Australia's National
Science Agency

Climate and Disaster Resilience

Technical Report

July 2020

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Executive Summary

The summer of 2019-20 was defined by a series of consecutive and at times coincident natural events involving a confluence of bushfires, floods, drought and heat extremes. Their cascading effects have impacted Australian communities and industries. Apart from loss of life, the cost to the community and government of these events is significant. For example, insurance losses for this year's bushfires already exceed A$2.3 billion[1], and for the 2019 North Queensland floods social and economic costs exceed A$5.6 billion[2].

Climate change influences the frequency and severity of these events and will be a factor into the foreseeable future, given the long timeframes associated with current climate trajectories. It is important to better understand and predict the interplay of these natural events and the challenges, risks and impacts they present over different timescales with an increasing population and changing human footprint. This is a complex undertaking. Much has already been done and achieved by all levels of government, response agencies and the community to increase Australia's resilience. However, there is both a need and an opportunity to take this to the next level as we face increasing climate variability and hazard exposure, and drive a truly national response to further build the resilience of our infrastructure, our land use practices, our communities, our industries and our environment.

In response to the widespread bushfires, CSIRO was tasked in January 2020 by the Prime Minister to deliver an independent study recommending ways in which Australia can increase its climate and disaster resilience, supported by an Expert Advisory Panel chaired by Australia's Chief Scientist, Dr Alan Finkel. This work has been guided by the following principles:

- Evidence-based analysis informed by literature, lived experience and expert inputs
- A focus on where research, science and technology can contribute to building resilience
- Acknowledgement of past improvements and the importance of complementarity, with a number of related reviews, reports and inquiries currently underway including the Royal Commission into National Natural Disaster Arrangements
- CSIRO's role in providing relevant insights to inform policy makers but not policy advice.

This Technical Report has been developed to underpin the Overview Report delivered to the Prime Minister in June 2020. It includes more detailed analysis and chapters have been developed such that they stand alone. Given the breadth of this topic, and the timeframe available, this is not intended be definitive treatment of climate and disaster resilience. Compromises in scope have been made, with a focus on acute events, and limitations in the depth of exploration possible on some topics.

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[1] Insurance Council of Australia figures May 2020

[2] Commonwealth of Australia, North Queensland Livestock Industry Recovery Agency, Annual Report 2018–19

The opportunities for improvement identified throughout this Technical Report have informed the findings and 25 recommendations included in the Overview Report delivered to the Prime Minister in June.

The opportunities to take Australia to the next level of building resilience broadly fall under the following six actionable themes outlined below. To realise these opportunities, this study makes a detailed series of findings and recommendations which form the basis for a forward plan of action. The themes of these are:

1. A harmonised and collaborative national approach is required to achieve global best practice
2. The national approach requires systems thinking and solutions to deal with complexity – including foresighting, management of risk and learning and education for all stakeholders
3. Availability of data is a key enabler – there is a compelling case to shift to common approaches and platforms for both resilience planning frameworks and operational management systems
4. The community plays an essential role in all phases of resilience building and must be appropriately included and engaged
5. Investment in targeted research, science and technology remains a key enabler of many of the improvements required to build resilience
6. We need to build back better. Resilience needs to be embedded as an explicit consideration in all future planning, agricultural and urban land use and zoning and investment decisions.

The United Nations defines resilience as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. Natural disasters and their impacts are extremely contextual and influenced by factors such as timing, intensity, geographic location and associated level of development, infrastructure and community preparedness. Preparing for and responding to these events demands a multidisciplinary, risk-based systems thinking approach. In addition, disaster risk and response management and resilience building are a distributed responsibility, shared by all levels of government, with critical involvement of and ownership by individuals, communities and the private sector

There has already been strong progress on increased adaptation and resilience measures for events such as tropical cyclones, as evidenced by decreases in the impacts on life and property. While Cyclone Tracy caused 65 deaths and damaged 70 percent of Darwin homes in 1974, analysis after cyclones Vance (1999), Larry (2006) and Yasi (2011) showed that updated regulations and standards have resulted in much less building damage and consequent loss of life. During Cyclone Yasi, for example, 12 per cent of older homes suffered severe roof damage, but only three per cent of newer homes. 2[3] In Innisfail, which was rebuilt after Cyclone Larry, insurance claims were half the cost of those nearby towns that did not experience the post Cyclone Larry rebuild.

Similarly, learnings from past events meant the lives lost in the 2019-20 bushfire season were markedly lower than in previous events as illustrated by the comparison in Figure 1.

Much has already been learned and applied from previous experiences, and improvements adopted to date are to be commended. However, there is clearly much more work to do to fully understand the future risks and put in place the appropriate and proportional actions and accountability necessary to further build climate and disaster resilience across the country to the next level.

[3] ACCC 2018 Northern Australia Insurance Inquiry First Interim Report https://www.accc.gov.au/focus-areas/inquiries-ongoing/northern-australia-insurance-inquiry/first-interim-report

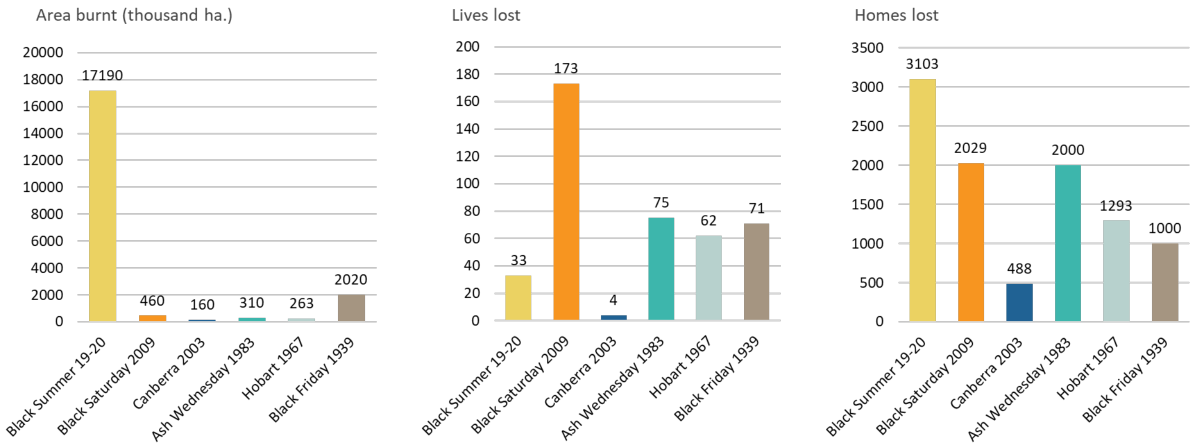


Figure 1 Areas burnt (thousands of hectares), number of lives lost, and number of homes lost in some significant fires between 1939 and 2019-20. Source Australasian Fire and Emergency Services Authorities Council (AFAC)

The lifecycle of managing climate and disaster resilience can be characterised as (i) planning and preparation, (ii) response, (iii) recovery and (iv) learning and improvement to build further resilience. Through improvement and resilience building, future events may be prevented from becoming disasters.

Effective planning and preparation require a better understanding of the future we face, and this understanding must be broadly shared and understood by all stakeholders. This includes acknowledging unknowns that shape our perceptions of the future. To achieve this there is a need for an inclusive national discussion about climate change and disasters, and how we best address them. This discussion needs to articulate: the many things we value and will work to protect; a shared vision for what a climate and disaster resilient Australia looks like; principles for determining how responsibilities for preventing and mitigating risks are to be negotiated and capabilities resourced; the uncertain nature of the causes and effects of future risks; and the need for an adaptive, values-based, and whole-of-society approach to address the system-wide causes of exposure and vulnerability to natural hazards.

This in turn forms the basis of a national and integrated systems approach. Such an approach will bring efficiencies and agility through common tools, increased interoperability, education and training, sharing of resources, scenario planning approaches and data and decision platforms. Australia currently has no standard approach to scenario planning, risk and vulnerability assessment, prevention or progress measurement; all of which are essential elements for better co-ordinated and effective national action.

The recently adopted National Disaster Risk Reduction Framework[4] provides a foundation point but more can be done, and it is important that this is implemented in a harmonised way with appropriate local customisation. There is appetite for increased levels of harmonisation, but it is not without challenge and to date has not been achieved across many sectors. There is opportunity to learn from other countries such as New Zealand and Canada where, most importantly, they have a common governance mechanism to actioning resilience measures.

It is also important to recognise that individuals and communities, with their intrinsic and planned resilience also play a critical role in effective preparation and subsequent recovery. They need to

[4] Department of Home Affairs (2018) National Disaster Risk Reduction Framework https://www.homeaffairs.gov.au/emergency/files/national-disaster-risk-reduction-framework.pdf

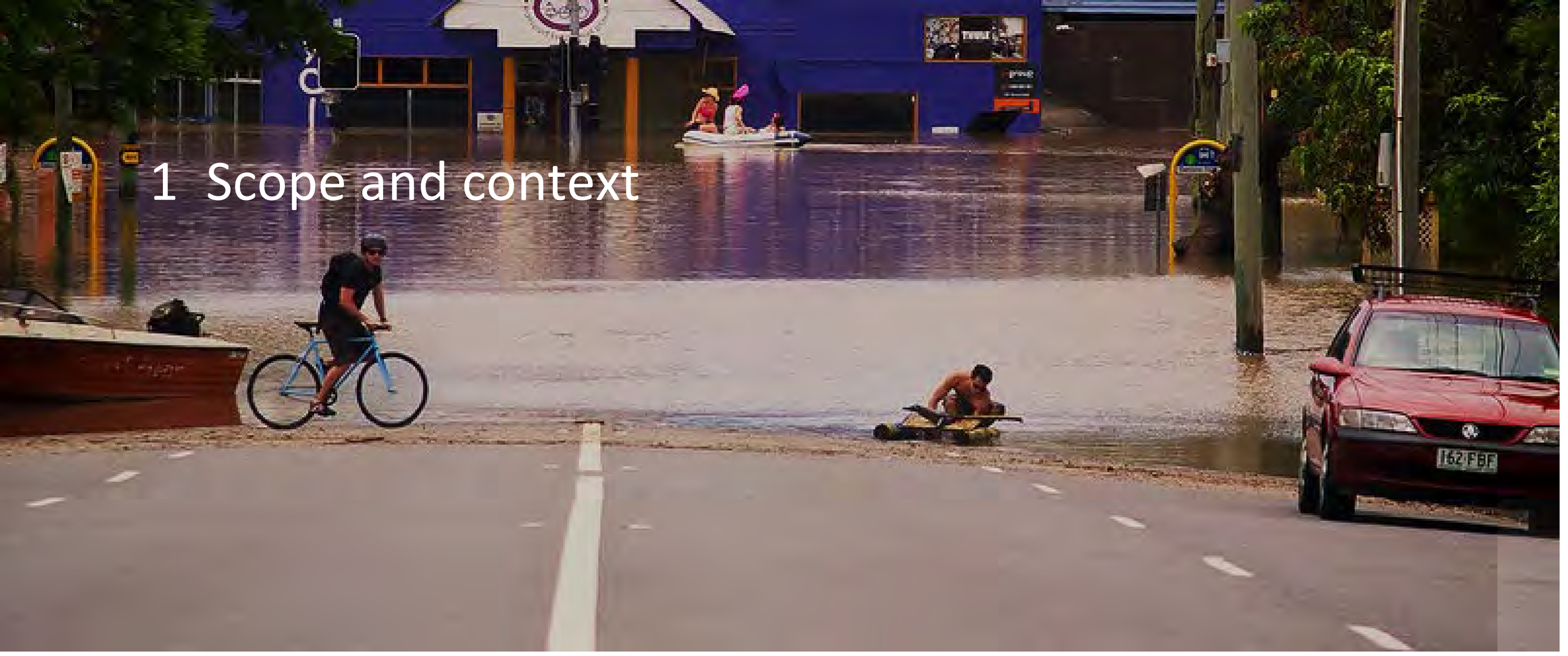
be well supported with regular engagement, trusted information and education, particularly on understanding and managing risk. This is a key factor in further building resilience.

Prior to, and at commencement of an event, there is no substitute for good situational awareness delivered through state-of-the-art operational management systems to inform response agencies and the community, to ensure as safe, effective and co-ordinated a response as possible. This is dependent on a range of effective and robust sensing, communication, data and visualisation systems. Operating agencies have a strong awareness of this importance and invest in various technological innovations. However, there is scope for more targeted and collective investment.

Successful recovery is responsive to the complex and dynamic nature of both the event and the community. While short-term recovery responses are vital, there is also a need to foster longer-term resilience, and reduce industry, community and environmental exposure to natural disasters. The current experiences of the National Bushfire Recovery Agency and the National Drought and North Queensland Flood Response and Recovery Agency reinforce previous experiences that recovery is enacted at the local and community levels. Therefore, to achieve faster and more effective recovery we need to understand not only national and state or territory drivers, but also local government and community perspectives and aspirations, in order to facilitate a coordinated disaster response across suppliers, industry, government and senior community leaders. This ensures the timely, efficient and cost-effective delivery of critically needed goods and services to affected communities across urban, regional and remote Australia.

It is important to drive continual improvement in resilience as experience grows and the nature of threats also evolves or becomes better understood. Ongoing regular review and update of risks and short-term and longer-term risk reduction measures is essential and can be conducted by both scenario planning and post-event assessments that capture new experiences. Most importantly, the concept of resilience must be incorporated into planning, land use and investment decision processes, including critical infrastructure and capability investment, to influence how and where we build and drive ongoing improvements in the standard and design of the built environment and critical infrastructure. This essentially forms the foundation of the next cycle of planning and preparation on which future resilience can be built.

The work conducted in this study is based on our current understanding of the relevant science, research and practical inputs from a broad range of stakeholders consulted from many sectors, including industry, government and community. There is a clear opportunity for further improvement and to take Australia’s approach to climate and disaster resilience to the next level alongside global best practice.



1 Scope and context

Authors (CSIRO): Russ Wise and Michael Grose

During the 2019-20 summer many parts of Australia experienced one or more major events caused by natural hazards. These events included bushfires, floods, drought and heat extremes that significantly impacted Australian communities and industries. In doing so they reinforced the case for increased focus and action on climate adaptation and resilience. As part of the response to these events the CSIRO was tasked by the Prime Minister in January 2020 to deliver an independent study recommending ways Australia can increase its climate and disaster resilience.

An Overview Report on this work was delivered to the Prime Minister on 30 June 2020 and is underpinned by this more detailed Technical Report. This work has been guided by principles of:

- Evidence based analysis
- A focus on where research, science and technology can contribute to building resilience in the short and longer-term
- Accepting and acknowledging significant improvements arising from past reviews, and complementing other current reviews and inquiries
- Maintaining CSIRO's trusted advisor role and providing relevant insights but no policy advice.

There is significant breadth, complexity and inter-dependency of numerous aspects relevant to the subject of resilience and initial investigation identified eleven topics for more detailed exploration and analysis, namely:

- Improved scenarios and models for disaster prediction, and early warning
- Harmonisation of approaches and frameworks including terminology, standards and protocols
- Adoption of Indigenous knowledge and practice into land and bushfire management
- Understanding fuel reduction efficacy and capturing learnings in models and approaches
- Reviewing knowledge platforms and tools for emergency services and others to identify gaps
- Understanding experiences to inform management of recovery and relief phase
- Infrastructure resilience and improvement needs
- Vulnerabilities and interconnectedness of critical infrastructure
- Integrating climate and disaster resilience into agricultural and environmental management
- National and international benchmarking and best practice
- Learnings from previous events, reviews and inquiries.

This deeper analysis has been conducted recognising that enhanced resilience will require improvements in:

- The capacity to project the likelihood, occurrence and consequences of extreme weather events and the locations that they impact
- Education, training and engagement of the community and individuals with respect to preparation and response to disaster events
- Reliability or alternative provision of critical infrastructure, including communications and energy
- Building standards and codes to reflect increasing severity of the events for which they are designed, based on research, testing and innovation, and
- Decision support tools for short-term operational and tactical decisions and longer-term strategic planning and investment decisions.

There has been strong progress on adaptation and increased resilience to climate risks by individuals, communities, all levels of government, and in the private sector, but improvement is still needed. To achieve this, more work is needed to fully understand and put in place the appropriate and proportional actions required to further build climate and disaster resilience across the country.

The United Nations defines resilience as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Australia is guided by the United Nations Sendai Framework [5] in its approach to risk and disaster resilience. The framework includes four priorities for actions.

1. Understanding disaster risk
2. Strengthening disaster risk governance to manage disaster risk
3. Investing in disaster risk reduction for resilience
4. Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction.

Apart from the nature and severity of an event, its impact depends on a range of factors including geographic location, landscape, level of development and type of infrastructure present, population size and density, and community preparedness and socio-economic standing.

Dealing with this contextual complexity requires a risk-based approach that takes account of location and enables scenarios to be generated for future timeframes aligned to planning horizons (for example 2030, 2050, 2070) so that resilience measures can be tested and prioritised. The need for ongoing co-design, development and application of these approaches is a recurrent theme and is critical to address short, medium and long-term planning horizons. Fundamental to this is the ability to:

- Leverage science and research to forecast and project the scale, severity and frequency of future natural events
- Understand exposure and vulnerability of communities, natural assets and infrastructure
- Undertake inclusive community-involved development of goals and objectives for interventions.

Australia currently has no standard approach to scenario planning, risk and vulnerability assessment, or measurement of resilience and progress in building it – all essential elements for better co-ordinated and effective national action. However, the agreement by the former COAG in March 2020 to adopt the National Disaster Risk Reduction Framework provides an excellent starting point for further building disaster resilience. This is now being progressed through development of an action plan under the stewardship of the Ministerial Council for Police and Emergency Management, led by Emergency

[5] UNDRR (2015) Sendai Framework for Disaster Risk Reduction 2015-2030 https://www.undrr.org/implementing-sendai-framework/what-sf

Management Australia in the Department of Home Affairs. Additionally, the 2015 National Climate Resilience and Adaptation Strategy provides framing in terms of climate resilience beyond disasters, which could be built upon to achieve a standard approach to these elements. The elements of systemic risk-informed sustainable development as intended by the NDRRF and NCRAS is illustrated in Figure 2 below.

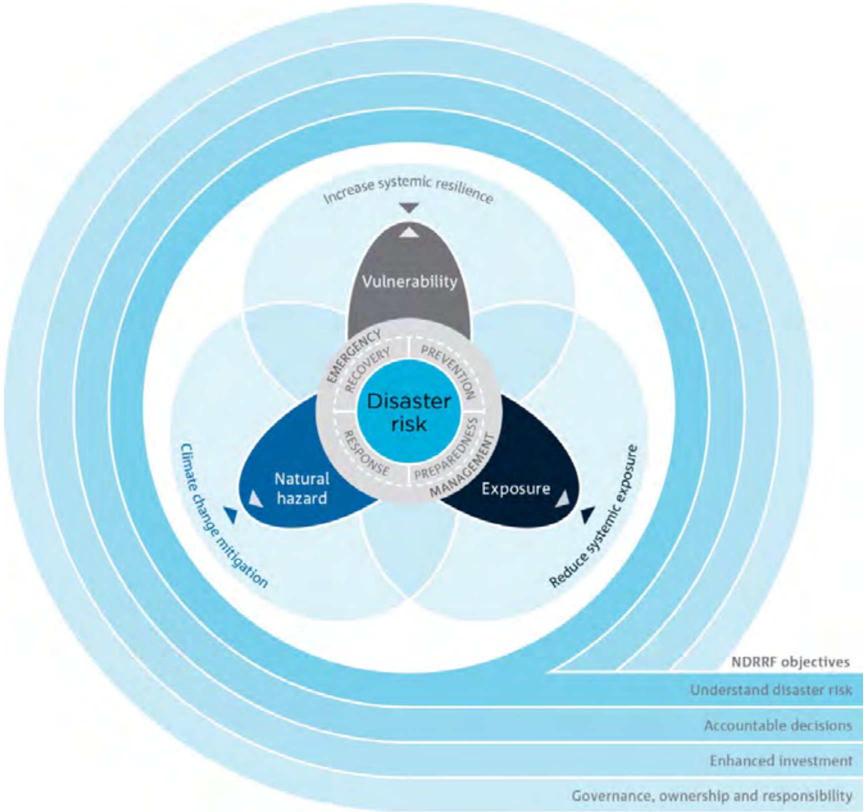


Figure 2 Illustration of a system-wide approach to disaster risk reduction that delivers on the NDRRF objectives of systemic-risk informed sustainable development. This is achieved through coordinated and targeted efforts that increase systemic resilience, reduce systemic causes of exposure and vulnerability, and integrate the strategic and operational dimensions of emergency and disaster management.

The management of disaster risk and response will always be a distributed responsibility, shared by all levels of government with critical involvement of individuals and communities. It is observed that there is a strong emphasis at the state level. However, the more consistent the underlying principles, frameworks, tools, supporting information and approaches can be, the greater the benefits that can be realised in terms of flexibility and sharing of resources across jurisdictions, scalability of response and systems, shared learning, common language and clarity of communications to community and stakeholders.

Individuals and communities are key to determining levels of acceptable risk and enabling the uptake of prevention and risk reducing resilience measures within their control. Hence capacity building, education and learning must be factored into the design and implementation of resilience frameworks and measures at all levels.

The immediate urgency of recent natural events has abated, and the focus has shifted to recovery. However, it is critical to plan and prepare for potential future events and where possible influence recovery actions to improve resilience. This will require ongoing commitment and progress to put in place the necessary systems approaches to drive resilience at all levels of government, business and community.

1.1 Scope of the Final report

At the time of writing, several concurrent inquiries and reports are being undertaken which overlap or are related to Climate and disaster resilience efforts. While a number of efforts are underway as listed in Section 10 ,the most relevant to this report are work being conducted by the:

- Royal Commission into National Natural Disaster Arrangements
- Independent NSW Bushfire Inquiry
- National Bushfire Recovery Agency
- National Drought and North Queensland Flood Response and Recovery Agency
- Australian Institute of Health and Welfare
- ACCC Northern Australia Insurance Inquiry

To avoid duplication, the work conducted in this Report aims to complement other activities and bring to bear a research and development lens as the national science agency. Where possible, relevant insights, case studies and findings arising from other work are referenced.

Given the breadth and complexity of the topic, and the timeframe available this Technical Report is neither intended nor able to be a definitive treatment of Climate and Disaster Resilience and how it should be specifically addressed for each type of natural hazard. Compromises have been made in terms of the breadth of event types considered, with a bias to more acute events, and the depth of exploration on some topics.

This Report intends to highlight the key concepts and approaches relating to building resilience and the broad systems approach that is required, provide some insight into future climate hazards Australia can expect to face and suggest initial priorities and common pathways that can be collectively advanced supported by scientific advice and research. The ongoing involvement of the relevant stakeholders and agencies at all levels of government, industry and the community who have shared responsibility for land use, transport, planning and disaster response in the co-design and ultimate customised implementation of these approaches is essential.

Insights have been gathered from a review of the relevant science, consultation with key organisations who deal with prevention, preparedness, planning and disaster response and recovery, and benchmarking against leading international approaches.

This Technical Report provides further underpinning of the high-level findings in the Overview Report delivered to the Prime Minister. The opportunities for improvement identified throughout this Technical Report have informed the Overview Report's Key Findings and 25 recommendations.

1.2 Disasters in a climate change context

1.2.1 Opportunities for improvement

- Support a thriving climate research community in Australia and close international links, with opportunities for fundamental or underpinning research
- Support targeted research programs that respond to our known knowledge gaps – particularly on the drivers and projections of extreme weather phenomena including fire weather, hail, storms, and compound extremes
- Support tools and structures to use new research into decision-making through appropriate risk management frameworks, including social and applied sciences.

To understand key climate related variables and trends, and their relevance to natural disasters, it is firstly important to define “weather”, “climate” and “climate change”, and understand how they relate to each other.

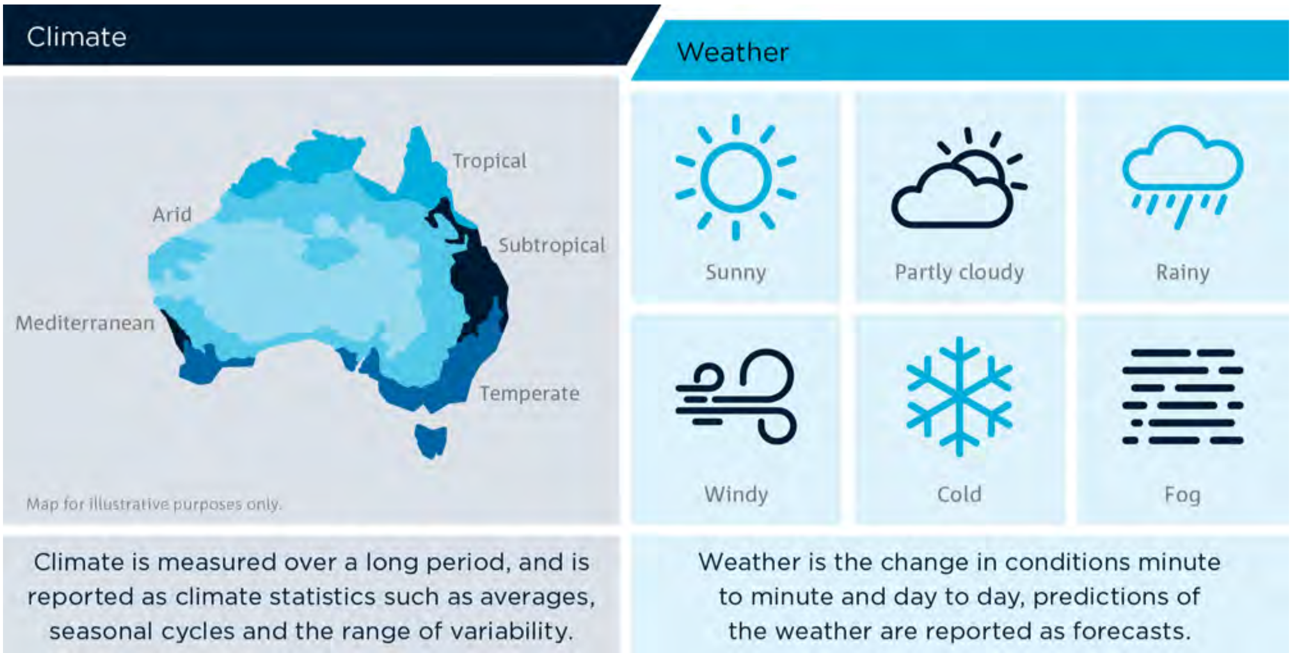


Figure 3 The difference between climate and weather

Weather is the day-to-day conditions. Climate is the prevailing weather conditions of a region throughout the year, averaged over years. Climate change describes the persistent trends in the underlying climate and prevailing weather, either by reference to the average or other statistics such as variability or the incidence of extremes. Natural climate variability refers to the variations in our climate at all timescales due to processes within the system or variations in natural external factors such as solar cycles and large volcanic eruptions. Anthropogenic climate change is a change in climate attributed directly or indirectly attributed to human activity (often referred to as simply ‘climate change’).

Also, to understand the impact of climate change, the key concepts of physical hazard, exposure and vulnerability (see Chapter 3).

1.2.2 Past changes

The international scientific community concludes that climate change due to human influence is an established fact. In particular, the increased atmospheric concentration of greenhouse gases due to human activity has been the dominant cause of the observed global warming and many other climate changes since the mid-20th century (IPCC 2013). Continued emissions of greenhouse gases will cause further warming and changes in the oceans land, ice and atmosphere, collectively known as the climate system.

Amid the very large natural climate variability Australia experiences, there are several notable climate changes in, both on land and in the seas, that have a clear signal from human influence on the climate. For example:

- Average annual temperature in Australia has warmed. Temperature change since the early industrial period taken as 1850 is a benchmark in frameworks such as the Paris Agreement, and since this time the global average temperature including oceans has warmed by around 1.1 °C (IPCC 2019). Australia has warmed by around 1.5 °C around 1.4 times the global average change including oceans and similar to the warming of the global land surface of around 1.44 °C (IPCC 2019; Trewin 2018). The warming is lower than in some regions such as the Arctic and large northern hemisphere continents.

- There has been an increase in hot extreme events including heatwaves, hot months and hot years, and a decrease in many cold extremes (Black et al. 2015; Black and Karoly 2016; Lewis and Karoly 2013; Lewis and King 2015). For example, high monthly temperatures that occurred 2% of the time in 1951-1980 occurred 12% of the time in 2003-2017. Also, heatwave days (using the Bureau of Meteorology definition) increased by up to almost two days per year in some locations between 1950 and 2013 (Perkins-Kirkpatrick et al. 2016).
- Warmer sea temperatures with an increase in the frequency and duration of marine heatwaves (prolonged warm water events that can have detrimental effects on corals, ecosystems, fisheries, aquaculture and tourism) (Hobday et al. 2016; Oliver et al. 2018).
- Higher sea levels, increasing the height of extreme sea level inundation events in many locations. Globally, sea level has risen by almost 25 cm since 1880 noting this change varies depending on location (Bureau of Meteorology and CSIRO 2018).
- There has been a shift in atmospheric circulation and the prevailing weather systems in southern Australia, leading to a reduction in rainfall, particularly in the winter to spring season and especially in southwest Australia (Bureau of Meteorology and CSIRO 2018; Dey et al. 2019; Hope et al. 2010), with more low rainfall and high temperature months (Kirono et al. 2017).
- An increase in some rainfall extremes, including hourly rainfall intensity (e.g. Guerreiro et al. 2018; Christidis et al. 2013).
- Studies of the fire conditions, and the heat and rainfall prior to recent damaging fire events in Australia, suggest that human induced climate change has increased the risk from these fires (Di Virgilio et al. 2019; Dowdy 2018; Dowdy and Pepler 2018; Grose et al. 2019 ; Harris and Lucas 2019; Lewis et al. 2019; van Oldenborgh et al. 2020; see also NESP ESCC 2019c).

Currently, there is a weaker body of evidence attributing the drivers of droughts, damaging hail, tropical cyclones, other storms and compound extremes (combinations, such as simultaneous drought and bushfire) to human induced climate change (Allen et al. 2014; Chand et al. 2019; Dowdy 2020; Dowdy et al. 2019a; Gallant et al. 2013; Walsh et al. 2016; see also NESP ESCC 2019a, b, d). This is primarily due to limitations in data, high natural variability and the challenges of simulating such events in models.

1.2.3 Future projections

As described by the International Panel on Climate Change (IPCC) Assessment Reports, Australia’s national climate change projections and recent scientific literature, significant further climate changes are expected in the future under any scenario of human development (IPCC 2013; CSIRO and BoM 2015).

Acknowledging that we have already experienced the climate changes outlined above, here we examine future change relative to a recent and relevant climate baseline of 1986-2005 (drawing on CSIRO and Bureau of Meteorology 2015). Due to an ongoing warming trend, in 2020-2039 the Australian mean annual temperature is projected to be 0.6 to 1.3 °C above the climate of 1986-2005. This means the average over the 20 years is projected to be somewhere in the 0.6 to 1.3 °C range, but with warmer and cooler years within the period (for reference, the year 2019 was 1.1 °C above the 1986-2005 average). Australia’s annual mean temperature in 2080-2099 is projected to be either 0.6 to 1.7 °C warmer than 1986-2005 under an emissions mitigation goal of zero global emissions by around 2070, or up to 2.8 to 5.1 °C warmer than the 1986-2005 average if greenhouse gas emissions continue to accelerate.

Along with further warming, projections for Australia indicate ongoing trends of further drying of southern and eastern Australia in some seasons. This will include reduced average rainfall, greater evaporation, lower humidity, lower soil moisture and less runoff on average. This long-term trend is expected to emerge amid high variability, with ongoing wet and dry years and seasons. Projections also indicate additional sea level rise, more intense rainfall extremes at hourly and daily timescales, decreased snow cover on mountains, ocean acidification and effects on vegetation from higher carbon dioxide concentrations.

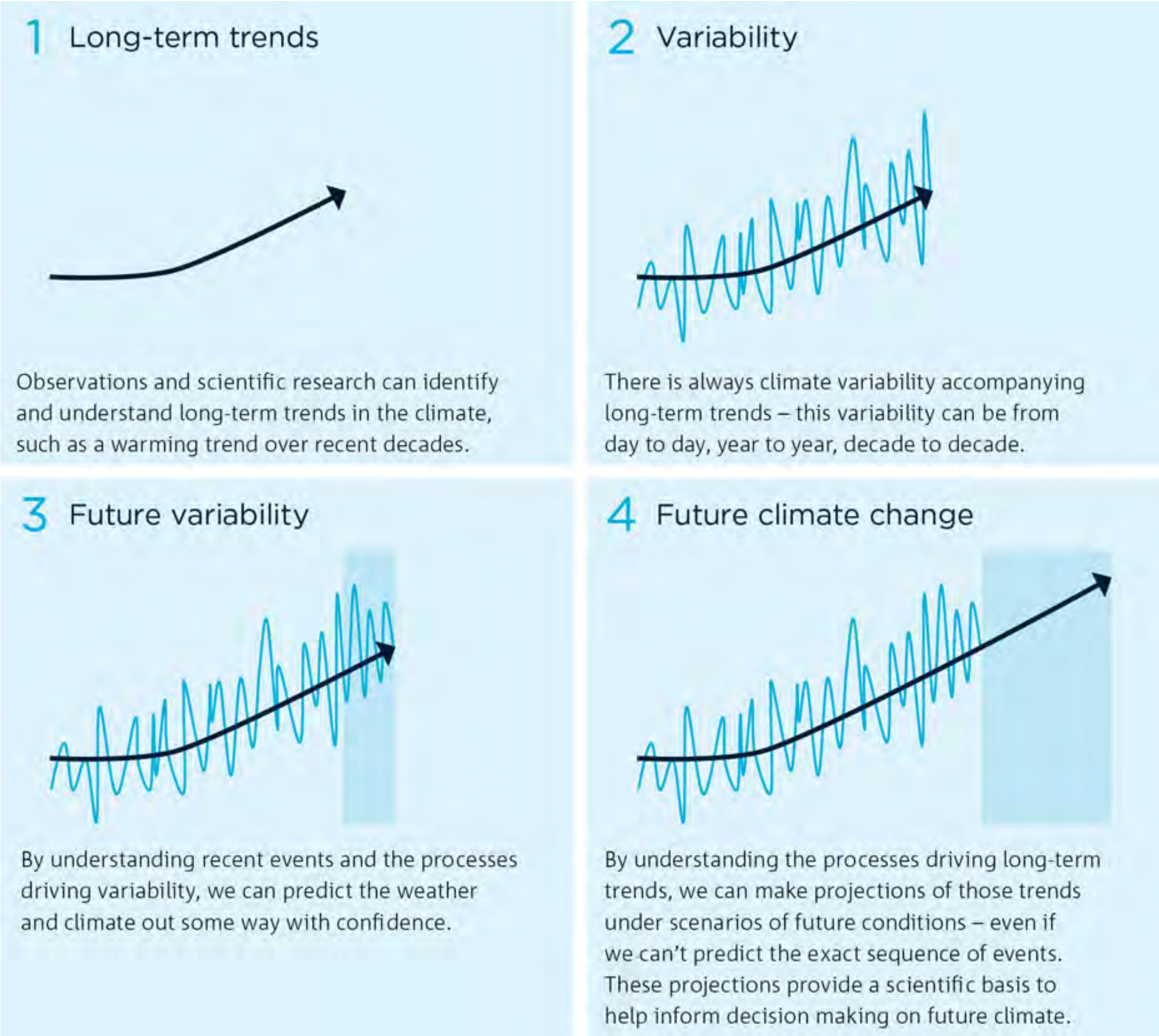


Figure 4 Climate variability and change are seen in our observations of the earth system. We see observed weather and climate variability - changes from day to day, and year to year, decade to decade. We also see underlying trends. Climate variability can sometimes appear to buck the trend or boost the trend in the short term. Through scientific observations, understanding and modelling of the system, we can both predict the upcoming climate variability and also make projections of the long-term trends.

1.2.4 Impacts of climate change on disasters

Impacts from climate change occur through changes in the underlying climate averages (sometimes called 'chronic' or 'slow burn' aspects), together with an increase in the frequency or intensity of some types of climate extremes (also called the 'acute' aspects). In terms of natural systems, these two aspects have been described as the 'press and pulse' of climate change impacts (Harris et al. 2018). An example is the mountain Ash forests in the Australian Alps, where rising temperatures provide a background chronic 'press', then multiple fires in short succession acted as the 'pulse' to reduce tree growth, seed production and seedling establishment. There are analogous impacts from mean and extreme changes working together to increase the risks or impact of disasters in Australia. For example, a rise in the average sea level accompanied by extreme sea level events that erode shorelines create increase risk from coastal inundation. A hotter, drier average climate together with a greater chance of the worst fire weather events creates greater impact from bushfires.

Due to change changes in the average climate and climate extremes described above, Australia is at increased risk of impacts from natural disasters, noting the confidence levels in relation to the increase risk of each type of event varies, as follows:

I. Meteorological Drought:

Increased impact from prolonged dry spells, known as meteorological drought, that may flow on to impacts in hydrological, agricultural and socio-economic drought. This includes an increase in multi-year droughts and 'flash' droughts, (possibly through increases in rainfall deficits, but also through hotter temperatures during droughts). Confidence in relation to the increased risk of drought varies, with higher confidence for increased impacts through hotter droughts, and for an increase in shorter duration droughts. Projections of multi-year droughts remain of lower confidence.

II. Bushfire weather:

There is a projected increased dangerous bushfire weather danger in southern and eastern Australia (CSIRO and Bureau of Meteorology 2015; Di Virgilio et al. 2019, see also NESP ESCC 2019c). This includes the danger described by indices such as the McArthur Forest Fire Danger Index (FFDI) with a higher accumulated index and more days of extreme fire danger (Dowdy et al. 2019b). The FFDI combines measures of air temperature, relative humidity, wind speed, and recent dryness. Confidence in this projection is high. Also, fire danger is increased through a background warmer and drier climate, plus possible climate impacts on ignitions through lightning strikes. The change in climate will also likely result in changes to bushfire fuel amount, structure and type.

III. Heat extremes:

Heat extremes of all kinds including hot days, warm nights and heatwaves are projected to increase. For both northern and southern Australia, in many places 1-in-20 year extreme hot days are expected to occur every two to five years by the middle of the century (CSIRO and Bureau of Meteorology 2015). There is a very high confidence in these projections.

Marine heatwaves include those linked to coral bleaching events in the Great Barrier Reef (such as in 2015/16, 2017 and 2020), aquaculture impacts in eastern Tasmania (such as in 2015/16) and off Western Australia (such as in 2011). More frequent, extensive, intense and longer-lasting marine heatwaves are projected which suggest more frequent and severe bleaching events and loss of many types of coral on the Great Barrier Reef (Frölicher et al. 2018; Oliver et al. 2019). The East Australia Current region is projected to continue to warm, which is linked to an increase in marine heatwaves and their impact. Some Australian regions face a "permanent marine heatwave state" by mid-century under a high emissions pathway. There is very high confidence in this projection. See the Appendix at Section 2.10 *Planning for marine heatwaves around Australia*.

IV. Floods, flash floods:

Greater short duration rain extremes associated with flash flooding. As the climate warms, heavy rainfall is expected to become more intense, based on the physical relationship between temperature and the water-holding capacity of the atmosphere. For heavy rain days, total rainfall is expected to increase by around seven per cent per degree of warming as a general rule. This rate may be more or less than this rule of thumb at any location due to changes in the dynamical processes that bring rain (e.g. the intensity of weather systems).

For short-duration, hourly, extreme rainfall events, observations in Australia generally show a larger than seven per cent increase (Guerreiro et al. 2018), and this is projected to continue.

V. Sea level rise and extreme sea level events:

In Australia the consequences of sea level rise will include increased flooding of low-lying coastal, including tidal, areas and are likely to result in coastal erosion, loss of beaches, and higher storm surges that will affect coastal communities, infrastructure, industries and the environment. There is very high confidence in this projection. Along with a background sea level rise, there may be changes to the storms and wind waves that bring the highest sea level inundation events.

Averaged around Australia, sea level is projected to rise by 26-55 cm by 2090 relative to 1986-2005 under a very low emissions scenario. Under a very high emissions scenario sea level is projected to rise by 45-82 cm (CSIRO and Bureau of Meteorology 2015). However, any rise will vary by region. It should also be noted that a greater sea level rise is possible depending on the collapse of the Antarctic ice sheet (IPCC 2019).

VI. Hail and damaging storms:

An increased risk from large hail is possible, but currently uncertain due to the limited period of consistent observations as needed for historical trend analysis studies, as well as due to the limited ability of models to accurately represent the physical processes required for simulating future hail events (Walsh et al. 2016). However, there is some indication of potential increases in severe thunderstorm environments for parts of eastern Australia, noting a wide range of uncertainty which represents a sizeable gap in current knowledge (Dowdy 2020; see also NESP SESCC 2019d).

Some types of damaging storms are projected to change in frequency, severity or other aspects including for example speed and size, due to a warming climate. East coast lows (intense low-pressure storm systems which occur off the eastern coast of Australia) are projected to decrease in number in winter (Dowdy et al. 2019a; see also NESP ESCC 2019b), however the impact from each storm may increase due to higher sea levels as well as associated changes to the extreme wind, rain and waves.

VII. Tropical cyclones:

Climate change may mean fewer total cyclones but an increase in the number of high category cyclones (Chand et al. 2019). However, it is not currently possible to quantify cyclone trends with a substantial degree of confidence. This is because tropical cyclone activity in the Australian region, which is specified as the ocean and land areas from 90° E to 160° E in the southern hemisphere, has large variability from year-to-year, due to the influence of naturally occurring climate drivers. The number of tropical cyclones in the Australian region generally declines with El Niño and increases with La Niña. Observations since 1982 indicate a downward trend in the number of tropical cyclones in the Australian region. In contrast to the number of tropical cyclones, cyclone intensity is harder to observe (especially prior to the satellite era), so it is not currently possible to quantify any trends with a substantial degree of confidence.

Tropical cyclones are categorised by their windspeed, but the impact from tropical cyclones come not just from the winds but also from heavy rains and contribution to storm surge. For a given cyclone, the increased rainfall due to warmer oceans and atmosphere and higher storm surge due to sea level rise are projected to increase the overall impact.

IX. Compound extreme events

Extreme events that occur at the same time (coincident), immediately following another extreme (sequential) can also be called multi-risk events and can be linked to multiple failures, amplified overall risk and cascading impacts. Some coincident extremes have a common cause, e.g. an intense low can bring coastal storm surge due to low pressure, intense rainfall leading to flash flooding and high winds, all contributing to impacts. Other coincident or sequential events may occur just due to chance. Projected changes each aspect of the risk is expected to increase the risk from compound extremes, however any change in the joint probabilities of these elements may enhance or offset the overall changing risk form compound events. Projected change to risk from compound extremes remains a relatively understudied area.

Table 1 Summary of climate related threats and their consequences

THREATS	IMPACT AREAS	CONSEQUENCES
Bushfires	Health & well-being	Loss of life; injury; illness or mortality due to smoke exposure; increased mental health problems
	Environment	Ecosystem damage; loss of wildlife and biodiversity; loss of cultural sites
	Agriculture &Water	Loss of crops, reduced productivity; tainted grapes; decreased water quality; impacts on and loss of livestock; damage to fencing and livestock
	Infrastructure	Loss of property; damaged infrastructure; road closures; impacts on aviation; impact on energy infrastructure
	Economy	Loss of property and stock; insurance costs and premiums; tourism
Droughts	Health & well-being	Increased mental health problems
	Environment	Impact on biodiversity; reduced ecosystem services provision
	Agriculture & Food security & water	Decreased productivity; soil and nutrient loss; crop damage; Impacts on and loss of livestock; constraints on water resources
	Economy	Loss of livelihoods; decline in agricultural yields
Heat waves	Health & well-being	Greater risk of injury, disease and death; increased demands on hospitals, aged care facilities and service providers; reduced labour force productivity; poor air quality
	Environment	Ecosystem damage; heat stress on wildlife
	Agriculture &water	Crop damage; impacts on livestock
	Infrastructure	Disruption of rail and energy infrastructure; damage to infrastructure
	Economy	Cost, particularly to cities and agricultural sector
Dust storms	Health & well-being	Illness due to exposure and poor air quality
	Environment	Soil loss through wind erosion
	Agriculture &water	Soil and nutrient loss, crop damage
	Economy	Disruption of transport services, especially air
Floods	Health & well-being	Loss of life; injury; infectious diseases
	Environment	Ecosystem damage; impact on biodiversity, cultural heritage
	Agriculture & Food security & water	Damage to or loss of crops; impacts on and loss of livestock; poor water quality
	Infrastructure	Damage to houses, roads and other infrastructure
Storms and cyclones	Health & well-being	Loss of life; injury
	Environment	Ecosystem damage; disruption of environmental processes
	Agriculture & Water	Damage to or loss of crops
	Infrastructure	Property and infrastructure damage; insurance costs and premiums
Sea level rise and storm surge	Environment	Coastal erosion; loss of coastal ecosystems; impact on biodiversity, cultural heritage
	Infrastructure	Damage to buildings, roads, coastal infrastructure
	Economy	Reduced access to coastal environments, tourism
Marine heat waves	Environment	Damage to marine ecosystems; new pest species
	Economy	Impact on fisheries; aquaculture; tourism

As mentioned at the outset, and covered in detail in Chapter 3, while there is a link between climate variables and disasters, there are other factors that contribute to the occurrence and the magnitude of disaster impacts. These include the element of chance as to whether compounding or mitigating factors are present, the location the primary events occur, the high variability of climate and the underlying vulnerability of the affected locations. For example:

- In the more populated area of southern and eastern Australia fires involving major losses are almost always associated with fire weather represented by forest fire danger index (FFDI) values that are extreme (75-99) or catastrophic or code red (>100). However, FFDI values that are 'severe' (50-74) or 'very high' (25-49) or lower can also lead to significant losses due to other factors such as hilly terrain, low separation distances, or preceding seasonal drying of vegetation. For example, losses in the 100s of houses for FFDI<75 are almost exclusively located in hilly terrain. Further, the severe dryness in Tasmanian highlands in early 2016 led to a greater loss of World Heritage Area. Conversely relatively high FFDI values do not always lead to high impact fires that cause losses of built assets and lives due to:
    - No ignition occurring (including through implementation of total fire bans)
    - Ignition occurring in areas that are relatively quick and easy to access for fire containment and being responded to rapidly
    - Events occurring in flat terrain which impedes fire spread
    - Built infrastructure having a lower vulnerability to fire arrival.
- The local impact of storm surges is subject not just to underlying sea level rise but also depends on the local regime of tides and waves, the nature of the coastline (slope, landform and processes) and local geology (hard rock, or soft, unconsolidated sediments), and what is exposed to the surge (what is built and how it is built)
- Tropical cyclone tracks – whether they make landfall, where they make landfall – and building codes make a big difference to impacts of tropical cyclones
- The impact of floods not only depends on the rainfall but also the antecedent conditions such as soil moisture, the vulnerability of assets to floods and flood protection measures.

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2 Scenarios, models and early warning systems

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2.1 Summary

This chapter relates to the biophysical models that are used for assessing, forecasting and projecting changes to the weather and climate, as well as the risks from climate impacts such as fire.

The modelling of our weather and climate in the past, present and future to produce useful intelligence for decision-makers is an impressive achievement of human ingenuity. Australia's weather and climate research capability is world-class and highly respected internationally but requires ongoing effort to remain as best practice.

The practices and methods differ at different timescales however the various outputs can be brought together to make coherent tactical and strategic decisions about managing weather and climate risk across all timescales. To produce useful outputs for applications in disaster risk we require ongoing model development as well as running a cascade of model ensembles in nationally and internationally coordinated programs. To fully exploit the value of this modelling requires ongoing progress in using forecasts in impact applications and into risk-management decision-making frameworks.

2.2 Opportunities for improvement

- Maintain Australia's position as an internationally competitive centre of weather, climate and earth systems modelling
- Support the ACCESS modelling system in its various functions, and expand its use to address more Australian-specific research and impact questions
- Support multi-model coordinated global and regional ensembles of weather and climate modelling with state and national consistency for the climate change projections timescale
- Respond to and keep pace with international best practice in the technical and delivery practices for the production and communication of forecasts and projections, with the benchmark of Copernicus from the EU. This includes improvements in the use of seasonal forecasts for tactical decision-making for coming seasons, and the use of climate projections to inform strategic decisions and looking to 'seamless' climate services across multiple timescales
- Enhance the links between forecasts and projections into analyses and decision-making around extreme events through appropriate institutional arrangements.

2.3 Climate and Earth System Modelling and information from weather to climate change scales.

This section is about generating weather and climate intelligence for future planning, and covers:

1. The production of weather and climate forecasts, climate projections and physical climate change scenarios
2. The extension of these products specifically to the area of disasters
3. The pathways and mechanisms to use this intelligence to inform disaster risk planning and decision-making.

2.3.1 Modelling systems

Sophisticated computer model simulations informed and evaluated against high-quality observations are a vital tool for understanding physical climate processes, making forecasts and future projections. Dynamical models that use the laws of physics and mathematical descriptions of earth system components are needed to understand the components of the system and how they interact and evolve but can be supplemented by purely statistical models where appropriate. For use in disaster risk applications, global models are needed to first understand global to regional scale processes and context but this must be supplemented by higher-resolution and secondary modelling to fully resolve extreme events and their impacts.

- The key tool utilised for many weather and climate applications is the ACCESS modelling system developed by CSIRO, the Bureau of Meteorology and Australian Universities, in a long-term strategic partnership with the Unified Modelling Partnership, including the UK Met Office, South Korea and New Zealand. There are a number of other, complementary models also developed and used within Australia, however as these models are used for different purposes, they are outlined by reference to their purposes in the section below
- Modelling of the weather and climate at all spatial scales from local to global, and at all timescales from hourly to century timescales involves many common physical components, including the physics of atmospheric and ocean dynamics, radiation balance, clouds and convection. Modelling relies heavily on international cooperation through data inputs (weather stations and satellite) to inform and evaluate models, and on development of computer code to best simulate different climate system components and phenomena.
- There are some important differences in the modelling practices between how to forecast weather (the day-to-day conditions) and to make projections of the long-term climate (the prevailing conditions of a region throughout the year, averaged over years), and at different spatial scales. Forecasting the weather largely relates to how well the current conditions are known, and weather forecasts rely heavily on a single high-quality modelling system such as the ACCESS system with a check of other modelling systems for consistency. In contrast, projections of longer-term climate change (i.e. multiple decades) depends on an estimates of the changing state of the system where there are structural differences between model results, so climate change projections usually use a formal multi-model ensemble methods and Australian model simulations are submitted to this database. The activities and models used, in order from past to future, from shorter to longer timescales are outlined below.

2.3.2 Past

The observed record of historical weather and climate are obtained, analysed and curated by the Australian Bureau of Meteorology (BoM) and CSIRO, and includes many international partnerships for many aspects including collecting satellite data.

Models can also be used for 'reanalysis', which builds a more complete picture of the climate in the past by using the full set of point observations of the few variables collected and filling in gaps in space and time using a model. Reanalysis is increasingly used for analysing and understanding past conditions and changes, including for bushfires, as a complement to weather station "point" measurements and gridded climate datasets. Atmospheric reanalysis is used in assessing past and current risk for a range of hazards including bushfire (through National Disaster Risk Information and Services Capability (NDRISC) and others), and ocean reanalysis is useful for marine and coastal hazards analyses. International best-practice models from overseas (e.g. Europe's ERA5) and from within Australia (BARRA: Su et al. 2019; Climate Analysis Forecast Ensemble; see https://research.csiro.au/dfp/activities/climate-forecasting-system/) are established or emerging and require ongoing development and support (e.g. compute resources, data storage, analysis).

2.3.3 Weather

Nowcasts and weather forecasts are produced by the BoM primarily using observations from the BoM's observation network, satellite data and predictions from the ACCESS modelling system run in weather forecasting mode (Puri et al. 2013). The ACCESS system utilises an ocean prediction system OceanMAPS, developed jointly by CSIRO and the BoM and run operationally by the BoM, to forecast the upper ocean state out to ten days, noting ocean temperature predictions are crucial to weather forecasts. Forecasts from modelling systems such as Europe's Centre for Medium-Range Weather Forecasts are also available in Australia through non-BoM websites and apps, and there is a small commercial sector in Australia for producing value-adds to weather forecasts and distributing these (e.g. WeatherZone, among many others), however hazard warnings are almost entirely the remit of the BoM.

Forecasts of runoff and streamflow are routinely produced, and there is a national flood forecasting and warning service. Marine forecasts of variables such as sea surface temperature, marine heatwaves and coral bleaching risk are now produced, but there are no operational warning systems or national planning strategies (see also the Appendix at Section 2.10 *Planning for marine heatwaves around Australia*).

Forecasts are communicated to the Australian community and to sector user groups in disaster management, agriculture, aviation, defence and others, and are used to make operational decisions out to 10 days. BoM forecasts extend these forecasts to inform disaster management in numerous ways, including through forecast and warning systems for hazardous weather (heatwaves, floods, tropical cyclones, bushfire weather). Warnings are communicated via the web, mobile apps, traditional media, as well as linking to warning systems such as text alerts. Technical aspects require ongoing support and development to maintain international best-practice, but the overall effectiveness of early warning systems also depends on community values and preparedness. Reviews into the early warning systems have found ongoing progress, with each major event stress-testing the system and inspiring improvement (e.g. 2009 Black Saturday heatwave and fires, 2011 Queensland floods). Major remaining issues include "...low levels of community preparedness and awareness of warning systems (for some hazards), lack of effective flash flood early warning systems, understanding of community responses to warnings and a lack of regular and consistent evaluations of the performance of early warning systems" (Dufty 2014).

2.3.4 Seasonal

Sub-seasonal to seasonal (S2S) outlooks (weekly to 3-months) are produced and communicated by the Bureau of Meteorology. Seasonal outlooks draw on the Australian modelling system ACCESS setup for seasonal scales (ACCESS-S, incorporating the European-developed NEMO ocean model), but also integrate the output from eight major international modelling groups. Forecast skill and therefore utility in decision-making varies by region, by season and by the specific setup of climate drivers (e.g. once an El Niño event has commenced, this imparts notable predictability of the coming seasonal climate). Technical aspects of producing seasonal forecasts require continual ongoing development.

Outlooks are communicated through the website, sector briefings and other means. Seasonal outlooks link to disaster management through flood outlooks from seasonal streamflow forecasts, and crucially through bushfire weather outlooks that are used to make tactical decisions (movement or retention of resources such as aerial fire-fighting assets, an indication of water availability etc).

Marine seasonal outlooks are produced and are informally used to manage of risks from marine heatwaves to coral bleaching, fisheries and aquaculture through things such as pre-summer reef health workshops at the Great Barrier Reef Marine Park Authority and targeted effort to inform risk management of the Tasmanian salmon aquaculture industry (Hobday et al. 2018; Smith and Spillman 2019; Spillman and Hobday 2014).

There are opportunities to enhance the link between seasonal forecasts and applied models and disaster planning platforms, and to integrate seasonal outlooks into more platforms. For bushfire this link could be enhanced through integrating seasonal forecasts into the National Disaster Risk Reduction Framework (NDRISC), including through the National Bushfire Intelligence Capability (NBIC), among others. Through these platforms and other mechanisms, these forecasts can inform tactical decisions on disaster management at the state, national and international scale. Such decisions include flood management (e.g. management of dam levels) and management of firefighting infrastructure (e.g. aircraft procurement or movements). Such decision-making needs clear guidance on forecast skill, appropriate delivery platforms and appropriate governance.

2.3.5 Forecasts beyond seasonal

Extended seasonal forecasts, and multi-year to decadal predictions are currently under development by the international research community and are not used operationally. Extending the BoM seasonal forecasts beyond three months using ACCESS-S is being trialled. The CSIRO Decadal Forecasting Project (https://research.csiro.au/dfp/about/) has developed and delivered experimental products on extended seasonal to multi-year forecasts using the new modelling system Climate Analysis Forecast Ensemble (CAFE) and is linking to the international research community in this field. CSIRO has met the World Meteorological Organisation requirements to become a decadal modelling centre, the only one in the Southern hemisphere. At these timescales, both the initialisation of the ocean state (including sub-surface) and the realistic process representation of ocean processes become critical factors that affect predictions of future atmospheric state. Technical methods, assessment and testing, forecast communication plans and the development of applications all need further development before operational multi-year to decadal forecasts are routinely produced and used.

