastructure and remove logistical issues that may rely on overseas suppliers.

7. Cyber threats to Australia's national and economic assets are increasing posing a threat to infrastructure security and the availability of advanced technologies to assist during disasters.

DISCUSSION AND CONCLUSION

There is considerable uncertainty regarding future conditions that may shape future catastrophic disaster events. This uncertainty arises, amongst other things, from the extreme difficulty of modelling changes in economic, societal and geopolitical conditions, the uncertain trajectory of climate change and its impact on extreme weather events, and the impact of advances in technology. Notwithstanding these uncertainties, our study has identified some factors that may act to change the risk profile posed by natural perils in an Australian context. These include climate change; urban development in at-risk areas; increasing urban density; systems inter-connectedness; cyber-security; societal reliance on technologies; and ageing infrastructure. Such influences will not be equally important across all areas of Australia and it is important that the intersection of factors be considered in further depth.

When considering a future National Mitigation Framework there are significant opportunities to influence future risk profiles through the adoption of improved building codes and land-use planning; urban renewal to enhance resilience of existing development; climate change adaptation; incorporating risk-resilience considerations into infrastructure design; and research and adoption of technological advances to understand and manage risk.

As recommended by the Australian Government Productivity Commission there is a need to invest more in mitigation to reduce the inevitable costs of disasters. It must be noted, however, that many large-scale mitigation initiatives take many years to design and build. For example the building of the Delta Works in The Netherlands and the Thames Barrier protecting London, were both initiated after a winter storm that caused large loss of life and extensive flooding in the Netherlands, England and Scotland. The former was not completed until 1997 while the Thames Barrier took some 10 years to build after construction started in 1974. Existing proposals to raise the height of Warragamba Dam in Western Sydney to reduce the likelihood of catastrophic flooding may take similar timeframes resulting in increased community exposure prior to mitigation becoming operational.

Consideration should also be given to how the various factors identified and discussed in this study may impact the relative risk profile of different catastrophic disaster scenarios so that mitigation funding and capability efforts can be prioritized accordingly.

The role and skills of emergency managers should also be considered as future changes emerge. More frequent natural hazard events may necessitate a greater focus on community-based capabilities to supplement those provided by traditional emergency management service delivery models. Emergency managers will need to be more collaborative and gain experience in engaging with communities and the business sector. Technological advances may necessitate greater skills in data analytics and cyber security to leverage new capabilities in particular regarding AI and autonomous systems.

REFERENCES

AFAC 2009. Climate Change and Fire and Emergency Services. Canberra: AFAC.
AUSTRALIAN BUREAU OF STATISTICS. 2013. Population projections, Australia, 2012. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/3222.0main+features32012%20(base)%20to%202101 [Accessed 6/3/2018].
AUSTRALIAN BUREAU OF STATISTICS. 2015. Household projections. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/3236.0Main%20Features42011%20to%202036.
AUSTRALIAN BUREAU OF STATISTICS. 2017a. 2016 Census QuickStats. Available: http://www.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/036 [Accessed 6/3/2018].
AUSTRALIAN BUREAU OF STATISTICS. 2017b. Apartment Living. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/2071.0~2016~Main%20Features~Apartment%20Living~20 [Accessed 6/3/2018].
AUSTRALIAN BUREAU OF STATISTICS. 2017c. Australia Today. Available: http://www.abs.gov.au/ausstats/abs@.nsf/mf/2024.0 [Accessed 6/3/2018].
AUSTRALIAN BUSINESS ROUNDTABLE FOR DISASTER RESILIENCE AND SAFER COMMUNITIES. 2016. Building resilient infrastructure. Available: http://australianbusinessroundtable.com.au/assets/documents/Report%20-%20Building%20Resilient%20Infrastructure/Report%20-%20Building%20resilient%20infrastructure.pdf [Accessed 6/3/2018].
AUSTRALIAN BUSINESS ROUNDTABLE FOR DISASTER RESILIENCE AND SAFER COMMUNITIES. 2017. Building resilience to natural disasters in our states and territories. Available: http://australianbusinessroundtable.com.au/assets/documents/ABR_building-resilience-in-our-states-and-territories.pdf [Accessed 6/3/2018].
AUSTRALIAN COUNCIL OF SOCIAL SERVICE. 2017. Inequality. Available: https://www.acoss.org.au/inequality/ [Accessed 29/5/2018].
AUSTRALIAN ENERGY MARKET OPERATOR 2018. AEMO observations: Operational and market challenges to reliability and security in the NEM.
AUSTRALIAN GOVERNMENT PRODUCTIVITY COMMISSION 2014. Natural Disaster Funding Arrangements. Canberra, Australia: Australian Government Productivity Commission.
AUSTRALIAN GOVERNMENT TREASURY. 2015. 2015 Intergenerational Report. Available: https://treasury.gov.au/publication/2015-intergenerational-report/ [Accessed 29/5/2018].
AUSTRALIAN INSTITUTE OF FAMILY STUDIES. 2016. Households in Australia. Available: https://aifs.gov.au/facts-and-figures/households-australia [Accessed 6/3/2018].
AUSTRALIAN INSTITUTE OF HEALTH AND WELFARE. 2017. Older Australia at a glace. Available: https://www.aihw.gov.au/reports/older-people/older-australia-at-a-glance/contents/demographics-of-older-australians/australia-s-changing-age-and-gender-profile [Accessed 6/3/2018].
BLACKBURN, J. 2014. Australia's Liquid Fuel Security Part 2. Sydney: NRMA Motoring and Services.
BOIN, A. & T HART, P. 2010. Organising for effective emergency management: lessons from Research. *Australian Journal of Public Administration,* 69, 357-371.
BROOME, R. A., JOHNSTON, F. H., HORSLEY, J. & MORGAN, G. G. 2016. A rapid assessment of the impact of hazard reduction burning around Sydney, May 2016. *The Medical Journal of Australia,* 205, 407-408.
BUSHFIRE CRC. 2008. Climate Change and Its Impact on the Management of Bushfire. Available: http://www.bushfirecrc.com/sites/default/files/managed/resource/fire-note-climate-change25.pdf [Accessed http://www.bushfirecrc.com/sites/default/files/managed/resource/fire-note-climate-change25.pdf].
CHEN, K. & MCANENEY, J. 2006. High-resolution estimates of Australia's coastal population. *Geophysical research letters,* 33.
CLARKE, H. 2015. Climate Change Impacts on Bushfire Risk in NSW. Sydney: Office of Environment and Heritage.
CLIMATE COUNCIL. 2017. Intense rainfall and flooding: the influence of climate change. Available: https://www.climatecouncil.org.au/uploads/5dafe61d7b3f68d156abd97603d67075.pdf [Accessed 2/6/2018].
COATES, L., HAYNES, K., O'BRIEN, J., MCANENEY, J. & DE OLIVEIRA, F. D. 2014. Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010. *Environmental Science & Policy,* 42, 33-44.