2.3.6 Climate change projections

Projections are the assessment of changes in the underlying climate state due to external 'forcings' such as human influence and are not a prediction of the sequence of upcoming events. Projections are useful to inform strategic decisions on mitigation and adaptation aspects of building climate resilience for coming decades. Projections of climate change at the multi-decadal scale require multi-model ensembles, so rely on international partnerships and efforts. Australia contributes two configurations of the ACCESS model to the World Climate Research Programme's (WCRP) Coupled Model Inter-comparison Project (CMIP; see Eyring et al. 2016). The newest set of model simulations is providing new insights into Australia's projected climate (Grose et al. 2020). Submitted models are primarily now Earth System Models (ESMs).

ESMs are Global Climate Models with an interactive carbon cycle that enable simulations to be done that quantify the interactions between the climate, biology, chemistry, hydrology and human systems. ESMs are needed to quantify how net carbon emissions change into the future, the role of land and oceans in managing carbon, and allows us to develop and explore mitigation strategies and proposed climate interventions. Given the importance of land, ocean and atmosphere interactions and feedbacks here, including the significance of fire in Australia, ESM is an important area of modelling that requires ongoing long-term support and investment alongside other areas.

2.3.7 Regional climate change modelling

Climate change modelling at higher spatial resolution can resolve high-impact weather and can be used to characterise impacts from climate and weather at a specific location by using regional climate models (RCMs) with global models as input. Through RCMs we can better simulate, understand and characterise event magnitude and frequency and derive the basis for confidence in forecasts and projections. Discussion of high-resolution modelling specifically for fire is found in Section 2.4.

Two spatial scales are particularly relevant to enhanced simulation of disaster extremes arising from a climate change context.

The first spatial scale is regional modelling at the intermediate scale (typically 5-50 km) produces new insight (known as 'added value') due to better representation of weather systems, the topography of Australia and similar factors. This scale of added value is useful for disaster risk management as it provides a more realistic regional depiction of the changing background climate conditions and of some extremes.

Secondly, modelling at the very fine scale (4 km or less) produces added value due to better simulation of processes such as convection, which are especially relevant to some types of weather extremes. This scale of added value is useful for disaster risk planning as it can more realistically depict the 'future extreme weather' associated with future climate change projections, and provides locally-relevant data and information about extreme events relevant to disasters.

RCMs are also useful for modelling how fire behaviour is affected by topography and spatially heterogenous landscapes (in terms of soil moisture, plant cover etc). The land surface model component of RCMs can be used to address questions of changing land use and land cover, bushfire fuel loads in a changing climate.

RCM modelling is computer-intensive and expensive to produce, but Australia has some significant datasets despite lower resourcing than some other nations. To date, regional modelling in Australia has typically been done to intermediate scale and on an *ad hoc* basis using a single RCM system for state government projects (e.g. in NSW, Victoria, Queensland, Tasmania). Coordinated multi-model regional modelling is now considered best practice. Intermediate-scale simulations are being coordinated and produced under the World Climate Research Program coordinated regional downscaling experiment (CORDEX) program (Gutowski et al. 2016), and early results from CORDEX-Australasia are evaluating well (Di Virgilio et al. 2019) and showing notable 'added value' that can now be quantified using this nationally consistent approach (Di Virgilio et al. 2020). However, resourcing is required to incentivise work to follow coordinated multi-model regional modelling and to move away from *ad hoc* studies using a single RCM system. Similarly, efforts to coordinate very fine scale climate modelling are at early stages of deployment and need further support and resourcing in order to deploy and gain the benefit from recent scientific advances in high resolution modelling.

2.3.8 Using climate change projections

There is no single best practice for linking climate projections to risk assessment, however there are some established and broadly agreed principles about the types of risk management frameworks that are suitable at the climate change timescale (see Chapter 3).

Future climate is determined by three factors:

4. The global socio-economic development and resulting emissions of greenhouse gases and aerosols (and other effects on the climate such as land use change)
5. The regional climate responses to those emissions
6. Ongoing natural climate variability.

The amount of climate change we experience beyond the next couple of decades depends strongly on the pathway of global emissions, and we don't know which pathway the world will follow. Therefore, climate projections beyond around 2040 must use a scenario approach. A standardised and documented set of emission pathways are used internationally, and the latest set integrates global emissions pathways with global socio-economic pathways (Gidden et al. 2019; Riahi et al. 2017). Given our incomplete understanding of the processes involved, it is best practice to derive a range of possible climate responses from the full range of model simulations for any given emissions scenario, rather than making a single projection based on a single model (see O'Neill et al. 2016). Therefore, the range of all acceptable GCM and ESM model results are used, not just the results from ACCESS. Substantial ongoing climate variability must also be accounted for, along with the climate change driven by human emissions.

To examine questions of regional climate change and changes to extremes, there is a cascade of modelling and analysis used. An ensemble of GCM and ESM simulations produced around the world every few years (the CMIP program) is often used as a core starting point, then a representative sampling of GCMs and ESMs is used as input in regional climate modelling (see above). Also, to fully explore future climate change and its impacts, various secondary models are used to extend what is done in climate models and Earth System Models, including models of coastal extremes, bushfires and their impact, runoff, stream flows and water availability and numerous others. Until the climate simulations from GCMs and ESMs are of very high spatial resolution and include all of these processes in a realistic and complete way, there will be a need for this model cascade.

There is now added impetus for increased standardisation of projection information, including through an increased focus from the financial sector. Disclosures of financial risks form climate change under the Taskforce on Climate-related Financial Disclosures (TCFD) need to be comparable, e.g. see statements from the Australian Prudential Regulatory Authority (APRA). This need for simplicity, standardisation and intuitiveness could be met by standardised climate scenarios or 'storylines', together with standardised climate extremes risk stress tests

Scenarios are set of discrete, self-consistent physical storylines of future conditions that representatively sample the range of possible future conditions under different pathways (Shepherd et al. 2018). Standardised stress tests are challenging but plausible sequences of climate extremes consistent with the projected future climate. Both scenarios and stress tests draw on coordinated global and regional modelling programs, together with other lines of evidence and inputs, then involve decisions to reduce the various aspects of future uncertainty into simpler options. Ideally this involves co-production of knowledge by the sectors involved to ensure the products are fit for purpose.

Some countries have used physical change storylines to produce a set of standardised physical climate change scenarios for broad use, such as the Netherlands: http://www.climatescenarios.nl/. Given Australia's diverse range of climate regimes and projected changes, the national projections don't currently present a single set of standardised national scenarios, but rather provides the Climate Futures tool for generating tailored change scenarios for user-defined specifications of region, timeframe, emissions scenarios and climate variables of interest. Indeed, there are advantages in tailored scenarios for different sectors and applications, and for different stress test scenarios for resilience planning (see Chapter 3). However, there is utility in further standardisation and consistency to enable the analysis of integrated risks across the economy, built and natural environment. This move would require guidance, standards and oversight, as well as tools to link projected biophysical changes in Australia with economic modelling to ensure that climate consistent economic pathways are developed that account for the regional impacts of climate change and variability. There will be a similar need for guidance and standards for the use of multi-year to decadal forecasts as they become operational.

2.3.9 Conceptual development

The terminology, definition and categorisation of various climate hazards and risks need ongoing development to allow these risks to be effectively understood and addressed. For example, the term 'marine heatwave' was only coined in 2011, but now a formal definition and categories similar to the categorisation of tropical cyclones has shown significant utility (Hobday et al. 2018). Definitions and categorisations for compound extremes has been evolving over time, and this practice is now becoming formalised, which will significantly aid in communication on these features. Similarly, the concept of 'climate impact drivers' is becoming more common, which means defining climate factors by the degree to which they impact rather than by a categorisation of a physical variable alone. The new fire danger rating system (see below) will allow the more targeted discussion of fire as it relates to impacts.

2.3.10 Strategic development

There are several relevant strategic documents in the area of weather and climate modelling. A strategy for the development of technical aspects of weather and climate research (but not modelling) is being developed through the National Climate Science Advisory Council (NCSAC) process. The current goals and the strategy for weather forecast development and delivery are covered in the Bureau of Meteorology Strategy 2017-2022 and the vision and strategy for weather and seasonal forecasting using ACCESS is outlined in the Research and Development Plan 2020-2030. Collaboration on ACCESS development is overseen by an inter-agency committee comprising CSIRO, BoM, National Computing Infrastructure (NCI) and university partners, and together these agencies contributed to an ACCESS National Research Infrastructure scoping study, with future directions depending on the outcomes of that NRI process and the vision for the upcoming National Environmental Science Program Climate Systems hub.

2.4 Manual bushfire spread prediction tools

Considerable effort has been expended over the last sixty-odd years to provide fire practitioners with the ability to predict the likely behaviour of a bushfire (whether intentionally ignited or not) based on observations of the current weather and fuel conditions (Cruz et al. 2015a). This work was initiated early in the previous century primarily by forest managers desiring to protect forest estates from damaging wildfires. These managers were interested in determining when conditions conducive to potentially destructive fires were likely such that additional firefighting resources and early detection of fire outbreaks could be deployed (Sullivan 2009). This later evolved into the need to predict the likely behaviour and propagation of an active fire to better conduct suppression actions.

Initially these manual prediction systems were not much more than rules of thumb but have evolved to incorporate developing fire science concepts and knowledge in more sophisticated predictive tools. Much of this knowledge is empirical in nature with a strong reliance upon study of large-scale experimental fires in which measured fire behaviour (rate of forward spread, flame height, spotting) is correlated with measurements of fuel and weather factors influencing that behaviour. Additionally, fundamental treatments of bushfire behaviour (e.g. physical considerations and laboratory investigation of key combustion processes and flame propagation mechanisms) have also contributed to the growing understanding of fire behaviour and the tools used operationally to predict it, particularly under conditions beyond that possible for empirical study in the field.

Cruz et al. (2015a; 2015b) reviewed all empirical fire behaviour models designed for use in predicting fire behaviour in Australian vegetation and provided a set of recommended models for operational use. This set represents the current best practice for the prediction of fire behaviour in Australia and it forms the basis of the training of Fire Behaviour Analysts (FBAns —those land management agency and rural fire authority individuals tasked with carrying out fire spread predictions for the purpose of issuing warnings and alerts and undertaking fire suppression planning and attack) in fire spread prediction. These fire behaviour models are generally designed to provide estimates of the pseudo-steady-state rate of forward spread of active fires utilising weather and fuel conditions averaged over periods of 15-30 minutes and will not accurately capture short-lived fire behaviour dominated by transitory structures such as gusts and lulls or brief changes in fuel condition (Cheney and Sullivan 2008).

While the individual fire spread models are easily programmed and exist in a wide variety of programs, online tools or mobile apps, only two software packages incorporating these models and designed specifically for the purpose of aiding operational manual fire spread prediction exist:

1. An Excel spreadsheet (FireBehaviourCalcs_Australian.xlsm) originally developed by the Victorian Department of Environment, Land, Water and Planning and subsequently utilised in FBAn training and distributed to all State and Territory FBAn agencies. This tool provides all fire behaviour models (included those not recommended for use) and relies upon expert judgement of the user as to which model to implement; and
2. Amicus (Sullivan et al. 2013; Plucinski et al. 2017), a decision support software developed by CSIRO that implements only the recommended fire behaviour models in an indelible form in a framework that allows the user to apply expert knowledge in tandem with best fire science. This software is currently formally used by WA Department of Biodiversity, Conservation and Attractions and informally by a number of other agencies and individuals (being freely downloadable).

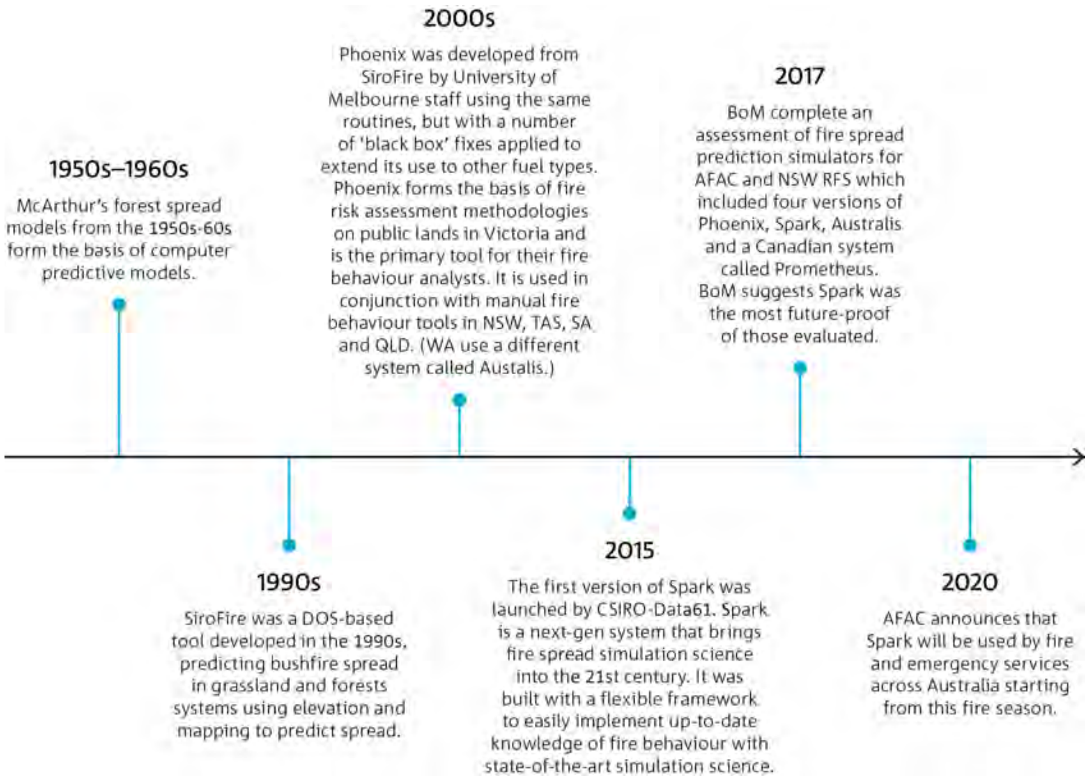

Figure 5 Timeline of fire behaviour model development

The manual prediction of bushfire spread involves determination of the mean rate of forward spread of a fire at a particular location utilising information on prevailing and forecast weather (wind speed and direction, air temperature, relative humidity, atmospheric stability), dominant fuel type and condition, and topography (elevation, slope, aspect). The FBAn then converts this forward rate of spread to a fire perimeter propagation rate based on rules of thumb of fire shape, experience and expert opinion, and plots this by hand on a map, incorporating local knowledge on location, fuel type and fire behaviour understanding in the process. This process is repeated at an appropriate rate (e.g. half-hourly, hourly, two-hourly, etc.) utilising appropriate forecast conditions as required. A hand-drawn map is produced and forwarded to an FBAn supervisor who approves the maps for release to the appropriate Incident Management Team or requests revisions.

Additional information gathered from the field or remotely (e.g. infra-red linescan) is often used to refine a manual fire spread map.

The issues with manual preparation of fire spread prediction maps suitable for the use of an incident management team include:

- The level of training and skills required to undertake such a task, in particular appropriate selection of suitable models and data
- The time it takes to access, collate and analyse input data, prepare the maps with suitable notes, descriptions and narrative
- The effort required to quantify the uncertainty in the input data, in particular fuel and weather, and output maps and information.

Despite the effort that has gone into the development of operational fire spread models, significant gaps in formal fire behaviour knowledge still exist (Cruz et al. 2014). These include:

- Vegetation types for which fire behaviour models do not exist or have been found to be inadequate
- Understanding of interactions of fire with the environment, particularly with topography and atmosphere; behaviour of fire under marginal burning conditions

- Behaviour of fire at sections other than the head of the fire (i.e. flanks and rear)
- Effect of suppression efforts on fire spread, particularly aircraft
- Understanding potential for break-out behaviour of quiescent sections of the fire perimeter
- Understanding of spatial and temporal dynamics of fuel moisture content across the landscape.

2.5 Automated bushfire prediction tools

Automated bushfire spread prediction tools are those mostly computer-based systems that attempt to automate the manual process of fire spread prediction to simulate the propagation of a wildland fire across the landscape, taking into account those changes in vegetation, topography and weather that vary in both time and space. These systems generally utilise the same fire behaviour models used in the manual preparation of fire spread prediction maps discussed above, as well as the rules of thumb necessary to expand these one-dimensional models of rate of forward spread to spatially explicit two- or three-dimensional simulations of fire perimeter spread. These rules of thumb generally take the form of geometric approximations of fire shape under constant conditions and take the form of templates applied to each element of a simulated fire perimeter.

The earliest efforts attempted to replicate the manual process using operational fire spread models and involved application of additional sub-model components to simulate fire perimeter expansion such as that of Huygens' wavelet principle in what is best described as a 'front-tracking' method. Models such as SiroFire (Coleman and Sullivan 1996), FARSITE (Finney 1998), Prometheus (CWFGM Steering Committee 2004) and Phoenix belong to this class. Other approaches employ computer science techniques that represent the spread of fire across a regular two-dimensional grid (or 'raster') representation of the landscape in which state transitions of fuel cells from unburnt to burning to burnt, determined by a set of simple rules defining the interaction of neighbouring cells and prevailing conditions, define the location of the fire perimeter. These rules can be parameterised by an operational fire spread model (Kourtz and O'Regan 1971), a heat-balance model (Frandsen and Andrews 1979), treated as a near-neighbour contagion (Green 1983) or a combination of methods (Green et al. 1990). Current operational models of this class are Australis (Johnston et al. 2008) which is incorporated in the Aurora fire simulator operated by WA Landgate.

A recent development has been the application of mathematical level set methods to fire spread simulation such as used in Spark (Hilton et al. 2015; Miller et al. 2015), in which the propagation of the fire is determined by empirical fire spread models, as per the raster, or front-tracking methods but the fire perimeter is represented only indirectly by the underlying computational framework with significant computational and fire perimeter interaction advantages over both front-tracking and raster approaches.

Another approach extends traditional numerical weather modelling to incorporate physical models of combustion, heat release and heat transfer to simulate fire spread. Models of this class, a form of computational fluid dynamics (CFD) at its smallest scale, include FIRETEC (Linn 1997) and Wildland-interface Fire Dynamics Simulator (WFDS) (Mell et al. 2007). Hybrid versions in which a full CFD model or lower resolution numerical weather prediction model of the atmosphere is coupled to an empirical or quasi-empirical fire spread model as used in front-tracking approaches that attempt to combine the best of both approaches to improve operational ability (e.g. WRF-Fire (Coen et al. 2013) and Coupled Atmosphere-Wildland Fire Environment (CAWF) (Clark et al. 1996)) yet to date remain unsuitable for operational fire spread prediction.

It is helpful to define three areas of, and applications for, high resolution weather modelling for fire applications:

i) High resolution weather forecasting, using numerical weather prediction models such as ACCESS at high resolution (ca. 500 m – 1 km) so as to represent interactions between fire and meteorology, such as pyrocumulus development and ember spread under highly convective situations (for example);
ii) High resolution atmospheric modelling – similar to weather forecasting in terms of the spatial scales resolved (i.e. 500 m – 1 km), but with a focus on the near-surface boundary conditions for applications such as post-processing numerical weather prediction model output and improving forecasted wind and temperature information for use in fire risk models being used operationally; and
iii) Very high-resolution atmospheric modelling at spatial scales of order 10 m, often using Large Eddy Simulation (LES) models, for the purpose of understanding fire behaviour and improving fire spread models – on flat and hilly terrain.

All of the above weather modelling approaches are highly relevant and add value to understanding and quantifying fire risk under current and future climates. At the very least, they assist in identifying gaps in our observations. We believe that there is already active R&D into i) high resolution weather forecasting and iii) very high-resolution atmospheric modelling within our operational weather (BoM) and fire agencies, and in CSIRO's development of Spark. However, our view is that there is important research required, for which the capability resides across CSIRO and its collaborators, to advance the science and applications of ii) high resolution atmospheric modelling.

By way of example we note that there are known situations in recent bushfire events where fire behaviour did not follow predictions due to interactions with complex terrain. In order to improve model predictions, and better manage risk into the future, it is appropriate to undertake detailed study and review of the sources of the prediction failures, including any role that complex terrain has in setting the meteorology experienced by the fire front and how fires behave differently over complex terrain across the range of fire types. This would be in addition to the ongoing need to improve our ability to predict the low probability-high impact events such as pyrocumulus.

Secondly, it is clear from next and end-users of our research and models that fuel moisture and relative humidity play a critical role in fire behaviour (in addition to wind and temperature). Our land surface models have advanced significantly in their fidelity and process representation; and so there is real scope for transformative improvements in predicting fire behaviour by utilising these advances to better simulate how fuel moisture varies across the landscape along with atmospheric humidity, by combining sophisticated modelling, machine learning and observations from new sensor technologies.

On 29 April 2020 the Australasian Fire and Emergency Service Authorities Council (AFAC) national council meeting endorsed a strategy for their subsidiary company Fire Protection Services Ltd to build a national simulator capability based on Spark. This will be the basis of the next generation of operational fire spread simulator, a minimal viable version of which is envisaged to be available for testing and evaluation by state and territory fire authorities and land management agencies prior to the 2020/21 fire season.

Automated bushfire spread prediction tools are often used in parallel to traditional manual fire spread prediction methods. Advantages include the reduced time taken to produce a prediction map, the ability to undertaken multiple simultaneous predictions as well as ensemble predictions of multiple input scenarios to better understand prediction uncertainty. Issues include access to necessary fuels data, the level of training required to use the software and understand outputs, the lack of ability to incorporate expert and local experience in predictions, danger of assuming outputs are truth (particularly by others not running the simulation), lack of formal identification in output of assumptions inherent in prediction, particularly of input data, fire behaviour modelling and perimeter expansion methods.

2.6 New information products such as a national fire map

Various models, data sources and platforms are used by jurisdictions to map both bushfire risk and spread during an event. A possible mechanism being explored is a National Bushfire Intelligence Capability (NBIC) pilot project under the NRRF's National Disaster Risk Information Services Capability (NDRISC) which would initially focus on preparedness and prevention through development of a national bushfire hazard planning map. It is designed to build on existing systems, including the AFDRS and to take a federated rather than centralised approach. Complementary initiatives in earth observation may provide tools for dynamic situational awareness. Currently the Northern Australia and Rangelands Fire Information (NAFI) system provides an exemplar in the use of remote sensing for fire management and cross jurisdiction cooperation between WA and the NT. While end-user requirements such as active fire detection and burn severity mapping may simply involve integration of new Earth Observation data into existing frameworks, deeper understanding of bushfire behaviour and impacts may require a rethink of our understanding of vegetation communities, their structural form, microclimates and how they respond to weather, climate and disturbance. Without this ecological intelligence, realising the benefits of development in national bushfire information systems and modelling is likely to be limited.

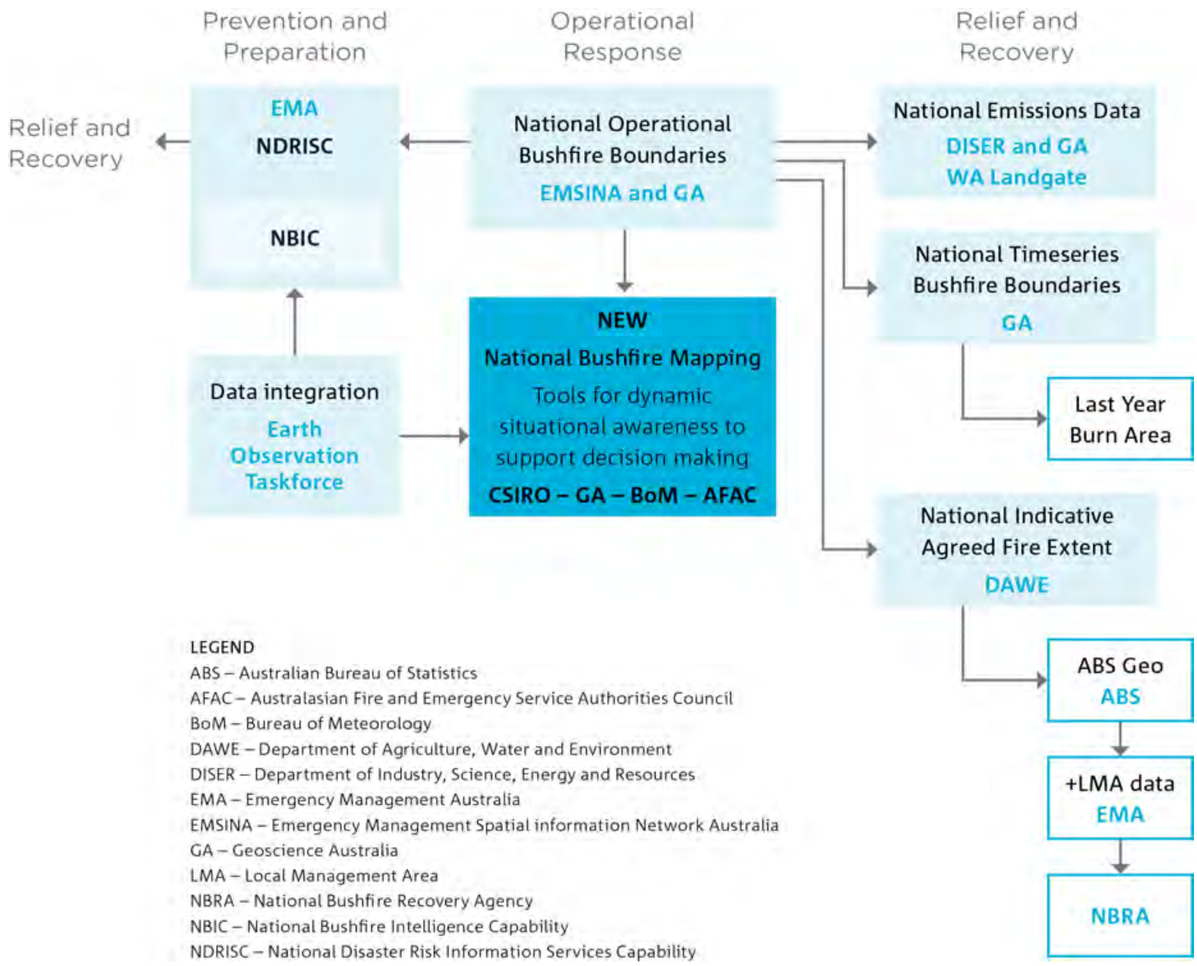

Figure 6 New opportunity to build on current data and platforms for mapping bushfire risk and spread

2.7 Implementing a new Australian national fire danger rating system

An accurate and robust fire danger rating system is an essential component of the functional early warning of, preparation for, and response to, the potential for bushfires. The development of the new Australian Fire Danger Rating System (AFDRS) was recognised as a national priority in 2014 and a staged approach to its development and implementation was approved by ANZEMC in 2016. A national board with jurisdictional and national representation coordinated by AFAC was established in late 2016 to oversee the AFDRS program to design, develop and implement the new AFDRS.

The objective of the new AFDRS is to introduce a significant change to the forecasting of fire danger nationally, using the latest science and technology to better reflect the effect of forecast environmental and weather conditions on potential for bushfires. The AFDRS aims to improve community safety by increasing community awareness of risk exposure to bushfire, providing greater scientific accuracy to support government and emergency services decisions and advice, and giving communities and business timely and reliable information upon which they can rely.

The NSW Rural Fire Service has technical lead on the development of the prototype system in collaboration with the Bureau of Meteorology (Matthews et al. 2019). AFAC is working collaboratively with jurisdictions to design the fire danger ratings framework and coordinate the operational implementation of the AFDRS.

Development of a new AFDRS software system and related tools to collect, analyse and display fire danger data and information is scheduled for completion in December 2020. These tools will undergo rigorous internal and field testing prior to and during the 2021/22 fire season, including assessment of performance under operational conditions. Training on the AFDRS system and agency tools is scheduled to take place across multiple agencies in all jurisdictions post the 2021/22 fire season to be ready for the 2022/23 fire season.

A unified system of clear, concise action-oriented messaging to support the AFDRS will commence in May 2020, with the framework scheduled for finalisation by the end of 2020. The design of physical collateral (e.g. signage) and community consultation is scheduled for the first half of 2021. Operational testing is scheduled to take place in the 2021/22 fire season before a national community education campaign to enable full implementation by the 2022/23 fire season.

Each jurisdiction is developing a plan for implementation of the AFDRS Program in terms of resourcing, legislative issues and stakeholder assessments. Finalisation of these plans has been delayed due to the COVID-19 pandemic and is now anticipated for September 2020. Confirmation of the national schedule is dependent on review of jurisdictional implementation plans and mitigation of risks they may identify.

2.8 Chapter 2 Acknowledgements

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2.10 Appendix Planning for marine heatwaves around Australia

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Over the past century, marine heatwaves have increased in frequency and duration around the globe (Oliver et al. 2018a). Marine heatwaves are prolonged, extremely warm water events (Hobday et al. 2016) that can have detrimental short-term and enduring impacts on marine ecosystems and ecosystem services, including fisheries, aquaculture, and tourism (Smale et al. 2019). Around Australia, three of the most notable marine heatwaves have occurred off Western Australia in 2011, off Tasmania in the Tasman Sea in 2015/16, and waters spanning across Northern Australia, including the Torres Strait and Great Barrier Reef, in 2015/16 (Figure 7). These marine heatwaves are significant because they were the most intense and longest on record at that time.

The 2011 Western Australia marine heatwave reached over +5°C above climatology (2000-2009), lasting over 3 months, causing widespread loss in marine life (Feng et al. 2013). These impacts included mass fish and invertebrate kills, including kills of commercially valuable species (Pearce et al. 2011), and habitat loss, including seagrass and kelp forests (e.g. Pearce et al. 2011; Wernberg et al. 2016) and coral bleaching along Western Australia (Pearce et al. 2011), including the Ningaloo Marine Park (Depczynski et al. 2013). This event occurred due to air-sea interactions and oceanic forcing from the Pacific Ocean to the Indian Ocean during one of the strongest La Niña events on record (Feng et al. 2013). The southward flowing Leeuwin Current was unusually strong (Feng et al. 2013), transporting warm, tropical waters and tropical fish species southward (Caputi et al. 2014). This event had long-term ramifications with some stocks of Roe’s abalone and western rock lobster not recovering after seven years (Caputi et al. 2019). There has been a large-scale ecosystem shift to more warm water species and a contraction in the distribution of kelp forests along Western Australia (Wernberg et al. 2016).

The 2015/16 Tasman Sea marine heatwave reached +2.9°C above climatology (1982-2005) and lasted 251 days, with a range of ecological impacts (Oliver et al. 2017). The event was caused by an intensified East Australian Current extension, where the extension is typically composed of eddies moving southward. This event was associated with abalone mortality, the first Tasmanian outbreak of an oyster disease (Pacific Oyster Mortality Syndrome), and observations of out-of-range fish species (Oliver et al. 2017). This region is a marine “hotspot”, where waters are warming faster than the global average (Ridgway 2007) and projected to continue to do so based on climate projections (Hobday and Pecl 2014). Climate projections indicate this region is susceptible to more intense and longer marine heatwaves (Oliver et al. 2019).

The 2015/16 Northern Australia marine heatwave was unique in that spanned waters in the Indian Ocean, off the North West Shelf and Northern Territory, Torres Strait, Great Barrier Reef, and into the Coral Sea. This event coincided with the strongest El Niño since 1997/98 (Santoso et al. 2017). Mass coral bleaching was reported across all these regions, including the inshore Kimberley and offshore Scott Reef and Ashmore Reef (Gilmour et al. 2019), remote coral reefs off Arnhem Land, in Torres Strait and the central to northern Great Barrier Reef (Hughes et al. 2017). Consequently, the Great Barrier Reef experienced a large-scale shift in species’ diversity and abundance (Hughes et al. 2018). There are likely flow-on effects to marine species dependent on the reef, but assessments are still ongoing. In 2017 and 2020, the Great Barrier Reef also experienced marine heatwaves, which resulted in extensive coral bleaching (Hughes and Pratchett 2020).

These extreme warm water events are occurring along with the global ocean warming trend (Oliver et al. 2018a). Climate models test climate emission scenarios to determine when ocean temperatures rise beyond natural variability without human influences. Marine heatwaves are projected to continue to increase in frequency and duration (Frölicher et al. 2018), with some Australian regions facing the possibility of a “permanent marine heatwave state” by 2040-2060 under the Representative Concentration Pathway (RCP) 8.5 emission scenario (Oliver et al. 2019).

Key scientific issues and knowledge gaps

Marine heatwaves have caused significant disturbance to Australia's marine ecosystems and the delivery of ecosystem services. Thus, the main issues that need to be addressed are those that bridge our understanding of the physical environment, and the mechanisms that control ocean temperature extremes and their trends, with the responses of marine life to heat stress. Extreme ocean temperatures can impact marine biodiversity, the availability of food resources (such as commercial fishes), facilitate spread of invasive non-native species, affect nutrient cycling and carbon sequestration processes (e.g. with seagrass mortality), lead to degradation of important marine habitats (e.g. through coral reef, seagrass or kelp forest mortality) which indirectly affects biodiversity and marine resources (Smale et al. 2019). Habitat-forming species, such as seagrass meadows, kelp forests, and tropical coral reefs, are also at particular risk to the chronic, long-term warming trends (see Figure SPM.3 of IPCC 2019), in addition to acute marine heatwaves.

We need to improve our understanding of the time scales of recovery from disturbances and time scales of adaption to heat extremes. With the increasing frequency of marine heatwaves, consequent changes in marine ecosystems' structure and function are unlikely to recover between events, especially for those events spanning a large extent of Australia's coastline (Babcock et al. 2019). If species composition and their heat tolerance changes as a result of successive events, how we define and use heat stress metrics will need to be reconsidered, as they are important for communicating risks within the science community and to the broader public.

For marine heatwaves arising weeks to months into the future, improved prediction is vital for pro-active planning and management. Marine heatwaves result from a combination of climate, weather, and oceanographic processes that can have feedbacks to amplify the intensity of an event and lengthen their duration. Climate modes of variability are associated with increased or reduced likelihood of marine heatwaves in certain regions (Holbrook et al. 2019). These climate modes are associated with changes in air-sea heat flux and ocean currents' strength and direction, which can lead to an accumulation of heat in certain regions (Holbrook et al. 2019). With global warming trends, how these climate modes will change is unclear. Studies have indicated more extreme El Niño (Cai et al. 2014a), La Niña (Cai et al. 2015), or Indian Ocean Dipole events (Cai et al. 2014b), where these modes are key drivers for Australian climate and ocean current variability. At a local scale, combined processes may amplify local warming, such as with strong air-sea heat fluxes in prolonged calm conditions, clear skies, and shallow waters (Holbrook et al. 2019), whereas other processes may mitigate marine heatwave events, such as upwelling (e.g. Baird et al. 2018), tidal processes and mixing (Green et al. 2019; Wijffels et al. 2018) or the passage of tropical cyclones and ex-tropical cyclones (Hughes et al. 2017). Progress toward an improved understanding of the interactions of climate, weather, and local oceanographic processes is important to identify and predict regions and time periods where marine heatwaves lead to increased or reduced risks.

Detection and attribution studies play a key role in evaluating how anthropogenic climate change increases the likelihood of extreme climatic events based on state-of-the-art climate model simulations (Ummenhofer and Meehl 2017). As an example, for the 2016 marine heatwave across Northern Australia's waters, the intense temperature anomaly and event duration were found to be at least 8.5 times and 53 times as likely, respectively, in 2006-2020 under anthropogenic climate change compared with a natural world with no anthropogenic forcing (Oliver et al. 2018b). For the Coral Sea during summer 2016, the extremely warm sea surface temperatures were assessed as 31% more likely in the current world and a 64% and 87% more likely in a 1.5°C and 2°C world, respectively, compared with a natural world (King et al. 2017). A fraction of attributable risk analysis found that the 2016 Coral Sea temperature anomalies did not occur in climate models without anthropogenic greenhouse gas forcing and anthropogenic climate forcing was the primary factor in elevating the risk of the anomalously warm temperatures (Lewis and Mallela 2018). These methods, combined with ecological response frameworks, offer a pathway toward quantitative assessment of causal factors for marine heatwaves and marine ecosystems.

Current progress and tools for preparedness

Since the 2011 Western Australia marine heatwave, the Australian and international research community has made progress in our understanding of marine heatwaves, with Australia taking a leading role. The term "marine heatwave" resulted from a Western Australia Department of Fisheries workshop in 2011 (Pearce et al. 2011). Since then, marine heatwaves have been more formally defined for consistency (Hobday et al. 2016) and categorised numerically from Category I (Moderate) to 4 (Extreme) (Hobday et al. 2018a), similar to tropical cyclone categorisations. This terminology has been key in communicating the relative severity of events, with successful adoption by the international research community. For example, the Marine Heatwave Tracker (http://www.marineheatwaves.org/tracker.html) provides daily maps of marine heatwave categories.

Through the Bureau of Meteorology and Australia's national Integrated Marine Observing System (IMOS), Australia has monitoring systems in place for daily sea surface temperature based on satellite remote sensing. The Bureau's ReefTemp Next Generation product (http://www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml) provides high resolution sea surface temperature and coral bleaching risk maps for the Great Barrier Reef. Another product, IMOS OceanCurrent (http://oceancurrent.imos.org.au/), is delivered at national and regional scales and displays temperature anomalies relative to a climatology from the Sea Surface Temperature Atlas of Australian Regional Seas (SSTAARS) (Wijffels et al. 2018). Importantly, IMOS OceanCurrent displays the temperature percentiles based on the SSTAARS climatology, where extreme temperatures are defined based on percentiles (i.e. greater than the local 90th percentile for marine heatwaves). This system also integrates and displays other data streams, such as ocean temperature data collected in near real time from IMOS Ships of Opportunity.

For short-range to seasonal forecasting, the Bureau of Meteorology's operational ocean models provide outlooks for sea surface temperature at 10-25 km resolution. The model OceanMAPS (http://www.bom.gov.au/oceanography/forecasts/index.shtml) provides forecasts out to 7 days and the ACCESS-S1 seasonal outlook (http://www.bom.gov.au/oceanography/oceantemp/sst-outlook-map.shtml) out to six months. These models have been used to assess coral bleaching risks (Smith and Spillman 2019) and management applications for fisheries and aquaculture (Spillman and Hobday 2014). Internationally developed systems are used to complement Australian products, including the National Oceanic and Atmosphere Administration (NOAA) Coral Reef Watch bleaching alert system (https://coralreefwatch.noaa.gov/satellite/index.php) for monitoring coral reef risks.

These tools provide methods for assessing the state of ocean temperatures around Australia and, combined with knowledge about climate and weather patterns, can be used for forward planning. For example, in mid-2015, Australian and international seasonal forecasts revealed a major El Niño event was occurring. For the Great Barrier Reef, El Niño events tend to correspond with warm late-summer sea surface temperatures (Lough 1994), when corals are at the greatest risk from thermal stress. With a major El Niño underway, the National Coral Bleaching Task Force was formed and monitoring plans were developed prior to the 2016 marine heatwave over the Great Barrier Reef.

Other observational and modelling efforts have contributed to progress in understanding marine heatwaves and ecological impacts around Australia. Based on long-term sites, including sites maintained by IMOS, coastal mooring observations have revealed marine heatwaves occurring with depth in coastal regions adjacent to the East Australian Current (Benthuysen et al. 2018; Schaeffer and Roughan 2017). In the Tasman Sea, ocean heat content has been found to be skilful as a predictor for marine heatwaves compared with atmospheric influences (Behrens et al. 2019). Off Australia's North West Shelf, relationships have been identified between climate modes and marine heatwaves to inform coral bleaching risks (Zhang et al. 2017). Around Tasmania, marine heatwave types based on region, season, and properties have been identified through ocean modelling (Oliver et al. 2018c). Ocean models, such as the eReefs model (https://ereefs.org.au/), are being used to determine the depth extent of marine heatwaves and to identify potential refugia, through the National Environmental Science Program (https://nesptropical.edu.au/index.php/round-4-projects/project-4-2/). Ocean models can be used to quantify the roles of different processes, including ocean heat transport or air-sea heat flux, in developing and sustaining marine heatwaves, such as the 2011 Western Australia event (Benthuysen et al. 2014). Marine ecosystem models provide opportunities to assess marine heatwave scenarios and the impact on marine habitats and species (Babcock et al. 2019).

Rapid mobilisation of resources for sampling marine heatwaves is another avenue being explored. Since 2018, the IMOS Event Based Sampling sub-facility (http://imos.org.au/facilities/oceangliders/event-based-sampling/) has deployed ocean gliders in marine heatwaves, including off Tasmania and in the Great Barrier Reef. These autonomous underwater vehicles provide near real time data on temperature and other water properties with depth. While our understanding of marine heatwaves has improved with these kinds of monitoring and forecast tools, there are gaps to be addressed for implementing timely and effective planning actions.

Planning measures, gaps, and opportunities

Unlike other extreme phenomena, such as atmospheric heatwaves, bush fires, and tropical cyclones, there are no operational warning systems or national planning strategies for marine heatwaves. A plan to prepare Australia for marine heatwaves would incorporate a risk assessment framework (Hobday et al. 2018b; Caputi et al. 2019) and a communication strategy, combined with a national sea temperature monitoring network, and an operational marine heatwave forecast system. Predictive capabilities are central for proactive response planning, and a pathway for decision making is another key element needed to guide marine managers and industries. Communication strategies and plans need to ensure that the latest information is available about ongoing and potential marine heatwaves around Australia.

There are coordinated approaches among government agencies, research organisations, industry, and the university sector for specific regions and marine species. For example, the Great Barrier Reef Marine Park Authority holds formal pre-summer Reef health workshops, bringing together managers and scientists to assess reef health risks and outlooks, including for marine heatwaves, and to coordinate program activities. During summer, a science advisory group may be formed to evaluate the sea temperature forecasts and early warning of marine heatwaves and coordinate responses based on the risk of mass coral bleaching. The Authority also provides weekly public updates on temperature forecasts and information on reef health. Through the IMOS Event Based Sampling sub-facility, a national steering committee assesses the status and outlook for marine heatwaves around Australia, involving stakeholders in areas of concern. There are other targeted efforts with marine industries, for example, to apply seasonal forecast systems with ecological models to predict salmon farm temperatures and inform risk management for the Tasmanian salmon industry (Spillman and Hobday 2014). Furthermore, during and after a marine heatwave, early management interventions have proven useful to assist stock recovery. For the 2011 Western Australia marine heatwave, early identification of the event, immediate monitoring of its effect on stocks, and annual pre-recruit surveys have assisted decision making for stock assessment and harvest strategies (Caputi et al. 2019).

While current observational systems are in place for ocean temperature monitoring, such as through IMOS, specific locations of interest to stakeholders might not have instrumentation in place, providing near real time temperature data, required to inform their decision making if a marine heatwave occurred. Rapid mobilisation of resources is one option for marine heatwave monitoring but may be challenged by remote locations and the time required to deploy instruments. Current monitoring would be strengthened by the establishment of a temperature monitoring network providing near real time ocean temperature in coastal waters around Australia, for identifying potential marine heatwave impacts on ecologically vulnerable habitats and economically valuable species. There is an increasing desire for finer spatial scale ocean temperature as managers, tourist operators, Traditional Owners and researchers want to know how a specific location, and potentially their livelihood, will be affected by a marine heatwave.

The time is now to combine observations with forecast models to produce locally tailored products, to assess and improve forecast models, and to further progress research on marine heatwave predictability. Early warning systems would help reduce negative impacts associated with marine heatwaves, by informing decision making for risk-based management, including site selection as part of future planning and harvest strategies to reduce losses in fisheries and aquaculture. Understanding which geographic areas are at higher risk from marine heatwaves also informs new intervention programs, such as the multi-institution Reef Restoration and Adaption Program (https://www.gbrrestoration.org/), which aims to develop solutions and interventions to protect Australia's assets from climate-related threats, including marine heatwaves.

There is growing awareness of marine heatwaves and their threats to sustainable development and management of Australia's marine estate. For Australia to continue to lead the way, coordinated efforts are required to improve marine heatwave predictions and forecasts and to establish a national plan to meet management requirements for early warning and response systems.

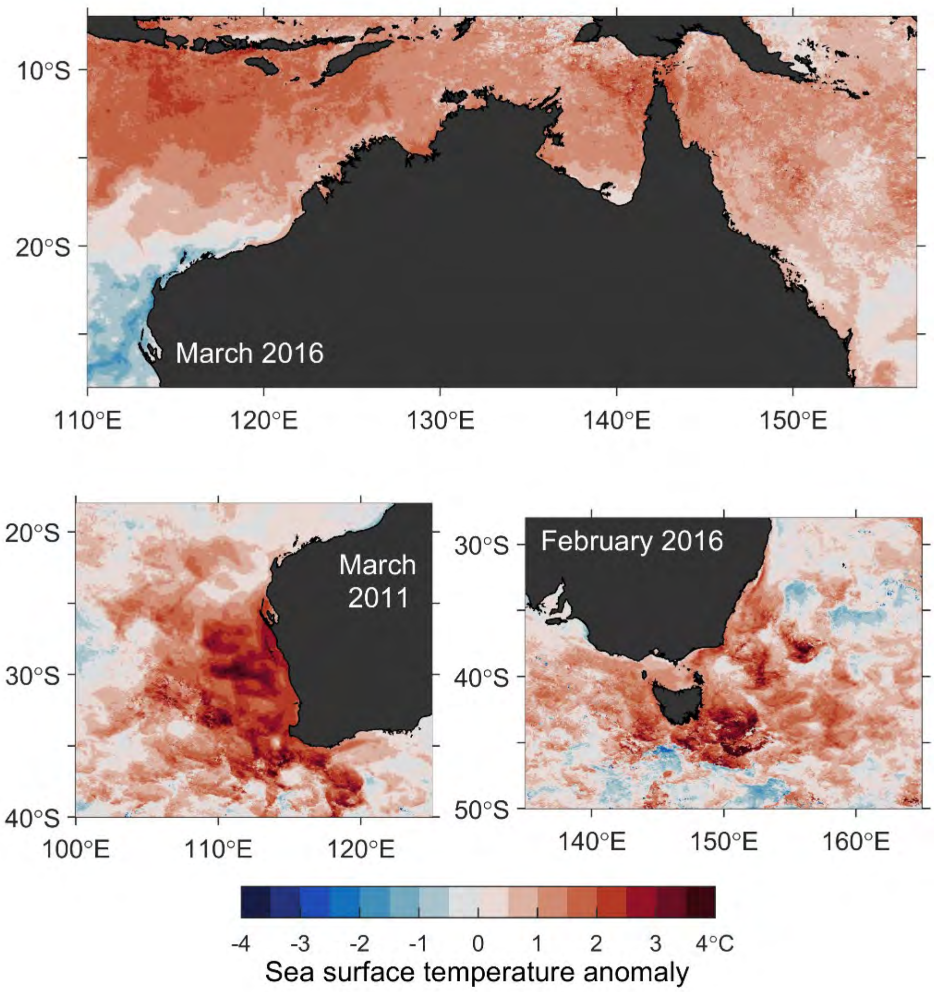

Figure 7 Monthly mean sea surface temperature anomaly during the peak of the three marine heatwaves
Monthly mean sea surface temperature anomaly during the peak of the three marine heatwaves, based on the Bureau of Meteorology and IMOS product (IMOS 2020). The anomaly is the monthly mean sea surface temperature minus the SSTAARS climatology (for that month centred on 2005)

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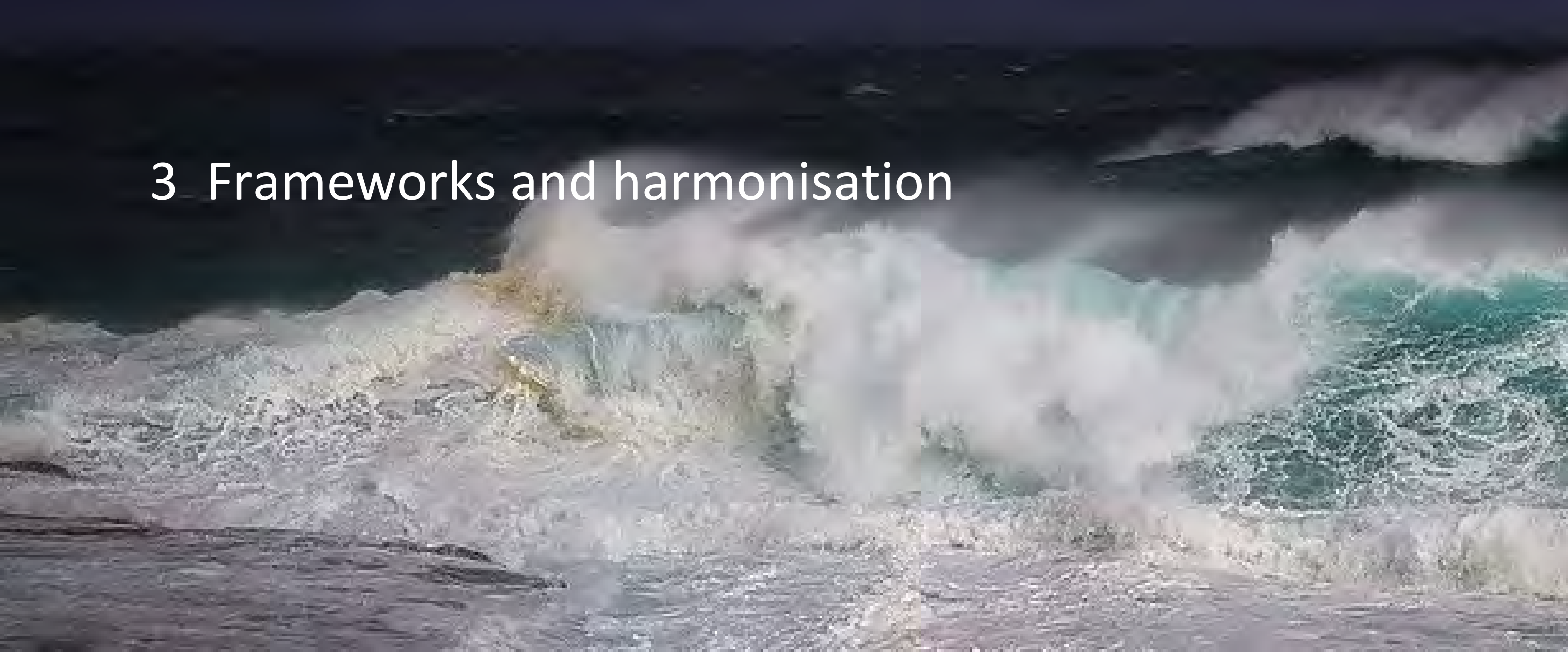


3 Frameworks and harmonisation

Authors (CSIRO): Russell Wise, Russell Gorddard, Paul Box, Erin Bohensky and Carol Farbotko

3.1 Summary

Climate and disaster risks are growing across Australia. This is due to intensifying natural hazards under a changing climate and increasing exposure and vulnerability of people, assets, and socio-economic activities in expanding hazard areas. Many of the causes of these increasing risks are systemic and require coordinated system-wide responses beyond emergency and disaster management to address.

There is growing demand – from society and the financial services and disaster management sectors in particular – for coordinated action across all economic sectors, government portfolios and levels of decision making to mitigate climate and disaster risks, build resilience and adapt to change. There are opportunities for a more harmonised, coordinated and collective approach which are hampered by under-developed, fragmented or uncoordinated awareness, understanding, and approaches to 'systemic risk' assessment and management in Australia.

Harmonisation involves actions to make plans, frameworks, policies, systems or laws common in different companies, sectors or jurisdictions. Harmonisation also involves interventions that support coordination and capacity in implementation. To progress an agenda of harmonisation therefore requires sufficiently widespread acknowledgement of the need and willingness to support it. Harmonisation involves reframing problems, assessment approaches and remits so that the issues of climate and disaster resilience and adaptation are addressed holistically.

Lessons from recent Australian and global experiences to harmonise and mainstream climate and disaster risk assessments into economic, social and land-use development policies and plans, as well as to coordinate implementation of responses, highlight Australia's need for:

- Leadership across all sectors of society to drive harmonisation and mainstreaming of climate and disaster risk management across sectors and levels of decision making
- Raising awareness and building capacity of all Australians to understand the relevance of and responsibilities for responding to climate and disaster risk reduction
- Acknowledging the difficulties in diagnosing and implementing system-wide responses to climate and disaster risks and therefore the need to undertake activities in:
- Harmonising concepts, framings, and processes as the basis for raising awareness and building shared thinking and understanding across sectors and jurisdictions
- Aligning and integrating climate and disaster resilience and adaptation considerations with other societal, technological and ecological trends and mainstreaming these into economic and social development planning (including COVID-19 recovery and data and modelling technologies)

  - Supporting community-led approaches to imagining and defining goals and visions of desirable futures under increased climate and disaster risks that provide the motivation and guidance for coordinated strategic responses
  - Building public service capabilities to undertake and translate systems-based evaluations of climate and disaster risks and possible interventions into coordinated policy responses and locally led implementation
- Strengthening and mainstreaming monitoring, evaluation and learning processes and the underpinning knowledge-management platforms and governance to support the assessment of effectiveness of cross-sector and cross-scale responses and capture lessons for supporting the transfer or scaling-up of successes.

3.2 Opportunities for improvement

The following suggestions are provided based on the key needs identified above. More detailed strategies for how each could be implemented in the short to medium term are provided at the end of the Chapter. These suggestions are complementary and inter-dependent. A coordinated approach to their implementation would yield greatest benefits. They will also need to be implemented adaptively and through inclusive engagement.

Build systemic risk literacy of leaders across all sectors of society. This will raise awareness and promote common framings and usage of concepts required for a coordinated, rapid, and nation-wide response to disasters and climate change. The intention is to create a shared understanding of the urgency and magnitude of the challenge, initiate and enable national conversations and champion and coordinate collective responses to reduce risk, build resilience and adapt to change.

Undertake a nationally coordinated process to resource locally led activities to develop goals and visions for a future under increased climate and disaster risks. This should include development of community narratives of successfully navigating these risks. It should also include the assessment, building, and supplementing of local capabilities and capacities to deliver climate adaptation and disaster resilience aligned with the distribution of roles and responsibilities across and within the three levels of government.

Embed climate and disaster resilience and adaptation as a national priority into planning and economic development and investments decisions, **making it the purview and responsibility of all agencies and portfolios**. This will need to be supported and enabled through purposeful comprehensive upskilling and capacity building across all levels of the public service and private sector organisations in accounting for and managing these systemic risks.

Develop national and thematic knowledge platforms and incentive structures to promote coordination in the co-production, measurement, analysis, sharing, and accessibility of knowledge, data and information. Substantial early gains can be realised from promoting cooperation and coordination amongst existing 'owners and operators' of data, modelling and analytical platforms, and supporting the evaluation and reprioritisation of investments in the types of knowledge produced to address the gaps in integrated, socio-economic, qualitative and co-produced forms of scientific, experiential and traditional knowledge.

Strengthen and mainstream cross-sector and cross-scale innovation (pilot programs) and learning, **underpinned by common incentive structures, measurement and evaluation to enable rapid scaling of successful initiatives**. Support and connect various high-level initiatives and ensure that the climate and disaster risk reduction objectives and agenda are embedded into other large reform programs, such as those following the Independent Review of the Australian Public Service, and COVID-19 recovery. Promote and support research, private sector and government partnerships in the delivery of climate and disaster resilient outcomes through the introduction of funding criteria, systemic risk assessment standards, and reporting requirements.

3.3 The growing need for harmonised and coordinated approaches to climate and disaster resilience and adaptation

Climate and disaster risks are growing across Australia. The costs of catastrophic events on communities, economic activities and infrastructural assets have averaged between $10 and $12 billion per year over the last two decades (Deloitte Access Economics 2016a; Andrews et. al. 2016). These costs from the impacts of natural hazards have been projected to increase to about $40 billion per year by 2050 (excluding the effects of climate change). This increase will be due to population growth and growth in the density and value of infrastructure assets and economic activities in high risk areas such as the coast (Deloitte Access Economics 2016a). Less than 40% of this cost is pre-funded by insurance and the Commonwealth government spends in excess of $500 million per year on average on post-disaster relief and recovery (Andrews et al. 2016). The sustainability of Australia's existing insurance and financial services models is increasingly coming into question as Australia represents 2% of the global market for insurance capital, but 8% of the losses (South East Councils Climate Change Alliance and Insurance Council of Australia 2019) and the gap between insured and total economic costs is growing (Deloitte Access Economics 2016a).

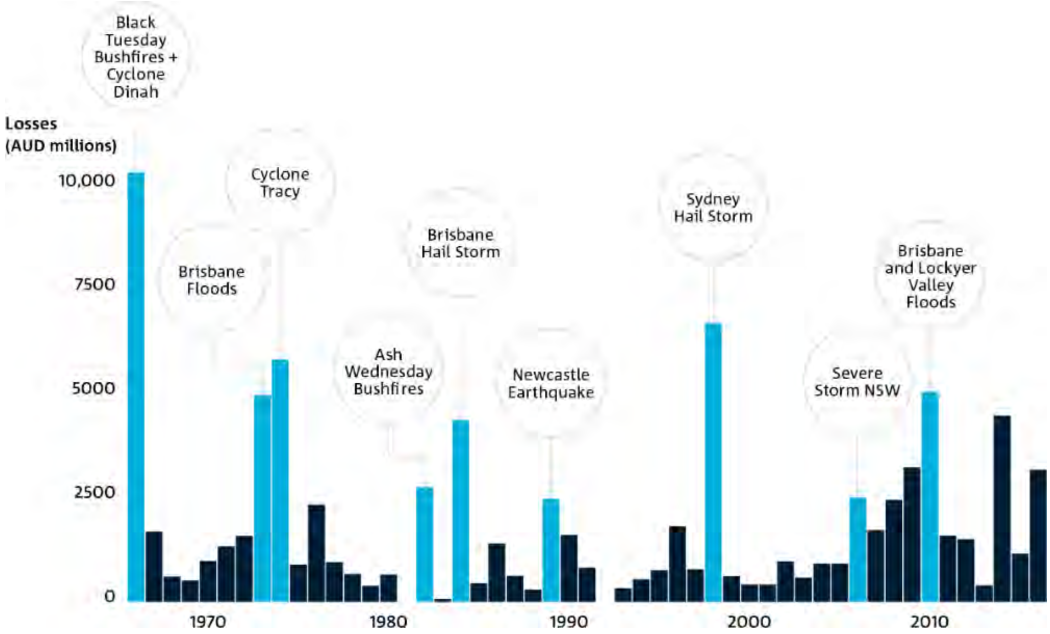


Figure 8 Normalised insurance losses 1966 – 2016 redrawn from *McAneney J, Sandercock B, Crompton R, Mortlock T, Musulin R, Pielke R Jr & Gissing A (2019) Normalised insurance losses from Australian natural disasters: 1966–2017, Environmental Hazards, 18:5*, with major disaster events superimposed.

Climate change, as a driver, is magnifying the impacts of climate and weather-related disruptions (Glasser 2019), as the frequency and severity of both slow and rapid on-set hazards increases (BoM and CSIRO 2018). Simultaneously, climate change also introduces novel transition and liability risks (Glasser 2019; IPCC 2012; IPCC 2018). Magnification of these risks is happening rapidly: there is currently underestimation of the threat posed by climate change and intensifying hazards as reflected in investment decisions in highly exposed or vulnerable assets and economic activities (Glasser 2019; Lawrence et al. 2020). It is also likely that the cascading impacts of climate change will ultimately be more severe than the direct physical impacts (Glasser 2019; Lawrence et al. 2020). Exacerbating these physical impacts of climate change are the legacy effects and path-dependencies of development policies, plans, standards and investments that have, and in many instances continue to, inadequately account for climate change or the systemic nature of climate and disaster risks (Andrews et al. 2016; Department of Home Affairs 2018; Commonwealth of Australia 2018, Investor Group on Climate Change 2017).

Figure 2 illustrates a system-wide approach to disaster risk reduction that delivers on the NDRRF objectives of systemic-risk informed sustainable development. Currently, focus tends to be on prevention, preparedness, recovery and response (PPRR) to disaster and emergency events. These efforts need to be complemented with comprehensive, coordinated approaches and investments across all economic sectors and government portfolios that mitigate the systemic causes of these risks. There are growing numbers of initiatives calling for and aligning with this agenda (listed in Table 2).

Coordinated efforts across sectors to pre-emptively reduce climate and disaster risks, during periods of stability and during the preparedness and recovery phases of disaster management, is only effective if there is harmonisation (commonality) of concepts, language and methodologies that builds shared and consistent understandings of risks and mutually beneficial agendas.

In this context, harmonisation is defined as the act of making systems, plans, frameworks, policies or laws the same or common in different companies, sectors or jurisdictions. It can mean building capabilities required for different groups to work together, or creating common goals, aligned beliefs and preferences, or agreed ways of doing things so they work together more easily. Entry or focal points for harmonisation include leadership and advocacy, legislation and regulation, Commonwealth, state and local policies, strategies and plans, standards, responsibilities for mainstreaming, capacity development, procedures and tools, promoting inclusiveness of diverse stakeholders, systemic risk awareness and education, and public and private-sector resource mobilisation (UNDRR 2019).

This chapter therefore:

- Describes the current approaches to climate and disaster risk reduction, resilience and adaptation in Australia to identify challenges in and opportunities for harmonisation.
- Identifies strategies that have been used internationally to harmonise frameworks and approaches to climate and disaster risk reduction and resilience and identify how these are broadly applicable to Australia's unique context.
- Suggests options for Australian governments on how to support and enhance harmonisation of existing frameworks and approaches, in order to collectively act on climate and disaster risks and build resilience. Existing approaches to climate and disaster resilience and adaptation

3.3.1 The need for harmonisation

The trends and drivers described in Section 3.2 have led to the proliferation of frameworks and approaches across all levels of government and the private sector in Australia to inform disaster risk reduction and climate adaptation responses.

Figure 9 Frameworks for natural disaster management at different geographic scales

At the national level, for example, Australia is making substantial investments in the Future Drought Fund, the Emergency Response Fund, the National Water Infrastructure Development Fund, the Disaster

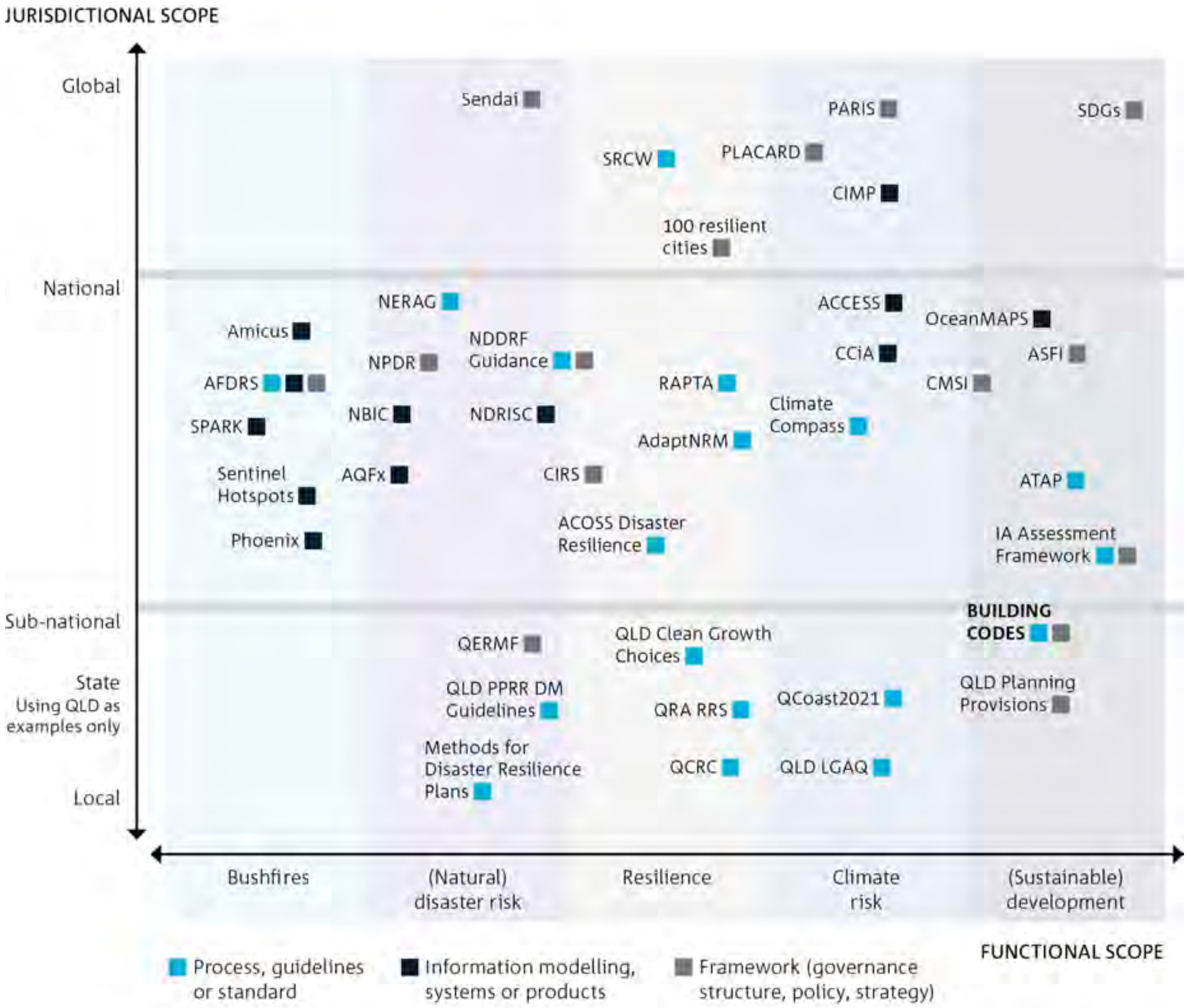
Recovery Funding Arrangements, and is implementing the National Disaster Risk Reduction Framework through the National Action Plan and National Partnership Agreement on disaster risk reduction. These initiatives are supported by investments in research and development and the creation of governance arrangements that support coordination across portfolios, jurisdictions and sectors – for example the Australia-New Zealand Emergency Management Committee and The Australian Government Disaster and Climate Resilience Reference Group. All these investments are focused on reducing climate and disaster risks, building resilience and enabling adaptation to a changing climate and therefore, align with the 2015 National Climate Resilience and Adaptation Strategy and the 2012 National Strategy for Disaster Resilience.

Along with these national level efforts are many state and local-level plans, policies and frameworks focused on disaster management and climate mitigation and adaptation. Figure 10 provides an illustration of these for Queensland as an example. Additional frameworks and initiatives have also been rapidly emerging to support private sector organisations assess, disclose and manage the physical, transition and liability risks from climate change (see Table 2).

Cyclone Damage to a banana plantation at Liverpool Creek. Photo Dan Metcalfe

Table 2 List of key drivers creating opportunities for Australian Governments to promote and support the harmonisation of approaches to climate and disaster resilience

KEY DRIVERS	EXAMPLES AND REFERENCES
The increasingly frequent occurrence of major climate and weather-related disaster events is combining with the growing realization that sustainable development needs to factor in repeated and pervasive damage from disasters (O'Brien et al. 2012).	Deloitte Access Economics estimated in 2016 that the costs of disaster to Australia average $9 billion per year and they projected this will conservatively increase to $39 billion by 2050, excluding the effects of climate change(Deloitte Access Economics 2016). The intangible social costs caused by disasters were also conservatively estimated in this Deloitte Access Economics study to be at least equal to the direct economic costs. In recent years, indications of these increasing risks (BoM and CSIRO, 2018) and impacts (Steffen et al. 2019) are becoming evident. In the 2019-20 summer bushfires, new high levels of drought and summer temperatures contributed to the loss of about 20 million hectares (Centre for Disaster Philanthropy 2020). Other effects such as hazardous air quality affected many Australians; there was a 75% increase in Australia's annual emissions of greenhouse gases (Schmidt 2020); wildlife and biodiversity were lost (Center for Disaster Philanthropy 2020) and there were at least $4.5 billion in losses to Australia's tourism industry (Carruthers 2020). There is a growing number of initiatives (see Figure 10) being developed around Australia, aligned with global initiatives, to build capabilities to better assess and respond to disaster risks.
There is a global shift by investors and insurers away from sectors, organisations and investments that create and/or exacerbate climate and disaster risks.	Investors have started to integrate climate change considerations into due diligence processes and risk management and investment strategies. Early findings provided by BlackRock suggest that investor portfolios integrating climate change are already outperforming those that do not (Blackrock Research Institute 2016) Yet BlackRock also suggests that most portfolios are still failing to fully account for climate related risks.
State and local governments are under pressure by credit ratings agencies to understand, report on, and mitigate their exposure to climate-related risks.	Rating agencies such as Moody's and S&P Global have started to incorporate climate change considerations in their risk rating of sovereign and sub-sovereign entities (Moody's Investors Service 2016). The infrastructure bodies of Australian jurisdictions now include climate risks in their assessment frameworks (Building Queensland 2020; Infrastructure Australia 2018).
There is international pressure from global economies (e.g. the EU and Canada) to align COVID-19 economic recovery with climate mitigation, adaptation and disaster resilience.	The European Green Deal is considered central to COVID-19 recovery by 17 European countries advocating for integrating a green transition and digital transformation into economic stimulation (Climate Home News 2020). Canada has made reporting climate risks a condition of receiving its COVID-19 bailout funding (Environmental Finance 2020).
There are widespread shifts in the private sector to assessing, reporting and acting on climate risks and opportunities. These shifts have been driven by sets of recommendations by the Taskforce on Climate-related Financial Disclosures (TCFDs) and the Network for Greening the Financial System (NGFS) (Task Force on Climate-Related Financial Disclosures, 2020, Network for Greening the Financial System 2020).	Over 200 entities dedicated to banking, asset management and insurance have become official supporters of the TCFD recommendations on disclosure of climate risk. Climate-related risk disclosures are commencing. See TCFD Knowledge Hub (TCFD, 2020) Similarly, voluntary disclosure frameworks such as CDP, GRI and SASB have started to align their disclosure frameworks to the Recommendations of the TCFD (Griesemer et. al. 2018). Others such as PRI are making it mandatory for members to disclose climate related information (Hamaker-Taylor, 2020). Rating agencies such as Moody's and S&P Global have started to incorporate climate change considerations in their rating systems, illustrating how climate factors positively and negatively impact on the risk rating of companies and municipal bonds. Investor organisations such as Climate Action 100+ (which represents 373 investor signatories with over $US39 Trillion in assets) focused on encouraging companies to respond to climate risk through improved governance, disclosure, and mitigation actions (Climate Action 100+ 2020).



100 resilient cities – a global network of cities working to improve their resilience

CIMP – Coupled Model Inter-comparison Project

PARIS – Paris climate agreement

PLACARD – EU PLAtform for Climate Adaptation and Risk reduction

SDGs – Sustainable Development Goals

Sendai framework for disaster risk reduction

SRCW – Stockholm Resilience Centre Wayfinder

National

ACCESS – Australian Community Climate and Earth System Simulator

ACOSS Disaster Resilience – 6 Steps to Disaster Resilience

AdaptNRM – The NRM Adaptation Checklist

AFDRS – Australian Fire Danger Rating Scheme

Amicus (Sullivan et al. 2013, Plucinski et al. 2017), a decision support software developed by CSIRO

AQFx – the air quality forecasting system

ASFI – Australian Sustainable Finance Initiative

ATAP – The Australian Transport Assessment and Planning (ATAP) Guidelines

CCiA – Climate Change in Australia

CISN – Critical Infrastructure Resilience Strategy

Climate Compass

CMSI – Climate Measurement Standards Initiative

IA Assessment Framework – Infrastructure Australia Assessment Framework

NBIC – National Bushfire Intelligence Capability

NDRISC – National Disaster Risk Information and Services Capability

NDRRF – National Disaster Risk Reduction Framework (NDRRF) Guidance

NERAG – National Emergency Risk Assessment Guidelines

NPDR – National Principles for Disaster Recovery

OceanMAPS – ocean prediction system, developed jointly by CSIRO and the BoM

Phoenix

RAPTA – CSIRO Resilience, Adaptation Pathways and Transformation Approach ver 2 Guidelines

Sentinel Hotspots

SPARK

State

Methods for disaster resilience plans at local level

QCoast2021 – Minimum standards and guideline for Qld Local Govts

QCRC – Queensland Climate Resilient Councils Program

QERMF – Queensland Emergency Risk Management Framework

QLD Clean Growth Choices – Transition strategy, regional plans

QLD LGAQ – Adapting to Climate Change: A Qld Local Govt Guide 2007

QLD Planning Provisions – Queensland Planning Provisions

QLD PPRR DM Guidelines – Queensland Prevention, Preparedness, Response and Recovery Disaster Management

QRA RRS – Queensland Recovery Agency Regional Resilience Strategies

Figure 10 Illustration of the plethora of initiatives, frameworks and assessment approaches for supporting decision making in emergency and disaster management, disaster risk reduction and climate change. This is not comprehensive.

Yet there are many more investments made by all levels of Government and the private sector that have not yet been comprehensively leveraged to strengthen Australia's climate and disaster resilience. Examples include the $100 billion National Infrastructure Investment Programme, which involves the Roads of Strategic Importance initiative and the City Deals initiative. Climate and disaster risk reduction and resilience considerations could be integrated and mainstreamed into these investment and development programs across all levels to achieve lower cost and reduced risk. Furthermore, the future potential effects of intensified hazards under climate change could be accommodated across sectors through the design of initiatives. For example, a road may be designed and built to a new specification based on climate and disaster risk analysis, but if combined with a consideration of city planning may also imply a need to change planning zones. Integration can be as simple as including 'climate and disaster risk reduction and resilience' as an additional principle or objective guiding the delivery of the initiative, with a pointer to the Infrastructure Australia Assessment framework guidance or the Strategic Guidance on Climate and Disaster Risk (Australian Institute for Disaster Resilience 2020) on how to do this.

Such issues are not only pertinent to infrastructure planning and implementation. As disaster events become more frequent, it is important for such events to be part of business-as-usual considerations of organisations across all sectors – health, agriculture, environment, tourism, communications, energy, etc – rather than be treated as unforeseen or exceptional. Additionally, the responsibilities for disaster management require a systems-wide response. This means that each sector must plan how they will contribute to the whole cycle of emergency and disaster prevention, preparedness, response and recovery. For example, agencies currently in emergency response need to broaden responsibility beyond the Emergency Management sector as currently defined. This need was powerfully illustrated in the case of the Canterbury earthquake. Recovery took longer, and was more complex, traumatic and costly than expected due to the broad legacy of reduced employment and social services, and the damage to communities, livelihoods, and peoples' psychological wellbeing (New Zealand Government 2019). The benefits of investment in building healthy and functional communities and robust supporting critical services highlight the need for more integrated and coordinated approaches to disaster prevention, preparedness and recovery across all sectors, including health and social services, land-use planning, and all critical services such as energy, water, food and communications (Department of Home Affairs 2018; O'Connell et al. 2018).

Fragmentation of disaster responsibilities tends to be amplified at the level of states and territories, as each jurisdiction has legislation and policies tailored to local contexts. Jurisdictional frameworks are shaped by these context-specific social, cultural, institutional and biophysical characteristics. These in turn drive and shape the collection of data and the production of information, which varies between jurisdictions. Furthermore, each resource-constrained jurisdiction can generally only provide small amounts of funding and additional capacity to support local government implementation of priorities to reduce disaster risk or to adapt to climate change. This siloed and often disaster-event specific approach to climate adaptation and disaster risk reduction is missing opportunities to leverage much larger pools of labour, capability and funding resources that each could potentially provide to support local governments, in areas such as transport, education, manufacturing, energy, water, health, tourism, agriculture and fisheries.

This scaling challenge is exacerbated by existing approaches to assessing public sector investment options that prioritise the delivery of projects unsuitable for private sector co-investment. Existing approaches tend to be narrowly focussed in their assessment, biasing towards projects in high density urban centres, measures of benefits that are readily monetizable, and qualitative measures of social and environmental outcomes (Coyle and Sensier 2018). These assessments tend to predict moderately recoverable revenues with low levels of certainty. This in turn negatively impacts investment ratings and leads to missed opportunities to leverage public-sector funds with funding from financial capital markets, which are increasingly seeking to invest in climate and disaster resilience. Approaches are required that prioritise pecuniary benefits that have a high expectation of monetisation and recovery, as this will increase the investment grade (Standard and Poor's Rating Services 2014) and make infrastructure projects more appealing for private investment. This requires broadening the scope and identification of potentially monetizable benefits, for example as advised in the Victorian Value Creation and Capture Framework (Victorian Department of Premier and Cabinet 2017). It also requires improved methodologies and capabilities in measuring and monetizing the resilience benefits generated by reducing climate and disaster risks (Climate Bonds Initiative 2019).

Collectively these dynamics hinder effective consideration of climate and disaster risk reduction and resilience in existing decision processes, and the coordination of efforts to manage these. Characteristics of the prevailing decision context, as outlined in Table 3 include:

- Low levels of public understanding of the causes and effects of climate and disaster risks,
- Widespread contestation of issues associated with climate and disaster risks,
- Limitations in ability to adequately assess, attribute, and collectively act on the systemic causes and cascading effects of climate and disaster risks,
- Variable capabilities and capacity amongst stakeholder groups, especially the most vulnerable and marginalised, to take part in approaches to assessing risks and developing inclusive strategies,
- An absence of common language, concepts, problem framings, and methodologies used to support climate adaptation, disaster management and resilience,
- A lack of a common view in government about common drivers and the coherent responses required,
- Conflicting priorities and incentives within and across jurisdictions, sectors and organisations,
- Existing approaches for allocating resources focused on cost-benefit tools rather than ideas of value creation and non-market benefits and trade-offs,
- Traditional 'risk assessment' framings that are designed for tame (quantifiable and manageable) risks and limit thinking about transformational change.

    - This discussion highlights that while climate and disaster risks cut across government, private sector and community interests at multiple scales, responses tend to focus on specific needs, interests and mandates and tend to be developed based on the established priorities, framings, tools and processes (e.g. drought vs water security). Ingrained and often inconsistent ways of collecting data and producing knowledge are shaped by local regulations, frameworks, disciplinary or cultural norms and practices and the mental models (assumptions, biases and values) of the stakeholders involved.

    - These effects combine to fragment climate change and disaster responses. While harmonisation needs to begin by building a common language and concepts, the multiple ways in which responses need to change – from governance processes to data collection – highlights the need for the purposeful resourcing and coordination of efforts to reform these. In many cases duplication of effort limits the resources available to pursue opportunities for cooperation and coordination and for building the new capabilities required to address climate and disaster risks.

Table 3 Characteristics of prevailing decision-making processes hindering progress on climate and disaster risk reduction, resilience and adaptation

CHARACTERISTICS OF THE DECISION CONTEXT	EXAMPLES AND REFERENCES
There are low levels of public understanding of the causes and effects of climate and disaster risks.	Many people lack adequate awareness of the natural hazards, underestimating the complex interactions between natural triggers and technological, medical, social and economic disasters. This is especially the case if natural hazards are accompanied by technological failures (explosions, fires, structural deficits) or behavioural responses (such as mechanisms of contagion). For example, when travelling as tourists, many people are unfamiliar with the natural hazard landscape of an area and may endanger themselves because they underestimate natural hazards (Schweizer and Renn 2019).
There is widespread contestation of issues associated with climate and disaster risks, including what to do about them.	In Australia, citizens have reasonable levels of general awareness of natural hazards, climate change and disasters, but there are high levels of contestation and disinformation about: i) The causes and effects of climate and disaster risks, ii) The likelihood, and magnitude of the impacts of disruption; and iii) The urgency and degree (extent) of the required responses, including what equitably shared responsibility look like (Department of Home Affairs 2018; O'Connell et al. 2018). A plethora of emerging and competing methods, tools and frameworks, at varying levels of maturity, also create confusion and subsequent inertia, because their differentiation leads to additional demands that are usually beyond the capacity, resource constraints and incentives of individuals and organisations to address. This is evident in the insurance sector (Swiss Re Institute 2020) among others.
There are limitations in understanding, capabilities, capacity and resources to adequately assess, attribute, and collectively act on the complex, highly uncertain and systemic causes and cascading effects of climate and disaster risks.	The literacy required to assess and manage systemic risks among most decision makers across public and private agencies is low. When combined with entrenched cultural and disciplinary norms and practices for risk assessment and management, built on assumptions of marginal change and system equilibria, this means that systemic risks are under-appreciated and insufficiently considered in strategic decisions (UNDRR 2019; OECD 2020). There is an absence of appropriate methodologies in insurance (Swiss Re Institute 2020). The methodologies predominantly used in risk, economic and business case assessments tend to insufficiently consider the systemic nature of these risks and consequently underestimate their magnitude (Mamuji and Etkin 2019; Australian Institute for Disaster Resilience 2020). This is the case even though many of the required appropriate methodologies have been developed (Australian Institute for Disaster Resilience, 2020; Jones et al. 2014; Marchau et al. 2019). It suggests the limited awareness, incentives or levels of capability or capacity to use these. New methodologies for the finance sector have recently been developed (United Nations Environment Program (UNEP) Finance Initiative, Cambridge Institute for Sustainability Leadership 2018) There is highly fragmented and uncoordinated development of climate adaption tools leading to some confusion amongst end users. There is also insufficient critical mass and continuity of resourcing to provide sustained product support and improvement (Webb and Beh 2013) There is an absence of required data on the benefits of disaster risk reduction and a need for consistency and accessibility in the measurement, modelling, analysis and sharing of data (Deloitte Access Economics 2016a; Andrews et al. 2016). Aspects of this are being tackled at the national level by the CSMI initiative, for example. Deloitte Access Economics in its report to the Australian Business roundtable: "Building an open platform for natural disaster resilience decisions" (Deloitte Access Economics 2016b) highlights that 'crucial natural disaster information is difficult and costly to access, often incomplete or out of date and frequently duplicated across sources. It is often single purpose and the needs of multiple stakeholders have not been considered." Typically, data that would be made available through this type of national platform would be historic data and would not adequately capture and reflect the complexity of interconnected systems and change. Other forms of knowledge such as scenarios would need to be developed to support long term adaptation and mitigation.

CHARACTERISTICS OF THE DECISION CONTEXT	EXAMPLES AND REFERENCES
There is variable capacity amongst stakeholder groups, especially the most vulnerable and marginalised, to take part in genuinely whole-of-government and whole-of-society approaches to assessing risks and developing inclusive mitigation, adaptation and transformation strategies.	The National Resilience Task Force states that "New mechanisms are needed to listen and engage in two-way (or multiple) conversations about vulnerability, risk and risk mitigation. The general public and government officials often do not know how to find or effectively engage with each other and opportunities to learn from one another are therefore missed" (Department of Home Affairs 2018). Yet even in more inclusive processes for assessing and devising strategies, vulnerable and marginalised stakeholder groups are the least likely to have the means to action any implementation of those strategies. Therefore, their capacity also needs to be built to action the results of engagement.
There is an absence of common language, concepts, problem framings, and methodologies used to support climate adaptation, disaster management and resilience.	There exists a diversity of legitimately contested framings and definitions of concepts such as resilience, vulnerability, adaptation, transformation and natural disasters (see O'Connell et al. 2016 for a coherent integration of these concepts as a common basis for their constructive application in assessments). This diversity is both a strength and a barrier to building shared understanding and agendas. Accepting this diversity in definitions enables inclusiveness, and can encourage individuals to clearly define what they mean when they use these terms (UNDRR 2019; Webb and Beh 2013). The challenge, however, is that processes to clarify definitions are rare, or difficult and time consuming to do due to entrenched disciplinary, cultural or ideological mindsets and an absence of incentives to do so.
There is no common view among government departments regarding common drivers and therefore the coherent responses required. Government agencies tend to go through their own processes of defining problems and suggesting solutions.	The science informing disaster management has tended to view specific hazards in isolation rather than in the wider context in which they interact with other hazards and with human systems and give rise to compounding impacts (Glasser 2019). This may be due in part to analytical challenges but is exacerbated by the management of hazards by specific agencies. The existing remits of most organisations are limited to issues manifesting within their sector, portfolio or jurisdiction (i.e. an absence of mandates, incentives and capabilities to assess and manage systemic risks). For example, drought and climate-related disaster are manifestations of the same set of climate-related drivers yet are dealt with separately by different agencies and sectors.
There are conflicting priorities and incentives within and across jurisdictions, sectors and organisations. This leads to climate and disaster risks being created across the system and insufficient incentives and resourcing to prevent and mitigate disaster risks.	Efficiency and cost-minimisation as objectives or principles in organisations and industries can lead to the transfer of risk to communities, increasing their vulnerability Department of Home Affairs 2018; O'Connell et al. 2018). There is an absence or unclear articulation and allocations of roles and responsibilities for assessing and managing risks, particularly risks originating or manifesting outside of defined (jurisdictional, organisational) boundaries Environmental Finance 2020; UNDRR 2019; Australian Institute for Disaster Resilience 2020). There are low levels of resourcing available to adequately assess and manage the causes and effects of climate and disaster risks as these have historically not been considered a priority requiring funding/resourcing (UNDRR 2019).
Prevailing approaches for allocating resources and budgets rely on cost-benefit tools that are not accompanied by appropriate methodologies or the data to factor in the ideas of value creation.	The siloed regulatory and procedural requirements and cultural expectations to focus on cost minimisation and/or profitability preference the delivery of a single asset over a 'value creation' lens applied at the precinct or regional scale which prioritises the creation of public value by public and private-actors co-creating shaping markets to solve societal problems (Mazzucato. and Ryan-Collins 2019).
Traditional 'risk assessment' framings, which start from the point of protecting existing assets, are designed for tame (quantifiable and manageable) risks, and limit thinking about the transformational change required to address longer term, systemic risk.	Standard risk framing focuses on protecting existing assets and restoring the status quo. Only direct, certain and quantifiable costs and benefits tend to be included. Analysis of costs and benefits that serve established interested tend to be better developed and legitimised. Present day prices and systems states are used as defaults. Novel hazards such as widespread smoke hazards are therefore ignored. Innovative options for building back differently tend to be sidelined (Wisner et al. 2011).

3.3.2 The potential benefits of harmonisation

There are many potential benefits that Australia could expect to realise from increased harmonisation of frameworks and approaches to planning, policy, budgeting, and program and project delivery to account for climate and disaster risks and resilience. These include:

- Increased efficiencies and lower costs from less duplication and more rapid action to reduce risk as a result of improved communication, coordination and alignment of agendas and actions
- Increased investment and provision of resources in generating data in standardised ways to produce nationally consistent products. This would reduce data harmonisation costs for end users and potentially reduce duplication of jurisdictional effort in producing and providing data
- Lower transaction costs as a result of wider adoption of a common terminology about climate and disaster risks, as well as increased shared understanding of problems and opportunities and how to manage these
- Policies and plans that are aligned and mutually reinforcing, leading to increased effectiveness and efficiencies in their implementation
- Widespread improvements in understanding and capabilities of local governments, individuals, organisations, across all sectors to collectively assess and manage risks leading to:
  - Reduced exposure and vulnerability and lower impacts and costs from natural hazards (e.g. one dollar invested in climate adaptation or disaster risk reduction saves $2 to $11 in post-disaster recovery and reconstruction (Global Commission on Adaptation 2019; World Economic Forum 2011)
  - Increased recognition of costs of inaction and potential opportunities leading to larger returns on investments in climate resilience and disaster risk reduction;
  - Increased investment in infrastructure and programs by governments, investors and the construction industry that realise multiple benefits, both during disasters and in 'normal' times or periods of stability;
  - Improved innovation and investment among individuals and businesses based on improved infrastructure and reduced risks to their livelihoods;
  - The direct benefit of more connected and capable communities that result from coordinated investment to strengthen them.

3.4 Learning from exemplary approaches to climate and disaster risk reduction, resilience and adaptation

An enabling environment for harmonising and coordinating efforts in climate and disaster risk reduction, resilience and adaptation can be promoted using entry points such as leadership and advocacy, legislation and regulation, Commonwealth, state and local policies, strategies and plans, standards, inclusive engagement, methodology and tool development, education and training, monitoring, evaluation and learning, and funding and financing. Importantly, the intent of interventions targeting these entry points is to make it easier for people and organisations in their diverse contexts to raise their awareness, develop shared language and understanding, enhance their systemic-risk assessment capabilities, and align, coordinate and collaborate in their decision-making, implementation and learning processes.

International and Australian examples of mechanisms to harmonise climate and disaster risk and resilience considerations within and across sectoral and jurisdictional frameworks and approaches to planning, policy and investments are presented below. These have been included as lessons could be adapted and applied from them to support the scaling up, better alignment, or introduction of new efforts across sectors or jurisdictions to more comprehensively and collectively assess and manage climate and disaster risks.

3.4.1 Emerging exemplars in Australia

There are a growing number of exemplars in Australia demonstrating elements of what is required to harmonise efforts to achieve climate and disaster resilience. The National Disaster Risk Reduction Framework (NDRRF), for example, is an important approach to integrating climate change and disaster risk. It explores the implications for all Australians' wellbeing and long-term prosperity under climate change.

The NDRRF emphasises the need for a shift in thinking about natural hazards and disasters: "that disaster risk is a product of hazard (a sudden event or shock), exposure (the people and things in the path of potential hazards), vulnerability (the potential for those people and things to be adversely impacted by a hazard) and capacity (the ability for those people and assets and systems to survive and adapt)" and that climate change is a fundamental driver of these components of risk. The NDRRF emphasises the need to develop better understanding of the root causes of increasing exposure and vulnerability to disruption, and where and how to focus efforts to reduce existing risks and prevent new risks being created. The NDRRF provides principles to guide and inform the interpretation and application of its intent including:

- Cultural change
- Shared and defined responsibilities
- Integrated action
- Inclusive engagement
- Leadership
- Data-driven decision making
- Continual improvement.

Guidance materials have been developed to help build the capabilities of individuals to understand and assess the strategic implications of systemic disaster risks (Australian Institute for Disaster Resilience 2020). The NDRRF also identifies priority objectives and strategies for diverse sets of stakeholders to act upon, across all economic sectors, private and public agencies, and all levels of government. It highlights the need for governance arrangements that:

- Promote transparency and accountability around risk ownership, that incentivise the reduction of disaster risks, and that support the rapid building of knowledge of all Australian's of climate and disaster risks
- Facilitate consistency in the way information is created, analysed and made available to support low regrets "good decisions" (Jones et al. 2014) and increased investments in climate and disaster risk reduction, resilience, and adaptation.

The NDRRF has been translated into a National Action Plan (NAP) to guide its implementation. The scope and potential effectiveness of this NAP could be substantially enhanced through the harmonisation of climate and disaster resilience into and across jurisdictional, sectoral and agency frameworks and approaches to planning, policy, budgeting and program delivery. This would promote and enable more comprehensive and coordinated collective actions based on shared agendas. A key element underpinning the NDRRF, and a priority initiative of the NAP, is the development of a national capability for climate and disaster risk information – the National Disaster Risk Information and Services Capability (NDRISC). NDRISC will provide an information and analytic capability, together with a 'service centre' and authoritative governance to:

1. Enable co-production, translation and brokerage of knowledge between information and service providers and decision makers
2. Steer the efforts of a significant number of discrete information providers and user communities to act on climate and disaster risk.

NDRISC will be developed through a program of interconnected 'development projects.' The National Bushfire Intelligence Capability (NBIC) is proposed as the first of a series of development projects that will iteratively build the key capabilities of the broader NDRISC. These are proposed for implementation in partnership with government, private sector and research organisations, to provide a practical means of linking together information communities to better support coordinated and collaborative efforts in systemic risk assessment and management.

In Queensland**,** where 60% of Australia's insurance claims related to disasters caused by natural hazards occurred in the 10 years to 2016 (Deloitte Access Economics 2017), there are numerous intersecting frameworks guiding disaster management at state and local government levels.

A suite of frameworks, plans, and strategies relate explicitly to disasters:

- Queensland Strategy for Disaster Resilience 2017 (Queensland Reconstruction Authority 2017) This provides the overarching all-hazards framework for resilience measures and activities to be taken by Queenslanders to anticipate, respond and adapt to changing circumstances, including climate risks. These are delivered through Resilient Queensland 2018-21, the accompanying implementation plan, and demonstrated through Resilient Queensland in Action
- Queensland State Disaster Management Plan (The State of Queensland 2018) This enables mitigation, preparation, response, recovery and building resilience to disaster events. The Plan makes provision for the Queensland Disaster Management 2016 Strategic Policy Statement (State of Queensland 2017) which identifies the strategic objectives underpinning disaster management, namely: to safeguard people, property and the environment from disaster impacts, and to empower and support local communities
- Queensland Emergency Risk Management Framework (Queensland Government 2017) This provides a risk assessment methodology for disaster management planning at all levels of Queensland's disaster management arrangements
- Queensland Disaster Resilience and Mitigation Investment Framework (Queensland Reconstruction Authority 2019) This provides guidance on effective investment decision-making and prioritisation to support disaster resilience and mitigation across Queensland.

Additionally, climate change and disaster risks have been acknowledged in some of the policies, plans and frameworks of core Queensland agencies. Among these are:

- State Planning Policy (The State of Queensland 2017) This stipulates that the risks associated with natural hazards, including the projected impacts of climate change, must be avoided or mitigated to protect people and property and enhance community resilience to natural hazards
- State Infrastructure Plan (Part B) (Department of State Development, Manufacturing, Infrastructure and Planning) This makes provisions for adapting infrastructure to the changing climate and incorporating energy efficiency into new constructions to reduce infrastructure emissions, in line with the Queensland Climate Transition Strategy (Department of Environment and Heritage (undated)) and the Queensland Climate Adaptation Strategy 2017-2030 (Department of Environment and Heritage Protection 2017)
- Building Queensland Business Case Development Framework (Building Queensland 2020) This guides development of business cases for infrastructure proposals and includes a sustainability assessment of proposed infrastructure resilience to climate change, including extreme weather events.

The two categories of frameworks outlined above – those specifically addressing disaster and those supporting climate adaptation - have largely evolved in parallel, and each framework is owned by a different implementing agency. Mechanisms for harmonising across agencies are developing. These include:

- Governance mechanisms such as the Queensland Resilience Coordination Committee (QRCC). The QRCC was established in 2018 to provide direction and coordinate actions under Resilient Queensland. This is done via Functional Recovery Groups, represented by lead recovery agencies and key partners across multiple sectors. While commendable, such mechanisms are yet to reach maturity and it is thus too early to evaluate their effectiveness. The need for better coordination of disaster resilience approaches is recognised, and a partnership between CSIRO, Queensland Reconstruction Authority (QRA and other state agencies is currently working to understand harmonisation needs as well as barriers and enablers to achieving and maintaining a more harmonised approach.
- The co-ordination of approaches, including CSIRO supporting Queensland agencies to identify overlaps and complementarity of inconsistent methodologies, which in turn will support the upcoming state-wide rollout of the Regional Resilience Strategies from July 2020. This includes harmonising the methods of Queensland Fire and Emergency Service (risk assessment), Department of Environment and Science (adaptation) and QRA (regional resilience strategies) which is an excellent step towards the practical harmonisation across agencies.

While horizontal harmonisation (e.g. between state-level stakeholders) is an important goal for more coordinated disaster management, the vertical dimension is equally crucial. Queensland's cumulative experiences with disasters have been an important trigger for climate and disaster risk to occupy a more prominent place in the economic planning and investment agendas of some local councils. Since 2017, more than half of Queensland's local government areas have experienced three or more major climate-related disasters that have required disaster "activations" (i.e. emergency financial support from state and Commonwealth governments) (Glasser 2020). For these local governments, the implication is a chronic (and unsustainable) situation of recovering from disaster.

The state-level initiatives, to varying degrees, specify roles and responsibilities of local authorities and communities in disaster management. The Queensland Strategy for Disaster Resilience 2017 (Queensland Recovery Authority 2017) aims to work with councils and communities to better anticipate, respond and adapt to the impacts of climate change and variability. The Queensland Prevention, Preparedness, Response and Recovery Disaster Management Guideline (Queensland Fire and Emergency Services 2017) nominates local governments as primarily responsible for management of disaster events in their Local Government Areas, being well positioned to act on local knowledge. Through their Local Disaster Management Groups (LDMGs), local governments are expected to play a role in both prevention and preparedness (to manage vulnerabilities) and response through coordinated and effective strategies.

Queensland's planning legislation in recent years has marked a significant change in the planning reform agenda to enable greater flexibility for local governments in the development of local planning instruments to incorporate local content and variation to reflect context. The Queensland Planning Regulation (State of Queensland 2020), which provides the mechanics for the operation and implementation of the Planning Act, supports key government priorities including:

1. Supporting quality urban design outcomes in our cities, towns and neighbourhoods,
2. Improving outcomes for housing supply and diversity,
3. Reinstating world-class coastal planning laws, and
4. Supporting climate change objectives.

Several initiatives of the Local Government Association of Queensland (LGAQ) support local governments to explicitly develop greater climate resilience. These include:

- The Climate Resilient Councils Program (QCRC), in which 40 councils are participating to strengthen internal council decision-making processes to respond to climate challenges (LGAQ and Department of Environment and Science 2020a). Through the QCRC, the LGAQ is preparing to release a draft of its Climate Risk Management Framework and Guideline for Queensland Local Governments (LGAQ 2020). The framework provides a standardised overarching approach and detailed activities for progressing holistic understanding, management and responses to all current and future climate risk within a Local Government Area It is primarily for use at the local scale, while integrating state-wide and regional strategies and plans, and in collaboration with industry and broader community. These products will be tested through two pilot studies.

- The Queensland Local Government Drought Action Plan calls for a comprehensive, integrated all-hazards approach, and recommends reform of drought governance arrangements to integrate drought into existing disaster management arrangements, and to adopt a systematic approach to the prevention, preparation, response and recovery from the impacts of drought.
- The Queensland Local Government Coastal Hazard Adaptation Program, or QCoast2100, is a three-year $12 million Department of Environment and Science commitment to support local coastal governments to more proactively plan for coastal hazards by providing funding, tools and technical support towards the development of a Coastal Hazard Adaptation Strategy (LGAQ and Department of Environment and Science 2020b). At its centre is an iterative process involving three phases: Commit and get ready; Identify and assess; Plan, respond and embed. Over the longer term, the program approach is designed to build knowledge, professional capability and networks between the private, research and state and local government sectors.

Parallel to these initiatives, renewed support has been announced by the Commonwealth Government to extend the Queensland Household Resilience Program (Queensland Government2020) The Program assists eligible coastal homeowners to make practical improvements to their homes to increase resilience to natural hazards and mitigate increasing insurance premiums. It marks a shared commitment by national and state governments to address systemic disaster risk combined with practical measures to deliver community outcomes on the ground.

The broad range of Queensland experience highlights that, while local knowledge and context is central to harmonising the response to climate related risk, local government alone is unable to address the variable and often inadequate levels of local capacity and capability to engage with these issues. Addressing this may require review of roles and responsibilities across government tiers. Specifically, the model of policy setting at state and Commonwealth level, with responsibility for implementation at the local level, may need revision. Acting on the idea that effective responses to climate related risks need to be locally led, regionally coordinated and state supported would require exploring other models of government service delivery.

In South Australia, the Regional Climate Partnerships is a collaborative approach to harmonising climate and disaster mitigation, preparedness and adaptation through a climate resilience lens. Eleven partnerships across the state deliver upon shared Commonwealth, state and local government priorities to strengthen the resilience of communities, economies and natural and built environments (Department for Environment and Water 2017).

- The partnerships have shifted the emphasis from planning to practice and efficiently delivered substantial on-ground outcomes in just a few years. Opportunities now exist to transfer and scale-up these hard-earned lessons and continue learning from each other through increased regional and central coordination with state and local government, community and private sector. There is anecdotal evidence that by collaborating across multiple partnerships, two recent initiatives delivered returns on investment (Jack Jensen Consulting 2020). This outcome emphasises both the financial attractiveness imperative and the societal benefits that can be achieved through collaborative and harmonised efforts across scales and sectors, when building understanding and managing escalating risks of climate change and disasters.
- The Regional Climate Partnership model highlights the broader challenges involved in rapidly building resilience to escalating systemic climate and disaster risks, which stakeholders in the Partnerships recognise they cannot address alone. Stakeholders are looking to strengthen and renew the Regional

Climate Partnerships, based on the evidence that they can function as a core delivery arm for the state priorities laid out in:

– 'Directions for a Climate Smart South Australia';
– Across-Agency Climate Change Strategy (soon to be released)
– Coastal Strategy
– Stronger Together Strategy
– Regional Development Strategy
– Public Health Plan
– Emergency Management Plan
– Climate Change Act
– Green Adelaide
– Landscape Boards;
– National Park City initiative.

- With South Australia commencing economic recovery from the COVID-19 pandemic and the 2019/20 bushfire season, the Partnerships is well placed to build in long-term resilience and enable the South Australian Government to rapidly facilitate shovel-ready job-and-resilience-building initiatives, such as constructing coastal protection works and stormwater infrastructure upgrades, retrofitting vulnerable homes for energy efficiency and climate resilience, upgrading streetscapes to install green infrastructure, bushfire planning and response, enhancing parks and gardens to improve liveability and manage urban heat, driving the circular economy through improved waste management, and stimulating uptake of electric vehicles and charging infrastructure.
- The benefits of such a harmonised and collaborative approach between state and local governments via the Regional Climate Partnerships are that the latter can leverage funding from all levels of government by applying their extensive experience and networks. In bringing together many sectors, disciplines and levels of government, along with a strong community interface, the Partnerships access and combine multiple sources of knowledge and provide a test bed for cost-effectively trialling new solutions. Successful innovations can be readily repeated across multiple councils and regions, and replication of failures avoided. Peer-to-peer learning networks mean that policy and research priorities are evaluated and adapted in real time, swiftly demonstrating whether policy is working and making rapid progress much more likely. By performing the dual functions of both informing strategic priorities and delivering practical action, the Partnerships are a uniquely effective mechanism for closing the gaps that so often occur between science, policy and on-ground implementation.

The Australian finance sector recognizes the urgency, materiality, and complexity of the systemic challenges posed by climate change to the sustainability of the financial system.

- The Australian Prudential Regulation Authority (APRA) March 2019 survey of regulated entities indicated that boards are increasingly recognizing climate risks and integrating them into business risk managing plans. APRA has advised regulated entities that climate risks are material and actionable now (APRA 2019). The Australian Securities and Investment Commission (ASIC) has focused on company disclosure and accountability and has made statements about the likely assignment of responsibility for climate risks. ASIC also indicates that regulatory responses to climate risk in the financial sector are being coordinated across the Reserve Rank, Treasury and regulators via the Council of Financial Regulators, in line with international movements such as the Taskforce on Climate-related Financial Disclosure (TCFD) (elaborated in the next section). Australian regulators are involved in these international reform processes and are leading efforts in the Sustainable Insurance Forum coordinated by United Nations Environment Program (UNEP).
- The Australian Sustainable Finance Initiative (ASFI) has high level engagement from across the finance sector and recognizes that finance plays a fundamental role in all aspects of disaster, notably affecting

investment strategies, and risk mitigation and allocation (ASFI 2019). The ASFI identified a range of diverse and fundamental challenges to adapting finance to climate risks. These include leadership; institutional and cultural barriers to addressing risks; the need for greater engagement and alignment with the communities and citizens whose funds the finance sector manages; the need for frameworks, standards and tools to account for forward-looking climate risks to support improved financial decision making; and the need for consistent regulatory guidance and oversight. Recommendations from the ASFI are expected to be released in June 2020 and are likely to provide a basis for the broader systemic reform of the finance sector.

- Notwithstanding these efforts, many challenges remain. The insurance industry recognizes that increasing risk may make insurance in many areas unviable, which may begin to compromise the sustainability of the entire industry. Yet initial responses to mitigating the risks are driven by a desire for the industry to survive in its current form (based on existing business models). Arguably, risk-sharing and management strategies will need to increasingly focus on longer-term risk and the risks to enduring livelihoods and lifestyles (New Zealand Government 2019), if the insurance industry is to serve the long-term interests of customers and remain viable as an industry (Swiss Re Institute 2020; ASFI 2019). Similarly, the green investment industry is well developed. For example, green bond initiatives focus on accrediting investment that does not exacerbate climate change or is not exposed to its risks. The more difficult and fundamental task of aligning financial incentives with the broader long-term public interest to reduce the causes of disaster risk is currently outside of the scope of this industry-driven initiative. Reasons for this include the absence of consistent and comparable measures of the beneficial outcomes generated by such investments. These challenges are now widely recognised and the ASFI is supporting the Climate Measurement Standards Initiative (CMSI) to begin addressing them (Climate KIC Australia 2020). The CMSI is an industry-led collaboration between insurers, banks, scientists, regulators, reporting standard professionals, service providers and supporting parties. It will develop open-source technical business and scientific standards for climate physical risk projections of future repair and replacement costs of residential and commercial buildings and infrastructure in Australia.
- The narrow focus of investment on (often short term) financial returns is an important point of disconnection of investment decisions from climate and disaster risk reduction. The legislative basis of the Future Fund provides an example of an opportunity to change the remit of investors to enable strategic investments that address the systemic and long-term nature of climate change (https://www.futurefund.gov.au/). The Future Fund board is required to focus on financial returns to the fund. The potential to account for positive spill-over benefits of investments - for example, to provide robust road networks that boost regional productivity and provide a resilience triple dividend including direct non-monetary risk avoidance benefits, increased financial security of local businesses, and increasing investment confidence – ought to be taken into account yet tend to be ignored. Similarly, the focus on minimization of the risks to annual financial return, rather than on the broader effects of investment on the financial and non-financial risks to the Australian economy, limit more strategic investments being considered. Closing the loop on investments to ensure that indirect and non-financial benefits from investment can be accounted for by the providers of capital involves both regulatory reform of financial intermediaries, as well as innovation to reduce the costs of this more complex accountability process.

The Australian infrastructure sector is increasingly recognising and responding to the challenges and opportunities posed by climate and disaster risks and resilience.

- Infrastructure Partnerships Australia's 'Infrastructure to you' interactive event series, for example, recently focused on the 'Coordination of Government and Industry through economic recovery'. The takeaways from this webinar that are relevant here are that COVID-19 presents an opportunity to reimagine society and infrastructure's role in it. A clear and reliable public infrastructure pipeline will drive economic recovery and underpin private sector confidence. Moreover, regional projects and resilience should be prioritised through the economic recovery. This resilience agenda within Australia's economic recovery and development will benefit from the harmonisation of frameworks and approaches accounting for climate and disaster risks.

- Infrastructure Australia (IA), in its recently updated assessment framework, highlights the need for proponents to factor climate risk into all stages of the assessment process. In doing so, IA indicates that the authoritative source of future climate risk scenarios is Climate Change in Australia (unless state climate risk scenarios are mandated). The guidelines require proponents to address uncertainty about climate risk and other factors through the use of scenarios in option development and assessment, "where appropriate, developing evidence-based scenarios (e.g. of population or climate change) and using scenario analysis to ensure that options can be robust in the face of uncertainty about the future" (Infrastructure Australia 2018). This includes conducting "sensitivity tests of the demand and cost modelling and the cost-benefit-analysis results, including testing for robustness across a range of future scenarios". Proponents are required to consider effects of climate risk on infrastructure benefits and costs through direct and indirect effects and transition risks.
- The assessment framework guides proponents to use other relevant frameworks in project design. Specifically, it asks proponents to describe how the problem or opportunity is consistent with relevant government policy objectives and points to disaster resilience and critical infrastructure strategies as key areas of required alignment. For example, the assessment framework references the use of the National Emergency Risk Assessment Guidelines (NERAG) (AIDR 2015) to assist in generating and evaluating mitigation options. It also references the Australian Transport Assessment and Planning Guidelines (Department of Infrastructure, Transport, Cities and Regional Development (undated)) as a framework for transport infrastructure planning that should be used by proponents.
- Resilience is also now used as one of the ten categories to describe a project on the Infrastructure Priority List with resilience defined as: "Enhancing the capacity and reliability of Australia's infrastructure networks and the Australian economy to regenerate after a particular shock and recover rapidly to the previous level of service or better."

Despite these exemplars, we are only just beginning to develop an integrated understanding of climate change and disaster risks, and to more effectively consider (frame, value, model, assess) the systemic nature of these risks and the benefits of harmonising approaches to climate and disaster risk, resilience assessment and planning. This activity, however, will enable reduction of risk through new investments and will provide a basis for understanding how to transition existing infrastructure stock to a more resilient footing.

The above initiatives, and the plethora of frameworks and approaches illustrated in Figure 10, can be enhanced and better enabled through purposeful and targeted actions to harmonise these into policy, planning and investment processes in ways that ensure consistency, repeatability and comparability in the consideration of climate and disaster risks and resilience.

3.4.2 International exemplars

New Zealand National Disaster Resilience Strategy

The New Zealand national disaster resilience strategy (NZ NDRS) was built on a two-year consultation process focusing on visions, goals and objectives in the context of changing disaster risks under climate change. The development of a common vision provided a basis for harmonisation across sectors and scales. This, combined with an understanding of the complex and systemic nature of disasters, enabled clearer and fairer allocation of roles and responsibilities for assessing, attributing and acting on the causes and effects of risks. For example, the importance of multiple sectors in building a resilient community was acknowledged and was built into sector specific plans and therefore not required to be duplicated in the NZ NDRS.

Once an overarching common cause was established, the overlap across sectors created opportunities for developing multiple benefits, cost savings and mutually reinforcing agendas across agencies.

The NZ NDRS used two frameworks to promote and drive these common agendas:

- Triple dividend of resilience: avoid losses, stimulate economic activity and entrepreneurship due to avoided disaster, and create co-benefits. This framing highlights the multiple benefits of resilience activities, improving the business case for investment.
- A collective impact framework as a strategy for tackling complex tasks, which focuses on building common agendas and mutually enabling activities. A key feature of this approach is that it needs one or more backbone organisations to ensure the process of knowledge brokering at the science-policy interface, communication and collaboration towards common goals is continually resourced. This collective impact framework is also proposed in the Guidance on Systemic Risk Governance, developed by the Department of Home Affairs to support the implementation of the NDRRF (Australian Institute for Disaster Resilience 2020).

The complex and systemic nature of resilience is also addressed by the bottom-up ethos of the NZ NDRS, which is embedded across the system in mutually supporting ways. For example, a fundamental principle of the NZ NDRS is that "emergency management in New Zealand is still based, first and foremost, on a principle of self-reliance." In this way, self-reliance, bottom-up processes, and resilience more generally, are mutually supporting and aligned, as resilience requires having the capability to connect and coordinate to meet prioritised needs of stakeholders. Additionally, local governments are expected and supported to find common regional-level goals and programs that build resilience as their communities see fit.

The NZ NDRS suggests that attributes of safe and resilient communities include: being connected, healthy, organised and knowledgeable; having strong attachment to place and strong cultural norms to draw on in times of upheaval; being able to create or exploit economic opportunities; essential infrastructure; and capacity to manage natural assets. This suggests that capacity building goes beyond the need to provide training and information, to develop the practices and processes in the region that allow it to self-organise and negotiate with other regions and levels of government to meet its needs. Regional scale environmental management, for instance, provides both established processes for dealing with environmental issues and helps establish shared values that inform objectives for disaster management. It may also establish the knowledge base, data collection, and monitoring and learning processes that can be used to address novel and complex disaster issues.

Nepal – an integrated approach to harmonise climate and disaster risk planning

The Policy and Institutions Facility of the UK's Department for International Development recently examined opportunities and challenges of harmonizing different frameworks and guidelines on climate change and disaster risk (Regmi et al. 2019). This recognised that climate change and disaster risk reduction and management are treated as separate thematic issues internationally, and in most national level policies and practices. The intent of the work was to stimulate discussion on the need for a common framework of understanding.

Key lessons from this work of the Policy and Institutions Facility, which focused on Nepal as a case study, indicated:

1. The need for harmonisation was motivated and exemplified by the overlapping objectives and responses in both disaster and climate adaptation planning.
2. Progress on climate and disaster resilience was being hampered by:

– Policy overlaps and capacity constraints related to lack of coordination, communication, political will, insufficient funds and absence of expertise
– Most of the climate change and disaster risk related frameworks, guidelines and tools have adopted parallel and standalone planning processes and developed complex tools and methodologies for assessment, design, and planning;
– unsustainable funding and financing of the design, planning and implementation priorities.

These lessons suggest that a 'risk ownership' or 'risk understanding' approach is vital for informing and supporting harmonisation of climate change and disaster risk approaches. This risk understanding and ownership approach helps government and stakeholders to consolidate values-based evidence on risk, attribute impacts on development, and help build understanding of the pros and cons of action or inaction towards risk reduction (Young and Jones 2016). "The intention of this approach is to stimulate interest of government to develop (regulatory) measures to address risk". In other words, harmonising approaches does not involve working out how to add on extra issues, but how to reframe problems, remits and assessment approaches so that the issues are aspects of the whole.

Finally, the following practical steps towards integrating and mainstreaming approaches to climate and disaster risk assessment and management are recommended:

- Work with state and local level governments to investigate how integration could be implemented effectively and efficiently in terms of capacity and funds
- Pilot integrated risk and resilience building activities at the local and state levels
- Work closely with Commonwealth Government to ensure that climate and disaster risk is well integrated within, and mainstreamed across, the policies, plans and budgeting process of all portfolios
- Convene dialogue among climate and disaster communities looking for opportunities to work together.