CROMPTON, R. P. & MCANENEY, K. J. 2008. Normalised Australian insured losses from meteorological hazards: 1967–2006. *Environmental Science & Policy,* 11**,** 371-378.
CROMPTON, R. P., MCANENEY, K. J., CHEN, K., PIELKE JR, R. A. & HAYNES, K. 2010. Influence of location, population, and climate on building damage and fatalities due to Australian bushfire: 1925–2009. *Weather, Climate, and Society,* 2**,** 300-310.
CROSWELLER, M. 2015. Improving our capability to better plan for, respond to, and recover from severe-to-catastrophic level disasters. *Australian Journal of Emergency Management,* 30**,** 41.
CSIRO 2016. Australia 2030.
CSIRO AND BUREAU OF METEOROLOGY. 2015. Climate Change in Australia Information for Australia's Natural Resource Management Regions. Available: https://www.climatechangeinaustralia.gov.au/media/ccia/2.1.6/cms_page_media/168/CCIA_2015_NRM_TechnicalReport_WEB.pdf [Accessed 7/3/2018].
CSIRO AND BUREAU OF METEOROLOGY. 2016. State of the Climate 2016. Available: http://www.csiro.au/en/Showcase/state-of-the-climate.
DO, H. X., WESTRA, S. & LEONARD, M. 2017. A global-scale investigation of trends in annual maximum streamflow. *Journal of hydrology,* 552**,** 28-43.
EPSTEIN, K. 2017. Thanks to Harvey, Snapchat's map feature went from being kind of creepy to really useful. *The Washington Post* [Online]. Available: https://www.washingtonpost.com/news/the-intersect/wp/2017/09/01/thanks-to-harvey-snapchats-map-went-from-being-really-creepy-to-really-useful/?utm_term=.ff7e8e00b7f7 [Accessed 5/3/2018].
FOSTER, H., WHITTAKER, J., HANDMER, J., LOWE, T. & KEATING, K. 2013a. Regional Victoria in 2021: changes and implications for the emergency management sector. *Australian Journal of Emergency Management,* 28.
FOSTER, H., WHITTAKER, J., TOWERS, B. & HANDMER, J. 2013b. Metropolitan Melbourne in 2021: changes and implications for the emergency management sector. *Australian Journal of Emergency Management,* 28.
GARTNER. 2015. Gartner Says 6.4 Billion Connected Things Will Be in USE in 2016, Up 30 Percent From 2015. Available: https://www.gartner.com/newsroom/id/3165317 [Accessed 25/3/2018].
GURRAN, N. & PHIBBS, P. 2018. Emergency and key services at risk due to property market boom. Available: https://sydney.edu.au/news-opinion/news/2018/02/05/emergency-and-key-services-at-risk-due-to-property-market-boom.html [Accessed 12/3/2018].
HANDMER, J., LADDS, M. & MAGEE, L. 2018. Updating the costs of disasters in Australia. *Australian Journal of Emergency Management,* 33**,** 40-46.
INFRASTRUCTURE AUSTRALIA. 2015. Australian Infrastructure Audit. Available: http://infrastructureaustralia.gov.au/policy-publications/publications/files/Australian-Infrastructure-Audit-Volume-1.pdf [Accessed 6/3/2018].
INFRASTRUCTURE NSW. 2017. Hawkesbury-Nepean Valley Flood Risk Management Strategy. Available: http://www.infrastructure.nsw.gov.au/media/1347/insw_hnvfloodstrategy_1_.pdf [Accessed 6/3/2018].
INFRASTRUCTURE NSW. 2018. The NSW State Infrastructure Strategy 2018-2038. Available: https://www.nsw.gov.au/improving-nsw/projects-and-initiatives/nsw-state-infrastructure-strategy/#resilient-infrastructure [Accessed 29/5/2018].
IPCC 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K Pachauri and LA Meyer (eds)]. Geneva, Switzerland.
KARSTEN, J. & WEST, D. 2016. Are you safe? Facebook's Safety Check and the future of emergency management. Available: https://www.brookings.edu/blog/techtank/2016/08/31/are-you-safe-facebooks-safety-check-and-the-future-of-emergency-management/ [Accessed 6/3/2018].
KRISTOF, N. 29/11/2017. Are we headed toward a new korean war. *New York Times*.
MARKUS, A. 2017. Mapping Social Cohesion: The Scanlon Foundation surveys 2017. Available: https://www.monash.edu/mapping-population/public-opinion/social-cohesion-report [Accessed 22/2/2018].
MCANENEY, J. & CROMPTON, R. 2014. What is Driving the Rising Cost of Natural Disasters? *Risk Frontiers Quarterly Newsletter,* 14**,** 3.
MCANENEY, J., MCANENEY, D., MUSULIN, R., WALKER, G. & CROMPTON, R. 2015. Government-sponsored Natural Disaster Insurance Pools: A view from down-under. *International Journal of Disaster Risk Reduction*.