The global financial services sector – TCFDs and NGFS

The Network for Greening the Financial System (NGFS) and the Task Force on Climate –related Financial Disclosure (TCFD) are major international initiatives that aim to address the financial dimensions of climate change risks. These are broadly aligned with a range of other international finance initiatives that vary in aspects of finance focused on, the scope and framing of the nature of the climate risks considered, and the scope and strategy of the reform.

The TCFD claims over 800 public and private sector supporters with control over US$118 trillion in assets. The TCFD has focused on private sector disclosure of financial risks through existing reporting processes, and transparency in the pricing of risk related to climate change. It recognises that improved disclosure is a multifaceted process and only part of the journey to respond to climate risk. Future work is likely to focus on development and use of climate scenarios to support organisations' climate risk reporting and inform required organisational governance changes (TCFD 2020).

In contrast to the TCFD focus on organisational level response, the NGFS focuses on system level and regulatory responses. The NGFS comprises 54 central banks that account for 57% of global GDP. It aims to accelerate central banks and supervisors' responses to climate risks. Its current work streams focus on supervision of climate risks, analysis of macro financial impacts of climate change, and scaling up green finance (NGFS 2020).

The NGFS has six recommendations - the first four apply to the work of central banks and supervisors while the last two address policymakers:

1. Integrating climate-related risks into financial stability monitoring and micro-supervision
2. Integrating sustainability factors into own-portfolio management
3. Bridging the data gaps

4. Building awareness and intellectual capacity and encouraging technical assistance and knowledge sharing
5. Achieving robust and internationally consistent climate and environment-related disclosure
6. Supporting the development of a taxonomy of economic activities.

To ensure such a smooth transition, there is still a significant amount of analytical work to be done to equip central banks and supervisors with appropriate tools and methodologies to identify, quantify and mitigate climate risks in the financial system. This calls for a close dialogue with academia and for further technical work to translate the NGFS recommendations or observations into operational policies and processes. The NGFS will also continue to leverage the best practices identified within its membership to help central banks and supervisors to better assess and mitigate climate related risks. In terms of concrete deliverables, the NGFS is planning to develop:

- A handbook on climate and environmental risk setting out steps to be taken by supervisors and financial institutions to better understand, measure and mitigate exposures to climate and environmental risks with detailed case studies
- Guidelines on scenario-based risk analysis: scenario-based risk analysis is complex, requiring further research and analytical input, and data-driven scenarios for use by central banks and supervisors in assessing climate-related risks
- NGFS members will develop a hands-on practical guide for central banks to integrate sustainability principles into their portfolio management.

The United Nations Office for Disaster Risk Reduction (UNDRR) Global Assessment Report on Disaster Risk Reduction

This 2019 Global Assessment Report (GAR) report by the UNDRR (UNDRR 2019) provides the basis for guiding and supporting signatories of the Sendai Framework for Disaster Risk Reduction to align and deliver on the Sendai 2030 priorities. The Sendai priorities point to the need for a global harmonisation agenda as described succinctly by António Guterres, the United Nations Secretary-General:

> *"If I had to select one sentence to describe the state of the world, I would say we are in a world in which global challenges are more and more integrated, and the responses are more and more fragmented, and if this is not reversed, it's a recipe for disaster."*

A key recommendation from the GAR Report relevant to harmonisation describes 10 elements to be covered by frameworks, policies, plans and budgeting processes for them to be aligned with the Sendai Framework. The 10 elements provide a basis to guide national and local efforts in harmonising frameworks and approaches to policy, planning and budgeting so that they**:**

- Consider multiple timescales, with targets, indicators and time frames
- Have aims to prevent the creation of risk, reduce existing risk, and strengthen economic, social, health and environmental resilience
- Build knowledge and capacities to assess and understand the causes and effects of all components of disaster risk
- Strengthen disaster risk governance through mainstreaming and integrating disaster risk reduction within and across all sectors with defined roles and responsibilities
- Promote and enable the allocation of the necessary resources and financial investments into the development and the implementation of disaster risk reduction strategies in all relevant sectors
- Enhance disaster preparedness for effective responses and promoting the "Building Back Better" that considers resisting, accommodating (adapting) and retreating (transforming) in recovery, rehabilitation and reconstruction
- Promote policy coherence relevant to disaster risk reduction such as sustainable development, poverty eradication, reduction of inequalities, and climate change, notably with SDGs and the Paris Agreement

- Have mechanisms to follow-up, periodically assess and publicly report on progress.

The GAR report describes integration and mainstreaming as *"a dynamic process that aims to understand risk at the heart of development decisions in policymaking, planning, budgeting, programming, implementation, monitoring and evaluation at national, sectoral and subnational levels, rather than seeing risk management as an add-on"*. As such, the integration of climate and disaster risk reduction into development strategies and plans is complex and highly context specific. The GAR report highlights that countries are using a range of different entry points in their quests to undertake risk-informed development, and there is no blueprint. Instead, learning and sharing from experience, including from other cross-cutting issues, has been of great value. The report identifies five entry points for integrating climate and disaster risk into core development and investment processes:

1. **Policy and law:** Providing the enabling environment for climate and disaster risk mainstreaming and achieving risk-informed development. Entry points include leadership and advocacy, legislation and regulation, Commonwealth, state and local policies, strategies and plans, and standards.
2. **Organization:** Supporting the implementation of risk-informed policies and plans. Entry points include, coordination and responsibilities for mainstreaming, capacity development, procedures and tools, and programmes and projects.
3. **Stakeholders:** Enabling the involvement of critical actors in mainstreaming, such as government, communities, the private sector, and partnerships and networks.
4. **Knowledge:** Driving the mainstreaming process through raising the risk awareness and understanding the links with development. Entry points include risk assessment, awareness and education, and monitoring and evaluation.
5. **Finance:** Providing the essential support for implementation. Entry points include budgeting and expenditure analysis, public and private sector resource mobilization, risk financing and transfers, and risk informing investments.

The GAR Report also provides numerous lessons from efforts in developed and developing countries to make progress towards the goals of the Sendai Framework. Since the NDRRF aligns with the Sendai Framework, these recommendations and lessons are pertinent to Australia's ongoing efforts to harmonise its national, state and local approaches to climate and disaster risk reduction and resilience. For example, the report highlights:

- Only a few countries have made good advances on aspirations to tap into synergies among interconnected policy and practice areas (e.g. disaster management, climate adaptation, green investments, economic development), and to overcome the related competition over resources and power. The reasons given for this slow progress include:
  - The lack of awareness, knowledge and capabilities of decision makers to assess and account for climate and disaster risk reduction and resilience in broader (infrastructure, land-use, economic) planning and project development processes
  - The variable abilities of stakeholder groups, especially the most vulnerable, to take part in such 'whole-of-government and whole-of-society' processes.
- It is often the case that climate and disaster risk reduction strategies, when integrated and mainstreamed, are too ambitious and not aligned with existing capacities. The report highlights the most common causes of this disconnect between the intent of strategies and plans and their limited implementation as:
  - Low awareness of stakeholders involved in implementation
  - Powerful disincentives in countries' risk governance systems that hinder prioritizing risk reduction (e.g. infrastructure design and delivery is governed by principles and priorities of cost-minimisation and urgency).

The recommendations to address these harmonisation challenges are to:

- Accompany these processes with awareness raising campaigns (which helped foster trust, understanding and ownership among involved stakeholders)
- Build capacity through training, education and guidance
- Make sure marginalised and vulnerable stakeholder groups have an equal say
- Introduce a diversity of incentivisation mechanisms (e.g. requirements and resourcing to develop and apply systemic-risk assessment approaches in key government agency strategy, planning, budgeting and procurement processes) to make it easier to account for these risks and demonstrate the benefits of pre-emptive risk mitigation.

Platforms to coordinate and exchange knowledge and resources

Under the Sendai framework and its predecessor, the Hyogo Framework for Action, numerous global, regional, thematic and national platforms have been developed to coordinate, provide and mobilize knowledge, skills and resources required for mainstreaming the complex and cross-cutting nature of Disaster Risk Reduction into development policies, planning and programmes (UNISDR 2007). Platforms do this by providing an overarching coordination and governance mechanism to orchestrate a complex ecosystem of discrete, disjointed and overlapping networks of policies, programs and activities together as a system to reduce disaster risk. National platforms are “officially declared national coordinating multi-sectoral and inter-disciplinary mechanisms for advocacy, coordination, analysis and advice on disaster risk reduction” (UNISDR 2007).

Australia’s adoption of the Sendai Framework affords significant opportunity to reconfgure governance arrangements to reflect its more holistic and broader framing of the disaster risk reducton challenge. In Germany, for example, following the adoption of the Sendai Framework, the German Federal Government restructured its national platform, setting up a Coordinating Office for the implementation of the Sendai Framework as a National Focal Point within the Federal Office of Civil Protection and Disaster Assistance (BBK). It embedded the national focal point in an inter-ministerial working group for the Sendai Framework which included representation from the German Red Cross. It is noteworthy that the BKK was itself established in 2004 as a central organisation integrating roles, functions and information to ensure the safety of the population (LGAQ and Department of Environment and Science 2020b).

National platforms play a key role in harmonisation efforts, driving data standardisation and enabling aggregation and improved access to data, and bringing together providers and users of information and modelling.

Australia could also learn from recent international experiences in the development of innovative thematic platforms, which are distinct from national platforms in that they are developed to enable providers and users of information and modelling capability within a sector or thematic area to collaborate at scale. Examples include:

- The Oasis Innovation Hub for Catastrophe and Climate Extremes Risk Assessment – an EU funded partnership with the Global Insurance Sector - constituted as a not for profit company - to develop a shared platform for natural hazard risk assessment (Oasis Horizon2020 Insurance 2020). Oasis comprises an open source platform for developing, deploying and executing catastrophe models. Oasis is a socio-technical system comprising:
  - The technology platform (the Loss Modelling Framework) (Oasis Horizon2020 Insurance, 2020) for running catastrophe loss models, development of hazard and vulnerability data standards to enable interoperability between models, and a model development toolkit
  - A community of experts from insurance and reinsurance and providers of products and services collaborating to develop open source models and tools.

- The EU Platform for Climate Adaptation and Risk reduction (PLACARD) was established as a platform for dialogue, knowledge exchange and collaboration between the climate change adaptation and disaster risk reduction communities. "It aims to enhance the coherence of and give direction to CCA and DRR research, policy and practices, strengthening cooperation and countering fragmentation between the domains" (European Union Horizon 2020). Effective strategies adopted by PLACARD include mapping the key concepts used in respective communities as a basis for building shared understanding.

The UK - National Infrastructure commission

The National Infrastructure Commission has recently completed a two-year examination of the resilience of the UK's infrastructure. The final report of this study was recently released and is titled: Anticipate, React, Recover: Resilient infrastructure systems (National Infrastructure Commission 2020). In this report the Commission concludes that there is a need for a new framework for resilience which anticipates future shocks and stresses; improves actions to resist, absorb and recover from them by testing for vulnerabilities; values resilience properly; and drives adaptation before it is too late. The Commission has made three recommendations to government, which will help to deliver the framework for resilience.

- Government should publish a full set of resilience standards every five years, following advice from regulators, alongside an assessment of any changes needed to deliver them
- Infrastructure operators should carry out regular and proportionate stress tests, overseen by regulators, to ensure their systems and services can meet government's resilience standards, and take actions to address any vulnerabilities
- Infrastructure operators should develop and maintain long term resilience strategies, and regulators should ensure their determinations in future price reviews are consistent with meeting resilience standards in the short and long term.

As part of this examination, the National Infrastructure Commission required infrastructure owners within the UK to provide written responses to six questions on the topic of managing infrastructure interdependencies for more resilient sustainable development. These questions, listed below, could be considered by Australian infrastructure investors, owners or operators could for application to their own contexts to guide future efforts in risk assessment and management.

1. *Do you work with other sectors to improve the resilience of your own infrastructure system? If so, can you provide an example(s) and if not, why?*
2. *What range of things do you do to understand and address the current and future vulnerabilities in the physical networks that arise from cross-sector dependencies and interdependencies? (This might include collaboration, partnerships, data gathering and sharing, peer review, sharing modelling capabilities and research findings, sharing responsibilities). What else would you like to be able to do, and what are the barriers?*
3. *What time horizons do you typically use when planning investment in your infrastructure system? Do you think the planning horizons you use promote resilience?*
4. *How do you prepare for high impact but infrequent hazards or failures?*
5. *Are there any examples of methods/tools/incentives used within your sector that support optimisation/resilience planning across infrastructure systems?*
6. *Can you give examples where resilience and efficiency are directly in tension and/or examples where the objectives of efficiency and resilience have both been met?*

The National Infrastructure Commission's study was informed by a detailed systems analysis of interdependent network vulnerabilities undertaken by Oxford University (Pant, et. al. 2020) and a systems diagram of the national-level decision making factors that have an impact on the Level of Service delivered by UK infrastructure sectors developed by ARUP consulting using a systems mapping approach (ARUP 2020).

3.5 Summary of key findings and priority needs for harmonisation

Climate and disaster risks are growing across Australia due to the increasing frequencies, intensity and distribution of most natural hazards under climate change and the growing levels of exposure and vulnerability of people, assets, and economic activities to disruption. The causes of these growing risks are systemic (Figure 2, Table 2) and require coordinated system-wide responses beyond emergency and disaster management that fundamentally shift the thinking and capabilities of leaders, decision makers and communities in systemic risk assessment and management. This entails broadening the focus of disaster management beyond prevention, preparedness, response, relief, and recovery around particular events to more integrated system-wide approaches that contribute to mitigating the causes of climate and disaster risks in the first place.

There is growing impetus for action to rapidly deliver these changes and to catalyse the much-needed investments in climate and disaster risk reduction, resilience and adaptation outlined in Table 2. Yet the understanding, approaches and responses to climate and disaster risks in Australia are fragmented, and at times competing. This is due to several limitations captured in Table 3, including:

- An absence of commonality in language, concepts, problem framings, and methodologies used in climate adaptation, disaster management and resilience activities and practice
- Existing remits of most organisations being limited to issues originating or manifesting within their sector, portfolio or jurisdiction
- Prevailing risk assessment approaches and capabilities developed for tame (quantifiable and manageable) risks) and unfit for the purpose of considering the uncertain and cascading effects of systemic climate and disaster risks.

This fragmented approach to assessing and managing climate and disaster risks is leading to missed opportunities and benefits that a more coordinated and collective approach across sectors and jurisdictions and between levels of decision making could realise.

The case studies of exemplary approaches to harmonising and mainstreaming climate and disaster risk reduction and resilience presented above reveal the conditions for effective horizontal and vertical coordination in the assessment and management of climate and disaster risk reduction, resilience and adaptation. Figure 11 presents the authors' synthesis from TCFD 2020; O'Connell et al. 2018; LGAQ and Department of Environment and Science 2020a; Department of Environment and Water 2017; APRA 2019 and the international literature reviewed above. These conditions are shared awareness, common ways of thinking and communicating (concepts, principles), capabilities for co-producing understanding and knowledge about systems and values, and good ('systemic-risk informed') decision making. In other words, harmonisation and coordination of approaches does not involve working out how to add on extra issues, but instead involves working out how to reframe problems, assessment approaches and remits so that the issues of climate and disaster resilience and adaptation are aspects of the whole. Key levers and intervention points to promote and enable this include: leadership and advocacy, inclusive engagement, education and training, monitoring, evaluation and learning, methodology and tool development, legislation and regulation, Commonwealth, state and local policies, strategies and plans, standards, and funding and financing aligned with community and values driven agendas (UNDRR 2019).

These findings and the many lessons from the Australian and global experiences presented above highlight the important and urgent need in Australia for:

- Leadership across all sectors of society to drive harmonisation and mainstreaming of climate and disaster risk reduction, resilience and adaptation across sectors and levels of decision making;
- Raising awareness and building capabilities of all Australians to understand the relevance of and responsibilities for responding to climate and disaster risks.

- Acknowledging the difficulties in diagnosing and implementing system-wide responses to climate and disaster risks and therefore the need to invest in:
  – Harmonising concepts, framings, language, and processes as the basis for raising awareness and building shared thinking and understanding across sectors and jurisdictions
  – Aligning and integrating climate and disaster resilience and adaptation considerations with other societal, technological and ecological trends and mainstreaming these into economic development plans (including COVID-19 recovery and data and modelling technologies)
  – Supporting community-led approaches to imagining and defining goals and visions of desirable futures under increased climate and disaster risks that provide the motivation and guidance for coordinated strategic responses
  – Building public service capabilities to undertake and translate systems-based evaluations of climate and disaster risks and possible interventions into coordinated policy responses and state-funded, locally led implementation
- Strengthening and mainstreaming monitoring, evaluation and learning processes and the underpinning knowledge-management platforms and governance to support the assessment of effectiveness of cross-sector and cross-scale responses and capture lessons for supporting the transfer or scaling-up of successes.

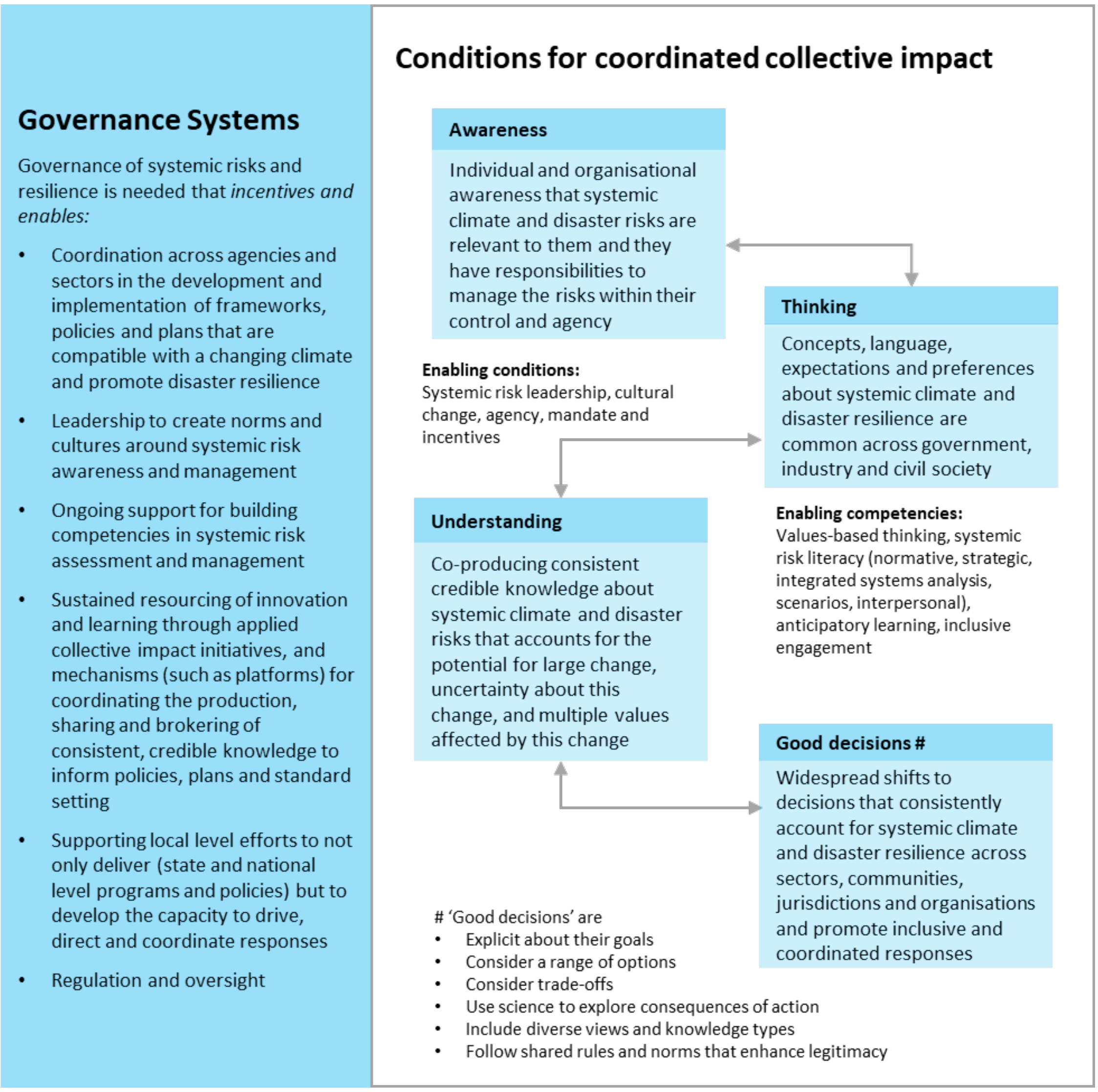


Figure 11 The conditions and intervention points for harmonising climate and disaster risk reduction

3.6 Strategies for implementing opportunities for improvement

The following suggestions are provided based on the needs identified above. Strategies for how each could be implemented in the short to medium term are described. These suggestions are complementary and inter-dependent and while they may be led by different implementing agencies, a coordinated approach to their implementation will yield greatest benefits. They will also need to be implemented adaptively and through inclusive engagement.

Build systemic risk literacy of leaders across all sectors of society that raises awareness, promote common framings and usage of concepts required for a coordinated, rapid, and nation-wide response to disasters and climate change. The intention is to create a shared understanding of the urgency and agency, initiate and enable national conversations and champion and coordinate collective responses to reduce risk, build resilience and adapt to change.

This can be done by:

- supporting the nation-wide roll out of the Australian Institute for Disaster Resilience (AIDR) Understanding Disaster Risk Forums and 'learning labs', systemic risk training courses for leaders, and the 'deconstructing disaster' vulnerability assessment processes in partnership with public and private agencies and research institutions. Sectors to prioritise for this are the emergency management and financial services sectors.

Undertake a nationally coordinated process to resource locally led activities to develop goals and visions for a future under increased climate and disaster risks. This should include development of community narratives of successfully navigating these risks. It should also include the assessment, building, and supplementing of local-level capabilities and capacities to deliver climate adaptation and disaster resilience aligned with the distribution of roles and responsibilities across and within the three levels of government.

This can be done by:

- Creating cross-agency coordination mechanisms at all levels of government, building on the momentum of existing approaches such as the Commonwealth Government Disaster and Climate Resilience Reference Group, that promote and coordinate the harmonisation of governments' collective efforts to mainstream systemic climate and disaster risk considerations.
- Supporting the roll out of regional vulnerability, resilience or adaptation assessments involving partnerships between relevant stakeholders, while also building capabilities through adaptive learning-by-doing. This can build off leading exemplary practices such as the South Australia Regional Climate Partnerships approach and the Profiling Australia's Vulnerability initiative.
- Develop models and modalities to support shared ownership of climate and disaster resilience and adaptation between Commonwealth, state and local governments while preserving each agency's autonomy to carry out its core functions.

Embed climate and disaster resilience and adaptation as a national priority into planning and economic development and investments decisions, **making it the purview and responsibility of all agencies and portfolios**. This will need to be supported and enabled through purposeful comprehensive upskilling and capacity building across all levels of the public service and private sector organisations in accounting for and managing these systemic risks.

This can be done by:

- Supporting the development and adoption of best practice principles, methodologies, tools and guidance on systemic risk assessment and management (e.g., foresighting techniques, scenario-based cost-benefit analysis, systemic vulnerability assessments, and robust decision making). Rapid progress can be made by raising awareness and building on the existing Guidance for Strategic Decisions on climate and disaster risks (Australian Institute for Disaster Resilience 2020) by supporting the further development of credible methodologies to enable consistent climate resilience assessment and prioritisation to inform investments.

- Evaluating and adapting existing processes and practices informed by collaborative cross-agency reviews of frameworks and approaches against leading best practice. This can build on the lessons in this Chapter and existing efforts of Queensland State Agencies and CSIRO to harmonise approaches to disaster resilience.
- Developing official training and education courses in climate and disaster risk assessment to build the required key competencies for systemic risk assessment and management.
- Supporting the Climate Measurement Standards Initiative to develop open-source technical business and scientific standards for climate physical risk projections of future repair and replacement costs of residential and commercial buildings and infrastructure in Australia.

Develop national and thematic knowledge platforms and incentive structures to promote coordination in the co-production, measurement, analysis, sharing, and accessibility of knowledge, data and information. Substantial early gains can be realised from promoting cooperation and coordination amongst existing 'owners and operators' of data, modelling and analytical platforms, and supporting the evaluation and reprioritisation of investments in the types of knowledge produced to address the gaps in integrated, socio-economic, qualitative and co-produced forms of scientific, experiential and traditional knowledge.

This can be done by:

- Scaling up support for the National Climate and Disaster Risk Information and Services Centre and aligned initiatives, such as the CSIRO Navigating Climate Change Mission, to rapidly build national and thematic platforms to support collaboration amongst research, public, private and non-governmental organisations and communities in the co-production, analysis, access, and exchange of credible, salient and consistent information, data and knowledge about climate and disaster risks and original options for building resilience (informed by, and potentially in partnership with, successful leading best-practice platforms (e.g., the EU PLACARD and Oasis).

Strengthen and mainstream cross-sector and cross-scale innovation (pilot programs) and learning, underpinned by common incentive structures and approaches to measuring and evaluating performance and scaling of successful initiatives.

This can be done by:

- Developing a strategic oversight and clear responsibility for whole of government strategy to support and connect the various high level initiatives described above and others such as the ASFI, and ensuring that the climate risk objectives and agenda are embedded into other large reform programs, such as those following the Independent Review of the Australian Public Service, and COVID-19 recovery.
- Promoting research, private sector and government partnerships in the delivery of climate and disaster resilient outcomes through the introduction of funding criteria, systemic risk assessments standards, and reporting requirements.
- Looking to the lessons and approaches recently adopted by the international leading practice for enabling action on disaster risk reduction in New Zealand. New Zealand's approach is considered best practice because it has a coherent governance context within which its over-arching strategic and planning frameworks are implemented. A core element of this is that climate and disaster resilience are embedded as a national priority into planning and economic development decisions and investments (and not pigeon-holed as a disaster management issue or a climate adaptation issue).

3.7 Chapter 3 Acknowledgements

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4 Empowering Indigenous leadership in cultural burning and natural disaster recovery and resilience measures

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4.1 Summary

Indigenous[6] people and cultural burning are key to delivering practical resilience measures in relation to bushfires and climate change. Fire has influenced how Australian Indigenous peoples live on, with and through their land for millennia, with Aboriginal Australians skilfully using fire to adaptively manage their local environments. Many of Australia's Aboriginal leaders are aware of this significance, which underpins their advocacy to sustain, rejuvenate and support cultural burning as a more holistic and Indigenous approach to fire knowledge and associated fire management practices.

This report identifies practical ways to support Indigenous burning activities that deliver a range of hazard reduction, livelihood and conservation benefits, which in turn enable Australia's communities and landscapes to flourish. There are now a plethora of cross-cultural fire management partnerships working across different tenures and across the nation. For example, Indigenous landscape burning partnerships have been established to reduce the frequency of high-intensity wildfires, thereby lowering greenhouse gas emissions, conserving important species and habitats, and protecting assets from bushfires. A review of these diverse partnerships and activities offers valuable insights to guide next steps in reconciling the ethics and practices of Indigenous cultural burning with contemporary landscapes and climate.

This report also considers practical measures to respond to the profound impact that natural disasters, including bushfires, have on Indigenous communities. Some innovative education, training and emergency bushfire recovery plans and strategies have been developed. However, more needs to be done to empower local Indigenous leaders to design pathways for building community efforts to respond, recover, re-build and prosper in the face of our changing climate, which includes longer, hotter, drier summers and increasingly frequent and severe bushfires.

Based on a review of Indigenous cultural burning and bushfire recovery activities and partnerships, several short- and long-term actions have been identified that can enable Indigenous groups to lead, facilitate and support bushfire prevention, response and recovery. Some of these measures focus on empowering Indigenous leadership and building Indigenous capacity. These include measures to expand employment opportunities and the skill base of Indigenous people working in land and bushfire management, support

[6] In this report, the terms Aboriginal and Indigenous refer to Aboriginal and Torres Strait Islander and First Nation peoples of Australia

disaster (including bushfire) management planning for communities, and empower Indigenous organisations to host forums on cultural burning and bushfire-related matters.

Other practical measures focus on actions non-Indigenous partners can take to support Indigenous cultural burning and Indigenous communities that are affected by natural disasters, including bushfires. These include measures to recognise and empower Indigenous fire knowledge and landscape management, support approaches that enable Indigenous fire practitioners to learn, share and pass on knowledge needed to negotiate, initiate, understand and interact with a cultural burn; support the positive health and well-being benefits for Indigenous communities that stem from cultural burning; and address challenges to Indigenous health and well-being resulting from the impacts of natural disasters such as bushfires. It is also important to resource Indigenous leaders to build the capacity of non-Indigenous partners and organisations to support cultural burning and Indigenous-led disaster recovery objectives and activities.

Practical measures to share knowledge and coordinate fire management as part of hazard reduction and land management activities are also identified. These include measures to enable further knowledge sharing between Indigenous leaders who are guiding cultural burning and/or community recovery. There are also opportunities to share practical lessons and strategies between Indigenous leaders and agency fire managers within and across jurisdictions. Indigenous and non-Indigenous partners need to be supported in building the necessary knowledge and confidence to burn together in landscapes that have not been burnt for some time, or where there is uncertainty about how to comply with rules for burning.

It is critical to recognise the fundamental role that fire plays for Indigenous people and across Australian landscapes, as well as the profound impact bushfires have on Indigenous people, their country and their livelihoods. In recent years, the impact of bushfires on Indigenous communities has increased in scale and severity. Contemporary Indigenous fire management programs have become larger, more sophisticated and more complex. There is now a need to continue refining existing Indigenous cultural burning and bushfire recovery approaches, expand the scope of their application, and keep trying new approaches to empower Indigenous leadership in bushfire prevention, response and recovery.

4.2 Opportunities for improvement

- Recognise that cultural burning is not just a recipe for landscape burning. It involves cultural protocols and landscape management practices done by Indigenous individuals who have obligations to care for their country. Empowering cultural burning into decision-making protocols and on-ground practices supports integrated approaches to nourish the significant values of Australia’s landscapes.
- Grow government and industry support for Indigenous cultural fire management as part of contemporary hazard reduction and land management activities.
- Enhance and build Indigenous leadership in cultural burning and land management. Indigenous leaders can share their cultural fire knowledge to build the capacity of other fire managers (Indigenous and non-Indigenous) via training and mentoring programs.
- Build fire and emergency risk management leadership and capacity in Indigenous communities. This could include resourcing interested Indigenous organisations and enterprises to develop and implement cultural burning strategies on all (government, private Indigenous) tenures and deliver culturally appropriate emergency services.
- Improve transport, communications and local energy provision systems in remote areas to reduce the impacts of fire and other natural disaster risks on remote communities.
- Resource Indigenous-led approaches to embed elements of cultural burning protocols and activities into digital planning tools and planning aids that protect strong Indigenous cultural and intellectual property and enable Indigenous and non-Indigenous fire practitioners to work together during fire planning and management.

- Empower Indigenous communities to recover and build resilience after a natural disaster. This includes supporting Indigenous leaders to enable community-led design of recovery strategies, health and well-being programs.
- Resource culturally appropriate forums to enable Indigenous people to share insights with others to inform future cultural burning, land management and disaster management responses.

4.3 Introduction

Fire has influenced how Australian Indigenous people live on, with and through their land for millennia, with Aboriginal Australians skilfully using fire to adaptively manage their local environments. Many of Australia's Aboriginal leaders are aware of this significance, which underpins their advocacy to sustain, rejuvenate and support 'cultural burning' as a more holistic and Indigenous approach to fire knowledge and associated fire management practices (e.g. Firesticks Alliance 2020a; NAILSMA 2020).

Cultural burning cultural is variable depending on the reason, season and vegetation type it is being applied (Garde et al. 2009). For Indigenous people, this physical impact is complemented by a cultural and symbolic significance that is passed on from generation to generation. Knowledge about landscape burning is not only about where, when and how to burn; it is also about ensuring that those who light fires are acting under the appropriate authority of the Indigenous Traditional Owners and managers of that country (Bright 1995; Champion 2016; Yibarbuk 1988). Senior Arnhem Land custodian Otto Champion (Robinson et al. 2016) explains:

> *'Our law, our knowledge, our people underpin these partnerships so we can learn together to manage fire today … Partnerships with scientists, business, government [are all] part of looking after our country, looking after our children, looking after our law.'*

Cultural burning activities are now conducted by Indigenous ranger groups, Indigenous land and sea management organisations and Indigenous enterprises across Australia. Work is carried out on a mixture of land tenures and developed via a suite of partnerships, including between Indigenous groups and with government agencies, scientists, non-governmental organisations and private landholders. Indigenous fire managers and their partners engage in a range of fire management-related activities, which taken together constitute their fire management work. These activities relate to different, sometimes concurrent phases of knowledge sharing and training, planning, site preparation, land management, burning, monitoring, evaluating and reporting.

Recent bushfires have re-emphasised the need to empower Indigenous communities and landscape burning experts to engage in bushfire prevention, preparedness, response and recovery. Many Indigenous leaders have drawn connections between recent bushfires and the ongoing colonisation of Australia and its care. As Oliver Costello (Firesticks Alliance 2020a) notes:

> *'Since colonisation, many Indigenous people have been removed from their land, and their cultural fire management practices have been constrained by authorities, informed by Western views of fire and land management.'*

Understanding and reconciling Indigenous cultural burning with contemporary land and bushfire management is often a key challenge. Indigenous leaders have highlighted how misrepresentations have impeded—and continue to impede—effective application of Indigenous fire knowledge (Langton 1998; Steffensen 2020). Concerns have also been expressed that some communities may lose their knowledge and confidence to burn because they have not been on their lands for some time, unable to access their land or practice cultural burning due to existing regulations, or that they may be unsure about how to comply with new rules for burning. Legal and policy solutions to these challenges vary depending on the state or territory in which fire projects are located and the land tenures on which they are conducted, both of which affect who manages landscape-scale fires, and how. As summarised in Chapter 5, these difficulties are exacerbated by reduced availability of experienced personnel and critical ground support logistics and result in decrease support for any form of prescribed burns. There are also challenging issues around who is resourced to do this work, and why Indigenous fire practitioners are often not paid as part of this effort.

4.4 Growing government and industry support for Indigenous cultural burning and bushfire recovery planning

Previous bushfire inquiries have made some references to the effectiveness of Indigenous landscape burning practices for reducing wildfires, but they have not focused on Indigenous people as residents or on cultural burning as part of contemporary fire management. However, policy and industry support for Indigenous leadership, cultural burning and land management practices is growing across the nation. Indeed, a national bushfire management policy statement for forests and rangelands endorsed by the Council of Australian Governments provides explicit recognition of the need to promote and empower Indigenous fire practitioners (Forest Fire Management Group 2014), as outlined in Goals 3 and 4:

- Promote Indigenous Australians' use of fire: Where relevant to Indigenous people, and appropriate, further integrate traditional burning practices and fire regimes with current practices and technologies to enhance bushfire mitigation and management in Australian landscapes.
- Employment, workforce education and training: Build employment opportunities and the skill base of people working in land and bushfire management (including Indigenous communities) to ensure that Australian agencies continue to have access to graduates, technical and field personnel with appropriate specialised education and training.

Similarly, the Australasian Fire and Emergency Services Council acknowledges 'Traditional Owner use of fire in the landscape' in its national position on prescribed burning (Australasian Fire and Emergency Services Council 2016a):

> *'Fire is culturally significant to Indigenous Australians … Where Traditional Owners have not been able to continue these practices the depth of spiritual and cultural knowledge and connection to the land is maintained through stories and memories. Integration of this retained knowledge into current agency practices should be actively supported and promoted. Where knowledge gaps exist, agencies should work with Traditional Owners to build that knowledge, and, where appropriate, revive practices' (AFAC 2016a).*

Fire authorities have established Indigenous inclusion plans (Country Fire Agency 2014; The Victorian Traditional Owner Cultural Fire Knowledge Group 2015; ACT Government et al. 2015; NSW Office of Environment and Heritage 2016; Queensland Fire and Emergency Services 2017a), and government agencies across the country have developed a range of partnerships with Traditional Owners. Research programs have also supported collaborative work with Indigenous people and practitioners within the natural hazard sector (see Neale et al. 2019; Russell-Smith et al. 2020b; Weir et al. 2020a), as part of the National Environmental Science Program[7], and through other programs supported by government agencies (Maclean et al. 2018).

Indigenous cultural burning is practiced in many forms. Some Indigenous family groups undertake burning of their country independently. Some Indigenous ranger groups have initiated and engaged in a diverse array of Indigenous cultural burning activities and partnerships across Australia, including fire management partnerships with local councils, state agencies and national program partners. Non-government and

[7] For example, see https://www.nespnorthern.edu.au/2016/10/11/developing-protocols-indigenous-fire-management-partnerships/; http://www.nespthreatenedspecies.edu.au/news/indigenous-action-vital-for-australia-s-threatened-species; http://www.nespthreatenedspecies.edu.au/news/partnerships-with-indigenous-communities-key-for-threatened-species

corporate collaborators have also invested in Indigenous cultural burning, including mining companies. In some cases, these partnerships cover large, remote areas. In other cases, Indigenous cultural burning has been recently re-introduced to the landscape for the first time in many years. Importantly, these cultural burning activities and partnerships are embedded in a range of on-ground, cultural and other non-fire-related activities that enable Indigenous people to care for their traditional country (Hill et al. 2013).

The diverse Indigenous cultural burning partnerships and activities that have spread across the country offer an important opportunity for Indigenous livelihoods and on-country economic enterprises, as well as innovative approaches to bushfire planning and management in Australia (Robinson et al. 2016c; Maclean et al. 2018). This includes early dry-season burning, which is used in northern Australia to reduce the frequency of high-intensity wildfires, lowering greenhouse gas emissions and sequestering carbon. National law that established Australia's Emission Reduction Fund created methods for reducing volumes of greenhouse gases (nitrous oxide and methane) released in the burning of grassy fuels, leaf litter and fine woody fuels. The savanna-burning methodology is based on Indigenous burning knowledge and practices and was designed to maximise Indigenous engagement and value. Indigenous communities and their organisations across northern Australia have enthusiastically seized opportunities to earn carbon credits through voluntary and Carbon Farming Initiative or Emissions Reduction Fund payment for ecosystem services (PES) agreements. By the end of 2019, Indigenous cultural burning projects were registered for over 300,000 km2 of northern Australia to deliver credits under formal contracts, with substantial penalties for under-delivery (Russell-Smith et al. 2020a).

Cultural burning activities have an important role to play in burning country appropriately and preventing the potentially devastating impacts and extent of future bushfire events. Empowering Indigenous leadership in cultural burning and land management practices is also important to better respond to and recover from future devastating bushfire events. Based on a review of Indigenous cultural burning activities and partnerships, several short- and long-term actions have been identified that can enable Indigenous groups to build their capacity and capability to become leaders, facilitators and supporters of bushfire prevention, response and recovery. These short- and long-term actions are presented in the following sections. Table 4, Table 5 and Table 6 in the Appendix at Section 4.11 summarise these actions and provide examples of practical programs and initiatives that already exist across Australia.

4.5 Short- and long-term actions to empower Indigenous leadership, cultural burning and land management practices to prevent future bushfire events

Across Australia, there is a diversity of skills, expertise and capacity among Indigenous people who wish to conduct cultural burning and land management in their local regions. Drawing on examples of innovation from across Australia, several short- and long-term practical actions have been identified to build Indigenous communities' capacity for bushfire prevention (see Table 4). These short- and long-term actions have been organised into the following pathways:

- Enhance and build Indigenous leadership in cultural burning and land management.
- Support collaborative partnerships between multiple sectors to better enable cultural burning and land management across different land tenures.

4.5.1 Enhance and build Indigenous leadership in cultural burning and land management

Acknowledging Indigenous fire knowledge, training Indigenous cultural burning practitioners and enabling knowledge sharing between Indigenous fire practitioners, and between Indigenous fire practitioners and non-Indigenous fire practitioner are key mechanisms for enhancing and building Indigenous leadership in cultural burning and land management. This, in turn, will enable Indigenous and non-Indigenous fire practitioners to work together to implement on-the-ground strategies to prevent future bushfire events.

Short-term practical actions

There are opportunities to support Indigenous organisations/enterprises that wish to develop a cultural burning program. This could involve:

- Acknowledging and resourcing Indigenous cultural fire knowledge training and mentoring programs. These programs will increase the adaptive capacity of Indigenous leaders to respond to future bushfire events.
- Resourcing attendance at training events and workshops for Indigenous groups to build networks with Indigenous and non-Indigenous fire managers for future partnership development. These partnerships are integral to the success of current and future cultural burning.
- Resourcing groups to develop culturally appropriate frameworks for assessing and reporting on the co-benefit outcomes of their work. This will enable the assessment of cultural, social and environmental benefits from cultural burning activities and partnerships.

Long-term practical actions

There are opportunities to support and reconcile Indigenous cultural burning with different land management strategies and activities. This could draw on lessons learned from successful fire management partnerships that exist across the country (see Table 4) and would involve:

- Resourcing interested Indigenous organisations/enterprises to develop and implement cultural burning strategies on all (government, private Indigenous) tenures. Bringing relevant leaders and communities together for discussion can take time and resources. However, the process itself can build community cohesion and resilience.
- Resourcing Indigenous leaders to build the capacity of non-Indigenous partners and organisations to support cultural burning objectives and activities. This could draw on guidelines and policies that have been developed in some jurisdictions in Australia.
- Resourcing Indigenous-led and co-developed research to address Indigenous cultural burning concerns, interests and knowledge needs.

4.5.2 Support collaborative partnerships between multiple sectors to better enable cultural burning and land management across different land tenures

Successful partnerships recognise the complexity of cross-cultural engagement and interactions, and respect Indigenous knowledge, know-how and protocols. They provide space and opportunities to support Indigenous and non-Indigenous people to develop new knowledge and skills in their own timeframes and create the necessary space for two-way knowledge exchange (Maclean et al. 2018; Robinson et al. 2016a; Woodward et al. 2020).

Short-term practical actions

There are opportunities to enhance the capability of Indigenous and non-Indigenous fire managers to better support Indigenous communities' cultural burning capacity and activities, as well as their fire preparedness and resilience. This would involve:

- Supporting fire managers to attend Indigenous-led fire management training programs. These could build on existing programs that have been developed to raise cultural awareness among non-Indigenous people, confirm to Indigenous leaders that government agencies and staff are beginning to recognise the value of Indigenous knowledge for local and regional fire management programs and partnerships, and pave the way for genuine partnership development.
- Enabling knowledge sharing between Indigenous leaders and agency fire managers within and across jurisdictions. This includes supporting regional and national forums, as well as resourcing joint walkovers (Indigenous leaders with agency fire managers) of planned burn sites and the co-development of more sensitive measures for fire protection. Providing opportunities for Indigenous fire managers to engage in all aspects of knowledge sharing is key.
- Resourcing agency–Indigenous fire management partnerships. This could involve identifying and resourcing pilots to showcase and test different institutional arrangements that can enable Indigenous leadership of cultural burning partnerships.
- Increasing permanent and temporary employment of Indigenous managers and leaders in government emergency management (bushfire), natural resource management and parks agencies.
- Ethical design and applications of digital technology that enables Indigenous knowledge and land management priorities to guide land and fire management during critical decision points. This would require collaboration with local Aboriginal organisations so that an Indigenous cultural and intellectual property base underpins digital platform design and application.

Long-term practical actions

There are opportunities to acknowledge and support Indigenous-led cultural burning strategies, training programs and collaborations. This would involve:

- Resourcing agencies to develop Indigenous engagement and collaboration strategies and protocols. This could build on initiatives that are already in place in some organisations and jurisdictions.
- Resourcing fire management agencies to enable cultural burning within the monitoring, management and evaluation frameworks used for fire and land management.
- Establishing performance indicators to evaluate how relevant agencies collaborate with Indigenous leaders, organisations and enterprises, and people in bushfire management.
- Monitoring and assessing the contributions of cultural burning to Aboriginal health and well-being outcomes.
- Establishing formal protection for Indigenous cultural and intellectual property in relation to Indigenous knowledge about fire.
- Negotiating agreed pathways for appropriate sharing, acknowledgement and integration of fire knowledge between Indigenous groups, and between Indigenous and non-Indigenous fire practitioners.

4.6 Short- and long-term actions to empower Indigenous leadership, cultural burning and land management practices to respond to disasters such as bushfire events

Drawing on examples of innovation from across Australia, several short- and long-term practical actions have been identified to build Indigenous communities' capacity to respond to future bushfire events (see Table 5). These short- and long-term actions have been organised into the following pathways:

- Empower fire and emergency risk management leadership and capacity in Indigenous communities.
- Improve transport, communications and local energy provision systems in remote areas to reduce the impacts of fire risk on remote communities.

4.6.1 Build fire and emergency risk management leadership and capacity in Indigenous communities

There are opportunities to support education and training in cultural burning and emergency fire risk management for Indigenous communities to develop Indigenous-led bushfire and other disaster risk plans and strategies.

Short-term practical actions

There are opportunities to provide education and training to prepare Indigenous communities for future bushfire events. Cultural resilience and adaptive capacity to respond to fires will be strengthened when the role of Indigenous knowledge and consideration of the local context is incorporated and respected in any such training program. Practical measures would include:

- Building the capacity of Indigenous (health, ranger and other local) organisations to understand and deliver culturally appropriate emergency services and support to affected Indigenous communities. This could enable Indigenous-led emergency teams to set up temporary hubs to identify and secure support for early recovery pathways.
- Extending opportunities for Indigenous people to engage in emergency management programs. This would include resourcing programs to support (bushfire) disaster management planning for communities.
- Supporting Indigenous organisations to host forums on cultural burning and bushfire-related matters. This would enable information sharing about cultural burning, recent bushfire management knowledge (scientific knowledge, Indigenous knowledge, government knowledge), partnership development, and community-based fire partnerships and strategies.
- Establishing and maintaining local Indigenous fire emergency plans to help respond to local Indigenous concerns and needs. Any such plan would include strategies that could be extended to natural disaster planning.

Long-term practical actions

There is an opportunity to include a section in government emergency disaster plans and strategies that focuses specifically on Indigenous people and their needs and requirements. This would involve:

- Understanding Indigenous perspectives on risk, hazard and disaster resilience—and what it means to be 'hazard-smart'—and acknowledging that these may diverge from the perspectives of scientists and government.
- Enabling and engaging with existing Indigenous institutions to work with communities to support bushfire preparedness.
- Developing effective emergency management partnerships with Indigenous leaders and communities (urban, rural, regional and remote).
- Learning from the past and building on existing or past government–Indigenous disaster management initiatives to help remote and regional communities prepare for bushfire events.
- Setting up Aboriginal advisory groups to work alongside bushfire recovery agencies. This would include enhancing local institutional capacity to enter into such partnerships, and encouraging inclusive, community-led processes to build emergency management plans and inform emergency management frameworks.
- Developing local adaptation responses to bushfire events.

4.6.2 Improve transport, communications and local energy provision systems in remote areas to reduce the impacts of fire risk on remote communities

There is a need to mitigate the risk of losing vital connections and services in Indigenous communities in the aftermath of a natural disaster event such as a bushfire.

Short-term practical actions

- Identify transport, communications and local energy provision systems needs in remote communities.

Long-term practical actions

- Improve transport, communications and local energy provision systems in remote communities—e.g. improving key access points, raising new and existing building standards, improving airstrips.

4.7 Short- and long-term actions to empower Indigenous leadership, cultural burning and land management practices to recover and build resilience after bushfire events

Across Australia, many sectors of society could be better supported to recover from future natural disasters and build resilience. This includes Indigenous communities, businesses and enterprises. Drawing on examples of innovative programs that already exist across Australia, several short- and long-term practical actions have been identified to build Indigenous communities' capacity to recover from future bushfire events (see Table 6). These short- and long-term actions have been organised into the following two pathways:

- Empower Indigenous communities and businesses to recover and build resilience after a bushfire event
- Continuously support Indigenous leadership in all aspects of fire management in Australia.

4.7.1 Empower Indigenous communities to recover and build resilience after a natural disaster

Empowering local Indigenous leaders to develop culturally appropriate strategies to support Indigenous people to deal with health and well-being issues that arise from impacts to their built and natural environments due to a natural disaster (e.g. badly burnt areas and the impact of bushfires) on their homes and communities is essential.

Short-term practical actions

Support is needed to identify and develop appropriate recovery responses to respond to the cultural and health and well-being needs of fire affected Indigenous communities. This would involve:

- Empowering Indigenous local leaders to design recovery strategies. The history and context of a local community, and the nature of Indigenous legal rights and interests, can mean that bushfires have different impacts and consequences for Indigenous rights-holders, non-Indigenous landowners and Indigenous community members
- Supporting local Indigenous leaders to develop natural disaster recovery health and well-being programs and initiatives specifically tailored for their communities
- Resourcing local Indigenous staff—or staff with experience in cross-cultural interactions—at regional recovery centres/emergency support hubs to support the Indigenous community to access relevant information and assistance
- Hardship assistance designed specifically for Indigenous communities and enterprises could ensure a timely and appropriate supply of essential goods, groceries and other critical items in the aftermath of a disaster. Information about assistance should be easy for people to locate and access. Involvement of local Indigenous leaders in recovery assistance design and delivery could ensure this support is appropriate for the local context.

Long-term practical actions

Indigenous connections to country and kin may require the geographical scope for determining the ‘fire affected’ status of some regions to be examined. Connections between Indigenous people and their country can also inform locally- driven approaches to build long-term resilience to natural events like bushfires. This would involve:

- Negotiating the geography of ‘fire affected’ declared regions so that it reflects local Indigenous rights and responsibilities for country. This has both policy implications (in terms of the targeting of government and non-government assistance) and cultural burning and fire management implications (in terms of understanding the extent of fire impacts).
- Supporting local Indigenous leaders to develop and guide framework to enable fire affected Indigenous people to access appropriate health and other cultural and human well-being services.

It is also vital to identify and enable economic opportunities for Indigenous leaders, organisations and enterprises that may arise from bushfire events. Such opportunities may support livelihoods, enhance the health and well-being of Indigenous communities in remote and urban settings, and build adaptive capacity to better respond to future (bushfire) emergency events. In addition to generating co-benefits, employment creation may also contribute to reducing government spending on Indigenous welfare programs. In the long term, this would involve:

- Resourcing payment for environmental services to support better management and restoration of ecosystems for biodiversity conservation
- Supporting and resourcing cultural burning activities to reduce the potential impact of future fires on infrastructure

- Repurposing government expenditure to enhance Indigenous economic well-being in Australia—including programs focused on rebuilding and disaster-proofing Indigenous enterprises impacted by a natural disaster
- Developing a collaborative policy framework involving emergency services organisations and Indigenous communities to mitigate and manage incidents while following Indigenous cultural protocols.

4.7.2 Continuously support Indigenous leadership in all aspects of disaster management in Australia

In the short term, support for Indigenous leadership in disaster management could include resourcing culturally appropriate forums that enable Indigenous leaders and communities to share insights with others to inform future disaster management responses. Such forums could enable continuous improvement of disaster management responses to better support Indigenous groups. They could also build the adaptive capacity and resilience of such groups to better respond to and recover from future bushfire events.

In the longer term, Indigenous advisory groups and representation could be supported to inform disaster management decisions across Australia. This could involve:

- Including Indigenous people in the terms of reference and membership of future post-bushfire inquiries
- Ensuring Indigenous peoples are represented on relevant government committees.

4.8 Conclusion

Indigenous leaders have an important role to play in ensuring that landscapes are burned appropriately, and in supporting Indigenous communities and enterprises to recover and prosper after bushfires and other natural disaster events. Empowering Indigenous leadership in cultural burning, land management, and community preparation and recovery activities is key to recognising and supporting these roles. The diverse fire management and bushfire recovery partnerships and programs that exist across the nation provide critical lessons and models to guide short- and long-term actions that can enable Indigenous groups to become leaders, facilitators and supporters of bushfire prevention, as well as natural disaster response and recovery (see Table 4, Table 5 and Table 6 in the Appendix at Section 4.11). Respecting the connections between Indigenous people and their country, and using those connections to inform locally driven approaches, are common features of successful Indigenous-led and collaborative fire and natural disaster management and recovery partnerships.

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4.11 Appendix – Short- and long-term actions to empower indigenous leadership

Table 4 Short- and long-term actions to empower Indigenous leadership, cultural burning and land management practices to prevent bushfire events

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
Enhance and build Indigenous leadership in cultural fire knowledge and practice	Identify and provide support to Indigenous organisations/enterprises that are interested in conducting cultural burning (Maclean et al. 2018; Robinson et al. 2016a). Support Indigenous-led cultural burning training and capacity building tailored for Indigenous people to enable Indigenous-led cultural burning activities. National Indigenous Fire Workshop and Firesticks Indigenous Alliance Corporation (Firesticks Alliance Indigenous Corporation Firesticks Alliance 2020a) Jigija Indigenous fire training program (Qld) (Walambarri Pty Ltd 2020) Kija Rangers (East Kimberley, WA) (Allam 2020) Mulong Indigenous on-country fire management workshops and training (Steffensen et al. 2018; Mulong Pty Ltd 2020) Indigenous fire forums (e.g. Savanna Fire Forum 2020; Firesticks Alliance Indigenous Corporation 2018b; Smith et al. 2018b; Firesticks Alliance Indigenous Corporation Firesticks Alliance 2020b)	Acknowledge and support (funding, partnerships, knowledge sharing) Indigenous-led cultural burning strategies, initiatives, partnerships, programs and collaborations (Maclean et al. 2018; Neale et al. 2020) The Victorian Traditional Owner Cultural Fire Strategy (The Victorian Traditional Owner Cultural Fire Knowledge Group 2019) Firesticks Alliance Indigenous Corporation truwana Rangers and the Tasmania Fire Service (TAS) (Department of the Prime Minister and Cabinet 2017) Witjira Waur Pulka (fire) Management Strategy, 2018-2028 (Natural Resources SA 2016)
	Establish collaborative monitoring and evaluation support (funding, partnerships, knowledge sharing) to enable **Indigenous leaders** to assess and enhance the benefits of cultural burning. Includes reporting co-benefits of Indigenous cultural burning (Maclean et al. 2018; Robinson et al. 2016b)	Support the development of fire management plans and guidelines for (cultural) fire management on state-owned/managed tenure. Aboriginal Cultural Guidelines for Fuel and Fire Management Operations in the ACT (Williamson 2015) ACT Aboriginal Fire Management Plan, 2015-16 (ACT Government et al. 2015) NSW Office of Environment and Heritage Cultural Fire Management Policy (Office of Environment and Heritage 2016) NSW Office of Environment and Heritage, Guidelines for Community (Low Risk) Cultural Burning on NPWS Management Lands (NSWOEH [State of New South Wales and Office of Environment and Heritage] 2016a) and Job Safety Analysis for Low Risk Community Cultural Burns (NSWOEH [State of New South Wales and Office of Environment and Heritage] 2016b)
		Develop cultural burning initiatives and partnerships between Indigenous groups and state/territory agencies for fire management on state/territory owned/managed land tenures.

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
		Djandak Wi cultural burning initiative between Dja Dja Wurrung Traditional Owners and Victorian Government fire and land management agencies (Neale et al. 2019) ACT Parks and Conservation Program's cultural burning initiative with Ngunnawal Traditional Owners (Weir and Freeman 2019) Fire mitigation partnership between Kanyirninpa Jukurrpa (Martu people) and WA Parks and Wildlife Service (Sage and Catt 2018) Bunya Mountains Murri Rangers' cultural burning with Western Downs' Regional Council, Burnett Mary Regional Group, at Russell Park (Maclean et al. 2018; Bunya Peoples' Aboriginal Corporation and Rangers 2016)
		Support cultural burning initiatives and partnerships developed between Indigenous groups and private and/or conservation landholders (including NGOs). Partnership between the Tasmanian Aboriginal Council with Tasmanian farmer Von Bibra (owner of Beaufront property), Tasmania Land Conservancy, Greening Australia, the Tasmania Fire Service and Professor Bowman (UTAS) (ABC 2018; UTAS 2018) Euroa Arboretum, Victoria (Euroa Arboretum 2018) Local landowners in Victoria (Maclean et al. 2018) Land for Wildlife landholders in SEQ (Jenyns 2019)
		Support local Indigenous groups to develop Healthy Country plans (including cultural burning) and incident response protocols (to assist with fire- and non-fire-related emergency incidents on traditional country) (Prober et al. 2016)
		Support Indigenous-led and co-developed research to address Indigenous cultural burning concerns and interests. Community resilience and sustainable economic development/enterprise opportunities (e.g. PES, Ranger groups) (Sangha et al. 2015) Reporting co-benefits for cultural burning (Maclean et al. 2018) Protocols for Indigenous fire management partnerships (Northern Australia Environmental Resources Hub 2017; Cranney 2020) Corporate and philanthropic investment in Indigenous cultural and natural resource management (Northern Australia Environmental Resources Hub 2020) Banbai Fire and Seasons Calendar, Wattleridge Indigenous Protected Area (McKemey and Banbai Enterprise Development Aboriginal Corporation 2018; McKemey and Pattterson 2018; McKemey et al. 2019) Walking Together: A Decolonising Experiment in Bushfire Management on Dja Dja Wurrung Country (Neale et al. 2019) Hazards, Culture and Indigenous Communities (Neale et al. 2019; BNFCRC n.d.; Weir and Freeman 2019; Weir et al. 2020a; Weir et al. 2018; Neale et al. 2020)

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
		Yanama Budyari Gumada – Reframing Urban Care as Daurug Country in Western Sydney (Ngurra et al. 2019) Understanding Country Outcomes from Low Rainfall Grassy Ecosystem Management Practices (Rumpff and Walse 2018)
		Use and develop collaborative planning tools (e.g. mapping-based tools) with Indigenous communities to assist in collaborative fire planning (Edwards et al. 2015) <u>Suggested research areas</u>: Appropriate state, federal and territory economic models for funding of cultural burning programs, projects, partnerships, initiatives (Neale et al. 2020); investigate the potential impact of cultural fire in restoring ecological functions and reducing fuel loads (Victorian Traditional Owner Cultural Fire Strategy 2018)
		Support (procedural, structural, tenure-related) the rights of local Traditional Owners to light fires on their traditional country, provided it is done the right way and does not create hazards for others (Prober et al. 2016; Maclean et al. 2018; Neale et al. 2019; Weir et al. 2020b; Firesticks Alliance Indigenous Corporation 2020a; Firesticks Alliance Indigenous Corporation 2018a).
Support collaborative partnerships between multiple sectors to better enable cultural burning and land management across different land tenures.	Support and engage with Indigenous-led fire management training programs, initiatives, organisations/enterprises (including acknowledging the role of Indigenous knowledge). National Indigenous Fire Workshop, Firesticks Indigenous Alliance Corporation (Firesticks Alliance Indigenous Corporation 2020a) Jigija Indigenous fire training program (Qld) (Taylor and Parkinson 2017; Walambarri Pty Ltd 2020) Mulong Indigenous on-country fire management workshops and training (Mulong Pty Ltd 2020) Southeast Australia Aboriginal Fire Forum (ACT) (Smith et al. 2018a; Maclean et al. 2018) Indigenous fire forums (Savanna Fire Forum 2020; Firesticks Alliance Indigenous Corporation 2018b) Develop knowledge sharing networks between Indigenous leaders and fire managers, across jurisdictions, to raise the capacity of all groups to develop partnerships (Maclean et al. 2018; Prober et al. 2016) Savanna Fire Forum (Savanna Fire Forum 2020) South-east Fire Forum (Smith et al. 2018b) National Indigenous Fire Workshop (Firesticks Alliance Indigenous Corporation 2020b)	Acknowledge and support (funding, partnerships, knowledge sharing) Indigenous-led cultural burning strategies, initiatives, partnerships, programs and collaborations (Maclean et al. 2018; Neale et al. 2020). Support government agencies tasked with emergency and/or fire management to work with Indigenous leaders to develop agency-focused Indigenous engagement and collaboration strategies and protocols. RFS Indigenous fire and rescue employment strategy (NSW) (NSW Fire & Rescue 2020b) CFA Koori Inclusion Action Plan (VIC) (CFA 2014) CFA Aboriginal Engagement Guidelines (VIC) (CFA 2018) Munganin-Daghaba 'Achieve Together', DELWP (VIC) Aboriginal Inclusion Plan, 2016-20 (Department of Environment 2015) Jijija Fire Training Program, with extensive support from Queensland Fire and Emergency Services (Queensland Fire and Emergency Services (QFES) 2019a).

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
	Build capacity within government fire management and natural resource management agencies, and the capacity of scientists, to develop partnerships with Indigenous leaders and organisations/enterprises for knowledge exchange about (cultural) fire management (Maclean et al. 2018). Forest Fire Management Victoria (DWELP) and Dja Dja Wurrung people (VIC) (Forest Fire Management Victoria 2018); the Djandak Wi cultural burning initiative (Neale et al. 2019) Tasmania Fire Services, the Aboriginal Land Council of Tasmania and the truwana Rangers (Department of the Prime Minister and Cabinet 2017; Ferguson 2018; Maclean et al. 2018) Northern Tablelands Local Land Services, RFS (NSW) and Banbai Enterprise Development Aboriginal Corporation (Maclean et al. 2018; Ingall 2019) Burnett Mary Regional Group (Qld), Western Downs Regional Council and Bunya Mountains Murri Rangers (Maclean et al. 2018) Quandamooka Yoolooburrabee Aboriginal Corporation (QYAC), QPWS and Queensland Reconstruction Authority (Queensland Reconstruction Authority 2019a; Haxton 2016) ACT Parks and Conservation Program's cultural burning initiative with Ngunnawal Traditional Owners (Weir and Freeman 2019)	Resource fire management agencies to embed cultural burning into existing monitoring and evaluation frameworks for fire management (Victorian Traditional Owner Cultural Fire Strategy 2018).
	Conduct joint (Indigenous with agency fire managers) walk-overs of planned burn sites and develop more sensitive measures for fire protection (e.g. creating breaks to protect heritage sites using a wet line, a small burn or by using rake hoes). Provide opportunities for Indigenous fire managers to serve as advisors in all aspects of fire management (Victorian Traditional Owner Cultural Fire Strategy 2018).	Identify pilots (over the next five years) to showcase and test different institutional arrangements that can enable Indigenous leadership of cultural burning partnerships (Victorian Traditional Owner Cultural Fire Strategy 2018). Increase permanent and temporary employment of Indigenous managers and leaders in government emergency management (bushfire), natural resource management and parks agencies. Forest Fire Management Victoria (DWELP) (Department of Environment 2017) Tasmanian Parks and Wildlife Service Aboriginal Trainee Ranger Program (Tasmania Parks & Wildlife Service n.d.)
		Support government agencies to establish performance indicators relating to how the agency collaborates with Indigenous leaders, organisations/enterprises and people in bushfire management (Neale et al. 2020) Ensure institutional objectives and settings capture the contribution of cultural burning to Aboriginal health and well-being outcomes through Caring for Country (Victorian Traditional Owner Cultural Fire Strategy 2018).
		Establish formal protection for Indigenous cultural and intellectual property and recognition of knowledge, including issues to do with data sovereignty and data-sharing agreements between partners (Maclean et al. 2018).

Table 5 Short- and long-term actions to empower Indigenous leadership, cultural burning and land management practices to respond to future bushfire events

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
Build fire and emergency risk management leadership and capacity in Indigenous communities	Tailor fire risk management training for Indigenous people (acknowledging the role of Indigenous knowledge) to receive fire management certification (Maclean et al. 2018; Neale et al. 2020). Aboriginal Communities' program (NSW) (NSW Fire & Rescue 2020a)	Ensure emergency disaster management plans and strategies (including for bushfires) incorporate a specific focus on Indigenous people and their needs and requirements (led by and developed in partnership with relevant Indigenous groups). Indigenous concepts of risk, hazard (Gould et al. 2015; Weir et al. 2020a; Weir et al. 2020b; c.f. Maclean et al. in review), disaster resilience (Morley et al. 2016) and what it means to be 'hazard-smart' (Sithole et al. 2019) likely diverge from those understood by scientists and in government police
	Tailor prescribed burning training modules to suit Indigenous people's learning approaches (Centre of Excellence for Prescribed Burning n.d.); RFS Hotspots program (NSW) (NSW Rural Fire Service n.d.; Bertram 2019) Office of Bushfire Risk Management (WA) (Department of Fire & Emergency Services 2020b) Savanna Regional Bushfire Management Plan 2018 (NT) (Department of Environment and Natural Resources 2018) Stronger Together – South Australia's Disaster Resilience Strategy 2019-2024 (Disaster Resilient Australia and Government of South Australia 2019)	Acknowledge and use existing Indigenous governance structures and institutions to work with communities to support bushfire preparedness 'Keeping Our Mob Safe', a national emergency strategy for remote Indigenous communities (Emergency Management Australia 2007) Minjerribah Bushfire Management Strategies (Qld) (Queensland Reconstruction Authority 2019a) Savanna Regional Bushfire Management Plan (NT)
	Support an Indigenous institution to host a summit on bushfire-related matters (c.f. Green et al. 2009) For example, the Savanna Fire Forum (Savanna Fire Forum 2020). Recent bushfire management science tailored to Indigenous audience. Hear from Indigenous presenters: perspectives, needs, adaptation strategies, etc.	Develop effective emergency management partnerships with Indigenous leaders and communities at multiple scales that recognise and value the distinct role and experiences of Indigenous people (national, state, urban, rural, regional, remote) (e.g. Gould et al. 2014).
	Bring federal, state, territory and local government together to build partnerships with Indigenous leaders/communities.	Acknowledge and use existing Indigenous governance structures and institutions to work with communities to support bushfire preparedness.
	Develop community-based strategies. Tailor emergency management training and capacity building for Indigenous people to enable Indigenous-led emergency teams to set up temporary hubs to start laying down early recovery pathways. Work with Indigenous leaders to tailor the Ready2Go Program for Indigenous communities – builds community capacity to care for vulnerable residents, with	Develop effective EM partnerships in (northern) Australia, including via research projects (BNHCRC 2019; Sangha et al. 2019a) and community partnerships (APRNET and NAILSMA 2018).

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
	a focus on social inclusion and personal planning (VIC) (Emergency Management Victoria n.d.a) Provide support, training, capacity building and opportunities for Indigenous people in emergency management programs (e.g. CFA, Red Cross, SES, Salvation Army) (VIC) (Emergency Management Victoria 2017)	
	Develop programs to support (bushfire) disaster management planning for community-level preparedness and response. Indigenous DM field officers to work in remote communities to support planning, preparedness, response programs (Climate Q program, Qld Department of Community Safety (2009-10) (Queensland Department of Community Safety 2010) National Indigenous Radio Service campaigns to increase disaster preparedness (Queensland Department of Community Safety 2010)	Build on existing/past government–Indigenous disaster management initiatives to help remote communities to prepare for bushfire events (e.g. Department of Community Safety 2009, 'Keeping our Mob Climate Safe' initiative). Set up Aboriginal advisory groups to work alongside bushfire recovery agency (see Weir et al. 2020a; Williamson et al. 2020). Enhance local institutional capacity to enter into such partnerships (Gould et al. 2015). Use an inclusive, community-led process to build community-led emergency management and inform emergency management frameworks (Sithole et al. 2019).
		Develop adaptation responses to bushfire events. Policymakers, researchers and (remote) Indigenous communities develop locally relevant adaption responses to potential bushfire events in (remote) communities (Green et al. 2009).
Improve transport, communications and local energy provision systems in remote areas to reduce the impacts of fire risk on remote communities.	Identify transport, communications and local energy provision system needs in remote communities (Green et al. 2009).	Improve transport, communications and local energy provision systems in remote communities (Green et al. 2009). Improve key access points, raise new/existing building standards, improve airstrips.

Table 6 Short- and long-term actions to support Indigenous communities to recover from future bushfires

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
Empower Indigenous communities to recover and build resilience after a bushfire event.	Recognise and fund Indigenous leaders and organisations to provide culturally appropriate support to affected Indigenous communities (Weir et al. 2020b; Weir et al. 2020a). Illawarra Aboriginal Medical Service and Dr. Marlene Longbottom Appeal (Wellington 2020) in NSW. Indigenous Crisis Response and Recovery Appeal (GoFundMe 2020) in NSW.	Policy-related research Consider ways to support remote Indigenous communities to supplement their income if bushfire affects natural resources and the related customary economy (Green et al. 2009). Repurpose government expenditure to enhance Indigenous well-being in Australia (e.g. from Indigenous welfare programs to programs focused on developing country-related opportunities) (Sangha et al. 2019c).
	Build capacity of Indigenous Ranger groups to provide emergency services in remote communities (Sangha et al. 2019a).	Develop a collaborative policy framework involving emergency services organisations and Indigenous communities to mitigate and manage incidents while following Indigenous cultural protocols (e.g. Sangha et al. 2019a).
	Develop health and wellbeing programs and initiatives specifically tailored for Indigenous people and communities.	Develop a framework to improve regional access to health services (Green et al. 2009).
	Establish emergency planning networks to respond to Indigenous concerns and needs. Emergency Planning Groups (VIC) (Emergency Management Victoria n.d.d)	Identify and enable economic opportunities for Indigenous organisations and enterprises that may arise from bushfire events. (c.f. Green et al. 2009) Such opportunities may support livelihoods, enhance the health and well-being of Indigenous communities in remote and urban settings, and result in adaptive capacity to better respond to future (bushfire) emergency events. In addition to generating co-benefits, employment creation may contribute to reducing government spending on Indigenous welfare programs (e.g. Sangha et al. 2015
	Provide easy-to-access information about grants and hardship assistance specifically for Indigenous communities and enterprises. Indigenous (or cross-cultural trained) staff at regional recovery centres (NSW; NSW Justice Office of Emergency Management 2020) and emergency support hubs (VIC; Emergency Management Victoria n.d.) Indigenous Land and Sea Corporation, Bushfire Emergency Response Grant (Indigenous Land and Sea Corporation 2020) Indigenous Business Australia Bushfire Crisis Support Grants (Indigenous Business Australia 2020) Landcare Australia Bushfire Recovery Grants (Landcare Australia 2020) Bushfire Recovery Victoria – small business bushfire support grants (Victorian Government 2020)	Build the capacity of Indigenous Ranger groups to provide emergency services in remote communities (Sangha et al. 2019a).

PURPOSE/AIM OF PATHWAY	SHORT-TERM ACTIONS (WITH EXISTING EXAMPLES)	LONG-TERM ACTIONS (WITH EXISTING EXAMPLES)
	Bushfire Biodiversity Response and Early Recovery Program (VIC DELWP; Department of Environment 2020)	
	Conduct early analysis of post-bushfire impacts on Indigenous people and their traditional country to inform government disbursement of early bushfire relief and recovery grants. Victoria's Bushfire Emergency: Biodiversity Response and Recovery (including funding for healing country) (VIC DELWP; Department of Environment 2020)	Resource PES to support better management and restoration of ecosystems for biodiversity conservation (Green et al. 2009; Robinson et al. 2016b). Support and resource cultural burning activities to reduce the potential impact of future fires on infrastructure.
Continuously support Indigenous leadership in all aspects of fire management in Australia.	Support culturally appropriate forums that enable Indigenous leaders and communities to share insights with others to inform future disaster management responses (e.g. lessons management, innovation, before-action reports) (Emergency Management Victoria 2018b). Living with Bushfire Community Conference (VIC) (Emergency Management Victoria 2016) Community/agency evaluations of emergency response (VIC) (Emergency Management Victoria 2018b) Regional roundtable discussion of psycho-social needs (VIC) (Emergency Management Victoria 2018b) Savanna Fire Forum 2020 (Darwin Centre for Bushfire Research 2020)	Support Indigenous advisory groups and representation to inform policy development. Include Aboriginal people in terms of reference and membership of future post-bushfire inquiries (Weir et al. 2020b; Weir et al. 2020a). Ensure Aboriginal representation on government natural hazard risk management committees (Weir et al. 2020b; Weir et al. 2020a). Support Indigenous-led and co-developed research to address the concerns and interests of Indigenous leaders. Develop effective emergency management partnerships in northern Australia (BNHCRC 2019). Build community resilience in northern Australia (Russell-Smith 2016). Consider emergency management opportunities for remote Indigenous communities in northern Australia (Sangha et al. 2018). Support a partnership between the Fire and Emergency Services Authority (FESA) and the Kimberley Language Resource Centre (KLRC) to promote the participation of Indigenous people in emergency management decision making by improving the accessibility and relevance of key emergency management literature (Kimberley Language Resource Centre and Australia 2008). Conduct research into an integrated framework to incorporate marketable and non-marketable losses incurred due to bushfire events to inform the development of emergency management policies that are effective in enhancing the resilience of (Indigenous) communities (Sangha et al. 2019b).

[1] In this report, the term Indigenous Peoples refers to Aboriginal and Torres Strait Islander and First Nation peoples of Australia.

[2] For example, see https://www.nespnorthern.edu.au/2016/10/11/developing-protocols-indigenous-fire-management-partnerships/; http://www.nespthreatenedspecies.edu.au/news/indigenous-action-vital-for-australia-s-threatened-species; http://www.nespthreatenedspecies.edu.au/news/partnerships-with-indigenous-communities-key-for-threatened-species

5 Hazard reduction efficacy, implementation and impacts

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5.1 Summary

This chapter summarises the current state of knowledge of the efficacy of hazard reduction in mitigating the behaviour and spread of unplanned bushfires in Australia's temperate native forests, particularly dry eucalypt forest, and the issues related to the implementation and impacts of such mitigation strategies. This knowledge is primarily based on a broad range of experimental, simulation and historical case studies and thus is dependent upon the individual geography, vegetation, fire history, climatic and weather contexts of the studies. There is presently little new information that can be used from the 2019/20 fire season due to its recentness and limited post-fire analysis completed to date.

- Vegetation and vegetation debris in the landscape provide the energy that is released in a bushfire (and thus is frequently called bushfire fuel). Australian native forests contain some of the most complex fuel structures in the world.
- Fuel is the only factor of those that influence the behaviour and spread of an unplanned bushfire (i.e. wildfire) that we can influence. Prescribed burning has been shown to efficiently reduce amount and structure (i.e. the hazard) of forest fuels in the landscape (i.e. hazard reduction burning).
- Reduction of forest fuel hazard moderates wildfire behaviour, reducing the rate of spread and intensity of fire under a broad range of weather conditions. Moderation of fire behaviour increases both the effectiveness and range of conditions in which firefighting may be safely undertaken as well as the effectiveness of other landscape elements such as breaks in fuel.
- The longevity and effectiveness of hazard reduction depends on the nature of the prescribed burn, the ecosystem in which it is applied and its response to climatology after the prescribed burn, as well as the conditions of the subsequent wildfire when it occurs.
- Under more severe (hotter, drier, windier) conditions, the importance of fuel decreases as the behaviour and spread of the head of a wildfire (the most energetic part) is increasingly dominated by the prevailing weather. Reductions in fuel hazard still enables effective suppression on other sections of the fire perimeter such as flanks and rear of the fire.
- Hazard reduction also reduces the amount of greenhouse gases emitted by subsequent wildfires, by reducing the amount of fuel consumed. However, this benefit decreases with time since prescribed burning and strongly depends on whether the location treated is subsequently burnt by wildfire. For example, any given location in temperate forests of southern Australia has a much lower probability of being burnt by wildfire compared to any given location in the savannas of northern Australia.

- Smoke volume released during a wildfire is generally less where fuels have been reduced because the amount of fuel consumed and resultant fireline intensity is lower. Smoke generated during prescribed fires tends to persist in airsheds longer due to milder burning conditions and the fact that prescribed burning is often undertaken under the influence of a stable airmass with a strong inversion. Exposure to smoke from any fire can have significant health implications due to the presence of both fine particulate matter and toxic compounds. Tools are in development to improve prediction of smoke transport which would allow better planning of prescribed burns to avoid smoke impacts.
- The frequency of application of prescribed fire (inter-fire period) required to maintain a given level of bushfire hazard may be shorter than ecologically desirable for some fire-prone ecosystems. However, this is an area requiring further research to fully understand the effects of fire regimes (frequency, seasonality and intensity) on environmental and ecological values. There may be necessary trade-offs between residual hazard and ecosystem vitality. Changing climates add to this uncertainty and make it more difficult to establish a resilient landscape.
- Windows of opportunity (i.e. suitable social and physical conditions) for conducting effective hazard reduction burns are changing and even diminishing in many regions for a number of reasons including climate change and altered demographics. In addition, a lack of availability of experienced personnel, critical ground support and resources is resulting in increased aversion to lighting of prescribed burns.
- Management of fuel in the landscape is critical to reducing the potential for landscape fires burning into the urban interface, particularly under severe weather conditions when suppression resources may be overwhelmed. Risk of impacts on private property and lives in the urban interface may be further reduced by adequate management of vegetation and other fuels in and around private properties.
- Hazard reduction to meet future needs will require refined and consistent focus of research specific to the operational implementation of prescribed burning and multi-purpose fuel management in the broad range of fire-prone and fire-dependent ecosystems of Australia, and increased operational capacity and capability including structure training, professional development and experience opportunities for both career and volunteer staff.

5.2 Opportunities for improvement

- More accurate quantification of bushfire risk across the landscape to inform prioritisation for hazard reduction.
- Improved monitoring and mapping of fuel hazard in the landscape.
- Improved methods for predicting outcomes of fuel hazard reduction activities in all critical ecosystems and determination of potential change in risk. This requires improved understanding and modelling of effect of hazard reduction on fuel hazard and subsequent fire behaviour under full range of weather conditions.
- More and improved guides for prescribed burning in fire prone and fire-sensitive ecosystems with a focus on subsequent change in fuel structure and distribution as well as impact of changed fire regime on ecosystem function, biodiversity and resilience over time.
- Better understanding of managing trade-offs among hazard, risk and ecosystem health.
- More and improved tools for operational implementation of planned burns including management of decision making, resource logistics and planning (including ground and aerial resources) and forecasting of opportunity windows (incorporating landscape fuel moisture modelling).
- Improved and more comprehensive training and professional development for prescribed burning practitioners, their agencies and support staff.

5.3 Introduction

Concepts such as danger, threat and risk attempt to quantify the probability of exposure to a specific hazard. A complex hazard is generally composed of numerous static and dynamic elements that combine to define the potential harm or damage that may result if a vulnerable target is exposed to it. In the case of a bushfire, the dynamic elements of the hazard include the weather driving the combustion of the vegetation and the spread of the fire, which can change on a minute-by-minute basis. The static elements of bushfire hazard include the topography in which the fire burns (the elevation, slope and aspect) the vegetation through which it spreads (type, age, condition), and the pre-existing climatic conditions (e.g. drought).

Of all the elements contributing to a bushfire, humans can only directly attempt to modify or mitigate the vegetation and vegetation debris that burns in a bushfire (Luke and McArthur 1978; Tolhurst and Cheney 1999; Fernandes and Botelho 2003), commonly referred to as bushfire 'fuel'. Bushfire fuel provides the energy for the fire and allows it to propagate or spread. Under severe burning conditions (i.e. high air temperatures, low relative humidities, strong winds) little can be done to mitigate a wildfire (through either suppression actions or *ad hoc* fuel modification in the form of firebreaks or backburning) until the weather moderates. Thus, management of vegetation well before the onset of threat of wildfire is the only truly cost-effective tool for fire management (McArthur 1965; Gill 1977).

In the context of bushfires, hazard reduction amounts to the removal, reduction or alteration of the structure and amount of available fuel; this is known as fuel management. There are a number of ways in which fuel management may be undertaken, including physical removal via grazing, burning or mechanical means such as mastication, or chemical or biological treatment to reduce combustibility or presence.

Hazard reduction, and prescribed burning more generally, is highly contentious (Morgan et al. 2020). Much has been written both for and against the practise, but these are largely limited to anecdote, case study analysis or simulation (Penman et al. 2020). Expert opinion and synthesis, of either the practitioner or armchair variety (see for example Leavesley et al. 2020; Adams and Attiwill 2011; Attiwill and Adams 2013; Collins 2006), still carries much of the weight of argument. Even where there is considerable weight of scientific evidence, uncertainty in inputs and outcomes, lack of statistical significance, and questions of scale still remain. Much of the current knowledge of the use and behaviour of prescribed fire is captured in Tolhurst and Cheney (1999), with little subsequent advance on this fundamental knowledge.

The recently completed National Burning Project, an initiative of the Forest Fire Managers Group (FFMG) and AFAC, collated knowledge of prescribed burning from across Australasia to develop guiding principles, frameworks and processes to create a more holistic and consistent approach to prescribed burning for a wide range of purposes (https://knowledge.aidr.org.au/resources/national-prescribed-burning-guidelines-and-frameworks/).

These products build upon the National Bushfire Management Policy Statement for Forests and Rangelands (FFMG 2014) developed for the Council of Australian Governments. In this statement, nationally agreed objectives and policies for the future management of broad area or landscape fire in Australia's forests and rangelands are outlined. These underpin the Australian Institute of Disaster Resilience's Centre of Excellence for Prescribed Burning, which provides a vehicle for prescribed burning practitioners to share knowledge and experience for increased capability and facilitates ongoing engagement across the fire and land management industries. These resources provide essential context and information for understanding the operational use of prescribed fire, particularly for hazard reduction, including risk frameworks, best practice and training. The final publication from the National Burning Project is a textbook, 'Prescribed Burning in Australasia: The science practice and politics of burning the bush' (Leavesley et al. 2020). This book attempts to review existing science to inform practitioners, stakeholders and community as well as to incorporate knowledge on Indigenous burning practices and practitioner expert opinion.

This chapter provides, as context, a brief background on the nature of vegetative fuels and their combustion in a bushfire. This is followed by an overview of methods for reducing or modifying fuels, a brief discussion on prescribed burning in general, and a more detailed analysis of prescribed burning for hazard reduction. Assessments of the efficacy of hazard reduction burning are then provided, along with a discussion of issues related to the undertaking of hazard reduction burning, and implications for firefighting, ecological, environmental and health outcomes. This chapter focuses on fire in native forests, particularly dry eucalypt forest, which was the dominant vegetation burnt by wildfires in the 2019-20 fire season.

5.4 Bushfire fuels

For most people, a bushfire may be the most terrifying and dangerous natural phenomenon they may have the misfortune of encountering. A high intensity bushfire can pose a serious threat to life and property and pose a grave risk to many iconic native species. A bushfire may be defined as 'a complex combination of highly chaotic chemical reactions and physical processes that continually and freely propagate through spatially variable biomass fuels across variable terrain influenced by spatially and temporally varying atmospheric conditions' (Sullivan 2017).

The fuel of a bushfire is the combustible live and dead components of the vegetation in the landscape and is frequently dominated by vegetation debris on the ground. The energy of a bushfire is provided by the thermal degradation of these cellulosic materials and the subsequent oxidation of volatile and char products which appear as flaming and glowing combustion.

While a bushfire can burn through a broad range of vegetation types as it spreads across the landscape, it is often described according to the dominant fuel type (Sullivan et al. 2012). For example, a grass fire, a forest fire, a shrub fire, etc. A bushfire may start as a grass fire before moving into forest fuels to become a forest fire, or vice versa.

Australia has a wide range of fire-prone vegetation and thus potential fuel types. However, while vegetation may be characterised using numerous attributes including structure, function and floristic composition, the number of attributes influencing fire behaviour is much smaller. While species composition, morphology and function may differ, the physical structure and arrangement of the combustible elements of a vegetation community may be similar enough to affect a fire in the same way. That is, different species assemblages may have similar fuel properties. To this end, a fuel classification system has been devised (Hollis et al. 2015; Cruz et al. 2018) to classify Australian vegetation according to the attributes affecting fire behaviour. This system reduces the hundreds of vegetation types to 32 top-tier fuel types consisting of nine native forest or woodland types, two plantation types, ten shrubland types, seven grassland types and four other fuel types.

Australian native forests, particularly dry forests, consist of a broad mix of genera (e.g. *Eucalyptus* spp., *Corymbia* spp., *Acacia* spp.) but are dominated by eucalypts. About 17% of the continent is considered to be forested, of which 98% is native and 76% is eucalypt (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee 2018).

Forest fuels are the most complex of all fuel types. In comparison with grass fuel, which has only one primary fuel stratum through which fire propagates, forest fuels are comprised of a number of strata, the combustion of which contribute to different aspects of the behaviour of a bushfire (Gould et al. 2011; Sullivan et al. 2012; McCaw and Burrows 2020):

- The loosely compacted layer of leaf litter, twigs and low shrubs on or near the forest floor which contribute to the flame height and primarily determine the speed of propagation of the fire front

- The upper part of the leaf litter layer and the larger twig components (6–25 mm diameter) embedded in it which contribute to the depth of flame behind the fire front
- The lower compacted part of the leaf litter layer, duff (decomposed) layer, dead fuels >25 mm diameter and decorticated bark of stringybark types which contribute to mostly to smouldering combustion and smoke generation, and may burn for hours
- Generally sparse elevated dead fuels, live fuels (including canopy) and some dead fuels that burn only when supported by the combustion of fine dead surface fuels
- Those that do not burn because of their location, moisture content or size (e.g. live trunks, moist logs).

Consequently, forest fuels can be divided into four distinct layers (Hines et al. 2010), broadly identified by a change in bulk density, to aid quantification of forest fuel hazard (Figure 12):

1. Surface fuels comprised of fallen dead leaves, bark and twigs in contact with the ground and which are generally horizontally oriented.
2. Near-surface fuels comprised of bark and twigs shed by overstorey trees and suspended in grasses, low shrubs, creepers and collapsed understorey shrubs without distinct orientation. The near-surface layer may vary in height from a few centimetres to more than a metre.
3. Elevated fuel includes live and dead components of shrubs and regenerating overstorey species and is generally vertically oriented.
4. Bark fuel, typically associated with trees forming the intermediate and overstorey strata of the forest, is a common source of firebrands for the generation of spotfires.

Figure 12 Schematic diagram illustrating the broad categories of forest fuel strata present in a forest. (Source: Gould et al. 2011)

Each fuel attribute can be quantified as a relative 'fuel hazard' score or rating based on the visual assessment of the quantity, arrangement, height and horizontal and vertical continuity of each layer (Hines et al. 2010; Gould et al. 2011). The individual fuel hazard score or rating for each stratum can be combined into an overall fuel hazard (OFH) score or rating for all layers at a given location. While operational guides for assessing fuel hazard also assign indicative fuel load ranges to hazard classes to enable estimation of fireline intensity, these relations were never intended for assessment of fuel load and have been found to be inadequate for such purposes, primarily due to the variability in fuel distribution and subjective biases in the assessments (Volkova et al. 2016).

Analysis of the influence of each fuel attribute on fire behaviour under dry summer conditions (Gould et al. 2007; Cheney et al. 2012) showed that fine dead surface fuels comprising the surface and near-surface layers most strongly influenced the rate of forward spread of a bushfire. These fuels constitute the bulk of fuel consumed on a weight basis in a fire front, and also contribute most of the energy released by a fire. It was determined that the critical attributes of these layers were, in order of importance, the near-surface fuel hazard, surface fuel hazard and near-surface fuel height. The hazard (height and density) of the elevated fuel layer had a major influence on flame dimensions, particularly flame height. Bark hazard had a major influence on the propensity for spotting. Other fuel attributes such as surface and near-surface fuel load were also found to be statistically significant in influencing fire rate of spread.

Spotting, the ignition of new fires downwind of a fire front via the lofting and transport of burning material (firebrands) out of the fire front, is an important mechanism of fire propagation in eucalypt forests, particularly under extreme fire conditions. Spotting is also a feature of fire behaviour in other fuel types, but to a lesser extent. Spotting allows fires to breach containment lines and cross breaks in fuel and topography that would normally impede fire front propagation (McArthur 1967; Luke and McArthur 1978). Leaves, needles, lichen, fruits, cones, bark, twigs, branches and even logs may become firebrands. Bark is the primary source of firebrands and spotting in Australian eucalypt forests. The properties of the bark strongly influence spotting potential from different forest types (Cheney and Bary 1969; Ellis 2000). Stringybarks (e.g. *Eucalyptus obliqua*) and similar types such as jarrah (*E. marginata*) are characterised by loosely attached fibrous flakes and are notorious for prolific spotting up to about five kilometres (Ellis 2011). Long ribbons of bark such as from candlebarks, ribbon gums and gum barks (e.g. *E. viminalis, E. delegatensis, E. rubida, E. diversicolor*) are more likely to be responsible for long distance spotting of tens of kilometres (Cheney and Bary 1969; Hall et al 2015) with maximum distances up to 30-40 kilometres (Luke and McArthur 1978; Cruz et al. 2012). Firebrands are also a significant cause of house losses during bushfires.

The quantified importance of physical structure and arrangement of fuel on the behaviour and spread of forest fires (Cheney et al. 2012) shows them to be more statistically significant than just the amount of available fine fuel as previously understood (e.g. Peet 1965; McArthur 1967). The lack of a dominating effect of fuel load alone in explaining rate of spread of fires has been found in other fuel types such as grassland (Cheney et al. 1993; Cruz et al. 2018), and heathland (Anderson et al. 2015) and by other studies in forest (Burrows 1999) suggesting that fire spread models utilising fuel mass as the only fuel attribute may be incomplete.

While the average forest contains large amounts of coarse woody fuel such as standing dead trees, stumps and downed branches and logs (coarse fuels are generally considered those greater than 25 mm diameter), and the consumption of these fuels may be two or three times greater than the amount of fine fuel consumed, these fuels do not contribute strongly to the energy from flaming combustion in the flame front due to their relatively slow ignition and combustion rates (Sullivan et al. 2018). However, combustion of coarse woody fuel does contribute substantially to the total heat released in a forest fire (Albini and Reinhardt 1995; Hollis et al. 2011) and adds greatly to the difficulty of suppression. Their contribution to increased radiant heat loads on firefighters (Sullivan et al. 2002), and as sources of reignition during suppression and mop-up phases of fire management, requires that they be part of the overall assessment of hazard. Furthermore, the combustion of coarse woody fuel also contributes to the amount and timing of atmospheric emissions from bushfires as well as the heating of soils and thermal impacts of fire on vegetation (Cheney et al. 1992).

5.5 Fireline intensity

Modification of fuel structure and availability to reduce bushfire hazard has long been the key objective of pre-emptive fire management (Cheney 1996). The physical basis of hazard reduction is that of reducing the energy released during the combustion of fuel in a fire front, thereby reducing the potential damage that that fire may cause and increasing the likely success of efforts to control or extinguish that fire.

The energy release rate of a bushfire is commonly and most simply quantified using the Byram (1954) fireline intensity relation:

$$I = HwR$$

where I is Byram's fireline intensity (W m^{-1}) giving the rate of energy release (J s^{-1}) per lineal metre of fire front, H is the heat yield or low heat of combustion (J kg^{-1}, assuming water vapour released during combustion remains in the gas phase), w is the mass of fuel consumed in the fire front (kg m^{-2}), and R is the rate of forward spread of the fire (m s^{-1}). While fireline intensity cannot be directly measured, calculated values have been shown in many fuel types to correlate positively with other attributes such as flame length and height (Byram 1959; Burrows 1994) and is a key determinant of limits of suppression capability (Plucinski 2019a; Plucinski 2019b). Fireline intensity also correlates positively with related fire behaviours such as convective activity, plume dynamics and spotting distance (the distance to which burning debris is transported ahead of a fire front) (Burrows 1997; Gould et al. 2007).

The direct proportionality between I and w is the primary physical argument for hazard reduction. Halving the amount (or load) of fuel consumed by a fire halves its fireline intensity as well reducing many associated attributes and increasing its suppressibility. Some models of fire behaviour also have employed relationships between fuel load and rate of spread (McArthur 1962; McArthur 1967; Cruz et al. 2015a; Cruz et al. 2015b). In these cases, reducing fuel loads could have a non-linear effect on fireline intensity if rate of spread is also reduced.

It is clear from Byram's equation that in the absolute absence of available fuel a bushfire cannot emit sufficient energy to sustain itself. The logical objective of hazard reduction is to remove all available fuel, starving fires of energy and causing them to self-extinguish.

Where fuels are reduced but not totally removed, a corresponding reduction in fireline intensity remains, even if rate of spread is not reduced.

It must be noted that in many fuel types, particularly those with multiple strata like forests, the amount of fuel consumed, w, is not solely a function of the fuel available in any particular stratum and can change depending on behaviour and intensity of the fire (Tolhurst and Cheney 1999). That is, the amount of fuel consumed can increase or decrease depending on how energetic the fire is. For example, a fire that temporarily decreases its energy output—perhaps as the result of a lull in the wind or a moister patch of fuel—will produce flames that are shorter and less able to ignite higher strata fuels. This will reduces the total amount of fuel consumed and the consequent reduction in fireline intensity at that particular time and location can be considerable. Conversely, a fire that temporarily increases its energy output —the result of a gust in the wind or a patch of fuel of greater combustibility—will produce taller flames that can ignite and involve higher fuel strata with the result that more fuel is consumed and fireline intensity increased.

The fireline intensity of a bushfire burning in fuels with complex multi-strata structure is clearly not as simple or linear as Byram's equation would suggest. Positive and negative feedbacks between the energy release of the fire, the physical dimensions of the flame zone, the fuels available for combustion in the flame zone and their combustion mean that fuel load alone is an inadequate measure of the influence of fuel on fire behaviour. Any effort to modify bushfire hazard through fuel modification in dry eucalypt forest must necessarily also address reduction in the presence and extent of the other fuel attributes, not just fuel load.

The availability of a given dead fine fuel for combustion is a function of both the mass of fuel present and also the combustibility of that fuel (Sullivan et al. 2012). Combustibility is a highly dynamic attribute of a fuel that determines its ease of ignition, ability to burn, and to sustain combustion (Sullivan and Matthews 2013) and is directly influenced by the fuel's moisture content. A fuel that is dry is easier to ignite and burn (i.e. greater combustibility) than when that fuel is moist (i.e. lower combustibility). The moisture content of a fine dead fuel is strongly influenced by the antecedent and prevailing weather (namely the available moisture in the air and solar heating) and the ability of that moisture to enter or leave that fuel through the process of vapour exchange (Matthews 2014), which depends on the nature of fuel.

Diurnal changes in the temperature and relative humidity of the air changes the magnitude and direction of vapour exchange into a fine fuel and thus the fuel's moisture content during the day. As a result, fine dead fuels undergo drying during the morning and early afternoon (desorption) and wetting during the afternoon and evening (adsorption) (Luke and McArthur 1978). Variation in fuel type and topography means that diurnal changes in fuel moisture across the landscape is highly variable both in time and space, with additional complexity added by topographic shadowing (Sullivan and Matthews 2013).

The effect of rainfall is to reduce the amount of fuel available for combustion over timescales longer than the diurnal cycles of vapour exchange. These timescales may range from hours, days or even seasons. The effect depends on the nature of the fuel, the amount of rainfall, and the rate of evaporation of rainfall (a function of time of year, latitude and exposure). The effect of rainfall deficit (or drought) is to make available for combustion fuel that would normally be too wet to ignite. As the period of rainfall deficit extends, fuels in moist locations such as southern aspects, gullies, creek lines and wet soaks dry out and become combustible. The drying of fuels in such locations can often result in more total available fuel than is normally the case, resulting in significant increases in fireline intensity as well as greater propensity for fires to spread unchecked across the landscape, increasing the probability of conflagration fires. This pattern is also seen on a seasonal scale in northern savanna and savanna-woodland systems, where creek line vegetation may inhibit or stop fire spread early in the season when it retains moisture and greenness, but late in the season may propagate fire when it is dry and offers a continuous fuel bed across the landscape.

Understanding the dynamics of fuel moisture content across the landscape diurnally, seasonally and under conditions of extended rainfall deficiency is essential for quantifying both fuel availability at that scale and also the likely behaviour, spread and intensity of landscape-scale fires.

The next steps – remote sensing assessment of fuel state

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Estimates of fuel moisture are a critical component of modelling fire behaviour and hazard. In the case of forests, these generally rely on weather inputs such as time since the last rain event. In the case of grasses, satellite-based observation of 'curing' are used and operational systems based on MODIS data are currently in use in some states to help assess grassland fire hazard, with assessments performed on a weekly basis leading into and during the fire season.

Despite these standards and accepted approaches, there is a growing recognition that simplified representations of fuels inhibit our ability to accurately predict fire behaviour and understand fuel re-accumulation through ecological recovery. For example, the vertical structure of fuels has a significant influence on fire intensity (Cruz et al. 2018). In additional to the direct impact of structure on fire behaviour, structure is also linked to the relative drying of different components within a multi-layered fuel arrangement. This is not a revelation, as plant species distribution can drive both structure and the microclimates within an ecosystem. For this reason, we should not consider fuel load, structure and moisture as unrelated, but use information about ecosystem distributions to inform a more complete understanding of all aspects of fuel state and change.

A significant barrier to moving towards an ecosystem-based framework for fuel assessment and modelling is our ability to map land cover at fine thematic detail and to track land cover change at a time scale relevant for bushfire management. National land cover mapping has been delivered by Geoscience Australia at biennial time steps using MODIS spectral index trend analysis (Lymburner et al. 2010). A new approach based on an implementation of the international Land Cover Classification System (LCCS, ISO 19144-2:2012) is currently under development. However, as with fire history data, states and territories have considered these national data less than adequate for many land-management tasks, due to the limited number of classes and low spatial precision. Consequently, jurisdictions have tended to utilise a mixture of data sources, including field survey, airborne and satellite data, to produce best available land cover mapping, with classes attributed an indicative fuel load as input to fire behaviour and hazard assessments. Unfortunately, this has also limited their ability to regularly update their land cover information, and to ensure consistent levels of accuracy.

The LCCS approach provides an opportunity to better integrate multiple Earth observation (EO) sensors (and non-EO data) for mapping important ecosystem types within a land-use change model data-assimilation system. The national consistency and regular update frequency of such an approach would better serve to underpin our future understanding of fuel dynamics and ecological recovery following bushfires. Ecosystem classes within the LCCS would exhibit an inherent structure, microclimate, recovery and vulnerability that could be modelled based on weather, long term climate impacts and disturbance events. Transitions between ecosystem types should be driven by EO observations, exploiting spatial, spectral and structural measurement strengths of different EO sensor types, but constrained by a stochastic framework underpinned by ecological transition theory.

5.6 Hazard Reduction

5.6.1 Prescribed burning

Organised hazard reduction originated in Australia in the mid part of the 20th century in response to a series of devastating wildfires (Pyne 1991; Morgan et al. 2020). Early efforts focused on prescribed burning for fire protection in forests (McCaw and Burrows 2020) which has been defined as 'the deliberate, lawful and controlled application of fire under specified environmental conditions to a pre-determined area and at a time, intensity, and rate of spread required to attain planned resource management objectives' (AFAC 2012; FFMG 2014; AFAC 2015). The 'specified environmental conditions' form the prescription of boundary conditions (primarily weather and fuel conditions but also ignition patterns) designed to result in fire behaviour that achieves the planned objective (McArthur 1962; Rawson et al. 1985).

The planned objective of a prescribed burn may include outcomes such as reduction of bushfire hazard, post-harvest slash removal, site preparation and seedling regeneration following timber harvesting, and managing habit for biodiversity conservation (e.g. habitat maintenance, forest health, etc.) (AFAC 2018).

Prescribed burning for hazard reduction (or hazard reduction burning) has the planned objective of reducing fuels such that any subsequent wildfire has reduced fireline intensity and rate of spread and increased suppressibility. As such, a hazard reduction burn is intended to consume, reduce or modify available fuels to reduce the impact of a subsequent wildfire and to facilitate better firefighting efforts (Morgan et al. 2020) for which it has been effective in many parts of Australia (Burrows and McCaw 2013). Hazard reduction burning is also understood to increase the range of environmental conditions under which a wildfire may be controlled and can enable firefighters to break the run of large fires (McCaw 2013). In practice all biomass burning achieves some level of fuel hazard reduction (McCaw and Burrows 2020).

World-wide many factors reduce opportunities to conduct successful hazard reduction burns (McCaw and Burrows 2020; Morgan et al. 2020). These include the increased complexity of integrating fire management with varied uses of public lands (McCaw and Burrows 2020), reduced incidence of and changes in timing and duration of appropriate burning conditions (Dowdy 2018), increasing public concern about air quality and health from smoke (Reisen et al. 2011; Cope et al. 2019), and fear of fire escapes and resultant litigation (Morgan et al. 2020). These external factors are compounded in Australia by the loss of operational experience and knowledge of prescribed burning (English 2018). The high level of resourcing required to safely undertake hazard reduction programs also puts pressure on many land management agencies to provide the necessary numbers of people and equipment when and where needed. Access to sufficient numbers of trained and experienced staff and volunteer workers and material may be pose challenges in many rural and regional areas if there is a demand for more hazard reduction burning.

The nature of prescribed burning for hazard reduction necessarily relies upon the combustion of components of the fuel bed to carry the fire and thus be consumed, reducing fuel hazard. The art and science of hazard reduction burning is then about finding the optimum balance of combustion and consumption such that a fire reduces fuel hazard without burning too much fuel and becoming uncontrollable. In many wetter parts of the landscape such as southern slopes and gullies or in ecosystems such as wet forests, however, the transition between combustible and uncontrollable is very fine. In such locations most fuels are normally too wet to combust but when they are dry enough to combust, so too are the natural features of the landscape at large such as creek-lines and wet soaks that would normally inhibit the spread of a fire, increasing the risk of the prescribed fire escaping or causing damage.

Backburning operations

Backburning is the act of extending the depth of an existing break in the fuel in the path of an active wildfire by lighting another fire to consume fuels on the fire side of the break in order to increase the probability of holding the wildfire at the break (Cheney and Sullivan 2008). Backburning is not to be confused with hazard reduction or prescribed burning, which are intentional fires undertaken prior to a fire threat arising. Nor should it be confused with burning-out, which is the intentional lighting of fire within fixed containment lines to consume fuel not in the immediate path of a wildfire (Cooper 1969).

Direct attack of the head of a bushfire is difficult and dangerous, particularly under conditions of very high or extreme fire danger, regardless of fuel type. When a fire is too intense to attack the head directly, the best chance of success is to hold it at a road or substantial mineral earth fuel break where the spread of the fire is most likely to be impeded. Sufficient firefighting forces must be available to control spot fires when the fire reaches the break and it is not feasible when the spotting intensity or development of the wildfire is too great to enable safe suppression.

In the case of a relatively slow-moving fire, the depth of the break can be extended by back-burning on the fire side, consuming fuels on this side to increase the fuel-free area of the break. Such backburns are generally of a width to provide a sufficient break to impede or halt the progress of the head of the wildfire. However, a backburn will spread only relatively slowly against the wind and often will not be drawn towards the wildfire unless the fires are very close. The depth of a backburn can be extended by lighting additional fires between the burn and the approaching wildfire. However, this is an extremely hazardous operation as firefighters may become trapped between the two fires, so these additional fires are often ignited using aircraft (Hodgson and Cheney 1969).

When the head of the wildfire reaches the break, the convective centre of the fire front will move across the break to the downwind side (Cheney and Sullivan 2008). Strong winds behind the flame front will cause the flames to lean over parallel to the ground (Wilson 1988) and firefighters on the break will be subjected to high levels of smoke and radiative and convective heat. On a narrow break, long enough flames may ignite fuels on the downwind edge, allowing the fire to cross the break. The convective winds will also blow embers, ash and other burning debris across the break for some minutes, with a strong potential for these to start spot fires on the downwind side of the break, also allowing the fire to cross the break. The depth of the break must be enough to allow firefighters to work safely outside their vehicles and suppress any ignitions across the break as soon as they occur. Working from a break that is trafficable (or larger) will enable firefighters to work comparatively safely to control the backburn.

Enough experienced and well-resourced crews with good knowledge of fire behaviour and what to expect are required to undertake this type of action safely and successfully. Such suppression actions should not be undertaken unless well-resourced and thoroughly planned in advance. Backburning operations are often conducted during the night when fire behaviour conditions have moderated and firefighters are more likely to keep it controlled, however the behaviour and rate of spread of the backburn is also commensurably reduced. Understanding the time it takes to prepare for a backburn is critical to its success. This includes:

- Knowledge of the location, speed and path of the wildfire and its behaviour (particularly spotting)
- The selection of a suitable location with a mineral earth fuel break or road that is wide enough to prevent the backburn from crossing it, advantageous topography, fuel and weather conditions
- Determination of the intended length of the backburn, ignition method and appropriate ignition pattern and expected rate of deepening of the burn (i.e. rate of spread against the wind), and likely impact on the wildfire
- The availability and experience of requisite firefighters and suppression resources
- The forecast weather conditions and likely changes to the behaviour, spread and direction of the wildfire and backburn.

The rate of spread of the wildfire and the time necessary to prepare and implement a backburn represent a difficult and highly dynamic optimisation problem that must be solved adroitly, a problem that is further complicated by the vagaries of the wind and local environment more generally. The farther away the wildfire from the intended backburn location, the more time there is to implement it safely but the greater the chance the direction of spread of the wildfire will change, potentially missing the backburn altogether. The closer the wildfire, the greater the probability of it impacting the backburn but the less time there is to safely implement it and achieve a depth sufficient to effectively impede the spread of the wildfire. If the wildfire is spotting, the larger the depth of backburn required to halt the fire's progress.

Under severe or greater fire weather conditions, the probability of successfully holding a backburn, particularly a large one in complex terrain and fuels, is relatively low, as is the probability of halting the spread of the head of the wildfire. Under such conditions suppression action on the flanks is preferable until conditions moderate (Luke and McArthur 1978). If a backburn escapes control it is essentially another wildfire under such conditions and may only result in increasing the size of the wildfire. Even when backburns are kept controlled, the use of this tactic can result in a significantly larger area burned and perimeter length (Backer et al. 2004; Bradshaw 2012) and thus potential for damage.

Little research has been undertaken to aid the planning and implementation of backburns (Plucinski 2019b), potentially due to the large number of variables that may be points of failure of a backburn. Backburns generally rely upon the experience of the firefighters involved and the command structure in which they operate. Research to aid in estimating likely spread of a backburn against the wind and in the conjunction zone between the backburn and wildfire is critical to enabling effective planning of backburns.

5.6.2 Non-burning hazard reduction

For many years, alternatives to prescribed burning for hazard reduction have been developed and applied where burning is not feasible, too costly or too risky. These include grazing by animals (e.g. goats, cattle or sheep), mechanical treatment and removal of vegetation and debris, and chemical treatment of live vegetation.

Mechanical modification or removal of vegetation from a site can include thinning of standing vegetation and mastication (grinding, shredding or chipping) of residues and understorey vegetation. Chemical fuel treatment is almost exclusively the treatment of live vegetation with herbicide.

Numerous studies have considered the effectiveness of mechanical and chemical fuel management in a range of vegetation types relative to other fuel management treatments (e.g. Brennan and Keeley 2015, 2017; Coop et al. 2017; Sikkink et al. 2017; Steele 1980). However, the impact of such treatments on the behaviour of subsequent fire is more rarely considered, and then only indirectly and for specific geographic locations or vegetation communities (e.g. North American Lodgepole stands (Alexander and Yancik 1977), South Australian radiata pine plantations (Cruz et al. 2017), Bluegum plantations in Portugal (Mirra et al. 2017), mixed species eucalypt forest in East Gippsland (Proctor and McCarthy 2015) and alpine ash forests of south eastern Australia (Volkova et al. 2017)) .

These studies mostly employ simulation modelling owing to the difficulties associated with evaluating fuel management treatments against live fire. Most northern hemisphere studies have used the US BEHAVE (Andrews 2014) fire behaviour model, or derivatives, and bespoke fuel models describing the change in fuel attributes arising from fuel treatment.

In a study of mechanical and chemical treatment of bluegum plantations in Portugal, Mirra et al. (2017) used the Australian Dry Eucalypt Forest Fire Model (Cheney et al. 2012) to determine likely changes in fire behaviour (rate of spread, fireline intensity) arising from treatments conducted up to nine years previously. They found that herbicide and manual fuel removal had less immediate effect on fuel hazard and thus subsequent fire behaviour than methods such as disk harrowing and slashing. Impacts on fuel hazard from low impact methods are not as immediate and were limited to near-surface and elevated fuels. Proctor and McCarthy's (2015) study assessed *in situ* changes in overall fuel hazard over a period of 15 years but did not consider changes in fire behaviour. Overall fuel hazard was reduced in thinned coupes compared to adjacent unthinned coupes, primarily due to reduced elevated fuel and bark hazards. Fine fuel from thinning slash had largely decomposed after four years while large woody debris increased as a proportion of total fuel for the entire 15 years. Opportunistic observations of wildfire burning through thinned and unthinned coupes suggested that the thinned coupes produced less intense fire with reduced crown consumption, although the authors acknowledge that more severe burning conditions may limit the effect of fuel hazard reduction.

Of the variety of non-burning alternatives, mechanical treatment of fuels has had the broadest application world-wide. In some situations, such as conifer forests of north America, mechanical fuel treatment serves as a pre-treatment for subsequent prescribed fire by modifying fuel structure and disrupting the continuity of elevated and ladder fuels and creating a less complex fuel bed. This has the effect of shifting the window of opportunity for burning to milder weather conditions where costs and risk of escape are much reduced. Mostly, however, these non-burning methods remain of unknown effectiveness in hazard reduction relative to prescribed burning. Similarly unknown are the full costs and efficiencies of implementing non-burning alternatives, particularly at the landscape scale. In all likelihood, they are more expensive and less efficient (on a per hectare treated basis) than prescribed burning. Research currently underway in Australia is attempting to correct this knowledge gap (Ximenes et al. 2017).

5.6.3 Use of fire retardants, foams and gels

A range of chemicals are used in modern bushfire firefighting, usually as enhancers to increase suppression effectiveness of water (Plucinski et al. 2017). These act to inhibit flaming combustion, reduce evaporative loss during delivery, restrict oxygen flow to fires or to reduce the combustibility of fuels. These may be delivered via aerial application (e.g. water bombers) or ground application (e.g. tankers or slip-on units). Most firefighting chemicals are sourced overseas from a small number of suppliers whose products have met the United States Department of Agriculture's wildland fire certification process. In Australia, fire authorities and land management agencies have agreed jointly through AFAC to the appropriateness of the USDA wildland fire testing standard for human and environmental safety, and for the safe use of such chemicals in firefighting appliances, especially aircraft in terms of corrosion risk (AFAC 2016). Some states, e.g. South Australia, apply an extra layer of approval over products deployed.

Firefighting chemicals used in Australia are of two main types. These are flame retardants and fire suppressant enhancers. Retardants are comprised of inorganic salts (mainly ammonium phosphates, also used as plant fertilizer) that inhibit flaming combustion (Giménez et al. 2004). They generally exist in the form of a powder and are mixed with water to aid delivery and a dye to aid visualisation. They can slow fire progression even after the water used to deliver it has evaporated. Retardants are typically used in indirect attack (i.e. not directly on flames) and delivered by aircraft where they coat unburnt fuels in the path of an active fire.

Suppressant enhancers are added to water to improve the effectiveness of water as a fire suppressant by modifying its physical attributes. Two main classes of suppressant enhancers are foaming agents and gel additives. Foaming agents consist of surfactants to reduce surface tension of the water, improving the ability of water to coat fuel particles and prolonging its wetting effect. Foams also allows air to mix with the water, forming an insulative foam barrier between the fuel and the fire, restricting heat transfer and oxidation. Gel additives are comprised of cross-linked hydrophilic superabsorbent polymers which can absorb up to 700 times their own mass of water. Gels increase water viscosity, increase adherence to fuels, slow evaporation and minimise drift and dispersion when applied by aircraft. Suppressants are typically used in direct attack (i.e. directly on flames or burning material) and may be delivered via aerial or ground-based firefighting resources. Foam is often used to facilitate mop-up after a fire has been controlled, particularly of residual combustion in coarse fuels.

Fire retardants currently used in Australia are of relatively low toxicity to people (Gould et al. 2000). The toxicological assessments suggest low-level irritation is possible before chemicals are mixed with water and recommend normal protective equipment be worn for handling (State of Victoria 2020). There is also a low risk to anyone drinking rainwater contaminated with retardant (NSW Health 2019) but the water may taste and smell unpleasant and consumption should be avoided.

When heated to high temperatures, as would be experienced in a bushfire, many retardants produce sulphur dioxide, ammonia and oxides of nitrogen in the gas phase. If not encountered by a bushfire, retardants are a direct source of nitrogen, phosphorus and sulphur and tend to be dispersed by the first rain, being washed into the soil or transported overland in run-off. Potential consequences on stream contamination may exist, although impacts are likely to be local. While retardants share many commonalities with fertilizers, their effect on the environment is likely to be significantly different, affected by the method of application, the reaction process and the concentration of application (Gould et al. 2000), although the area affected is typically small in comparison. Most environmental ecotoxicological assessment is based on North American studies utilising US standards, though a small number of Australian studies have been conducted. Given the notably nutrient-poor ancient soils across much of Australia, plant communities have adapted to thrive in these contexts, so ammonium- and phosphate-based retardant additions can increase plant-available nutrients in soils, both inhibiting native plant growth and stimulating weed growth (Bell et al. 2005). Agency guidelines for the aerial application of suppression chemicals prohibit their use near water bodies and organic farms. A study of the impact of firefighting foams in a stream on Kangaroo Island found a limited pulse of increased nutrients with no discernible effect on macroinvertebrates (Boulton et al. 2003). Further detailed assessment of the ecotoxicology of firefighting chemicals in the Australian context is required.