MCANENEY, J., VAN DEN HONERT, R. & YEO, S. 2017. Stationarity of major flood frequencies and heights on the Ba River, Fiji, over a 122-year record. *International Journal of Climatology,* 37, 171-178.
MCDONALD, P. & TEMPLE, J. 2011. Projections of Housing Demand in Australia, 2008-2038. Available: https://treasury.gov.au/publication/projections-of-housing-demand-in-australia-2008-2038-narrative-report [Accessed 6/3/2018].
MCKENNA, M. 2018. Medicine's long, thin supply chain. Available: https://www.wired.com/story/medicines-long-thin-supply-chain/ [Accessed 11/3/2018].
NASA. 2018. Global Climate Change Vital Signs of the Planet. Available: https://climate.nasa.gov/ [Accessed 2/6/2018].
OECD. 2017. OECD Economic Surveys March 2017. Available: https://www.oecd.org/eco/surveys/Australia-2017-OECD-economic-survey-overview.pdf [Accessed 29/5/2018].
RESERVE BANK OF AUSTRALIA. 2016. The Growth of Apartment Construction in Australia. Available: https://www.rba.gov.au/publications/bulletin/2016/jun/pdf/bu-0616-3.pdf [Accessed 6 March 2018].
ROBERTS, D. & CHANG, A. 2018. Meet the microgrid, the technology poised to transform electricity. *Vox* [Online]. Available: https://www.vox.com/energy-and-environment/2017/12/15/16714146/greener-more-reliable-more-resilient-grid-microgrids [Accessed 27/5/2018].
U.S GLOBAL CHANGE PROGRAM. 2017. Climate Science Special Report. Available: https://science2017.globalchange.gov/ [Accessed 7/3/2018].
UNITED NATIONS. 2017. New globalization report: Three mega-trends expected to impact our future. Available: https://www.un.org/development/desa/en/news/ecosoc/new-globalization-report.html [Accessed 11/3/2018].
WALSH, K., WHITE, C. J., MCINNES, K., HOLMES, J., SCHUSTER, S., RICHTER, H., EVANS, J. P., DI LUCA, A. & WARREN, R. A. 2016. Natural hazards in Australia: storms, wind and hail. *Climatic Change,* 139, 55-67.
WEBBER, D., GISSING, A., DUFTY, N. & BIRD, D. 2017. Community participation in emergency planning: NSW state emergency service case study. *Australian Journal of Emergency Management, The,* 32, 28.
WORLD ECONOMIC FORUM. 2018. The Global Risk Report 2018 - 13th Edition. Available: http://www3.weforum.org/docs/WEF_GRR18_Report.pdf.