Generally, retardants and suppressant enhancers are applied in direct response to an active fire threat, with suppressants generally applied directly to the flames to knock them down and retardants generally applied to fuels in the expected path of the fire (i.e. indirectly) to stem the fire's potential progress. In both cases, application by aerial resource is intended to facilitate direct attack by ground resources, not suppress the fire. Occasionally, suppressants (foam or gel) and retardants may be applied in advance of a fire threat arising as a prophylactic treatment (Xanthopoulos et al. 2006; Yu et al. 2019) but the effectiveness of such strategies is dependent on the time between application and fire arrival and the intervening conditions, and the behaviour of the fire when it arrives (Plucinski and Pastor 2013).

While retardant generally acts to reduce the propensity for flaming combustion in treated fuels, its effect on the propagation of an active fire in forest fuels can be inconsistent as a result of quality of the application, the prevailing conditions, or being diluted or washed away in rain. Consequently, a retardant line can fail to inhibit the spread of an active fire in forest fuels for a number of reasons. These including burn-around, where the fire spreads around the drop and can be a result of poor drop anchoring; burn-through, where the fire passes over a drop and may be a result of poor coverage on the ground or subsequent dispersal of retardant; and spot-over, where embers from the fire are transported over the drop and ignite fuels on the down-wind side (Plucinski and Pastor 2013).

Lack of necessary ground resources to attack the fire soon after being impacted by or impacting on an aerially applied treatment, increases the probability that the fire will eventually re-establish itself and continue spreading.

On rare occasions retardant is used to provide critical assistance in the preparation for backburning operations, particularly where an existing mineral earth or otherwise suitable fuel break does not exist (see text box on backburning operations, above).

5.6.4 Efficacy of hazard reduction burning

Numerous scientific and non-scientific articles have been published and opinions expressed on the topic of hazard reduction burning. In particular, debate persists about the efficacy of hazard reduction burning in many fire-prone regions around the world, the magnitude required to achieve useful efficacy, and whether the costs and consequences associated with implementing such hazard reduction (i.e. economic, environmental and social - triple bottom line) are balanced or outweighed by the benefits. As noted by Fernandes and Botelho (2003) and McCaw (2013), much of the debate, both for and against, is based primarily upon anecdotal evidence, computer simulations of resultant fire behaviour and impacts (Fernandes 2015), or case study and empirical analysis of potential interactions or indirect measures of performance (Penman et al. 2020). There are clear difficulties in quantifying both the effect of hazard reduction burning on fuels and the subsequent effect of hazard-reduced fuel on resultant fire behaviour, particularly under the conditions associated with the occurrence of wildfires.

These difficulties stem in part from the lack of robust definition of the problem to enable it to be addressed meaningfully at the spatial and temporal scales at which it is important (Omi 2015). Fundamental independent variables such as the state and condition of fuels often remain poorly identified and described and thus inadequately quantified. Along with poorly defined and quantified dependent variables, these limit our ability to derive meaningful correlations between variables and thus draw conclusions about effect.

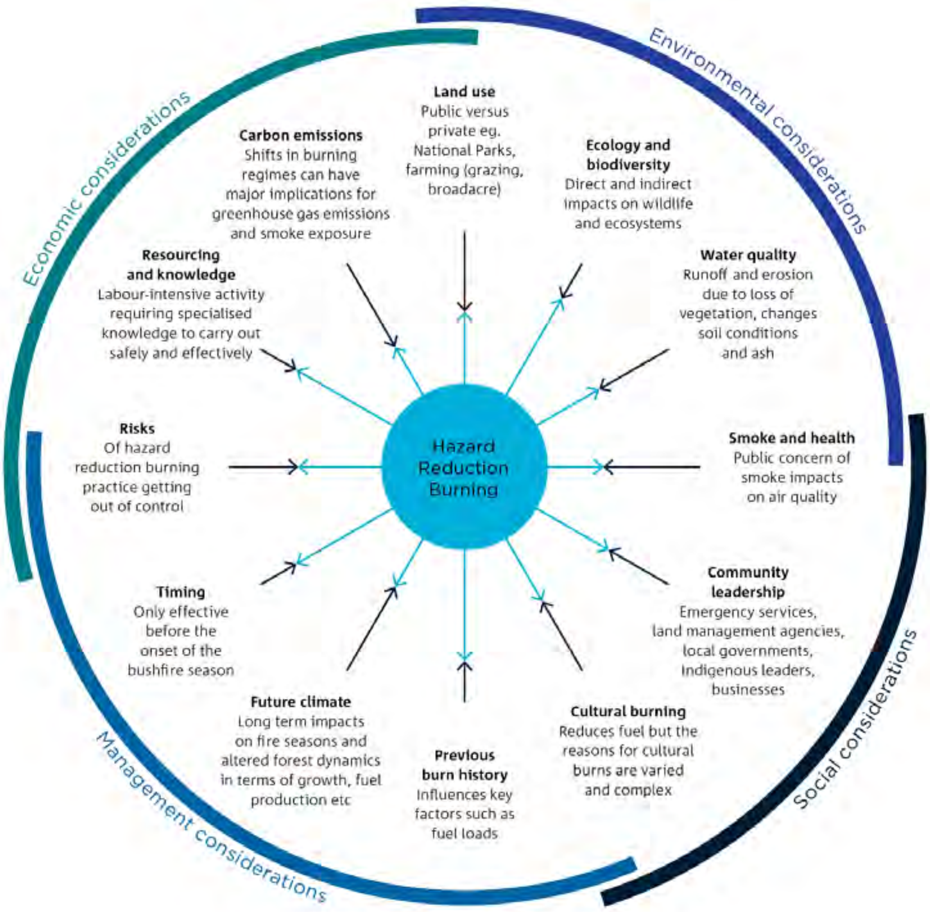

Figure 13 Hazard reduction burning remains an important tool for fire management to be used well before the onset of bushfire threat. Its application and effectiveness are complex, highly contextual and resource intensive. More research and learning from experience are required to refine how and where it can bring best value and protection.

Furthermore, the extraordinary range of fuel types and structures, fuel and climatic conditions, and topographic influences experienced in Australia reduces our ability to reliably extrapolate and apply knowledge from one locality to another.

There has been a recent shift in government policy from one based on known effects of hazard reduction on fire management (e.g. suppressibility, fire extent, etc.) to one based on perceived risk (Penman et al. 2020) in particular residual risk. Residual risk is the level of risk that remains after mitigation (i.e. hazard reduction) and is often conveyed as the reduction in fire severity and impact (Fernandes 2015). This change has been argued to result in more strategic and cost-effective hazard reduction (Morgan et al. 2020). However, it relies heavily upon the arbitrary selection of an acceptable residual risk value, as well as the method for calculating that residual risk. Reliable and accurate wildfire simulation models are thus integral to this policy approach and ensuring robustness, objectivity and calculation-method independence of the method is critical.

Factors affecting hazard reduction burning of fuels

There are surprisingly few studies of the effect of hazard reduction burning on fuels, with far more articles in the literature on the effect of prescribed burning on other aspects of vegetation such as ecological impacts (e.g. Bradstock et al. 1998; King et al. 2006, Olivera and Bell 2008). Many studies are based on computer simulation and not direct measurement of fuel or vegetation attributes. Furthermore, notably fewer articles may be found on the study of efficacy of hazard reduction burning in Australian ecosystems than north American ecosystems (c.f. Omi 2015; Stephens et al. 2012).

Omi (2015) outlined the extant theory and practice of fuel management for north American wildland ecosystems, highlighting that most methods for analysing treatment efficacy suffer analytical shortcomings, especially the linkage of efficacy to treatment objective as it affects fire behaviour, arguing for future research to address the need for a cohesive theory on the role of fuels in combustion dynamics in these ecosystems.

Understanding the effect of hazard reduction burning on fuels begins with the prescription underpinning the hazard reduction burn. While there are numerous operational burning guides in use in each state and territory around Australia for determining conditions suitable for burning (e.g. Department of Environment and Natural Resources 2011), these appear to be based on extant models of fire behaviour. For example, the *Control Burning in Eucalypt Forests* guide (McArthur 1962), the *Forest Fire Behaviour Tables for Western Australia* (Sneeuwjagt and Peet 1985) and the *Prescribed Burning Guide for Regrowth Forests of Silvertop Ash* (Cheney et al. 1992). These guides enable likely behaviour of prescribed fire to be forecast based on burn prescription conditions but do not provide detailed insight into the level of reduction in fuel hazard that would result from a successful fire. From this it appears that both the operational burn prescription parameters and the models of prescribed fire behaviour are used to determine the limits of fire behaviour that can safely be undertaken, rather than the likely change in fuel hazard that would result. That is, the resultant level of fuel reduction following a hazard reduction burn is largely implied rather than explicitly given by prescribed burning guides.

All prescribed burn guides and models used operationally in Australia predate the advances in fire science that have been made over the past two decades or more. Many of these models contain simplistic functions with minimal variables, designed to be used with a minimum of measurements and knowledge. Many do not consider features such as the role of fuel structure in fire propagation that feature in more modern models (Cheney et al. 2012). The absence of models quantifying fire sustainability or extinguishment and the behaviour and effects of prescribed fires is a major limitation for the application of scientific knowledge to support forest fire management in Australia. Improved prescribed burn models would help ensure that burns are effectively scheduled and achieve fuel reduction targets and would also help predict the likelihood of escapes and the suppression requirements for dealing with these (Plucinski et al. 2017).

If it is the case that hazard reduction prescriptions are based on fire behaviour that at a minimum sustains active spread and at a maximum does not become uncontrollable or cause unwanted damage to specific values, then any effect on hazard reduction appears to be secondary and perhaps a matter of good luck fostered by experience and good judgement rather than prognostic ability. Analysis of burn coverage outcomes from prescribed burning in dry forest in south-east Australia (Penman et al. 2007; McCarthy et al. 2017) shows that results can be highly variable ranging from 5—98% of planned area.

The factors that have been found to influence the success of prescribed burning for hazard reduction (i.e. the extent to which fuels are reduced at any one particular location and the area of coverage of a burn) encompass a broad range of site-specific and burn-specific variables (Duff et al. 2019).

Site-specific variables include:

- Dominant and sub-dominant vegetation types which may be a function of site climatology
- Site history (i.e. silvicultural, fire occurrence and intensity (Volkova et al. 2019), and land use) which may influence the amount of type, amount and rate of accumulation of fuel present (McCaw and Burrows 2020; Duff et al. 2013) and its vertical and lateral distribution
- Site topography which may influence vegetation productivity and micrometeorology including fuel moisture content and rate of debris decomposition

- The size of the area being treated.

Burn-specific variables include:

- Environmental conditions prior to and at the time of the burn (e.g. antecedent rainfall/drought conditions, wind speed and direction, air temperature and humidity) which can influence the behaviour and spread of the fire
- The condition of the fuel, particularly combustibility influenced by fuel moisture content
- The ignition technique including timing, type, method and extent (Tolhurst and Cheney 1999).

To some extent other burn-specific variables such as suppression resources available, projections of smoke dispersal, forecast subsequent weather and other prescribed burns in the district can also influence decisions regarding ignition timing and method, extent of burn, etc.

Analysis of six years of prescribed burns in Victoria (Duff et al. 2019) found that annually almost 30% of planned burns never eventuated or were delayed significantly and burnt area within planned area was highly variable with wetter sites and fuel types having lower likelihood of being completely burnt. Delays of burns may be an indication of prudent management if suitable conditions or sufficient resources were not available during the initial planning timeframe. This points to the need for evaluation of such activities over extended periods relevant to the dynamics of the fuels being treated.

The duration of effect of hazard reduction is a major concern in many ecosystems and post-treatment management (i.e. re-treatment) is important, particularly in faster-growing fuel types, to ensure the level of hazard reduction remains viable (Stephens et al. 2012). Understanding the trade-offs between managing desired levels of fuel hazard and consequences for ecological values and ecosystem function is critical to ensure that an appropriate balance of needs is met (Gharun et al. 2017).

In dry eucalypt forests, studies of post-treatment fuel dynamics are few, particularly of fuel attributes such as near-surface, elevated and bark strata (Penman et al. 2020). Most studies of fuel assessment and fuel dynamics (e.g. Watson 2011; Thomas et al. 2014) focus only on load of surface fuels. Many utilise the default theoretical exponential model of fuel accumulation of Olson (1963) and apply parameters for surface litter fall, decomposition and time since treatment to estimate surface fuel load (e.g. Walker 1981; Keane 2016; Cook et al. 2016). Such studies typically do not consider the structure or distribution of the fuel in this layer, only its mass, perhaps due to the ease with which it may be measured or approximated. Similarly, application of such standard models of fuel accumulation for other fuel layers such as elevated fuels have been found to be inappropriate (Volkova et al. 2019). Consequently, many extant models of fuel dynamics provide little insight into likely subsequent fire behaviour in forest vegetation. Accurate forecasting of the future state of fuels, particularly under climate change (e.g. Matthews et al. 2012), via robust physiological models is a critical component to understanding future fuel hazard (Duff et al. 2013; Volkova et al. 2018) and accurate calculations of future bushfire risk.

The factors that affect the duration of effect of hazard reduction include previous burn history, conditions and effectiveness of the treatment including continuity, extent and amount of material not treated, subsequent climatology (especially rainfall), site productivity, species type and specific species abundance (Duff et al. 2019) and species response. Effects of climate change may alter climatology and thus forest dynamics and response to perturbations such as hazard reduction burns, complicating the ability to determine likely changes in fuel attributes without direct measurements. The conditions and behaviour of the subsequent wildfire against which the hazard reduction is being assessed may also be said to determine the duration of the effect of hazard reduction with milder wildfires more likely to be moderated than higher intensity wildfires.

The only study published on the dynamics and structure of fine fuel in dry eucalypt forest following prescribed fire is that of Gould et al. (2011) utilising data to drive an exponential fuel accumulation relation for the key fuel attributes of surface fuel hazard and near-surface fuel hazard. In this study of time since fire in jarrah forest (*Eucalyptus marginata*), it was found that, over the 20-year period of the study (1979-1999) while surface fuel loads continued to increase indefinitely (up to and beyond 20 years), attributes such as percent cover and hazard score essentially plateaued after 6-9 years. Similarly, near-surface fuel loads were found to stop increasing significantly after 15-18 years whereas near-surface height and hazard score stopped increasing significantly after 9-12 years and 12-15 years, respectively (Figure 14). Bark hazard was found to be affected by hazard reduction burning for up to 12 years after hazard reduction burning.

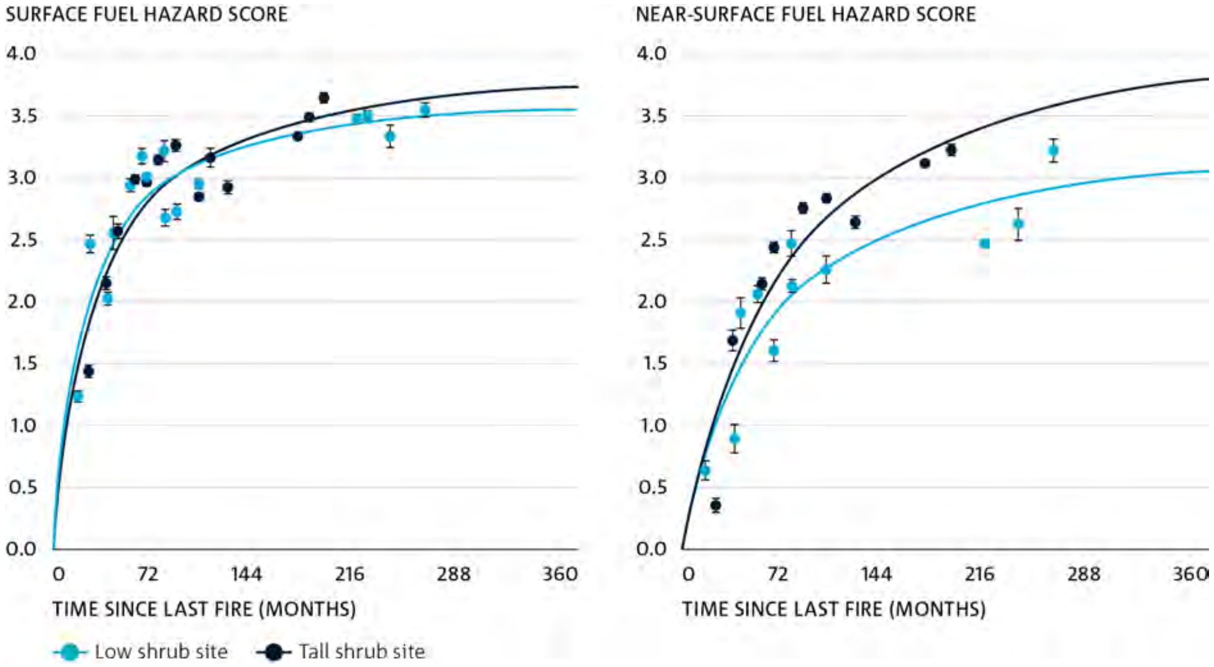

Figure 14 Recovery of surface (left) and near-surface fuel hazard (right) in Jarrah forest following hazard reduction burning. Under these conditions these fuel attributes returned to equivalent long unburnt state after approximately 12-15 years but the response in the first few years following burning is extremely rapid, achieving 75% of fuel hazard within 4 years (surface) and 5-7 years (near-surface) depending on presence of shrub layer (Redrawn from Gould et al. 2011)

Detailed post-treatment evaluation and regular ongoing assessment of fuel hazard recovery in the landscape is critical to understanding fire hazard at any point in time. However, physical assessments in the field are tedious, time-consuming and costly. The relation between fuel load and non-destructive (i.e. predominantly visual) assessments of fuel hazard is generally weak in most forest types (Volkova et al. 2016). Post-treatment assessments using remote sensing such as LIDAR (Price and Gordon 2016; Fernandez-Carrillo et al. 2019) offer a possible cost-effective solution for identifying effectiveness of hazard reduction treatments, particularly at the landscape scape, but the need for robust models of forest fuel dynamics for the broad range of forest types is essential (Volkova et al. 2018).

Without detailed understanding of the exact nature of fuel hazard reduction resulting from prescribed burning, it is necessary to utilise other measures such as change in fire behaviour, fire impacts and other consequences to quantify the change in fuel hazard, but these necessarily introduce additional variables and further complication.

Factors affecting fire behaviour in hazard-reduced fuels

Numerous studies have attempted to quantify the effect of hazard-reduced fuels on fire behaviour and other metrics of fire management (e.g. ignition potential, suppression difficulty, containment likelihood, extent, severity, etc.) (e.g. see Fernandes and Botehlo 2003; Boer et al. 2009; Fernandes 2015; McCaw 2013; Penman et al 2020). However, due to limitations in many of the methods used to undertake these studies, such as relying upon anecdotal evidence, utilising case studies of fire events constructed afterward or relying upon computer simulation of outcomes often using outdated or unvalidated models of fire behaviour, there has been no clear and conclusive answer to the efficacy of prescribed burning of forest fuel to reduce bushfire hazard.

Given the complex structure of forest fuels consisting of multiple strata, it is not feasible to assume that all available fuels are removed by any hazard reduction activity, particularly by prescribed burning that relies upon chaotic physical and chemical processes for propagation and fuel consumption. While hazard reduction can dramatically reduce the fireline intensity of a subsequent wildfire for some period soon after treatment (the effect), the highly dynamic nature of vegetation growth and reaccumulation of fuels as discussed above means that the key questions are:

- What is the magnitude of the effect?
- Under what conditions does the effect persist?
- How long does the effect last?

However, meaningful answers to these questions cannot be had without detailed and accurate information on the independent and dependent variables involved as well as consideration of the highly spatially and temporally variable nature of these variables. That is, quantification of the level of fuel hazard prior to the arrival of the wildfire, the environmental conditions of the active sections of the wildfire and the condition of the fuel at that time and those locations, and the resultant behaviour of the wildfire. Due to the nature of wildfire being a largely landscape phenomena driven predominantly by large-scale weather patterns, it is necessary to obtain this information also at the landscape scale which, as previously identified, is tedious, time-consuming and costly if done manually but also still awaiting robust alternatives utilising remote sensing or other methods.

Similarly, quantifying actual behaviour of wildfire burning through treated fuels is also difficult and uncertain. Detailed reconstructions of major wildfire events (e.g. Cruz et al. 2012) frequently resort to limited temporal resolution of isochrones (e.g. hourly or greater) due to lack of higher resolution data on fire spread. At such resolutions, zones of treated fuel are often too small to be perceived in subsequent analysis and only those of substantial dimension (i.e. > 1000 – 5000 ha) may be contemplated (McCaw 2010). Similarly, while final burned extent is often precisely known from a variety of sources (e.g. remote sensing, GPS mapping, etc), details of how and when the fire reached that extent are often unknown, as are details of the suppression actions taken and their effectiveness. Fine scale weather conditions across the fire area, particularly on large fires burning in complex topography, are also not available.

Consequently, methods for assessing changes in fire behaviour resulting from hazard reduction activities generally rely upon broad-scale assumptions of fuel hazard treatment (including extent, coverage, level of consumption and level of reaccumulation), indirect measures of fire behaviour such as level of consumption of remaining fuels or highly subjective assessments of thermal impact on vegetation (i.e. fire severity often obtained from remote sensing sources such as Landsat imagery), wildfire extent, and suppression effectiveness.

It is only the very small handful of detailed peer-reviewed Australian wildfire case studies where the level of information about fuel state and condition and subsequent wildfire behaviour was obtained accurately enough at high temporal and spatial resolution that meaningful interpretation of the effect of fuel treatment on fire behaviour can be made. These include the case studies of the 2003 Alpine fires in Victoria

(Tolhurst and McCarthy 2016), and the 2005 Pickering Brook fire in Western Australia (Cheney 2010). Results of these published case studies provide substantial evidence to support the view that hazard reduction burning significantly reduces the spread and fireline intensity of wildfires. There are a large number of similar case studies undertaken by agency staff that may also provide useful information on the effect of hazard reduction on fire behaviour but these tend not to be published in peer-reviewed journals (e.g. Billing 1981, Buckley 1990; Grant and Wouters 1993).

In the case of the 28,000 ha Pickering Brook fire, analysis concluded that the effects of prescribed burning on reduced spread rates were observed for at least eight years after treatments. Fire in fuels hazard-reduced three years earlier spread at one-sixth the rate and 1/20th the intensity of fire in 20-year-old fuel.

Analysis of >1 MHa burnt by the 2003 Alpine fire in eastern Victoria found evidence for some reduction in fire severity from hazard reduction up to ten years after treatment but that the magnitude of the effect on severity and suppression assistance from hazard reduced fuels declined substantially when the Forest Fire Danger Index (FFDI – see text box below) exceeded 50 (Tolhurst and McCarthy 2016). Beyond this FFDI limit it was found that landscape fires became ‘weather-dominated’ and variation in fuels and topography were less important to continued fire spread. Hazard reduced fuels less than ten years since treatment also acted to increase burn area patchiness (i.e. incomplete areal combustion) and decreased canopy consumption.

An analysis of the effect of hazard reduced fuels on the 2009 Black Saturday fires by McCaw (2010) found only a few examples where hazard reduced areas were impacted directly by headfires prior the arrival of the major wind change. These were equivocal in their impact on different fires due to their relatively small size (< 300 ha) which would have allowed the wildfire to readily burn around or spot over them. Some reduction in severity of crown damage on the two largest fires was observed in areas treated one-to-two years previously which slowed fire spread. Similar results were found by Gellie and Mattingley (2013) in their analysis of effect of hazard reduced fuels on Black Saturday fires. They determined that once weather moderated on this day only prescribed burns less than three years old and more than 600-1000 ha in area had any significant impact on fire severity.

Forest Fire Danger Index

FFDI is the scale of fire danger currently used in Australian forests and combines observations or forecasts of wind speed, air temperature, relative humidity, rainfall, time since rain and soil dryness to quantify the relative danger of a fire starting, spread and doing damage in forest fuels. The scale ranges from 1 (fires will not burn) to more than 100 (fires are so hot and fast control is virtually impossible). The scale is categorised into six fire danger ratings comprising Low-Moderate, High, Very High, Severe, Extreme and Catastrophic. An FFDI of 23 has a rating of High.

The only experimental investigation of the effect of fuel age (time since treatment) on the behaviour and spread of bushfires is that of Project Vesta (Gould et al. 2007; Gould et al. 2011; McCaw et al. 2012). This project undertook a burning program over three years of lighting large (4 ha) experimental burns under dry summer conditions simultaneously in fuels that had been prescribed burned at different times in the recent past (2-22 years previously). Fireline intensities ranged from 0 (did not spread) to 10.5 MW m^{-1} with flame heights up to 25 m. Results showed that hazard reduction by prescribed burning in dry eucalypt forest will reduce fire rate of spread, flame height and fireline intensity as well as the number and distance of spotfires through changes in the structure and total load of all key fuel strata (Figure 15) (Gould et al. 2007; McCaw et al 2012). The persistence of the effect was found to be determined by the rate of change of fuel characteristics over time and that the hazard score of fibrous-barked species will continue to increase even after other layers have stabilised. It was found that stimulation of shrub understorey layer regeneration after burning will not increase fire rate of spread until the near-surface layer accumulates.

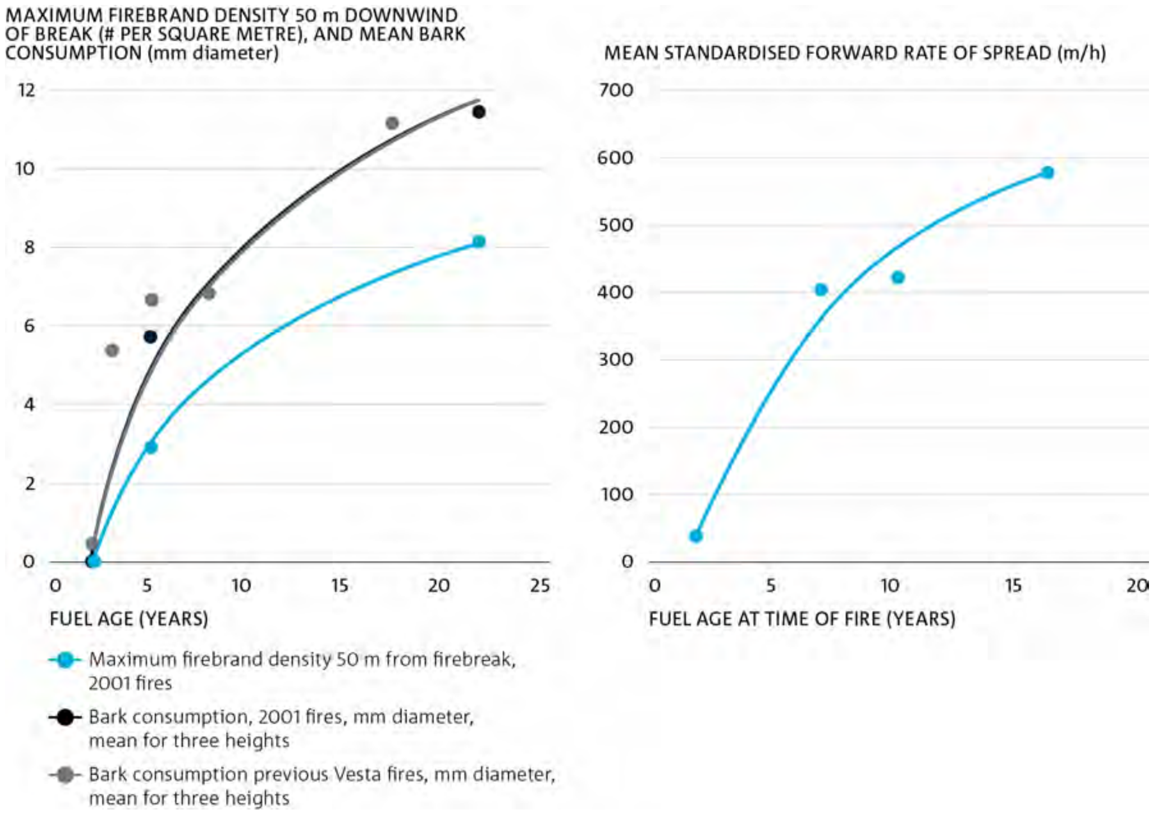

Figure 15 Impact of fuel age on rate of spread and firebrand density. Left: Rate of spread normalised for fuel moisture content and slope versus fuel age (time since treatment) for forest with tall shrub understorey Right: Maximum measured firebrand density (number of brands per square metre) versus fuel age (time since treatment). (Redrawn from: McCaw et al. 2012.)

A limitation of the Project Vesta study is the range of conditions under which experimental burns could be safely conducted. For purposes of ensuring successful management of the experimental fires, the maximum FFDI under which fires were conducted was 23. The highest wind speed measured in the open at 10 m during experiments was 16.5 km h^{-1}, potentially limiting observed fire behaviour and spread rates.

Analysis of observations of the spread of 118 high intensity wildfires burning in a diverse range of fuel types spanning temperate shrublands, dry eucalypt forests and North American conifers found that the speed of these fires was largely independent of fuel type or condition (Cruz and Alexander 2019). The speed of these fires was found to be consistently about 8% of the average wind speed measured at 10 m above ground level in the open. Analysis of error in this approximate rule of thumb showed that errors were lowest when fuel moisture content was less than 7.5% and average wind speeds were greater than 30 km h^{-1}.

While these conditions are not as extreme as the FFDI 50 determined by Tolhurst and McCarthy (2016) to be ‘weather dominated’ (these conditions result in an FFDI ~20-25), this result does concur with the observation that once fire weather conditions deteriorate beyond a certain threshold, the behaviour of bushfires is less influenced by the static conditions of fuel and topography (Price and Bradstock 2012) and its behaviour becomes dominated by dynamic conditions driven primarily by the wind. However, while the focus of many studies is of the effectiveness of hazard reduction under extreme conditions, the contribution of hazard reduced fuels to suppression and fire control under more moderate weather conditions is also important (McCaw and Burrows 2020) as the majority of fire suppression activity occurs under these conditions.

The factors that directly influence the behaviour of fires in fuels that have been hazard-reduced compared to a fire in fuels that have not been hazard-reduced include:

- The nature of the hazard reduction and its effectiveness (i.e. completeness, level of fuel modification
- The time since treatment was applied
- The subsequent response of the vegetation and re-accumulation of the fuel which may depend on the intervening climatology, weather and species composition.

Leverage is a concept that attempts to capture the relationship between the amount of area treated by hazard reduction and the corresponding area that is likely to not be burnt by wildfire as a result (Loehle 2004; Price et al. 2012). That is, for every hectare burnt for hazard reduction, how much area is likely to be avoided being burnt by a subsequent wildfire? In the savannas of northern Australia, where late season wildfires commonly burn extremely large areas of the landscape each year, the leverage of early-season burns conducted under mild burning conditions approaches a value of 1—that is, for every hectare burnt under mild conditions early in the season, one hectare burnt by high intensity wildfire in the late season is avoided (Price et al. 2012).

This concept, however, is most relevant to regions that have a high annual area burned by wildfires (Price 2012) as wildfires are more likely to encounter hazard reduced zones (Penman et al. 2020). In temperate forests of southern Australia where annual wildfire occurrence is much lower and thus the probability of a wildfire occurring at any one particularly location each year is much less than in the savannas of northern Australia, such a concept becomes less meaningful. Observed leverage values in these regions are generally between 0.1 and 0.45 (see Boer et al. 2009; Price et al. 2015), suggesting that up to 10 times the annual average area burnt by wildfire is burnt in hazard reduction. Simulation of wildfire extent in fire-prone landscapes (e.g. Cary et al. 2017) suggests that significant areas, greater than 30% of the land, would need to be treated each year to reduce the area burnt by wildfire. Achieving even a fraction of this currently has been problematic in many regions. Unless areas treated for hazard are large enough to be encountered by a wildfire, they may either be burnt around or spotted over by a wildfire and not have any effect on its behaviour, spread or impact (McCaw 2010; Gellie and Mattingley 2013; Fernandes 2015). Even where hazard reduction is effective, it may be difficult to quantify the relative effect. For example, ignitions in areas that have been hazard reduced and which do not initiate wildfires cannot be easily quantified.

The success that Western Australia has had in applying hazard reduction burning to its forest estates since the 1960s (Boer et al. 2009) to reduce the impact of wildfires demonstrates that a coordinated and consistent approach to fuel management via prescribed burning can be achieved. Western Australia is the only state to have consistently maintained a program to prescribe burn more than 5% of its public forest estate annually (Adams and Attiwill 2011; McCaw 2013).

In this context it should be noted that even though it may not be possible to apply prescribed fire a frequency necessary to keep fuel hazard below a critical threshold level to mitigate fire behaviour under severe conditions, it can still contribute to a reduction in overall bushfire risk at the landscape scale. For example, it may be necessary to burn a dry eucalypt forest every 5 years to keep fuels below the critical level. However even if areas within the forest are burnt on a rotational basis only every 15 years, the overall risk of bushfire in the forest is reduced by one third. That is, undertaking burning on a largely random basis annually across a forest means there would be a one in three chance of a fire igniting in an area hazard reduced less than five years previously.

Understanding the full picture of landscape fire management, including ignition prevention, early detection, effective initial and extended attack, and critical fuel hazard reduction at the full range of scales where feasible, is essential to successfully managing the annual threat of wildfire in the landscape. Utilising this understanding to develop the necessary policies and frameworks and combining with the necessary resources (social, financial and physical) to implement management actions in an effective and timely manner is critical to reducing the impacts of future wildfires.

5.6.5 Other consequences of hazard reduction burning

Suppression

One of the often-cited purposes for conducting hazard reduction, in addition to reducing fire behaviour and spread potential, is to increase opportunities for, and effectiveness of, suppression (Morgan et al. 2020). Here suppression is defined as any activity concerned with controlling, containing or extinguishing a fire following detection (Plucinski 2019a). Plucinski (2019b) summarised previous research where effect of fuel management, specifically hazard reduction, on suppression was investigated at fire incident and landscape fire scales. Suppression was found to be both more productive and effective in fuels that had been hazard reduced. Conversely, fires in fuels that were not reduced had a greater risk of escaping control, particularly under elevated fire weather and via spotfires breaching containment lines (McCarthy and Tolhurst 2001). This analysis of a large number of wildfires in Victoria found that the probability of hazard reduced fuels contributing to successful suppression operations persisted for four years following treatment with decreasing probability up to 10 years since treatment, mostly through reduction in bark and elevated fuel hazards.

Suppression by tanker and aircraft resources on more than 300 Australian wildfires in forest and shrubland vegetation were analysed for probability of initial attack success and potential for large fire occurrence (Plucinski 2012). Logistic regression analysis determined that the most significant predictor variables for initial attack success were the size of fire at first arrival of suppression crews (initial attack), the level of fuel hazard in which the fires were burning and the response time of the aircraft. Potential for a fire to become large was related to fuel hazard, size of fire at initial attack and the fire weather as represented by FFDI. Reduced level of fuel hazard increased probability of initial attack being successful and decreased the potential for a fire to become large if it escaped initial attack (Figure 16).

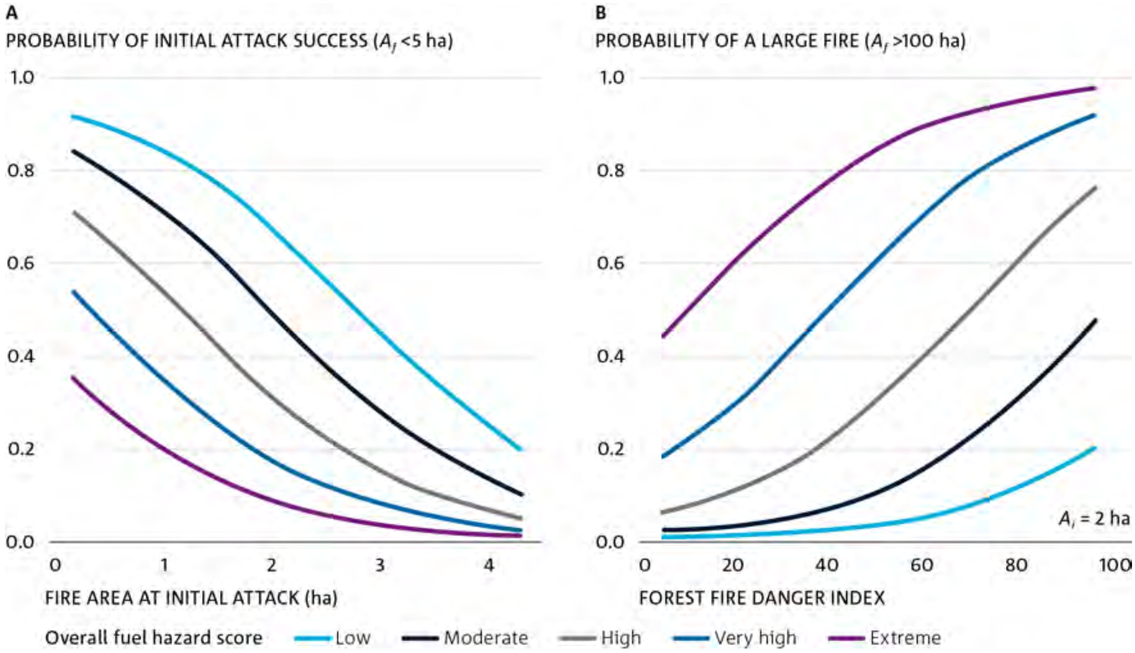

Figure 16 Influence of overall fuel hazard score on a) the probability of initial attack success as a function of area of fire at initial attack, and b) the potential for a fire to become large (> 100 ha) as a function of fire weather. (Redrawn from Plucinski 2012)

Analysis of suppression operations of the Great Divide Complex of fires which initiated in Victoria in 2006 found that both resourcing and containment success of the wildfires was strongly associated with level of fuel hazard with contained fires in fuels of lower fuel hazard (McCarthy et al. 2012).

Similarly, strategically placed firebreaks (consisting of fuel-free mineral earth lines or less frequently fuel-reduced zones) or 'fuel breaks' have also shown to be more effective when placed in conjunction with hazard reduced fuels (Cruz and Alexander 2017; Oliveira et al. 2016).

Ecological and biodiversity consequences

The long-term average frequency or return period of naturally occurring fire, its intensity and its season of occurrence define the fire regime for a given location (Gill 1975). Management of ecological and biodiversity values are generally focused on maintaining conditions conducive to continued ecosystem function and species (flora and fauna) presence. Many Australian native plant species have evolved to coexist with fire, however while a particular species at a given location may be adapted to the prevailing fire regime, it is not necessarily adapted to fire itself (Gill 1975). Plant species may be described as fire tolerant (less than 50% adult mortality with 100% leaf scorch after fire) or fire sensitive (>50% adult mortality with 100% leaf scorch after fire) (Morrison et al. 1996).

Tolerance may result from decreased vulnerability to fire, such as thick protective bark, or increased potential to recover from thermal damage, such as greater ability to resprout following fire (broadly classified as 'resprouters'). For those that are fire sensitive, strategies such prodigious seed production to guarantee succession are employed (broadly classified as 'obligate seeders'). The key consideration then for survival of a plant species in the presence of fire is the time required for juvenile resprouters to reach fire-tolerant size or age, or the time required for juvenile obligate seeders to reach sexual maturity and first reproduction, and the time required for adult plants to recover to reproduction, after the last fire. The specific plant conditions for survival depends, of course, on the intensity and behaviour of the subsequent fire to which it is exposed, with a lower intensity fire having lower likelihood of resulting in local extinction than a higher intensity fire.

An ecosystem that is subjected to a fire regime that has an interval between fire events shorter than the minimum time required for species in that ecosystem to reach tolerance or reproduction age (primary juvenile period) have the potential to result in local extinction of those species and potentially other connected species as well (Gill and McCarthy 1998). Conversely, too long an interval between fires may also lead to extinction for fire-obligate seeders (Morrison et al. 1995; Penman et al. 2009). In this sense, many species characteristic of Australian vegetation are said to be 'fire-dependent' for their survival. Factors such as the size and longevity of soil-stored seed bank for obligate-seeder species, and the extent to which a fire results in mortality of the adult population of plants also influence the response of such ecosystems to fires. Mild or patchy fires may to allow some individuals in a community to persist and give rise to uneven-aged populations where the older plants can develop a larger seed store (Heemstra 2007; Bradstock et al. 2005).

It is this potential inherent dichotomy, between the need to burn frequently enough to ensure that hazard of accumulating fuels is maintained at or below an acceptable level (which may be in the order of 3-5 years in some ecosystems), and the minimum frequency required to ensure continuity of species presence (which may be as much as 20 years in some ecosystems such as alpine ash (Bowman et al. 2016)), that underlies much of the complexity of landscape fuel management for multiple objectives.

A potential benefit of using prescribed fire on relatively longer rotations compared with that necessary to achieve a desired level of reduction in hazard is that it may more nearly approximate to the historic burn regime, especially if burns are conducted under conditions that enhance rather than detract from land management objectives. This can help to alleviate the cycle of very intense fires that cause major changes in forest structure and composition which promote very dense regeneration of young sapling forests and shrub understoreys. Much of eastern Victoria and parts of the Australian Alps are now caught in this cycle of repeated high intensity wildfire events. A similar example in the Great Western Woodlands of Western Australia is discussed in Chapter 7.

Implementation of mosaic or patchwork burning (whereby smaller, non-contiguous patches are prescription burnt at different times and intensities) and variability in prescribed fire intensity may achieve a spatially-distributed range of fuel age and states (including unburnt islands) and thus improve likelihood of reduced detrimental effects on ecological and biodiversity values (Bradstock et al. 2005; Leonard et al. 2014) or ecosystem resilience (Tolhurst 2012). However, as identified by McCaw (2010) and Gellie and Mattingley (2013), unless these are of sufficient size to be encountered by a wildfire at sufficient scale, they may not be effective in reducing hazard or mitigating impacts of a wildfire burning under condition of severe or greater fire weather.

The high thermal output from the head of a large, high intensity wildfire burning under severe or greater fire weather conditions is likely to result in extensive broadscale ecological damage. Full involvement of all fuel strata in such a fire can result in complete consumption of fine dead fuels and partial or greater consumption of fine live fuels, organic soils and larger dead components (Hollis et al. 2011), often with complete defoliation of the forest canopy (Cruz et al. 2012) and exposure of mineral soil. The consequences of such impacts on the fabric of an ecosystem and its function (from soil properties, microbes and invertebrates through to fauna) can be extensive and of long duration (e.g. York and Lewis 2017; Bowd et al. 2019; Liedloff et al. 2018).

Understanding the consequences, particularly on the triple-bottom line, of different management options (including non-burning methods) and necessary trade-offs of those options underpins successful strategic land and fuel management, but often the knowledge of the dynamics of fuel accumulation and species lifecycles in the full range of potential conditions is lacking or deficient to enable effective holistic and balanced land management with meaningful monitoring and evaluation of performance (Penman et al. 2020; see also Chapter 7.)

Air quality, smoke impacts and human health

The most obvious output from a fire burning biomass fuels is smoke, which can make the presence of a fire visible over tens of kilometres. Smoke is a common product of the incomplete combustion of complex carbohydrate fuels (Sullivan 2017). Where combustion is complete, fuel components are completely oxidised and the only products released are water and carbon dioxide with little if any smoke evident. However, due to the uncontrolled nature of bushfire combustion open to the vagaries of chemical reactant mixing and rapid changes in the efficiency of energy release and transfer, partially combusted gaseous and particulate matter are released, appearing as smoke. Highly chaotic rapid heat release rates in the flaming zone results in incomplete oxidation of volatiles and thick black smoke with high levels of soot. The slow, low temperature and inefficient oxidation of residual charred and partially combusted material behind the flaming zone (Ohlemiller 1995; Reisen et al. 2018) results in large volumes of pale coloured smoke comprised of partially decomposed material of higher atomic mass that also does not fully oxidise.

The chemical composition of smoke depends strongly on the manner in which it is burnt and can consist of a very wide variety of gas phase and condensed phase organic and inorganic chemical compounds including respirable particles (Reid et al. 2005; De Vos et al. 2009) and volatile organic compounds. Inefficient combustion and partial thermal decomposition generally results in greater presence of larger, heavier molecules, whereas more complete combustion results in a greater presence of smaller, lighter molecules. Bushfire smoke consists primarily of carbon dioxide (indicating level of complete oxidation), water, carbon monoxide (indicating partial oxidation), hydrocarbons (including methane, indicating partial thermal decomposition), nitrous compounds (including oxides and ammonia) and a large amount of trace compounds (e.g. Hurst et al. 1994a; Hurst et al. 1994b; Urbanski et al 2009), many of which are toxic or even carcinogenic (Reisen and Brown 2006; Reisen et al. 2011; Reid et al. 2016). Smoke from prescribed fire has been shown to be a significant source of fine particulates (Reisen et al. 2018). Fine particulates (<2.5 µm) are particularly harmful to human health (Haikerwal et al 2015). The respiratory health impacts of smoke are discussed more fully in the Appendix at Section 5.10.

The smoke generated by a bushfire generally forms a plume or convection column, the vertical structure of which depends on the buoyancy generated by the fire (a function of its fireline intensity and energy release rates) and the atmospheric boundary layer wind flow (Raupach 1990; Heilman et al. 2014). A very intense wildfire can produce an extremely tall convection column up to six or more kilometres high and inject smoke into the lower stratosphere (Cruz et al. 2012; Siddaway and Petelina 2011) that can be transported considerable distances downwind including around the globe.

The typically lower intensity combustion of a prescribed fire does not generally generate a strong plume that acts to draw smoke away from the surface near the fire; instead, the usually milder burning conditions with lower surface winds tends to keep smoke near the surface in the vicinity of the fire. The prevailing mild weather conditions of a prescribed burn also often act to limit smoke dispersal and retain the smoke in the airshed where it is generated until a major change in the weather acts to disperse it. This can result in a greater exposure in both concentration and duration to smoke at ground level by those conducting the burn as well as local communities which can have deleterious effects on public health and wellbeing (Reisen et al 2011a; Reisen et al 2011b; Haikerwal et al. 2015). Smoke has been found to also have detrimental impacts on other values such as tourism and the wine and agricultural industries (Hayasaka et al. 2010; Krstic et al. 2015).

Health impacts from bushfire smoke are influenced by four primary factors (Williamson et al 2016). These are:

- The chemical composition and concentrations of smoke constituents
- The intensity and duration of the smoke exposure event
- The number of individuals exposed to the smoke event and their underlying level of health
- The extent to which individuals can protect themselves from the exposure.

Reid et al. (2016), in their analysis of scientific literature on effect of wildfire smoke on health effects, found consistent evidence for associations between wildfire smoke exposure and general respiratory health effects (specifically exacerbations of asthma and chronic obstructive pulmonary disease). Increasing evidence suggested associations with increased risk of respiratory infections and all-cause mortality but mixed evidence for cardiovascular effects. Insufficient research exists to clarify which causes of mortality are associated with smoke exposure and if certain populations are more vulnerable to smoke effects.

Studies of smoke impacts on firefighters at prescribed and wildfires showed that exposure levels were highly variable with level of exposure dependent upon particular work tasks (such as direct suppression and patrol) and fire behaviour. While the majority of exposures were at low and moderate levels, levels exceeding occupational exposure standards occurred (Reisen et al. 2011a). The health effects of acute exposures beyond susceptible populations and the effects of chronic exposures experienced by firefighters are largely unknown (Adetona et al. 2016).

The unprecedented scale of the wildfires in south-eastern Australia during 2019-20 generated enormous volumes of smoke that exposed large sections of the population to high concentrations of pollutants for extended periods with deleterious impacts on air quality and human health. Prior to the onset of the fire season, prescribed burning typically also exposes populated airsheds (e.g. the Sydney basin) to considerable quantities and durations of pollutants (Adetona et al. 2016). Tools such as the Air Quality Forecasting System (AQFx)(Cope et al. 2019) developed by CSIRO, the Bureau of Meteorology and the university sector aim to provide the ability to accurately forecast potential smoke dispersal from both prescribed fire and wildfire to better warn communities and industries of potentially damaging smoke events and also identify potential smoke impacts from planned prescribed burning (see Chapter 6). The latter will enable specific identification of weather conditions necessary for satisfactory dispersal of smoke from planned burns to reduce negative impacts from these activities.

Carbon and greenhouse gas emissions

Many of the gaseous emissions from a bushfire that contribute to smoke are also considered greenhouse gases (GHG). Prescribed burning for GHG emission abatement has been widely used in northern Australian savannas for many years, trading off area burnt early in the fire season against area burnt late in the fire season in order to reduce the volume of GHG released through reduced fire behaviour, reduced fuel consumption and changes in emissions profiles (Russell-Smith et al. 2009; see text box).

The Emissions Reduction Fund Savanna Burning Methodologies: an overview

Garry Cook, Stephen Roxburgh, Mick Meyer

The Emissions Reduction Fund (ERF) savanna burning methodologies grant Australian Carbon Credit Units to participating land holders in northern Australia who use prescribed burning and thereby reduce greenhouse gas emissions and increase carbon sequestration. The scheme works because fires across northern Australia are very frequent (> 3 per decade per location) and careful fire management can reduce overall fire frequency and resulting emissions (Cook et al. 2012) The scheme has co-benefits to regional employment, biodiversity management, and protection of property.

There is no scientific evidence to support a “savanna burning” type emissions reduction scheme in the forest zone of south-eastern Australia. Rather the converse is true as frequent prescribed burning is likely to increase average carbon emissions per year, even after taking into account any potential reduction in the future frequency of wildfire arising from the prescribed fire.

Modelling of the potential for prescribed fires to mitigate carbon emissions from wildfires in south-eastern forests found that prescribed burning was unlikely to yield a net reduction in carbon emissions (Bradstock et al. 2012a).

Direct measurements of emissions from prescribed fires and wildfires in south-eastern Australia forests showed that frequent prescribed burning releases more carbon emissions than occasional wildfires (Volkova et al. 2014).

The profile of emissions of greenhouse gases (GHG) from combustion of bushfire fuels has been found to be strongly influenced by the mode of fire spread (i.e. whether the fire is spread with or against the wind resulting in the fire being a more intense head fire or a less intense backing fire, respectively) (Surawski et al. 2015, 2020). Fires spreading as a head fire were found to generate significantly more carbon dioxide, mostly in the form of smouldering behind that flame front, than either backing or flanking fires. Similar results were found for other GHG such as carbon monoxide, methane and nitrous oxide. A correlation of this result is that heading fires had less than half as much pyrogenic carbon in combustion residues, showing that burning by flanking or backing fires sequesters more carbon in more stable forms such as char.

As a result of this asymmetry in carbon oxidation and sequestration resulting from fire spread mode, it is possible that applying prescribed fire in a way to preferentially burn fuel with low intensity backing or flanking fire could reduce the amount of carbon dioxide-equivalent emissions by more than 10-20%

compared to a more intense heading fire and increase the amount of carbon remaining on the ground post-fire by more than 200%. While it is generally not possible to operationally limit behaviour of a large prescribed fire to a single fire spread mode, and the choice of mode may be limited by operational requirements in many situations, variations in lighting pattern could be used to judicially influence the overall outcomes of a burn.

Water quality and erosion

One of the most obvious impacts of a wildfire is the consumption of understorey vegetation including shrubs, grasses and other vegetation types that generally flourish under the canopy of overstorey forest. Less obvious is the consumption of organic soil or humus layers between the litter layer and the mineral soil. Removal of these layers of vegetation and debris ground cover exposes the soil to the danger of erosion, particularly if the wildfire is followed by significant rainfall events, and can change the hydrology of the area through changes in the structure and behaviour of the soil. The loss of riparian vegetation means high volumes of sediment and combustion debris can be transported by over surface flows (i.e. runoff) and enter gullies and streams and, in water catchment regions, eventually reach rivers and reservoirs, contaminating them and reducing water quality (Blake et al. 2020). Increased sediment and debris can also lead to blockages of drainage and localised flooding.

Hazard reduction will act to decrease the consumption of critical fuel layers in a wildfire, particularly organic soil layers, reducing the potential for loss of essential ground cover that protects and suppresses sediment transport during rain events. The conditions of prescribed burns for such purposes need to ensure that these critical layers, particularly that of organic substrates in the soil, are not disturbed greatly.

In many catchments, post-wildfire recovery of affected vegetation can greatly influence catchment flows and water yields, with increases of contaminated water in the immediate period after fire, and then subsequent decreases in flow as vegetation regenerates, possibly for many years after the wildfire in some forest types through increases in rates of evapotranspiration (Brookhouse et al. 2013; Gharun et al. 2015). Reducing the severity of wildfires through hazard reduction increases the likelihood that catchment function will not be unduly affected by impacts of wildfires.

Property loss

In many regions, the cost and logistic complexity of hazard reduction burning at the landscape scale has led in the last decade to a shift in focus toward 'strategic' burning primarily for the purpose of reducing impact of wildfires on people and property. Much of this shift appears to have coincided with analysis of the impacts of specific fires in the recent past such as the Black Saturday fires of 2009 in Victoria, specifically in regard to effect of hazard reduced zones on overall fire behaviour and property loss (e.g. Gibbons et al. 2012). As observed by McCaw (2010), the lack of meaningful interaction between the wildfires and hazard reduction treatments during the Black Saturday fires makes it difficult to draw any substantive conclusions about the effect (or lack thereof) of such treatments on impacts such as property loss.

The conclusion of Gibbons et al. (2012) is that only treatment of fuels in the immediate vicinity of properties (up to 40 m) is necessary to reduce the risk of property loss. Similar thinking is applied to calculation of residual risk and determination of the most cost-effective risk mitigation strategy in some jurisdictions. While it is clear that if only risk to property is considered, and the treatment in the immediate vicinity of the property is the cheapest strategy, then it must be the most cost-effective alternative, but this approach relies greatly on the ability to accurately quantify the risk to properties and its reduction through mitigation actions. Existing systems used for such purposes (e.g. Phoenix Rapidfire bushfire simulator (Tolhurst et al. 2008)) utilise fire behaviour models that consider only fuel mass and not fuel structure, which has been shown to inadequately determine bushfire behaviour potential (McCaw et al. 2008; Cruz et al. 2015a) and the prospective change in that bushfire behaviour potential through effective hazard reduction as a result.

While fuel management only at the scale of individual properties allows supported simplifications to be made at a strategic level, the reality is that fuel management on private property is extremely difficult to ensure in a consistent and effective manner and does not adequately consider the likelihood of the arrival of large fire fronts into the urban or peri-urban interface. As shown from analysis of wildfire behaviour (McCaw 2010; Price and Bradstock 2012; Tolhurst and McCarthy 2016), small non-contiguous treatments of fuel have little potential to affect the behaviour of large established wildfires, particularly under severe fire weather conditions. While stringent and extensive management of fuel at a property may aid the probability of that property withstanding the fire front, it is the resistance of the broader neighbourhood to the impact of fire that determines the level of success, particularly from extended ember attack (for up to 5-10 hours potentially) from the adjacent forest and neighbouring properties.

While it has been shown that most property losses occur on days of elevated fire danger (Severe or greater) (Price and Bradstock 2012; Blanchi et al. 2010), and many wildfires breakout on those days (e.g. Plucinski 2014), the losses of properties do not always occur on the day they breakout (Collins et al. 2016). Many wildfires start many kilometres from houses and urban interfaces and take time to develop and reach their maximum potential rate of spread and behaviour (Cheney and Gould 1997). As a result, a fire may breakout many kilometres from where it eventually does damage, later that day or even many days later. When it does, it will generally have a broad front that can impact a wide expanse of the bushland-property interface when the fire weather deteriorates, as was experienced in the Canberra fires of 2003 and numerous incidents during the 2019/20 fire season when fires spread continuously for many days at a time. In such a situation, multiple properties will come under simultaneous fire attack, leading to rapid escalation of emergency conditions, swamping of available firefighting resources, loss of situational awareness and potentially significant loss of life.

Opportunities to restrict the spread of a wildfire in the landscape before the fire reaches urban or peri-urban fringes will be increased if the fuel hazard has been reduced and fire behaviour and speed moderates sufficiently. Such impacts on fire behaviour may not always be possible, especially under severe or worse fire weather when headfire behaviour is dominated by the weather or if the area of treatment is too small. However, it remains that increasing the potential for both reduced fire behaviour and increased effective suppression when conditions are suitable before the fire reaches critical assets is essential to reducing the potential impact of a wildfire. Even if the weather conditions remain unfavourable for suppression of the head of the fire, reduced fuel hazard is still beneficial for attacking the flanks of the fire (McCaw and Burrows 2020).

The enabling of effective suppression on a wildfire that will threaten assets at the urban-rural interface is particularly important when that fire starts some distance away and has the space and time to become a large fire with an extensive front. Unless suppression efforts, fire-breaks and natural features in the landscape are given the best opportunity to effectively restrict the spread of that fire before the onset of severe weather through effective fuel management in the broader landscape, it has been shown that the coincident arrival of fire at the urban-rural interface under severe weather conditions can have deleterious results (e.g. 2009 Kilmore East fire, 2003 Canberra fire, 1983 Ash Wednesday fires). This may be best summarised by the adage 'don't bring the fire to town'[8].

However, once a fire is 'brought to town', actions by residents can further limit the potential impact of that fire on property loss (Penman et al. 2013). Residents can decrease the risk of loss of their property when they stay to defend (Wilson and Ferguson 1984), however properties and defenders need to be properly

[8] Mr J. S. Gould, CSIRO Honorary Research Fellow, retired Principal Research Scientist.

prepared in order to do so safely (Penman et al. 2013). The exposure of the property (i.e. siting), its ability to withstand exposure to fire (i.e. design and construction materials), and the state of the garden and other combustible items around the property have been associated with the likely level of damage and ability to provide effective shelter for residents. Removal of combustible items around a property, particularly in direct contact with the property, and creation of defensible space between properties and structures, as well as providing nearby waterbodies, have been identified as key components for mitigating risk of property loss (Penman et al. 2019). The inter-relationships of building standards, setbacks, supplementary (domestic) fuels, topography and weather are discussed at length in Chapter 8.

5.6.6 Meeting operational needs

The task of implementing prescribed burning operations for hazard reduction is not a simple one, necessitating considerable balancing of planning, policy, legislative, social, environmental and management objectives. The National Bushfire Management Policy Statement for Forests and Rangelands (FFMG 2014) identifies 14 goals under four broad banners :

- Effectively managing the land with fire (maintaining appropriate fire regimes, balancing the environmental impacts of fire; and promoting Indigenous Australians' use of fire)
- Involving capable communities (engaging communities; and public awareness and education)
- Creating and maintaining strong land, fire and emergency partnerships and capability integrating and coordinating
  - Decision making and management
  - Workforce training, education and employment
  - Bushfire risk management
  - Bushfire response
  - Safety in fire operations
  - Bushfire recovery
  - International responsibilities
- Actively and adaptively managing risk (risk management procedures; and investing in and managing knowledge).

A key outcome from these goals was the establishment of the National Burning Project (initiated jointly with AFAC) and the creation of the Centre of Excellence for Prescribed Burning with the aim of creating a more holistic and consistent approach nationally to prescribed burning. Out of this arose a national position on prescribed burning and national guidelines for prescribed burning. These guidelines encapsulate 27 high-level principles underpinning strategic and burn program planning as well as operational planning and implementation. Risk frameworks and objective and monitoring frameworks have been established to aid design and implementation of prescribed burning programs.

Despite this effort, finding an optimum or appropriate balance between competing requirements is not easy, particularly when there is rapid growth in peri-urban communities adjacent to public lands (McCaw and Burrows 2020), often with little experience or prior exposure to fire and fuel management, and rapid and sometimes dramatic changes in the surrounding social and political sphere (Bradstock et al. 2012b; Morgan et al. 2020) and detrimental impacts on local industries such as vineyards and beekeeping. Prioritisation of risk reduction in complex landscapes (Howard et al. 2020) and optimisation of impacts of hazard reduction for multiple outcomes (Gharun et al. 2017) encapsulate a multi-dimensional dimensional problem for which no simple answer exists.

This complex operating environment is then often complicated by extensive lead times (possibly as great as ten years (McCaw and Burrows 2020) required to integrate planned burns with other land management activities, ensure community engagement and social license, and negotiate approvals processes. These difficulties are then often exacerbated in many jurisdictions by critical gaps in the practical knowledge and experience within the burning agency (English 2018) and limited resourcing necessary on the ground to achieve burn plans in a timely and effective manner (Morgan et al. 2020; McCaw and Burrows 2020). Such gaps lead to risk-averse decision making in which the fear of lighting a prescribed fire that might escape control outweighs the fear of not lighting it (Burrows 2018).

5.7 Conclusion

A critical recent recognition is that the focus of fire science research for the last 50-odd years has largely been wildfire behaviour (Heirs et al. 2020). Understandably, a driver of this focus has been the impacts of high intensity fire on the infrastructure and the environment. Unfortunately, this has been to the detriment of a better understanding of the behaviour and application of prescribed fires, particularly for hazard reduction.

Specifically, absent are models quantifying fire sustainability or extinguishment under marginal conditions, and the effect of prescribed fire behaviour on fuel structure and distribution. Improved knowledge is needed of the conditions necessary to effectively reduce hazard in particular ecosystems without adverse impacts on other values. New knowledge is needed to predict with greater certainty the longevity of such reductions under future climatic conditions, and the implications of changes of fire regime on the full suite of environmental and ecological values.

Operationally, improved systems are essential to enable more efficient application of prescribed fire in the landscape, including resourcing logistics at the district, region and state level, and better capturing available windows of opportunity through more accurate prediction of fuel availability via critical variables such as landscape moisture content (Matthews 2012), expected fire behaviour, smoke production and transport, and likely effect on fuel hazard and risk. Improvements in performance in such areas are particularly critical under the effects of climate change. Overall, better understanding, quantification and potential for mitigation of the risk of conducting prescribed fire is essential. Furthermore, better systems are needed for determining risk (particularly identifying areas of high risk in the landscape) and the potential for risk reduction by the full gamut of options (physical, chemical, biological) along with associated costs (social, environmental and economic) is also necessary.

Articulating a robust, reliable, consistent and continuous arrangement for bushfire research in Australia is central to addressing the critical knowledge gaps inhibiting the successful management of fire and fuels in our landscape. Given the complexity of the issues underlying bushfire fuels and their management within the broader social and ecological contexts across Australia's many fire-prone and fire-sensitive ecosystems, a tightly focused research governance, rather than one for which fire is but one of many concerns, is essential. Similarly, the most appropriate balance of research types (i.e. academic institutions, research organisations and applied fire agency research) to meet research and operational needs cost-effective must be determined.

The research needs of the nation in this space must be matched by available operational capacity to implement research outcomes and meet management requirements. Ensuring long-term capability to manage fuels and forests responsibly is a key concern in many jurisdictions. Building capacity and capability through a broad range of structured training, professional development and experience accrual activities is critical to meeting this need, for both career and volunteer staff.

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5.10 Appendix – The health impacts of bushfire smoke in Australia

Geoff Morgan, University of Sydney

Fire seasons globally are becoming longer with more extreme fire weather causing extraordinarily intense and destructive fires (Bowman 2017), a trend that is likely to worsen according to climate projections (Abatzoglou 2016). While landscape fires are an inherent feature of the Australian environment, the 2019/20 South Eastern Australia fire season was nationally and globally anomalous given the geographical scale of the fires burning over 8 million ha. These fires were driven by prolonged drought and dangerous fire weather (Nolan 2020) that has been attributed to anthropogenic climate forcing (van Oldenborgh 2020) with ignition from dry lightning, storms and a variety of anthropogenic causes.

Bushfire smoke, as well as smoke from prescribed burns, contains a complex and dynamic mixture of particles and gases that are chemically transformed in the atmosphere and transported by the wind over long distances (Reid 2016; Williamson 2016; Johnston 2017). In this context, a major public health concern is population exposure to atmospheric particulate matter (PM) with a diameter < 2.5 µm ($PM_{2.5}$), which can penetrate deep into the respiratory system, inducing oxidative stress and inflammation, (Lodovici 2011) and even translocate into the bloodstream (Brook 2010).

Such exposure can adversely affect health. Australian epidemiological studies have found periods of increased $PM_{2.5}$ from fire smoke are associated with increased mortality, hospital admissions, emergency department attendances, ambulance callouts and general practitioner consultations, particularly for respiratory conditions (Morgan 2010; Martin 2013; Johnston 2014; Salimi 2017; Borchers Arriagada 2019). The risks from air pollution are amplified when combined with high temperatures during heatwaves (Shaposhnikov 2014).

Health Impact Assessment (HIA) methods for quantifying the burden of disease attributable to air pollution have also be applied to estimate the substantial health burden due to fire smoke (Héroux 2015; Fann 2018). These studies use well-established associations between PM2.5 and admissions to hospital and premature mortality, particularly for cardiovascular and respiratory conditions (Cascio 2018; Doubleday 2020; Lipner 2019; Gan 2017; Lassman 2017).

During the catastrophic 2019/20 fire season in South Eastern Australia, large urban and regional populations were affected by extreme air pollution for periods ranging from weeks to months. A recent Australian study used HIA methods to assess the health burden due to 19 weeks' of continuous fire activity in the states most severely affected and found that bushfire smoke was responsible for 417 (95% CI, 153–680) excess deaths, 1124 (95% CI, 211–2047) hospitalisations for cardiovascular problems and 2027 (95% CI, 0–4252) for respiratory problems, and 1305 (95% CI, 705–1908) presentations to emergency departments with asthma (Borchers-Arriagada 2020).

A Sydney study of the health burden of historical fire smoke pollution found that daily air pollution from 2001 to 2013 was high on 184 days due to fire smoke pollution resulting in an estimated 197 premature deaths (95% CI, 101 to 295 deaths), 436 cardiovascular hospitalisations (95% CI, 163 to 717 hospitalisations), and 787 respiratory hospitalisations (95% CI, 119 to 1494 hospitalisations) attributable to fire smoke pollution on these days (Horsley 2018).

Hazard reduction burns can cause high smoke pollution and a study of an episode of high smoke pollution during May 2016 found 14 premature deaths (95% CI, 5 to 23), 29 cardiovascular hospitalisations (95% CI, 5 to 53) and 58 respiratory hospitalisations (95% CI, 0 to 124) attributable to smoke from hazard reduction burning on the six smoky days (Broome 2016).

These Australian fire smoke and health burden studies used publicly available data on population and health status combined with daily fire smoke exposure data and relevant exposure–response risk coefficients. Sensitivity analyses are generally conducted to assess the influence of important underlying assumptions including the robustness of the fire smoke mapping used to estimate population exposure. Sophisticated methods are available to combine measured (e.g. government regulatory monitors, low cast sensors, satellite data) and modelled air pollution data (e.g. chemical transport models, land use regression models) to obtain high spatial and temporal resolution air pollution exposure maps (Chen 2019; Hanigan 2017; Poole 2000; Knibbs 2016). These methods have been applied to fire smoke measured and modelled data in Australia and are increasingly being used to develop improved fire smoke forecasts and to estimate the health burden in near real time to inform health risk communication and fire management practices (Larson 2020).

Certain population groups are at higher risk from exposure to smoke, either because they typically breathe in more air per bodyweight and their organs are still developing (young children), spend more time outdoors (outdoor workers, homeless people), or are more vulnerable to smoke due to old age or a pre-existing health condition (asthma, chronic obstructive pulmonary disease or other respiratory condition, cardiovascular illness, or diabetes). There is evidence that exposure to bushfire smoke during pregnancy is associated with reduced birthweight in babies and higher risk of gestational diabetes in mothers (Holstius 2012; Melody 2020). People in lower socio-economic groups are potentially at higher risk as they may have poorer housing, lower health literacy and limited ability to take preventive measures.

Current health protection advice related to bushfire smoke mainly focuses on short term actions aimed at reducing personal exposure to pollution. This includes advice to stay indoors with windows and doors closed, and reduce strenuous physical exercise outdoors, particularly if individuals experience health symptoms or have pre-existing respiratory or cardiovascular conditions. Reducing prolonged or heavy physical exercise outdoors may become impractical over longer periods. Advice to reduce strenuous physical exercise outdoors also becomes problematic over longer periods owing to the recognised health benefits from active travel (i.e. walking and cycling) and regular outdoor exercise.

Health advice also includes having access to regular medication, such as asthma medication, checking on older neighbours, and seeking medical attention if needed. Such advice, however, has been tailored to brief air pollution episodes that last only a few hours or days. In situations like the 2019–20 bushfire smoke events in eastern Australia, where severe smoke pollution persists over longer periods (weeks to months) and affects large population centres, there is a need for more nuanced and detailed health advice based on location-specific air quality data and forecasts (Vardoulakis 2020).

Currently, state and territory government departments use a range of different air quality metrics (such as a composite Air Quality Index based on multiple pollutants), averaging times and thresholds to stratify health messages into colour-coded bands (very good, good, fair, poor, very poor, hazardous). The discrepancies in the presentation of this air quality information and related health advice across jurisdictions is confusing for the public.

Nuanced and balanced public health communication that takes into account health risks, people's concerns and the effectiveness and practicality of protective measures is needed. Bushfire smoke alerts, near real time air quality data and forecasts, and related health protection advice can help affected populations assess their local air quality and reduce exposure to hazardous air pollution, by enabling individuals, particularly those more sensitive, to plan their daily activities accordingly (where possible). A priority for those affected by high fire smoke pollution should be to create a clean air space within their home by sealing doors and windows and using air conditioning and filtration if possible, where they can spend most of their time during prolonged periods of bushfire smoke (Laumbach 2015). However, many people may not be able to afford air conditioning and filtration units. High resolution smoke pollution forecasts linked to real-time air pollution data could identify periods of cleaner outdoor air quality when people could ventilate their homes to cool down indoors and avoid build-up of indoor air pollutants and fire smoke that has penetrated indoors (Vardoulakis 2020).

Managing the health impacts of fire smoke should be integral to landscape fire planning activities, such as planned hazard reduction burns, as well as bushfire emergency response. Close collaboration between health, education, environmental, fire management and emergency response agencies is essential for achieving the best overall outcomes for population health and wellbeing. Further research is needed into the medium- and longer-term impacts of bushfire smoke, as well as the effectiveness and health equity implications of related health protection advice.

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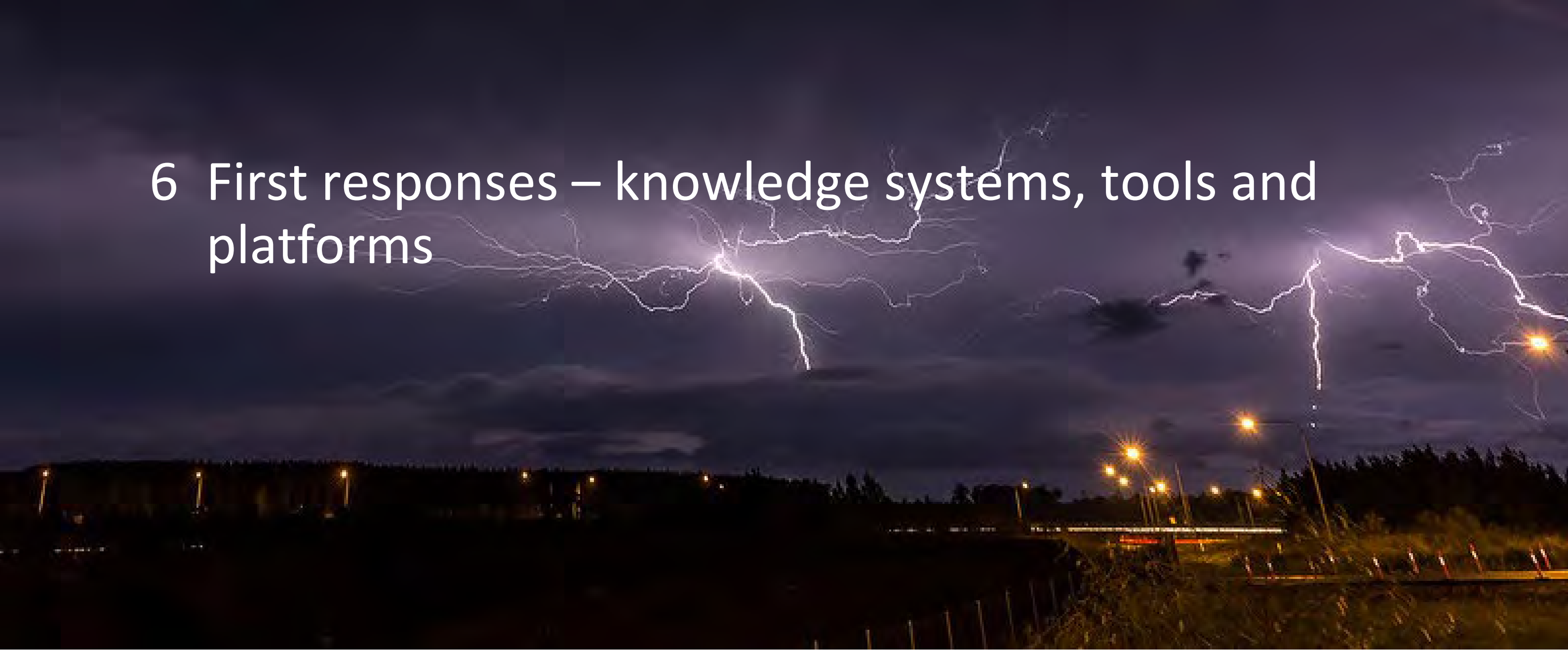

6 First responses – knowledge systems, tools and platforms

Author (CSIRO): Fabienne Reisen

6.1 Summary

Intelligence and technology play a key role in enhancing our first responders' capacity to deliver effective, consistent, coordinated and timely planning and decision-making during natural hazard events. Identification and performance of the key technology, knowledge systems and tools that aid first responders during emergency events were guided by findings from in-depth post-event reviews into bushfires, floods and cyclones undertaken in Australia over the past decade, as well as discussion with stakeholders.

Wider consultation with stakeholders, and in-depth exploration of individual incidents, experiences and systems, was not possible within the scope and timeframes of this report. While this chapter has a stronger emphasis on bushfires, key findings have a broader applicability to other natural hazard events. The review process served to gather recurring themes and challenges and to highlight areas that require further exploration and identify opportunities for improvement and innovation.

Accurate, reliable and up-to-date weather forecasts, observations and predictions underpin effective strategic and tactical decision-making of natural hazard events.

- Weather forecasts provided by the BoM are a key trusted source of information for first responders and the public during all hazard events. Accuracy of forecasts are improved through evolving advances in numerical weather prediction modelling as well as radar and satellite technology.
- The availability and use of multiple observational platforms (e.g. ground-based, aerial and satellite) ensure provision of timely observations that enhance situational awareness and safety of first responders and the public. Further development and integration of earth observation technologies has great potential to enhance this process.
- On-going development of prediction tools such as flood and fire behaviour models and the incorporation of new tools such as the smoke forecasting system based on the best data available at the time significantly assist first responders in providing improved incident management and community protection.

Harmonisation and integration of systems and tools used by emergency services across states and territories can provide a more efficient and transparent approach to manage natural hazard events.

- The issue of radio band availability and suitability for emergency services and a lack of integrated communication technologies between entities significantly impact on the effective response to a multi-agency natural hazard event. Breakdowns in communication potentially put first responders and the public at risk.
- Clear, concise, targeted and actionable community warnings and messages empower the public to make informed decisions about their safety prior to and during natural hazard events and save lives. The lack of universal warning levels and symbols and different alerting apps across states created confusion during the 2019/20 bushfire season and reinforced the need for harmonisation of warning mechanisms across all hazards.
- A critical, challenging and recurring issue highlighted in post-event reviews is effective sharing of intelligence and information flow between entities so that resources can be coordinated, prioritised and shared to meet operational requirements. Implementation and more effective use of technology platforms to manage incident information have enhanced cross-agency information sharing. A data analytics/augmented intelligence approach could be a cost-effective way to further integrate disparate data streams. On-going training is also essential to unlock the full potential of these technology platforms.
- Consecutive and compounding natural hazard events will increase competing demands on resources at incident, state and national level. To effectively manage and coordinate deployments to meet these demands, well-functioning integrated resource management and tracking systems are critical. Prolonged events also put systems and tools at capacity and result in breakdowns if adequate systems are either not available, not fully integrated, or there is no capacity to use them efficiently.

6.2 Opportunities for improvement

- Better integration and connectivity of incident information and resource management systems across different agencies and disaster management groups to achieve inter-operability at state, regional and local levels. This will lead to more effective decision-making, improve situational awareness, enhance personnel safety through real-time tracking of deployed resources and ensure more effective use of limited resources within and between states and territories.
- Implementation of integrated and reliable radio communication networks to ensure inter-operability between State and Territory jurisdictions.
- Fundamental need to further develop and integrate Earth observation technologies including satellite and aerial surveillance in disaster preparedness, monitoring and response to enhance timely and accurate intelligence and improve situational awareness.
- Further investment in research to improve existing natural disaster forecasts and impact prediction tools such as flood and fire behaviour models and the incorporation of new tools such as a national smoke forecasting system.

6.3 Introduction

Natural hazard events are complex and dynamic situations that can have profound impacts on communities and the environment. Timeframes range from hours to days (e.g. storms and cyclones) to days/weeks (e.g. flood, bushfires) or even months as was the case for the 2019/20 bushfire season. Natural hazard events such as floods and bushfires can cover vast areas, making coordination of response challenging. Intelligence and technology assist emergency services in each of the key phases of disaster management and are important for strategic planning and decision making. To ensure effective decision-making, it is critical that intelligence and technology capabilities are fully utilised, integrated and shared. It is important that innovation and adoption of new technologies occurs in concert with training and capability development for first responders to ensure the effective use of new tools and systems.

Each natural hazard event brings its own challenges for emergency services to effectively respond to and protect life and property. While this chapter has a stronger focus on bushfires, reviews into floods and cyclones were also considered and showed that the knowledge systems, tools and platforms assessed in this chapter have a broad applicability across all-natural hazards.

This chapter:

- identifies and defines the knowledge systems and tools for first responders with a focus on the response phase;
- assesses the effectiveness and limitations of these systems and tools during natural hazard events based on post-event reviews and inquiries into bushfires, floods and cyclones;
- evaluates the capacity of agencies involved in natural hazard events to fully utilise the systems and tools;
- identifies gaps and improvements based on post-event reviews and inquiries and discussion with stakeholders.

6.4 Overview of knowledge systems and tools for first responders

A range of knowledge systems, tools and technology are used in emergency management events to gather data and information to assess the current situation and forecast potential impacts; translate collected data and information into relevant, accurate and timely intelligence; and share that intelligence to support decision making, build situational awareness and convey messages/warnings to communities. Figure 17 provides a conceptual framework to illustrate the process from data and information to intelligence which is used to support decision-making. Key tools that inform this process are observational networks and platforms, including information provided by the community through 000 calls and social media, mapping systems (to visualise current and forecast situations), as well as weather forecasts and predictive tools. These critical elements are combined, processed, visualised, analysed and shared to create a common operating picture (COP) that assists with building situational awareness and enables effective, consistent, coordinated and timely decision making. Components that are critical for building and maintaining situational awareness include a continuous stream of up-to-date intelligence, a resource management system to capture and manage information regarding the availability and status of resources allocated to an incident, and reliable information and communications technology (ICT).

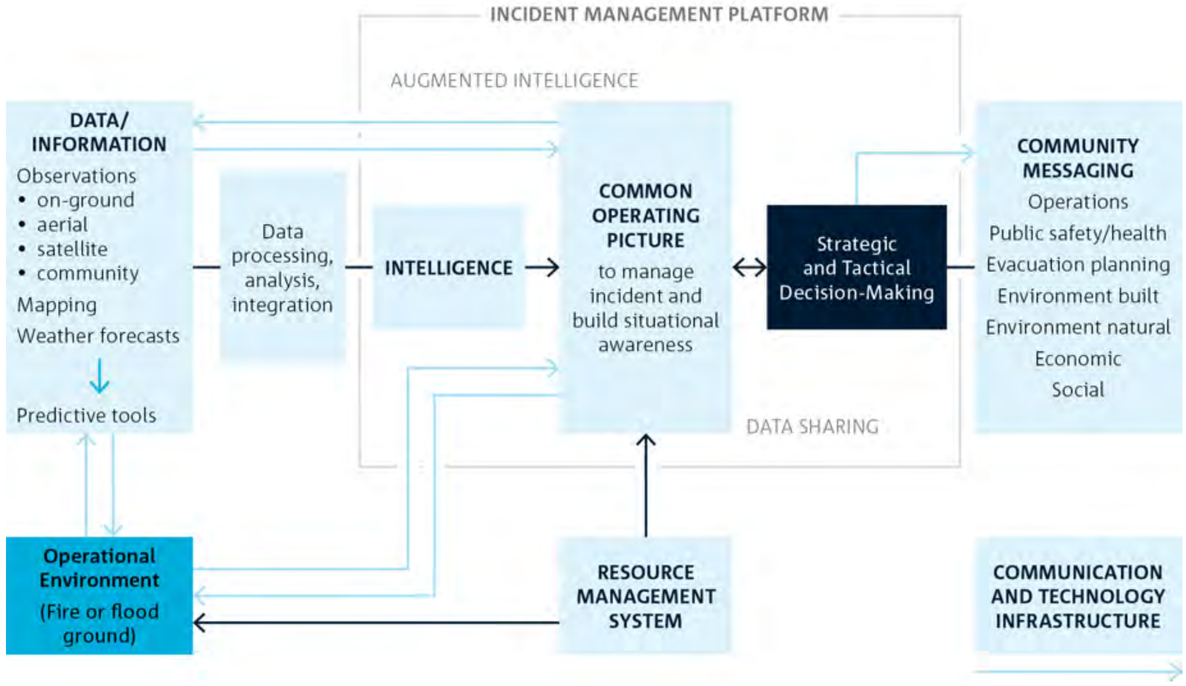

Figure 17 Conceptual framework of the dynamic linkages between the different knowledge systems and tools

6.4.1 Tools to gather intelligence

Maps and observational monitoring have long been a mainstay in coordinating first response. Accurate and clear mapping and timely, reliable observations from ground-based monitoring networks, airborne, and more recently satellite platforms, provide intelligence critical to build and maintain situational awareness. Additionally, availability of mapping with overlays that identify critical assets and infrastructure, vulnerable people and high-risk areas is critical to coordinated, targeted first response in many natural hazard events. Arguably, one of the most critical pieces of intelligence for almost all natural-hazard event responses is accurate and up-to-date weather forecasts provided by the BoM.

Vital observational networks that assist with responding to natural emergency events include the following and are discussed further in the current and proceeding sections of this report:

- Fire detection and mapping platforms (Table 7)
- Weather stations, rainfall gauges and radars for enhanced weather forecasts for cyclones, fires, floods and storms (see also Chapter 2, and text box below)
- Manual and automated rainfall and river gauges, and dam level monitors for enhanced flood modelling and predictions
- Community information through 000 calls and social media.

Table 7 provides an overview of the capabilities of satellites, aircraft and on-ground systems in use as fire detection platforms. Each of these have benefits and limitations in terms of the type and timeliness of intelligence they can provide and their spatial coverage.

Table 7 Fire detection platforms

PLATFORM	CAPABILITIES
Satellites (geostationary and orbiting)	Satellite imagery is emerging as a key player in bushfire risk management. The Bushfire Earth Observation (EO) Taskforce preliminary report identified the future opportunities for the improved use of space-based EO capabilities by emergency agencies (Australian Space Agency 2020). Satellite imagery provides the advantage of large spatial coverage although the optical imagery is subject to cloud cover masking issues. Information such as hotspot data from MODIS or Visible Infra-Red Imaging Radiometer Suite (VIIRS) is extensively used by emergency services to identify fires, due to its reliability, accuracy and consistency. The spatial and temporal resolution of satellite imagery is variable and dependent on the satellite.
Aerial intelligence	Aerial intelligence offers a high rate of data acquisition, with spatial and temporal flexibility. Air observers provide effective information on fire location, fire front, burnt areas and spot fires. The accuracy and quality of mapping from air observers is dependent on pilot and air observer skills, visibility and situational awareness of air observer personnel. Line scanning technology, which builds up an image of thermal infrared radiation one line at a time, has been shown to be the most useful and reliable method to accurately identify fire location in a timely manner due to its high spatial resolution, time stamp capabilities, coverage of large areas in a short time-frame and operability during day and night. The information transmitted via satellite, radio or mobile can be displayed in near real-time in the Incident Management Team (IMT). However, line scanning is constrained by cloud cover and not well suited for detailed assessment of the on-ground situation. Interstate deployment of line-scan tech-aided aircraft is straight forward. Use of Forward-Looking Infra-red cameras (FLIR) on board aircraft has proven to be very useful for both tactical and strategic mapping and can be operated day and night. The images are processed automatically on board the aircraft and transmitted via meshed high-frequency network (developed for ACT) or mobile phone network (may be limited) to produce live feeds of IR-georeferenced information to IMT. Compared to line scanning, FLIR is better suited to provide more detailed assessment that is relayed to ground crews (e.g. identify fire edge, hot spots, areas that require blacking out). Unlike line scanning, the communication and image processing/receiving systems for FLIR are not consistent across states and may lack georeferencing capabilities if deployed interstate. FLIR can be used under cloud cover, therefore is less constrained by cloud compared to line scanning. Continued improvements in night vision goggles and night vision imaging systems enable aircraft to safely operate at night for effective aerial fire-bombing (Australian Institute for Disaster Resilience 2019).
Remotely Piloted Aircraft (RPA) or drones	Recent improvements in technology provide real potential to increase the role for RPA in emergency management and firefighting primarily in an intelligence gathering role. Current systems with integrated visual cameras, IR or thermal imaging capabilities can provide extra local intelligence and situational awareness and were used during the Tasmanian fires in 2019 for this purpose. The advantage of RPA is their ability to more safely operate in hard-to-reach areas, under low visibility, cloud cover and night-time which are limitations for traditional aerial intelligence gathering. However, there is a need to ensure that RPAs are tracked the same way as other aerial fleet for effective management of the air space. Mid-sized RPAs (as used by the military) can have more sophisticated equipment; however, this requires large overheads to manage and operate them (in comparison to aircraft), and regulatory restrictions may make it challenging to use for fast-evolving environments (i.e. requirements for advanced notice and planning). There is a potential for RPAs flying at high altitude (c. 2km; e.g. Airbus Zephyr) to provide additional intelligence on fire detection and mapping.
On-ground systems	Fire detection lookouts are still in operation across parts of Australia. Visual detection of smoke columns is often more accurate in early detection of fires due to IR limitations for small smouldering fires under heavy forested canopy.
Social media	Reports from the public via 000 and social media are key to early fire detection in populated areas and, agencies such as the NSW RFS report this is often the fastest and most accurate fire detection method (NSW RFS engagement meeting).

Combining natural hazard risk assessments and mapping with observational data and weather forecasts enables prediction and effective response to natural hazard events. For example, fire mapping intelligence in conjunction with weather forecasts are significant inputs into bushfire prediction tools, as highlighted in Chapter 2. Likewise, the use of GIS tools to identify and map flood risk areas and improved monitoring via expanded radar and flood gauge networks used in combination with advanced weather forecasts has enhanced the ability to predict and respond to flood events.

Effective use of observational data is enhanced by quick digitisation which allows for rapid production and sharing of standard maps and relevant spatial information that are critical for incident management teams. An example of this is the incident mapping on-line tool (IMOT) developed by the SA Department for Environment and Water (see the Appendix at Section 0).

6.4.2 Systems and technology platforms for incident information management and situational awareness

As shown in Figure 17, a common operating picture (COP) sits at the centre of incident management between intelligence, resource management and decision-making. As defined by the Australian Disaster Resilience Knowledge Hub, a COP is “a description of the shared and consistent understanding, the Incident Management Team and other stakeholders have of the incident to support decision making”. For larger-scale and complex incidents, access to a COP is also essential at the regional and state levels. A COP in a complex, dynamic environment needs to be flexible and adaptable, and provide relevant, timely information that is readily accessible in a consistent and well-understood format to ensure the safety of first responders and community, and to inform strategic and tactical decision-making between disparate entities. Developing an accurate and timely COP and maintaining situational awareness is critical across all-natural hazard events.

Multiple technology platforms and systems exist to enable reliable transmission and display of situational awareness components. These include web-based EOC (Emergency Operations Centre) management systems, COP systems, incident information management systems and incident command or control online systems. Additional technology is used to maintain situational awareness via spatial support systems or GIS based situational awareness platforms.

These technology platforms assist with effective sharing of intelligence and information flow between entities (within and across agencies) so that resources can be coordinated, prioritised and shared to meet operational requirements. Sharing of information has been identified as a critical and challenging issue, and can be the result of inherent siloed responsibilities, different systems and programs that cannot communicate with one another, or complex problems of protecting proprietary data. Table 8 summarises some technology platforms in use by jurisdictions to manage the information during emergency incidents.

Table 8 Technology platforms for incident information management used in different jurisdictions

STATE/ AGENCY	TECHNOLOGY PLATFORM FOR INCIDENT INFORMATION MANAGEMENT	
NSW RFS	ICON (Incident Control On-Line system) COP System	Multi-agency system accessible and shared with all stakeholders GIS based system
NT Emergency services	WebEOC	Web-based critical incident management information monitoring system adaptable to all hazards; supports a COP and information sharing between all relevant agencies
Qld	Queensland Disaster Management Arrangements (QDMA) Data sharing group State Disaster Coordination Centre (SDCC) Situational Awareness Platform (SAP)	Data-sharing system created within ArcGIS Online relevant to all disaster management activities across all phases of emergency events Centralised source of disaster management-related spatial data from various sources that can be utilised during an event or for planning purposes
SA CFS & MFS SA SES SA DEW	Critical Resource Incident Information Management System Online Network (CRIIMSON) SES Incident Information Management System (SESIIMS) Incident Mapping Online Tool (IMOT)	System to enhance operations and incident management activities, interagency communication, and sharing of information between agencies Based on WebEOC Mapping tool for fires, with ability to expand to other hazards
TAS PES TFS	WebEOC COP system	Multi-agency system for strategic level management and data sharing Situational awareness (fire spread predictions)
VIC Emergency Management	EM-COP	Multi-agency incident management system for situational awareness, data sharing, resource tracking for all hazards
WA Emergency Services DBCA DFES	WebEOC Spatial Support System (SSS) FES Maps	Multi-agency incident management system Situational awareness platform & resource tracking Geospatial system for all hazards
Australia	ARENA	National system for firefighting aircraft operations within Australia and New Zealand

6.4.3 Resource management system

A resource management system captures and manages the status and location of available and deployed resources to an incident including personnel, vehicles, equipment and aircraft. Effective emergency resource management ensures that available resources are easily identified and located so that they are safely, efficiently and strategically used in emergency response. Resource management starts with registration of vehicles, aircraft, equipment and personnel available (including details on skills and qualifications of deployed personnel), which can then be used for planning, tasking, tracking, and coordination of emergency response at national, state and incident levels. Figure 18 provides an overview of resource management and coordination at the national, state and incident level.

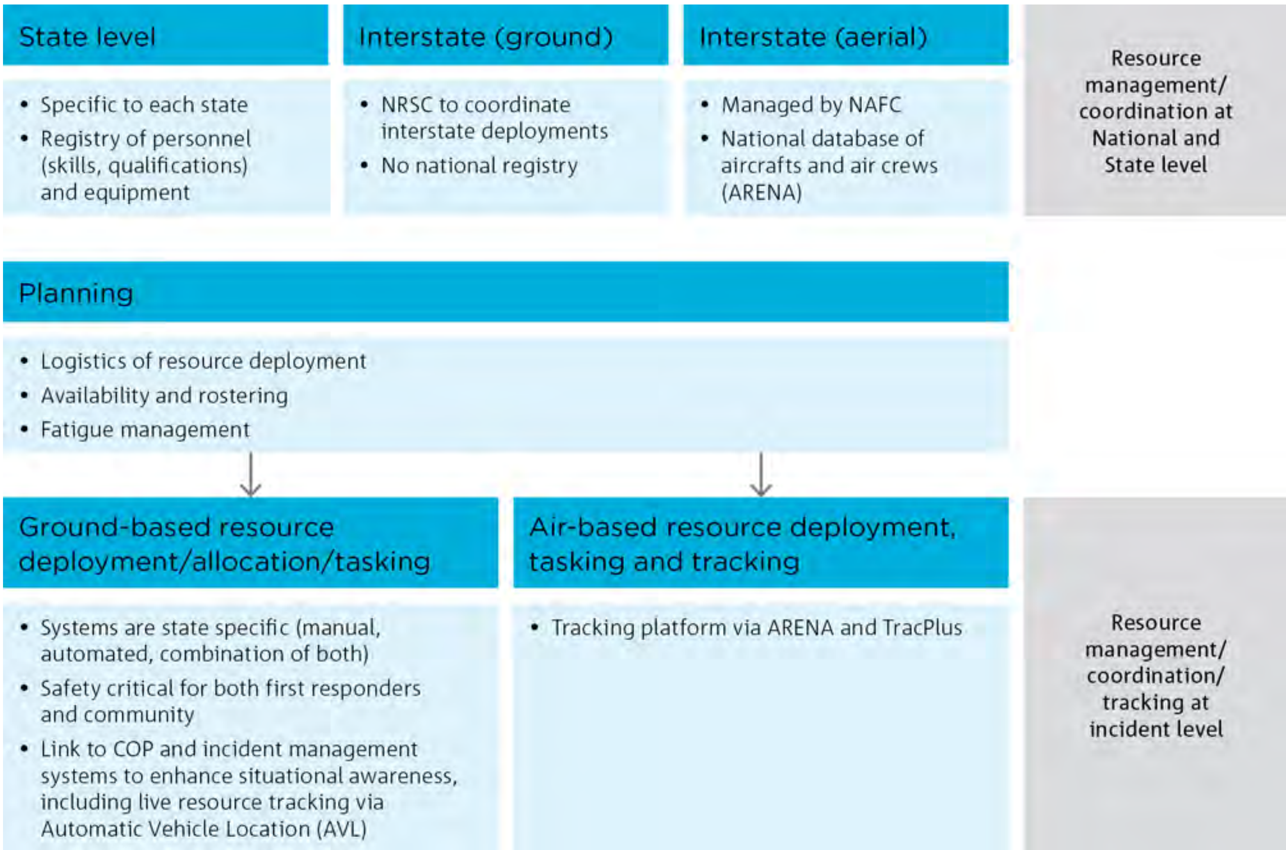

Figure 18 Overview of resource management at national, state and incident level applicable to all emergency services

The National Aerial Firefighting Centre (NAFC), formed in 2003, has a well-developed, highly regarded national resource management system (ARENA). The ARENA system is a fully integrated national system that registers the details of most firefighting aircraft operating within Australia and New Zealand. These aircraft may be required by contract to be equipped with tracking equipment that reports to ARENA and to agencies via a contracted tracking integration provider (TracPlus). Integrated data and real-time tracking and visualisation of all firefighting aircraft are made available to all NAFC members and their agencies. While the system requires standardised, consistent data attributes, each aircraft operator can select their preferred hardware and tracking provider. This is a more cost-effective and workable option compared to a "Single tracking -provider" solution and allows the provision a common operating picture of firefighting aircraft across Australia.

The National Resource Sharing Centre (NRSC) was established in 2016 to support and coordinate the deployment of interstate and international deployments of ground crews for all natural hazards. This system allows for exchange of emergency service and management expertise across jurisdictions. It enables deployment of specialised skills to areas where they may not be locally readily available or deployment of additional resources to assist with response to large natural hazard events (e.g. Cyclone Debbie, 2019/20 bushfires). While a database registry of personnel (including relevant skills and experience) exists for international deployment, there is no similar database established for interstate deployments.

States and agencies take a variety of different approaches to resource management systems and these are a mix of manual and automated systems. Career-based services that need to combine availability systems with payroll functions are generally more evolved in this area than large, volunteer-based agencies. Few agencies would be able to interrogate a system from a central location and be able to ascertain what resources they had committed, where, and what was left in reserve.

6.4.4 Community messaging and warnings

The Bureau of Meteorology plays a crucial role in providing warnings during severe weather events and supporting emergency services around Australia. Dissemination of community warnings about the potential impact of an incident, including defining triggers for action, are provided by emergency services and other statutory authorities. Fire agencies are responsible for issuing warnings during bushfires, while the SES is the lead hazard agency to provide warnings during floods. Currently there is a national approach for bushfires which will be updated as part of the AFRDS review. No national frameworks currently exist for other hazard events.

One of the findings from the 2014 National Review of Warnings and Information (Emergency Management Victoria 2014), was to optimise emergency warnings for fire and other hazards and to develop a national approach to multi-hazard public information and warnings. The development of the national multi-hazard warning system currently underway is built on existing hazard warning frameworks and is designed to be scalable to all hazards. The national warning system was expected to be endorsed in July 2020.

A national approach to hazard warnings will ensure that consistent symbols, hazard icons, warning levels and standards are used for all hazards across Australia. The system will be based on three levels of warnings with action statements at each warning level. The new warning system will also be embedded within the BoM forecasting and warning system.

6.5 Performance of knowledge systems and tools for first responders

This section provides an evaluation of the performance of systems and tools available to first responders described previously. This evaluation is based on examination of reporting from post-event reviews and inquiries into bushfires, floods, the 2016 South Australian extreme weather event and Tropical Cyclone Debbie, as well as discussion with stakeholders.

It is important to note here that wider consultation with stakeholders, and in-depth exploration of individual incidents, experiences and systems, was not possible within the scope and timeframes of this report. Rather, this process served to gather recurring themes and challenges in relation to disaster resilience that have been produced from the multiple in-depth post-event reviews undertaken in Australia over the past decade, and to highlight areas that require further exploration and identify opportunities for improvement and innovation.

When the reviews are considered in chronological order, there are tangible improvements seen in the knowledge systems, tools and technology available and the capacity of first responders to use these during disaster events, largely driven by lessons learned and research and technological developments. Common themes emerged that contributed to successful first response and highlighted the challenges and opportunities for improvement and innovation that remain. We applied these themes to inform a set of criteria to evaluate the performance knowledge systems, tools and technology used by first responders in these past events.

The criteria used to evaluate the performance of systems/tools included:

Quality, accuracy and reliability	→	confidence in systems/tools/technology
Consistency/clarity	→	data, information and communications are presented in consistent formats and are clearly defined to ensure common understanding and effective use by first responders and communities
Timeliness and currency	→	up-to-date information that enhances the ability to plan and work in a dynamic environment
Integration/inter-operability	→	ability to work in a complex environment with multiple entities able to access, share, integrate and cooperatively use information effectively
Accessibility, visibility and awareness	→	data are integrated and disseminated effectively to increase visibility of critical and relevant data

As discussed in the previous section, intelligence is the key input to systems for situational awareness, resource management, and communication that form the emergency response. Intelligence available to first responders to assess the current and forecast situation of an emergency incident include:

- ground, aerial and satellite observations
- mapping systems
- weather forecasts
- predictive modelling tools

In the following sections, the five criteria listed above will be used to examine the performance of each intelligence system as well as systems used for incident information management and situational awareness, resource management and communication.

6.5.1 Monitoring and mapping

Accurate up-to-date monitoring is key for coordinated first response, provision of reliable predictions and development of accurate maps, that assist first responders with building and maintaining situational awareness. Table 9 provides an overview of the performance of ground-based, aerial and satellite observation platforms and mapping systems in providing intelligence in past responses to disasters and potential opportunities for improvement and innovation.

Table 9 Intelligence provided by ground-based, aerial and satellite platforms and mapping systems

CRITERIA	PERFORMANCE
Quality, accuracy & reliability	New technologies provide enhanced fire intelligence (see Table 7). LiDAR (light detection and ranging) and satellite data are emerging as valuable tools to more accurately assess fuel loads, structure and condition, that are critical for fire behaviour analysis. Multi-spectral imaging by satellites provide improved spatial coverage than aerial depictions and thereby improve knowledge available to Fire Behaviour Analysts (FBAn) of vegetation, fuel, and weather for more accurate and timely fire behaviour predictions. A reliable and suitably-located rainfall and river gauge network significantly improves flood intelligence by providing real-time, on-the-ground monitoring of river conditions that assist with warning for rapid flood onsets. However, gaps in gauge network, damage to gauges during flood events, difficulty in accessing manual gauges during flood events and lack of readings from automated river gauges due to loss of telecommunication limit the capacity to maintain optimal monitoring, predictions and warnings (Blake 2017; Inspector-General Emergency Management 2019b). LiDAR imagery can further assist with developing more accurate and comprehensive flood modelling and inundation maps (Blake 2017).
Consistency	Inconsistencies in mapping systems and mapping layers can make it challenging to use information effectively (Blake 2017, Inspector-General Emergency Management 2020). Inconsistencies in flood mapping and planning impacted on effective emergency management during the 2016 Tasmanian floods (Blake 2017). The Victorian Floodplain Management Strategy (The State of Victoria Department of Environment 2016) which builds on the Government's Response to the Victorian Floods Review (Comrie 2011), is highlighted as an excellent example of a coordinated approach to flood mapping, For fire intelligence, non-consistent formats in FLIR image processing limit the full utilisation of this technology across states.
Timeliness & currency	The demand for provision of "live" information to first responders and the community is considerable. The use of multiple observational platforms (ground-based, aerial and satellite) enable frequent observations of fire movement that enhance situational awareness and fire predictions. While observations and mapping from ground-based and air observers can provide critical up-to-date local intelligence, technologies such as aerial line scanning and FLIR have the potential to provide fire mapping in near real-time at a larger spatial scale. Unless data is provided from geostationary satellites (e.g., Himawari), currency of satellite data is dependent on frequency and timing of satellite passes. Aircraft are a valuable source of near real-time intelligence. However, with stretched capacity, aerial technology resources may not be available for use in every incident (e.g. late provision of FLIR capability during the Qld fires (Inspector-General Emergency Management 2020); strain on capability due to increase in concurrent fires) or frequent updates may not be feasible. Provision of up-to-date aerial intelligence may also be limited by weather conditions and visibility. In combination with current risk assessments that map high risk areas, up-to-date observations and forecasts are critical inputs for situational awareness during events. The lack of timely intelligence can impact the safety of ground crews and assets. Early detection of lightning fires is critical and can be successfully achieved using a fire observation tower (Inspector-General for Emergency Management 2016) or aerial surveillance and remote sensing; the latter being limited in fires starting in organic soils or areas of closed canopy vegetation (Environment and Communications References Committee 2016). During flood events, provision of near real-time peak dynamics of impacted areas using aerial intelligence and up-to-date upstream river height information enable forecasting of likely impacts of rising river levels and provide timely warnings (Inspector-General Emergency Management 2019b).
Integration/ Inter-operability	The 2019 Qld Bushfire review recommended that the ability to share, analyse, interrogate and display information should be progressed as a matter of urgency (Inspector-General Emergency Management 2020). GIS-based spatial systems used across numerous agencies are a great step forward in integrating and visualising multiple data feeds. The use of different systems to produce maps can make it challenging to share them easily across entities. This can be overcome using systems such as geocoded maps which facilitate accurate transfer of information between mapping products. The Australian Flood Risk Information Portal developed by Geoscience Australia is a great way to integrate relevant data; however, issues related to data access and copyright may limit successful sharing of flood studies on the portal (Blake 2017).
Accessibility, visibility & awareness	Digital mapping data bases provide consistent and accessible spatial data products. As mapping and intelligence products are increasingly automated and digitised their accessibility is increasingly vulnerable to failures in power and communication systems which are often under pressure during events. Data ownership can be a barrier to having access to critical data that inform response actions and evacuation plans as experienced during the 2016 Tasmanian floods (Blake 2017).

6.5.2 Weather forecasts

Availability of accurate, frequent and up-to-date weather forecasts provided by the BoM are the keystone in building an accurate intelligence picture around current and forecast weather conditions for bushfires, floods and cyclones, informing predictive models, operational decision making and community warnings/messaging, as stated in Chapter 2 of the report.

Table 10 Performance review of weather forecasts provided to first responders

CRITERIA	PERFORMANCE
Quality, accuracy & reliability	In general, the post-event reviews and inquiry reports consulted here found that weather forecasts were of high value, accurate and reliable within bounds of reasonable expectation. Systematic verification work is undertaken by the BoM to monitor performance of forecasts in order to improve accuracy and reliability. Advances in numerical weather prediction modelling enable accurate weather information at increasingly higher spatial and vertical resolution. Additional technologies that have assisted bushfire response through better quality information include: BoM's improved lightning strike tracking capability enabling early fire detection (AFAC 2019); improved detection of pyrocumulonimbus phenomenon using Himawari-8 satellite images and volumetric radar to assess the structure of pyrocumulonimbus; improved weather intelligence at a meso- and micro-meteorological scale assisting with improved predictions on fire behaviour including plume depth, structure and development and spotting potential and directions (Sturgess and Peace 2019). Advancements in radar and satellite technology provide more accurate tracking and forecast of rainfall improving forecasts and predictions. Sparse networks of weather stations and radar in some areas limit forecasting accuracy.
Consistency	The BoM forecasts utilise consistent methodologies and are presented at regular intervals, using consistent, defined terminology, symbols and visualisation which are critical for issuing clear advice/warnings and alerts for first responders and communities.
Timeliness & currency	Embedded meteorologists within State Control Centres (SCC) and IMTs provide frequent weather briefings. The BoM also provides frequent, timely forecasts and alert watch/warnings to communities. The BoM's weather grid updates are provided about every 4 hours or on request by the Incident Control Centre (ICC). Accurate timing and strength of wind changes, which can be influenced by local topographical features, are critical during bushfires. In some cases, community expectations exceeded the BoM's ability to provide up-to-date observations and forecasts especially at local scales in rapidly evolving events, such as the 2016 Tasmanian Floods (Blake 2017) and the 2019/20 bushfires.
Integration/ Inter-operability	The development and validation of accurate forecasts prior to and during events is enhanced by the integration of multiple intelligence data streams into model systems. During emergency events, meteorologists are often embedded within IMTs providing weather briefings, interpretation of radar and satellite observations and timely relays of forecast uncertainty and warnings (Noetic Solutions Pty Limited 2016; Burns et al. 2017; AFAC 2019; Inspector-General Emergency Management 2019a). They assist incident controllers to interpret certainty of forecasts and understand risks. For example, during the 2018 Qld fires there was a very high demand for meteorological information, in particular for real-time interpretation to fire behaviour (Sturgess and Peace 2019). In emergency response, forecast outputs must be easily integrated into situational awareness and mapping platforms that identify high risk areas, critical infrastructure and emergency response assets and personnel. Interagency collaboration to discuss weather impacts on evolution of disasters is instrumental to disaster management.
Accessibility, visibility & awareness	Reviews indicate BoM forecasts are a key trusted source of information for first responders and the public during events and are accessed via a variety of digital platforms (websites, apps) and the media especially via the ABC, Australia's official emergency broadcaster. In terms of forecast inputs, the BoM's access to intelligence data for forecasting can be limited by complex access arrangements as a result of multiplicity in data streams, ownership, and technology (Example: flood gauge systems).

6.5.3 Predictive tools

The availability of predictive data and intelligence for fire behaviour, flood studies and modelling are valuable and important to enable first responders to make strategic and tactical decisions, identify high risk areas for target response and anticipate likely impacts.

Post-event reviews and inquiries into bushfires highlighted that predictions directly influenced key decisions (e.g. suppression strategies, community warning messaging, evacuations) (HCB Dillon 2015; IGEM 2016; AFAC 2019). As an example, during the 2015 Wye River-Jamieson Track fire, "the detailed options analysis considering weather, fuel loads, risks to communities, assets and consequences of failure resulted in effective strategy planning and implementation that most likely contributed to the successful outcome of preserving life and minimising further losses" (Inspector-General for Emergency Management 2016). Similarly, products from Phoenix fire spread simulator used in conjunction with QFES's Simulation Analysis-Based Risk Evaluation (SABRE) user interface provided an estimate of uncertainty in predictions, which "directly influenced decisions" in the 2018 Qld Bushfires (IIGEM 2019a).

The performance of predictive tools is highly dependent on currency of the data inputs, consistent approaches, availability and quality of data/information and suitable scale. This section focuses on performance of fire spread predictions as described in Chapter 2 (Table 11) and the air quality forecasting system that assisted with managing smoke hazards to health, aviation and the Australian Defence Force operations during the 2019/20 bushfire season.

Table 11 Performance review of fire predictive tools available to first responders

CRITERIA	PERFORMANCE
Quality, accuracy & reliability	Availability of accurate and reliable intelligence (e.g. fuel load, fire location) that feeds into predictive models is essential to produce high quality, accurate and reliable outcomes. Quality and accuracy of predictive tools are critical for emergency services to have confidence in their outputs; uncertainty in model predictions can prove challenging for emergency service managers (HCB Dillon 2015). Inaccurate predictions can have flow-on effects on accurate and timely community messaging and warnings. There needs to be clarity around limitations of predictive models and the reliability of predictions to ensure that there is not an over-reliance or diminished trust in these tools. Guidance for first responders as to the practical limits of predictions is critical. As the sophistication and capacity of fire simulators develops, their accuracy improves. However, there are still limitations which need to be understood, for example, identified limitations occur under extreme fire behaviour and weather conditions (e.g. highly stable or unstable atmospheric conditions). Expert fire behaviour analyst (FBAN) skills are essential for interpretation of model outputs (Plucinski et al. 2017).
Consistency	Extensive and exhaustive options analysis is a key part of strategy planning. Running and interpretation of predictions is highly dependent on skilled personnel and may not always have consistent methodologies.
Timeliness & currency	In a dynamic fire, predictions of fire spread require timely information on the present fire situation which can be challenging (Ferguson 2016). New EO technologies can provide more timely and current information on fire location and progression (see Table 7). Availability of aerial intelligence may be limited at night which restricts information on the fire location and behaviour to observations on the fire ground (Ferguson 2016).
Integration/ Inter-operability	As fire spread predictions are important for building situational awareness and to ensure safety on the fire ground, frequent updates and sharing of predictive modelling information between operational levels and agencies are important. Reviews have identified instances where this worked effectively (Department of Fire and Emergency Services 2016), and opportunities for improvements in the timely sharing of predictive fire predictions especially in the early stages of a fire (Noetic Solutions Pty Limited 2016). The use of different fire prediction systems and tools between agencies can create delays in reconciling outputs and agreeing on a common view of likely fire behaviour and tactical/strategic decisions (Department of Fire and Emergency Services 2015). Effective integration of up-to-date EO products enables continuous refinements of model forecasts which improves accuracy of predictions.
Accessibility, visibility & awareness	FBAN training and skilled expert advice are required for interpretation of outcomes and predictions being relayed to IMT, to minimise the risk of over-reliance on predictive models (Plucinski et al. 2017; Inspector-General Emergency Management 2019a). For fire spread predictions to effectively support situational awareness, they need to be included in situation reports (Noetic Solutions Pty Limited 2016).

Adoption of CSIRO's Spark (see Chapter 2) as the national bushfire simulator has significant benefits in providing an integrated and consistent approach to fire predictions across jurisdictions. Spark is consistent with the emerging Australian Fire Danger Rating System (AFDRS) and includes a wide range of fire behaviour models that cover most of the Australian vegetation types. It is flexible to evolve with new scientific development, such as inclusion of fire-atmosphere feedbacks.

Performance review of the air quality forecasting system (AQFx)

The 2019/20 bushfire season highlighted the significant impact of smoke on communities with an estimated 417 deaths and over 3000 hospital admissions for cardiovascular and respiratory illness (Borchers-Arriagada et al. 2020), as well as impacts on industries (e.g. viticulture estimated $40+ million losses (ABC 2020a)). This section will discuss how AQFx can assist fire and emergency services and other stakeholders to forecast and manage smoke impacts.

The multi-tiered AQFx system was initially designed to support Victorian Government decisions on whether and where to safely conduct fuel reduction burns to minimise community exposure to smoke. During the 2019/20 fire season, the smoke forecasts provided by AQFx focussed on bushfire activity and were used in Victoria and NSW to help manage hazards to health, aviation and Australian Defence Force operations.

Performance of AQFx forecasts

Figure 19 and Figure 20 show the AQFx forecast of airborne particles (including smoke and dust) in comparison to visible satellite imagery taken by a multi-spectral camera on Himawari-8, a Japanese geostationary weather satellite during the same time period. The observed fire hotspots (red dots) are also shown in the Himawari-8 images. The colours in the AQFx plots indicate forecast ground-level particle concentrations. The concentration ranges are consistent with the Victorian State Smoke Framework (Teague et al. 2014).

Figure 19 shows Himawari-8 images and AQFx forecasts of particles for Victoria for 20 December 2019.

Both the AQFx forecast and Himawari satellite image show how the Alpine region formed a physical barrier to the smoke plumes from fires in the north and south of Victoria.

Figure 20 shows the AQFx forecast of particles for south-east Australia (Victoria, Tasmania, and NSW) for 21 December 2019 in comparison to visible satellite imagery during the same time period. The forecast clearly highlights the scale of the air pollution, with elevated concentrations of fine particles spanning multiple states and territories. This demonstrates the need for a national approach into smoke forecasting.

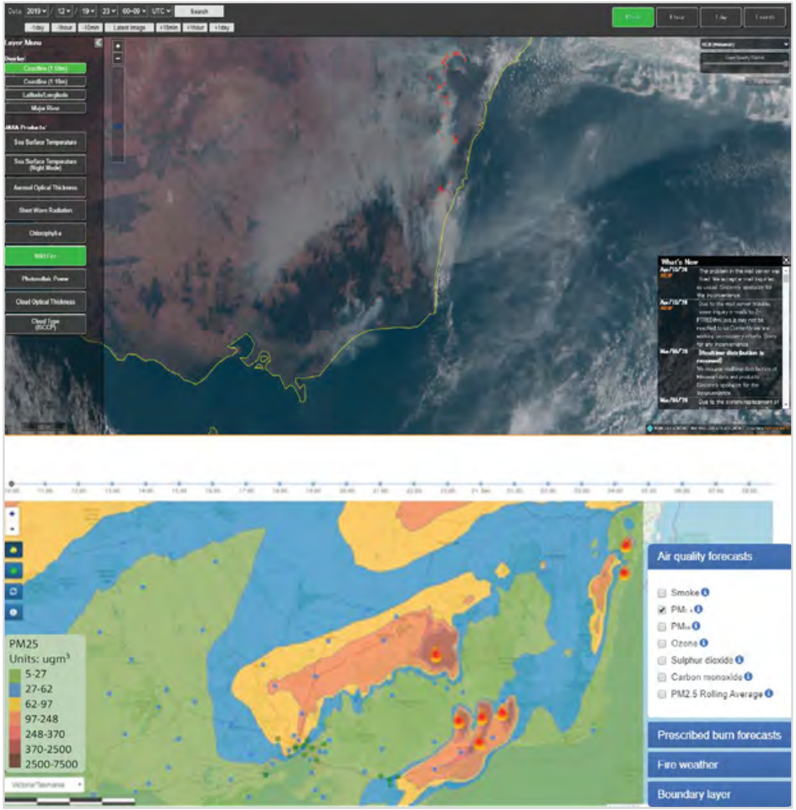

Figure 19 Visible satellite images taken by Himawari-8 on 20 December (top); AQFx combined fine particle forecast for Victoria domain for 20 December (bottom)

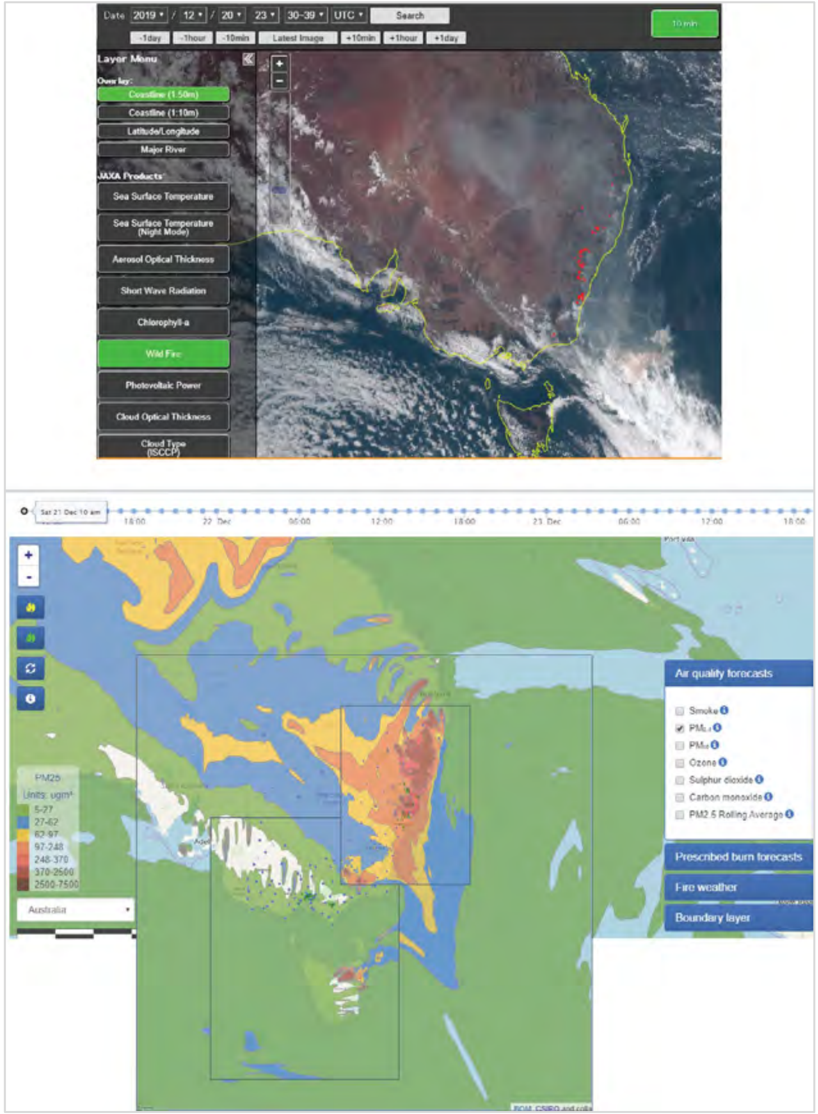

Figure 20 Visible satellite images taken by Himawari-8 on 21 December (top); AQFx combined fine particle forecast for Vic-Tas and NSW domains for 21 December (bottom)

Use of AQFx forecasts during the 2019/20 bushfire season

During the 2019/20 bushfire season, EPA Victoria used AQFx forecasts in combination with ground-based air quality observations to inform community health messaging via daily air quality forecasts. Figure 21 shows how this messaging was packaged for the community, with the AQFx forecasts being automatically processed to generate region-specific advisories for the following three days.

DISTRICT	TODAY	Mon, 13 Jan	Tue, 14 Jan	Wed, 15 Jan
MALLEE	GOOD	POOR	POOR	GOOD
WIMMERA	GOOD	POOR	POOR	GOOD
NORTHERN COUNTRY	MODERATE	POOR	MODERATE	POOR
NORTH EAST	POOR	VERY POOR	VERY POOR	POOR
EAST GIPPSLAND	VERY POOR	VERY POOR	HAZARDOUS	HAZARDOUS
WEST AND SOUTH GIPPSLAND	MODERATE	VERY POOR	POOR	VERY POOR
CENTRAL, INCLUDING MELBOURNE	MODERATE	VERY POOR	POOR	VERY POOR
NORTH CENTRAL	MODERATE	VERY POOR	POOR	POOR
SOUTH WEST	GOOD	POOR	POOR	MODERATE

Figure 21 Screenshot of a region-specific summary four-day air quality forecast provided by EPA Victoria 12-15 January 2020 distributed via Facebook.

Similarly, NSW RFS used AQFx to provide smoke advisories to communities and at times to inform aircraft operations locally and State-wide. For fire agencies, one of the valuable attributes of the system is that it combines the smoke modelling and meteorological products. The meteorological products were often used for analysis in conjunction with the smoke modelling.

Further development and improvements to AQFx

AQFx is an emerging tool that has the potential to provide significantly improved smoke forecasting for bushfires and planned burns. The smoke forecasts will assist emergency services in managing the impact of smoke on public health and can also be applied to road safety and other industries such as aviation and viticulture. Several post-event reviews addressed concerns due to smoke impacts on health (AFAC 2016; Environment and Communications References Committee 2016; Ferguson 2016; Inspector-General for Emergency Management 2016; Emergency Management Victoria 2019), implementation of road closures due to safety concerns related to the potential for smoke (Hyde 2013; Inspector-General for Emergency Management 2016; Inspector-General Emergency Management 2019a) and the potential impact on viticulture (Hyde 2013). During the 2018 fires in south west Victoria, dense smoke over a prolonged period due to burning peat required comprehensive smoke management to ensure the safety of emergency services personnel and the community (Emergency Management Victoria 2019). The implementation of the smoke management arrangements and procedures were guided by the Victorian State Smoke Framework that was developed in response to the 2014 Hazelwood Mine Fire (Teague et al. 2014).

Further validation and improvement to AQFx are needed to address a number of challenges that reduce its effectiveness and user confidence in its outputs. These include:

- Challenges in forecasting the magnitude of peak smoke concentrations during prolonged smoke events.
- The lack of flexibility in configuring (and rapidly updating) fire behaviour inputs is limiting its potential to accurately forecast smoke and reduces its reliability. For example, backburning operations cannot currently be added to the system resulting in inaccurate smoke predictions.
- Usefulness of overlaying AQFx outputs and population density to provide more detailed risk-scored intelligence.

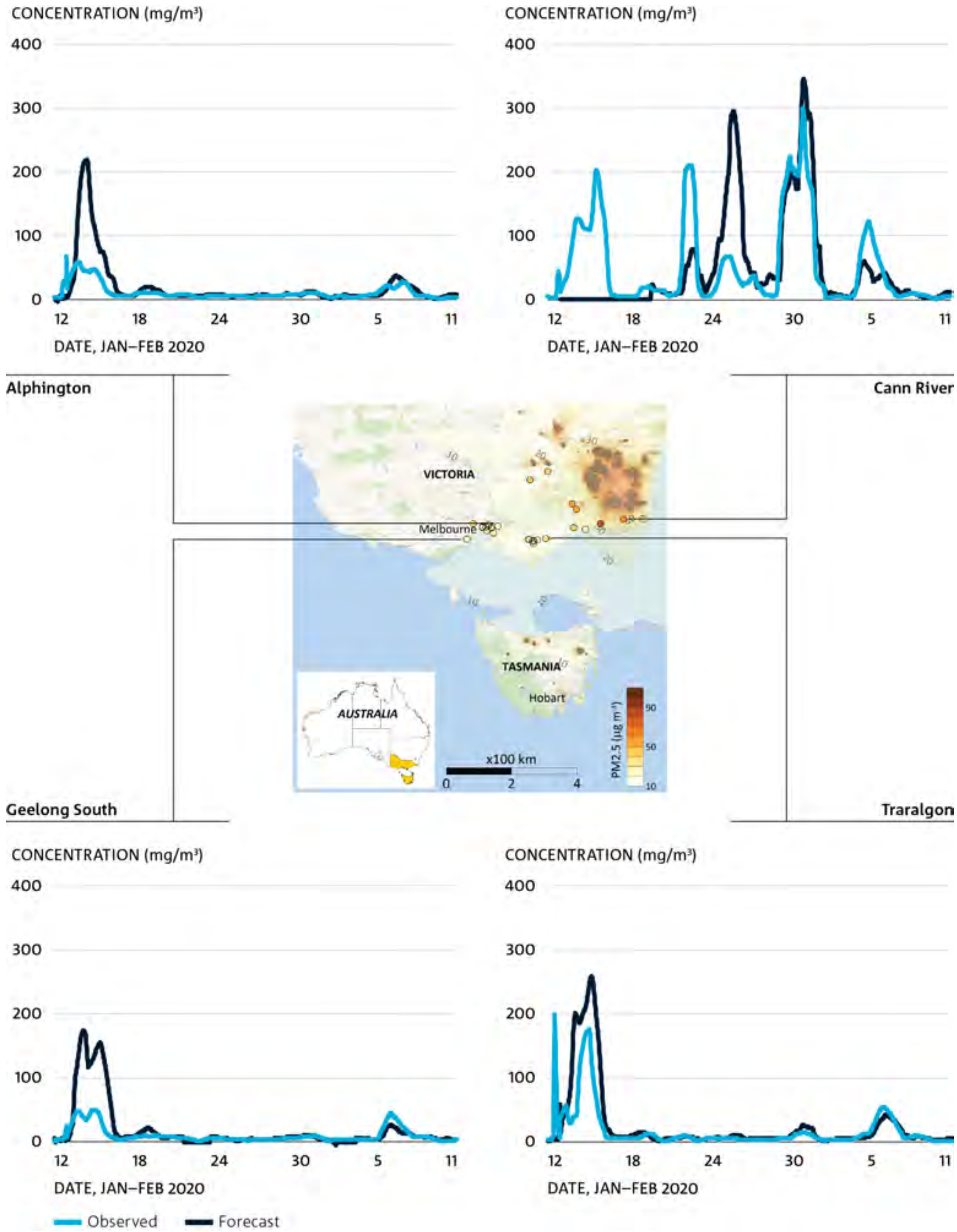

Figure 22 The spatial plot shows the average forecast (contours) and observed (coloured circles) PM2.5 concentrations for the period 12 January-12 February 2020. The time series plots show the forecast and observed 24-hour average PM2.5 concentrations (the horizontal line shows the 24-hour PM2.5 ambient air quality standard)

6.5.4 Systems and technology platforms for incident information management and situational awareness

Post-event reviews and inquiries have highlighted the need for establishing procedures that allow rapid production and dissemination of intelligence and facilitate effective interagency coordination for large-scale emergencies (AFAC 2013; Hyde 2013; Department of Fire and Emergency Services 2016; Noetic Solutions Pty Limited 2016; Burns et al. 2017; Office of the Inspector-General Emergency Management 2017; Inspector-General Emergency Management 2019a). A case study that compared aspects of state-level incident management approaches also highlighted the challenges associated with operating multiple systems and technology platforms in an incident, and achieving effective multi-agency emergency management coordination (Bhandari and Curnin 2012).

Due to the multiplicity and constantly evolving nature of systems for situational awareness, data sharing and incident information management, the following discussion serves to highlight important factors in their performance. More detailed information on the various technology platforms is provided in the Appendix at Section 0. Some of the limitations that inhibit effective decision making and provide accurate situational awareness include:

- Inter-operability, integration and connectivity between levels of agencies, platforms and systems
- Data sharing and availability of data feeds
- Timeliness of data and intelligence feeds
- Visibility and accessibility
- Awareness, training and understanding of available resources
- Technical capacity and volume
- Reliable communication infrastructure.

Table 12 provides an overview of factors which affect the development of a common operating picture, situational awareness and interagency information sharing.

Table 12 Performance review of developing a common operating picture to build situational awareness and interagency information/intelligence sharing

CRITERIA	PERFORMANCE
Quality, accuracy & reliability	The quality and accuracy of intelligence (forecast, maps, on-ground incident reports) underpins situational awareness. Post event reviews reported instances of poor situational awareness potentially hampering incident management and public messaging. This potentially put crews and communities at risk (Department of Fire and Emergency Services 2015; Noetic Solutions Pty Limited 2016) and highlights the need for succinct, accurate and reliable situation reports and up-to-date incident logs accessible to all agencies to improve situational awareness (Inspector-General Emergency Management 2019b). These would enable informed decision-making that protects the safety of public and first responders and assists with effectively managing resources.
Consistency	Situational awareness is not always adequately communicated back to decision makers and the public. There is a need to ensure that consistent situational awareness is achieved at every level. Incident management systems or COP systems aim to provide effective communication, but good reporting capabilities, including a consistent approach to data formats and information inputs into incident management systems are required to reduce time lags and optimise the information flow for accurate and timely decision-making (Department of Fire and Emergency Services 2015). For example, during the 2018 fires in south-west Victoria the "use of intelligence and the sharing of information between the operational layers of the incident, region and state was challenged by the protracted nature of the complex fires and inconsistencies in the use of information technology systems" (Emergency Management Victoria 2019).
Timeliness & currency	Regular updates of fire behaviour, fire predictions and spot weather forecast are critical to maintain situational awareness at all times. Ground crews and air observers who are in constant communication with the Incident Control Centre, as well as line scans and near real-time feeds from satellites, can provide valuable situational awareness. Considering the dynamic, and often data-rich operational environment, there is a significant opportunity to use augmented intelligence systems to assist with managing information flow in a timely manner (Burrows 2019). Real-time task sharing and situational awareness through streamlined and automated exchange of information enables a more efficient response.
Integration/ Interoperability	Post-event reviews and inquiries highlighted that although information sharing has improved (Inspector-General Emergency Management 2019b), there is further work needed to better integrate various technologies that are used for data sharing, visualisation and analysis and to achieve full interoperability (Burns et al. 2017; Office of the Inspector-General Emergency Management 2017). In the past, complex, multi-agency responses to events have suffered when incident management systems were not integrated resulting in duplication of efforts, confusion, potential errors and conflicting messages (Burns et al. 2017; Office of the Inspector-General Emergency Management 2017). Breakdowns in communication and information flow between SCC, IMT and ground crews impact on situational awareness (Department of Fire and Emergency Services 2016). Both vertical and cross-agency communication are critical during emergency events and improvements in cross-agency

CRITERIA	PERFORMANCE
	platforms, such as EM-COP (VIC), WebEOC (WA, TAS, NT) and CRIIMSON and SESIIMS (SA), can help facilitate this process. In the Major Incidents Report 2018-19 (Australian Institute for Disaster Resilience 2019), observations from the WA 2019 bushfires stated that "Open, honest and valued interagency communication provides greater understanding of specific agency needs, enabling timely and accurate decision making".
Accessibility, visibility & awareness	Technical barriers to developing and distributing a COP may inhibit developing and sharing situational awareness. When using multiple incident information management systems at a coordinated emergency event, it may be difficult to know which system to access for specific and up-to-date information (Burns et al. 2017), creating potential confusion and delayed response. It is critical to have information visible and accessible to all entities at state and local level to aid with decision making and minimise risk of conflicting decisions being made (Office of the Inspector-General Emergency Management 2017). Information confidentiality has been flagged as a barrier to intelligence sharing on platforms that provide access to multiple entities. This can be overcome by either restricting user access to sensitive information or by enhancing trust that sharing information will not adversely affect those who own the information (Office of the Inspector-General Emergency Management 2017). During the Hobart flash flooding (May 2018), the WebEOC platform was a valuable and trusted tool to share critical intelligence between entities (Australian Institute for Disaster Resilience 2018a). Similarly, open, honest and valued interagency communication led to timely and accurate decision making during the WA 2019 Bushfires (Australian Institute for Disaster Resilience 2019).
Training	While the cross-agency, inclusive management systems provide a common platform for intelligence gathering, analysis and sharing, the data-rich environment can be challenging to effectively process and navigate without adequate training (Department of Fire and Emergency Services 2016; Burns et al. 2017). Reporting capabilities of these systems are dependent on the timely updating of situation reports, incident action plans, requests and logs within the system and on personnel understanding how to use the systems effectively (Department of Fire and Emergency Services 2015). Appropriate training for operators and end-users of these systems is key to unlocking the full potential of these technology platforms.
Technical capacity	Reliable and sufficient ICT capacity is required to run integrated systems capable of dealing with high volumes from multiple data feeds in a timely manner. Although the COP is not a technology platform, technological resources are required to develop and distribute a COP.
Communication	Increasing reliance on mobile and computerised systems requires reliable and robust phone and internet connectivity and IT setups at ICC, which was not always available (Department of Fire and Emergency Services 2016; Burns et al. 2017). Reliable radio communication is also critical to relay intelligence between ground crews and IMT and between jurisdictions (Department of Fire and Emergency Services 2016; Noetic Solutions Pty Limited 2016; Inspector-General Emergency Management 2019a; Inspector-General Emergency Management 2020).

Following the recommendations of post-event reviews and inquiries, emergency management agencies have implemented changes to their incident information management systems to create a more integrated approach across jurisdictions. This enables a COP of emergency incidents to be shared across multiple entities, providing a more efficient and transparent approach to deal with emergencies, assist with building and maintaining situational awareness, and enhance cross-agency collaboration and information sharing. Examples include EM-COP, an all-hazard platform implemented by Emergency Management Victoria (EMV); WebEOC implemented in Tasmania, Western Australia and NT, CRIIMSON and SESIIMS in South Australia, and the Queensland Disaster Management Arrangements (QDMA) Data Sharing Group. These cross-agency platforms in conjunction with GIS-based technology for situational awareness, aim to assist with interagency communication during complex incidents and increase visibility of allocated and available resources. Tools used to maintain situational awareness provide the ability to monitor events in near real time in a GIS-based mapping system. Additionally, automated vehicle location (AVL) technology, which enables the real-time tracking of resources, has been more widely adopted across emergency services with live data feeds linked into the COP systems or situational awareness platforms.

The ideal is to have a fully integrated situational awareness platform for first responders and community safety with the following capabilities:

- Fast and reliable gathering, processing and analysis of live data feeds that are shared and utilised between front line, IMTs and public, that are accessible across agencies within states and between states. A consistent and coordinated approach of provision and visualisation of information for cross-border emergency events has been a critical and challenging issue highlighted during the 2019/20 fire season.
- Near real-time situational awareness obtained through data feeds, maps, and live imagery that can be integrated into a mobile data platform (like those used by urban fire agencies), accessible in SCC, IMT and fire ground and able to assign tasks. Briefings and task allocations could be done en-route to the emergency event, so that first responders can arrive to an incident with a clear understanding of hazards, priorities and tasks. Platforms have already been developed in various formats by agencies and are being updated as new technology becomes available. The reliability of these mobile platforms is dependent on reliable communication technology.
- Real-time tracking of resources through national implementation of AVL to ensure the safety, health and well-being of first responders.
- Radio network inter-operability to ensure that agencies can directly communicate with each other.
- Improved communication resilience and technology as transmission and connectedness are key to supporting situational awareness.

A continual stream of information is vital to maintain situational awareness and develop a COP. This dynamic, complex and information-rich operating environment can prove challenging to achieve effective processing, integration and sharing of intelligence. Innovations in augmented and artificial intelligence (AI) have the potential to play a role in managing and integrating the large information flow to provide smarter, faster and more efficient emergency response. For instance, given the resources already spent on existing systems, it may be more cost effective to develop data analytics/AI approaches to integrate disparate data streams rather than shift to universal systems (ABC 2020b).

6.5.5 Resource management systems

Effective management and coordination of resources was highlighted as a significant issue in the majority of post-event reviews (Department of Fire and Emergency Services 2015; Department of Fire and Emergency Services 2016; Ferguson 2016; Inspector-General for Emergency Management 2016; Burns et al. 2017). As each agency operates its own resource management system to capture and manage available resources and track the status of resource allocation to an incident, a lack of integration between systems can be challenging for cross-agency resource management and for enabling forward planning of resourcing and adequately managing fatigue of personnel during large-scale emergency events. A common recommendation from post-event reviews and inquiries was to adopt an emergency services resource management and tracking system that can provide more effective logistical support and reduce the exposure to risk for the deployed personnel (Department of Fire and Emergency Services 2015; Department of Fire and Emergency Services 2016; Ferguson 2016; Inspector-General for Emergency Management 2016; Burns et al. 2017). Improved awareness of the location of operational resources on fire and flood grounds was also highlighted in reviews (HCB Dillon 2015; AFAC 2016; Burns et al. 2017; Office of Emergency Management 2018; Lessons Management Centre 2019),with the Bega Valley Fire Review, stating that "Automatic Vehicle Location capability will offer the opportunity to fight fire with the quickest and most appropriate resource regardless of agency" (Office of Emergency Management 2018).

Table 13 Performance review of resource management based on post-event reviews and inquiries

CRITERIA	PERFORMANCE
Quality, accuracy & reliability	Accurate records of deployed resources are important to ensure both personnel safety and effective resource planning. While a manual tracking system is effective for small and medium incidents, integrated computerised resource management and tracking systems provide more effective resource management for large and complex incidents involving multiple entities. A breakdown of systems and processes for deployment and tracking of resources (Department of Fire and Emergency Services 2015; Ferguson 2016; Noetic Solutions Pty Limited 2016), and discrepancies in deployed and logged resources (Inspector-General for Emergency Management 2016), potentially impact firefighter safety and the effective allocation of available resources. AVL assists with accurate tracking of vehicles on the fire ground with the information displayed in the COP systems or situational awareness platforms. AVL is currently not used across all jurisdictions.
Consistency	Post event reviews reported instances where prolonged events such as the Qld Floods and the 2018 South west fires in Victoria strained resources leading to personnel fatigue (Emergency Management Victoria 2019; Inspector-General Emergency Management 2019b). A consistent approach to resource management and deployment minimises the risk of either under-utilisation of available resources or fatigue due to long shifts resulting from long deployment and commute times and enhances timely and effective resource allocations.
Timeliness & currency	Due to rapid changes during emergency events, timely and regular reports on crew location and availability are critical for incident controllers to effectively distribute resources and ensure personnel safety. In some instances, this information was not always available to IMT (Department of Fire and Emergency Services 2016; Noetic Solutions Pty Limited 2016). In the absence of automated systems, tracking the location and status of all deployed resources during a coordinated response of a major emergency event can be a time-consuming task within the IMT, resulting in delayed resource allocations and valuable time which could have been spent on other critical tasks.
Integration/ Inter-operability	Cross-agency resource management has shown to be challenging, resulting in reduced visibility of resources deployed, capacity to enable forward planning of resources, and potential issues with fatigue management of crews. These challenges are being addressed through implementation of integrated cross-agency resource management systems that “enable authorities to make sensible, strategic decisions about the allocation of limited resources and the location of their personnel and assets” (Inspector-General Emergency Management 2019a).
Accessibility, visibility & awareness	Low visibility of deployed and available resources across agencies make it challenging to plan, manage and coordinate resource deployments effectively. Manual systems to allocate and track resources rely heavily on verbal communication (radio or mobile) which is likely to increase congestion (see communication) and is prone to breakdowns. The 2016 extreme weather event in SA which resulted in widespread blackouts exposed some of the vulnerabilities of SES ICT equipment to power and communication failures and highlighted the need for redundancy in these critical systems (Burns et al. 2017).

The recommendations from the post-event reviews and inquiries led to the implementation and adoption of cross-agency incident resource management systems (IRMS) (e.g. adopted in WA) with the intent to improve inter-operability at multi-agency incidents, increase visibility of available and allocated resources, facilitate planning of deployments and assist with fatigue management.

Better systems to monitor first responders’ exposure to heat and smoke and manage fatigue would also be valuable. Fatigue management was raised as a concern in several post-event reviews (Department of Fire and Emergency Services 2015; Ferguson 2016; Burns et al. 2017; Lessons Management Centre 2019; Inspector-General Emergency Management 2019a), as shift hours were not tracked and were inconsistent due to resourcing challenges.

Climate variability and change are contributing to more extreme weather events as well as longer and often overlapping fire seasons across Australian states, with increasing severity and frequency of bushfire events occurring within prolonged fire seasons. Consecutive and compounding events as highlighted in Chapter 2 are also more likely to occur in the future, engaging all emergency services. Resource management planning and preparedness will need to account for more extreme, long-lasting, consecutive and compounding events. Consequently, resource sharing within and between states and emergency services will become increasingly subjected to pressure from competing demands, requiring well-functioning integrated and strategic resource management and tracking systems at incident, state and national level (AFAC 2019, Lessons Management Centre 2019). A good example of effective resource sharing across emergency sectors was the utilisation of trained SES officers to refill aircraft with water during the 2019 Qld fires. This allowed for trained fire fighters to be freed up to fight fires. The Review stated that this “case study represents good practice in capability integration and inter-operability and demonstrates how service areas within QFES shared capacity to reduce the impact of the fires on the community” (Inspector-General Emergency Management 2020). Similarly, Surf Life Saving Queensland crews were tasked by Emergency Management Queensland to assist with evacuations across south-east Queensland during the 2011 Brisbane floods (SLSQ 2020).

While a database registry of personnel (including relevant skills and experience) exists for international deployment, there is no similar database established for interstate deployments, resulting in the lack of a consistent picture across Australia of where and when resources are deployed. The approach of the NAFC in managing aerial resources could be considered by the NRSC to improve the national coordination of interstate deployments of ground crews and assets both for fire and flood grounds. Such a system would streamline the resource sharing process and make it easier and more efficient to manage and coordinate deployments. However, this requires significant funding (potentially jointly funded by AFAC member agencies and the Commonwealth) and standardisation of resource typology. For such a system to work, it also requires all hazard emergency services from states and territories being able to provide more robust advice as to what resources they have available for deployment taking into account

i) Total resources available

ii) Resources currently committed

iii) Resources required for strategic reserve ‘in-state’.

6.5.6 Incident area and inter-agency communication technology

Effective, reliable two-way communication is a critical factor that links all phases of emergency response from intelligence through situational awareness and resource management to incident response and public awareness. In this section, an assessment of communication factors relevant at the incident area and inter-agency level is provided, with a separate assessment of community messaging and warnings provided in the proceeding section.

During an incident, agencies and their first responders on the ground typically rely on radio, mobile and internet platforms for communication. Post event reviews have emphasised issues in achieving reliability and inter-operability and the call by the Australian emergency services for a dedicated broadband data network to support the existing narrowband communications. A formal evaluation on whether such a network would be the most efficient way to provide more reliable and effective means to communicate and co-operate should be progressed.

Table 14 Performance review of on the ground communication

CRITERIA	PERFORMANCE
Quality, accuracy & reliability	Effective response to an emergency event heavily depends on reliable communication which is paramount to protect people and critical infrastructure during major emergency events (see also Chapter 8). Issues with mobile coverage and radio frequency, congestion and communications infrastructure which is damaged or is unreliable, can lead to communication breakdowns and potentially put first responders and the public at risk (Queensland Floods Commission of Inquiry 2012; Department of Fire and Emergency Services 2016; Noetic Solutions Pty Limited 2016; Inspector-General Emergency Management 2019b). The Qld flood reviews of 2012 and 2019 underlined that "ongoing enhancement of communication technology is vital for the effective management of emergencies and disasters, and the safety of emergency responders" (Queensland Floods Commission of Inquiry 2012; Inspector-General Emergency Management 2019b).
Consistency	Confusion with radio channels and agency-specific lines of communication can result in communication breakdowns during multi-agency incidents (Queensland Floods Commission of Inquiry 2012; Department of Fire and Emergency Services 2015). Regular training and clear protocols in the use of radio networks will maximise the efficiency and effectiveness of radio communication (Burns et al. 2017).
Timeliness & currency	Unreliable communication infrastructure resulted in delayed or no communication between IMT and crews on the fire ground (Department of Fire and Emergency Services 2015; Department of Fire and Emergency Services 2016; Noetic Solutions Pty Limited 2016). This can also lead to a delay in receiving critical data feeds.
Integration/ Inter-operability	Lack of integrated communications technologies between entities impacts the effective interoperability at state, regional and local levels (Queensland Floods Commission of Inquiry 2012; Inspector-General Emergency Management 2020), which has also been highlighted in the 2019/20 fire season.
Accessibility, visibility & awareness	Limited connectivity or IT capacity at ICC can affect access to computerised communication, resource or incident management systems, which hampers effective functioning of the IMT (Noetic Solutions Pty Limited 2016; Emergency Management Victoria 2019). Due to an increasing use of automated and digitised systems that improve efficiency, there is a need to have back-up systems and redundancy in ICT infrastructure.

6.5.7 Community warnings and messaging

Community information and warnings are a key component in managing emergencies and are used to empower the public to make informed decisions about their safety prior to and during events. The handbook on Public Information and Warnings (Australian Institute for Disaster Resilience 2018b) is intended to support organisations in developing and disseminating community information and warnings. Reflections on key elements of community warnings and messaging from post event reviews were as follows.

Warnings and alerts are more effective when:

- communications use plain language
- the community receives relevant, timely, consistent and easy to understand information
- they meet the needs of the community
- they are linked to actions to ensure public are aware of ways of mitigating adverse effects of an event
- they are tested for understanding and effectiveness.

While there needs to be a 'single point of truth' approach to avoid conflicting messaging, the dissemination of warnings and messaging to communities is most effective when using multiple channels of communication. While apps such as 'Vic Emergency' and NSW 'Fires near Me' have proved to be valuable messaging platforms, more needs to be done to provide a consistent approach for cross-border emergency events. The lack of universal language/messages in communication with the public (e.g. different warning levels and symbols across states) and different alerting apps, created confusion. The 2019/10 bushfire season reinforced the need for a unified national approach for warning mechanisms across all hazards (see Chapter 2).

Table 15 Performance review of community messaging

CRITERIA	PERFORMANCE
Quality, accuracy & reliability	Accuracy of operational systems is critical for community to trust and accept the reliability of the community messaging information. There was an overall positive feedback on focused safety messaging and safety-critical warnings to the public (AFAC 2019; Inspector-General Emergency Management 2020). Pro-active and open engagement with public by live-streaming of community forums with authoritative speakers to provide timely, accurate and relevant situational information and key messages resulted in better informed and more proactive communities (AFAC 2019; Emergency Management Victoria 2019; Inspector-General Emergency Management 2020). Concise, clear messages with instructions were acted upon. Simple messaging that included fire locations and direction maps were more effective (Office of the Inspector-General Emergency Management 2017; Inspector-General Emergency Management 2020). Apps are considered a valuable messaging and warning platform providing the community with real-time updates, interactive mapping and clear, simple messaging. There were reports of instances where messaging being sent out was not accurate and did not reflect what was happening on the ground, i.e. road closures (Inspector-General Emergency Management 2020). Reference was also made to messages being too focused on the short term and not on the future development of a fire or flood event that would have enabled communities to develop appropriate responses (Noetic Solutions Pty Limited 2016).
Consistency	Consistent defined terminology, symbols and visualisations enhance messaging (Office of the Inspector-General Emergency Management 2017; Spatial Source 2020). Having different warning mechanisms and thresholds within each state creates confusion, as highlighted in the 2019/20 bushfires when fires burnt across multiple states. Linking and referencing messages from different sources ensured that a consistent understanding of the emergency event was conveyed to the community (Inspector-General Emergency Management 2019b). There is a potential of 'warning fatigue' for protracted and significant incidents (AFAC 2019).
Timeliness & currency	Timeliness is a critical factor, and the chain of approval for messaging can result in unacceptable time lags. Delays in operational information feed during fast moving fires can result in delays updating community messaging (Noetic Solutions Pty Limited 2016; Office of Emergency Management 2018). Errors in predictions can result in no alerts or inaccurate messaging being issued to community (HCB Dillon 2015).
Integration/ Interoperability	Lack of integration of apps between states presented an issue at state borders during the 2019/20 bushfire season (Spatial Source 2020). The lack of spatial information across borders (Victoria/NSW and SA/Victoria) caused significant hurdles to the public to understand the fire situations and work out evacuation routes at State borders. Effective linkages between multiple entities was integral to successful community engagement(Inspector-General for Emergency Management 2016). An 'all-hazards' approach such as 'Vic Emergency' app allows integration of alerts relating to multiple incidents i.e. fires, road closures, air quality.
Accessibility, visibility & awareness	Awareness is increased by the use of multiple communication platforms including agency websites, smart phone apps (considered a great way for community messaging), social media, broadcast media, mobile phone messages, 1800 information line and door knocking. This ensures that messaging also reaches those with no or limited internet connectivity and meets the needs of diverse communities. More can be done to improve visibility of reliable sources of information and provide mutual links. Multiple end-user channels can be confusing in particular for tourists and people not living in hazard-prone areas (Spatial Source 2020). Community meetings (face-to-face or live streamed) are greatly valued (Emergency Management Victoria 2019, Inspector-General Emergency Management 2020). There are opportunities to further improve engagement practices with key stakeholders and the media to ensure that they are better informed about critical warnings (Inspector-General Emergency Management 2019a). There is a risk of over-reliance on technology that may be vulnerable during large emergency events (Burns et al. 2017; Office of the Inspector-General Emergency Management 2017). In rural areas, communities have repeatedly fed back about the primacy of ABC local radio for warnings and advice.

Over the past 10 years, significant research conducted by Bushfire and Natural Hazards CRC (BNHCRC) on community messaging and warnings has been driving improvements that underpinned the insights and guidelines provided in the AIDR Public messaging and warnings handbook (Australian Institute for Disaster Resilience 2018b) and are strongly embedded in agencies' practices. These improvements led to more targeted, tailored, clear and actionable messaging, empowering people to make informed decisions and take protective action. Both improvements in community messaging and warnings and successful community engagement programs have resulted in better prepared communities which resulted in the relatively low loss of life during the 2019/20 bushfire season. A strong emphasis on preparedness, engagement and education with communities helps to build resilient communities that can better cope with stressful situations during the emergency event and recover quicker after the event. This can be further enhanced by having disaster resilience education mandated in the school curriculum given the large fraction of the Australian population impacted by natural hazard events. For example, it was estimated that 80% of Australia's population was impacted by smoke during the 2019/20 Bushfire season (Dr Fay Johnston submission to Royal Commission https://naturaldisaster.royalcommission.gov.au/system/files/2020-05/Hearing%20Block%201%20Day%201%20-%20Final%20Transcript.pdf).

Work is underway to establish and build a national warning system that will provide consistency in regards of warning levels, hazard icons, hazard warning frameworks and minimise the cross-border issues (see Chapter 2).

6.6 Capacity to use knowledge systems and tools

New scientific and technological developments and a surge in real-time data feeds enhances accuracy and timeliness of intelligence that is critical to decision-making for first responders. Furthermore, ICT developments and adoption of incident information management systems assist streamlining of information flows resulting in increased efficiency and transparency. However, for these tools to be used effectively, there needs to be capacity and capability to use them so that relevant intelligence can be deduced through timely processing, analysis and interpretation.

The following section identifies capacity needs in terms of technology requirements as well as human resourcing and training.

6.6.1 Technology capacity

There is a high demand for real-time data feeds which are critical to providing enhanced situational awareness as well as timely inputs into predictive tools. Current capacity of aerial intelligence is stretched which means that high-level surveillance by aerial platforms, including line-scans, cannot always be provided. As the 2019/20 bushfire season evolved the Commonwealth government acknowledged the need for additional aerial firefighting capability with an $11 million boost. EO platforms have great potential to fill the gap through the provision of high spatial and temporal resolution imagery and data, contributing to fire detection, mapping as well as improved weather forecasts. In order to effectively use satellite data, further research and funding is needed to develop the algorithms and augmented intelligence systems that convert data into relevant and accurate intelligence and maps (Australian Space Agency 2020).

A robust information technology infrastructure at the ICC is also required to meet the demands of large data flows that need to be processed in a timely manner. The capacity of communication networks must cope with the often-high volumes of data, phone, internet and radio traffic during times when these infrastructures are under pressure.

6.6.2 Training

FBANs play a key role in interpreting the range of intelligence and modelling information streams and providing predictions of fire behaviour to incident managers. To enhance their capacity to effectively use these tools, a training strategy has been developed for FBANs (Gibos et al. 2015), as it is critical to provide on-going training and upgrading of skills to keep pace with the technological and scientific advances (Cruz et al. 2014). Furthermore, on-going training should be provided on reliable and relevant interpretation of fire simulation outputs to ensure accurate fire spread predictions and warnings are generated. Developing fire behaviour analyst capability is an on-going need.

Embedded meteorologists within IMT and SCC can provide the capacity to effectively use forecasts and advice during events. Extreme events can significantly increase demands on forecasters, and responding to multiple concurrent, prolonged or sequential events will put a significant strain on the BoM's capacity.

Incident information management systems used across all emergency sectors are a valuable tool for effective information flow, sharing of intelligence and communication. However, there are varying levels of capability in using these systems. On-going training and upskilling of personnel is required to ensure that there is a consistent approach in using these systems, so that efforts are not duplicated (Emergency Management Victoria 2019).

6.7 Gaps and improvements to enhance response to emergency events

Recommendations from post-incident reviews and inquiries and discussion with stakeholders are valuable resources for identifying gaps and improvements in systems and tools available to first responders.

Gaps and improvements have been identified across all aspects, some of which can be addressed through research and innovation as well as emerging technologies (e.g. remote sensing products). The review of the knowledges systems and tools available to first responders also highlighted potential barriers that may limit achieving improvements, including resourcing, capacity and implementing national integration/harmonisation of systems and processes.

6.7.1 Observations

Reviews have identified that many of the tools and technologies available for intelligence building could be improved by enhancements in the type and quantity of observations being incorporated in the response to disaster events. This would enhance the first responder's ability to forecast, model and monitor extreme events and contribute to building an accurate intelligence picture.

- The BoM's ability to forecast and monitor flood events could be improved with more on-ground intelligence systems, such as rainfall and river gauges and increased spatial coverage of automated weather stations and radar (see text box below).
- Improved spatial coverage of rainfall, river flow, flood and weather data will contribute to the reduction in inconsistencies in flood risk data and maps.
- Improved lightning detection and weather station networks in remote locations will assist with early fire detection and fire prediction.
- Increased number of sites with upper air soundings will help to predict unstable fire behaviour.

All of these improvements will require increased resourcing and co-ordination with local service providers, such as councils.

Improvements in aerial and satellite intelligence capabilities will result in more timely fire detection and mapping, as well as flood intelligence, contributing to building and maintaining situational awareness. This can be achieved through increased use of proactive flights for surveillance and early detection of fires and further development of IR line scan, FLIR and night-time capabilities. Aerial intelligence is also needed to create essential baseline data. For example, aerial LiDAR campaigns ensure that nationally consistent high-resolution terrain models are available, which are important for flood risk modelling as well as for improving our ability to reregister and correct optical and radar satellite imagery for fire and fuel-load mapping. Situational awareness will increasingly need to be 3D, which requires 3D reference data. Greater integration and use of remote sensing products such as multispectral data from geostationary satellite Himawari, will only be realised by increased capability development, research (see below) and international collaboration (Australian Space Agency 2020).

Predictive tools will also be improved by the inclusion of additional real-time observations from monitoring networks, weather stations and satellite data. Enhanced use of remote sensing products can provide more information and data on parameters such as finer scale mapping of fuel types and fuel conditions and landscape dryness measures, as well as providing critical 3D reference data. Inclusion of the variance of wind direction into fire weather predictions will enhance fire behaviour predictions.

Opportunities to improve BoM warning systems for disaster resilience

Significant disaster resilience benefits can be achieved from investment in BoM warning services across the value chain, including investment in improved observations or modelling with a focus on understanding user needs to enable the provision of tailored information, and through appropriate channels, to inform decision making across time scales so that communities, government and industry can take appropriate action. This is a not a linear process and the value across the whole warning system can be derived in situational awareness, before, during and after an extreme weather event.

To deliver a multi-hazard, impact-based forecast, warning and alerting capability that provides user-specific alerts, data and information would require uplifts to the BoM's existing hazard services to provide impact-based predictions, as well as future integration with other data sources, such as exposure and vulnerability information, as they become available. To realise the full benefits of this new capability requires uplift of the BoM's data capability. This will allow a more informed use of the multiplicity of available data as well as partnering with other institutions to gain access to real-time impact, vulnerability and exposure information. The extension of this may be to make automated assessment through the combination data layers related to hazard, vulnerability and exposure. Taking this to the next level would imply the use of deep learning algorithms combined with other data sets to build knowledge of individual users and their needs, and target alerts based on their routines or lifestyles.

Monitoring and Situational Awareness

Data access and compatibility: Decision-making by emergency responders could be more efficient and situational awareness improved by developing capability that allows for rapid data exchange and visualisation between the BoM, Emergency Management and other agencies (e.g. Geoscience Australia).

Improved use of remote sensing systems: Radar and satellite data is a critical component in the forecasting of severe weather, and as inputs into numerical weather prediction. There are opportunities to better use these data to detect and monitor severe weather, particularly in bushfire areas where it can be used to monitor the development of fire-generated thunderstorms, ember transport and rapid changes in intensity.

Observational networks: The BoM has an extensive observational network of radars, rainfall gauges, weather stations plus other equipment. However, there is potential to use portable equipment (radars and weather stations) in areas and at times of high risk, to ensure the best observations of extreme weather are available to forecasters and emergency responders.

Modelling and Forecasting

Modelling for bushfire weather: A research program focussed on the modelling of the weather conditions known to produce the most dangerous fire behaviour including pyro-cumulonimbus, downslope winds, wind changes and dry-lightning would improve fire fighter and community safety.

Flood inundation modelling: The BoM currently provides forecasts and warnings for more than 550 communities across Australia that contain timing and flood wave heights at hydrologic gauging station locations and include a classification of community impact-based standard definitions of Minor, Moderate and Major Flooding. Many countries around the world are moving into hydro-dynamic or hydraulic modelling of flood extent down to property level. This provides much greater information to decision makers on potential impacts including inundation areas, travel route closures and depth and velocity of water.

Real-time tsunami modelling: The BoM's current tsunami warning system identifies the closest scenario from a library of pre-computed scenarios which model tsunami propagation from trenches. The system takes the scenario and determines the impact (severity) on the coastline, based on the model-predicted tsunami wave heights in water deeper than about 20m. This could be improved with real-time modelling. The most likely improvement coming from real-time modelling is to reduce the conservativeness in the system and reduce the frequency of over-warning. In addition, the existing system cannot provide guidance for earthquakes that do not occur on known subduction zones. Real-time modelling, and the objective use of observations, could also provide a framework for tsunamis generated by non-earthquake sources.

Ensembles and uncertainty: Ensemble weather forecasts are obtained through the parallel running of meteorological models starting from slight differences in initial condition, all compatible with the initial true state of the atmosphere, that will evolve into different equiprobable scenarios. The BoM has an operational ensemble capability for seasonal forecasting and is developing this capability for forecasts up to 10 days' lead time and ultimately for all timescales between days, weeks and out to months and seasons. Services developed from this capability are inherently probabilistic and provide the capability to obtain scenarios with different probability of occurrence, that can assist emergency responders prepare for high impact events.

Erosion and Landslip: Heavy rainfall, abnormal ocean activity or the reduction in vegetation through bushfires or land clearing can heighten the risk of erosion, landslip and coastal erosion. This can lead to loss of life, property, the natural environment or impact the quality of our waterways. There is an opportunity to bring together modelling expertise to be able to analyse parts of the country that are at risk of erosion, landslip and coastal erosion to inform appropriate mitigation activities.

Coastal Storm Surge: Coastal storm surge can cause coastal erosion, damage to infrastructure and property and loss of lives. A national capability has been developed to inform planning, mitigation and response activities for storm surge events (both associated with tropical and non-tropical lows). Further development of this capability is required to incorporate the varied tidal regimes experienced across the country and to develop tailored impact-based products.

Health Related Services: Extreme heat events are associated with significant increases in population mortality and morbidity in Australia and represent a growing threat to Australians' health (Dean and Green 2017). Similarly, air pollution is a significant health problem in Australia, causing about 3,000 premature deaths a year. Smoke impacts from the 2019/20 bushfire season were devastating (see Chapter 6).

Dissemination and Communication

Multi-lingual messaging: Effective message dissemination through multiple channels and the Australian Government Common Alerting Protocol will help to ensure the reach of forecasts and warnings. Tailored services are possible for culturally and linguistically diverse communities in terms of message construction and dissemination, with the opportunity to utilise new channels and platforms for impact.

Perception and Interpretation

Impact-Based Warnings: A move to impact-based warnings, describing what the weather will do rather than what the weather will be responds to the disconnect between accurate forecasts and warnings and the understanding of their meaning by communities and governments. Enablement of impact-based services requires insight into exposure and vulnerability to a hazard and the capability to bring together diverse data sets in meaningful ways.

People respond to warnings when they are aware that they are at risk. Partnering with relevant agencies to provide critical information about potential natural hazard risk for emergency response planning and education is important. The increasingly complex and inter-connected nature of society and the increasing frequency and severity of natural hazards means that we need to be aware of and prepare for extremes.

Nationally consistent, scalable, multi-hazard warnings that describe the impact of the hazard and an appropriate call to action are better understood and acted upon by communities. People respond to warnings better when messaging is consistent, therefore linking across the emergency management sector, through co-branded and consistent messaging, is important.

Information Use/Decision Making

Decision Support Services: The decisions that communities, emergency management and industry make are influenced by their specific circumstances, risk tolerances and capacities. Decision support services which bring together hydrological, climatological and meteorological information are of great relevance, especially if the data provided could be seamlessly embedded in the user decision-making systems.

6.7.2 Technology

Mapping and monitoring can be improved by development and implementation of new technologies.

Earth observation technologies are emerging as key players in disaster response through improved spatial and temporal resolution of fire detection, mapping of fuel conditions and bushfire hazards. These opportunities are further explored in the EO Taskforce report (Australian Space Agency 2020).

EO technologies can be further supported on a local scale by the use of RPA (Remotely Piloted Aircraft systems), which is a promising emerging technology. The use of RPAs can enhance observational data gathering, particularly in areas where current platforms (including EO) are limited. RPA has potential to contribute to building and maintaining situational awareness on the fire and flood grounds (as highlighted during the Tasmanian fires in 2018/19) and thereby increasing safety of first responders and communities. A national program to roll out RPA for enhanced situational intelligence and rapid recovery assessments requires significant technology and capacity development and resourcing, as well as further research into their operational use over large areas in a reliable way.

Further improvements are needed for information and communication technology to ensure that reliable communication infrastructure is maintained during extreme events when these systems are under pressure. Furthermore, redundancy is required in the communication systems available during emergency situations. A number of reviews identified communication limitations and failures during past events. Many modern warning systems rely on telecommunications devices and mobile data networks that require power and hence become unusable during a power outage, for example reliance on the National Broadband Network. A reliable back up system for communication to the public is absolutely required. Further research into emerging mesh technologies to support current communication infrastructure would be valuable.

A continual stream of information is vital to maintain situational awareness and develop a COP. There is further opportunity to do more to convert that stream of information into intelligence. The dynamic, complex and information-rich operating environment can also prove challenging to achieve effective processing, integration and sharing of intelligence. Innovations in augmented intelligence have the potential to play a role in managing the large information flow to provide faster, efficient and smarter emergency response.

There is opportunity to investigate the uptake in the use of mobile data terminal/tablet-based systems in urban areas for rural fire situational awareness. This is limited by resourcing requirements (cost).

Emergency Evacuation Modelling

CSIRO and RMIT have developed an evacuation modelling decision support system (DSS) that is intended as an aid to:

- Carry out an analysis of the potential impact of a predicted hazard on a road network
- Design an evacuation scenario to be simulated
- Run an evacuation simulation
- Visualize the outcome of the simulated evacuation and produce summary results.

The DSS was first developed for bushfire applications in partnership with Emergency Management Victoria and Surf Coast Shire, with financial support from the Department of Premier and Cabinet (CSIRO 2020).

The project addressed a significant gap in evacuation planning and risk mitigation capabilities. It delivered an evacuation modelling platform that can support emergency management organisations in undertaking evacuation planning and through that, help communities to prepare themselves for natural disasters. Evacuation planning is still largely performed manually, which limits the number of scenarios and data sources that can be studied by the decision makers and their ability to make informed and robust decisions. The DSS allows local authorities and emergency services to explore a multitude of scenarios in a limited amount of time.

An innovative approach of the DSS is that it is designed to better support decision-making, rather than validate decisions already made by the user (i.e. simulate the execution of an existing evacuation plan). Another innovative aspect of the DSS is the use of a combination of state-of-the-art transport modelling simulators with advanced models of human behaviour. This allows complex scenarios to be reproduced in a very realistic way.

An important factor to consider in order to develop realistic simulations (i.e. not an exact description of reality, but accurate enough that a variation in its parameters results in a quantifiable variation of its outcome) is the human behaviour component. In a real evacuation, people will continuously make decisions based on a number of external factors (such as how far away the fire/flood front is, how they intend to travel, how well they know the routes out, what advice they are receiving from authorities, etc.) as well as their own individual characteristics and goals (what are they leaving behind and may therefore lose, are they responsible for the lives of other family members or animals as well as their own, etc.). This paradigm has been encapsulated in a Belief-Desire-Intention model (Singh et al. 2016), and it allows a modelled individual agent to disrupt their usual daily plans by taking the exceptional circumstances into account.

Moreover, while such advanced methods usually require advanced technical skills from the end user, here an intuitive interface has been built for practical use of the DSS.

Future applications could include predicting traffic flows to avoid bottle-necks and obstruction of emergency-service response vehicles, and local planning to ensure that alternative escape routes exist from areas threatened by hazards such as bushfire, flooding or storm-surge, especially as new developments are considered in peri-urban or regional settings.

6.7.3 Research

Reviews have identified that continued research drives improvements in the tools and systems available for intelligence building, which need to be adopted and integrated into the operational environment. The following section identifies areas where research is underway and where more research is required (noting that this is not a comprehensive, in depth review of current research projects).

In terms of weather forecasts, identified areas for improvements include:

- improved predictions of drought, heatwave and strong wind events to forecast scale of bushfire risk and manage community impacts
- improved prediction of cloud to ground lightning for enhanced early fire detection
- better understanding on the causes and effects of pyrocumulus weather occurrences on fire behaviour.

Some of these aspects are being addressed through a current research project conducted by the BoM on 'Improved predictions of severe weather to reduce community impact'. This project develops the underpinning science in areas such as ember transport by bushfire plumes and predicting the potential for pyrocumulus cloud formation.

Predictive modelling tools are constantly improving through more accurate and higher spatial and temporal resolution of data feeds, new scientific developments and increased computer capacity to automate and simulate close to real life conditions. For example, a number of current and future opportunities for scientific developments will enhance the predictive capabilities of fire behaviour.

Opportunities exist for improved prediction and forecasting of fires by the development and inclusion of a national simulator capability based on Spark (https://research.csiro.au/spark/), which was endorsed by AFAC's national council in April 2020. The highly flexible and configurable simulator allows for greater integration with the AFDRS data standards and incorporation of ongoing and future research such as fire spread prediction across Australian fuel types and fire-atmosphere feedbacks. Additionally, current research into fire coalescence and mass spot fire dynamics will enhance our understanding of ember transport processes and mechanisms leading to improved predictions of the commencement of effective short distance, medium distance, long distance and or pseudo flaming front (ember storm) spotting. Further research is required to develop the models that can predict flank and heel fire behaviour for better fire spread predictions.

A new capability in fire predictions is coupled fire-atmosphere models which are increasingly being used internationally. They contribute to improved fire forecasts by resolving the complex interactions between the fire, topography and the atmosphere. The ACCESS-Fire model developed by BoM aims at better understanding and predicting fire-atmosphere feedback processes to depict how a fire may evolve (Peace et al. 2018). Currently, the computational requirements limit its operational use; however, as technology capabilities increase, the barriers to its use will be lowered.

While all these improvements lead to more accurate predictions, there is a need for further research into probabilistic modelling and how to effectively communicate the uncertainty associated with predictions. There is also a need to review and assess how the predictive potential of the models perform for unprecedented events, the frequency of which is escalating in a changing climate. This is partly being addressed through research into threshold conditions for extreme fire behaviour (BNHCRC 2017).

Further research into longer-term predictive/forecasting tools may also be of value to protect critical infrastructure and homes in high bushfire risk areas as well as research into rural urban interface fire specific models to inform response tactics during extreme events.

Earth observation platforms provide great future research opportunities that will enhance mapping and forecasting of both bushfire and flood risk. Further developments of remote sensing products to derive fine scale mapping of fuel type, fuel conditions and soil moisture and how to effectively translate those into operational use will improve fire predictive models. Research into improving remotely sensed measures and forecasts of land dryness will improve drought prediction and fire prediction tools. Emerging sensors on EO technology and machine learning are also contributing to data blending and assimilation of the smoke forecasting system AQFx.

In parallel to research activities into the applications of various new EO sensors that inform models, there is also a need for dedicated research into the data platforms that host, process and analyse the diverse EO data streams, such as CSIRO's Earth Analytics Science and Innovation (EASI) Datacube, Digital Earth Australia (DEA) and Space Future Science Platform projects.

Research into aspects of resource management can help to improve sharing of resources across jurisdictions. This includes research into understanding how resource sharing and management operates (and its effectiveness) during unprecedented events.

Research into the development of methods and systems to monitor the health and well-being of personnel (fatigue management, heat, smoke exposure, dehydration) as well as technologies to protect fire trucks against falling trees will improve fire fighter safety.

6.7.4 Harmonisation/integration of systems

As highlighted in Chapter 3, harmonisation aims to make systems consistent so that both inputs and outputs can be integrated more easily. This aspect has been recommended in multiple reviews of past events. A national and harmonised approach has been adopted or is being developed for critical aspects such as the Australian Fire Danger Rating System, the proposed national warning system, a national fire map, a national bushfire simulator capability and a national smoke forecasting system. This section highlights areas where harmonisation and integration of systems could be further improved.

Integration of intelligence systems can be improved by the development of systems that overcome complex accessibility and ownership arrangements of jurisdiction-specific intelligence systems. This will improve consistency and timeliness of data reporting and use. The Australian Flood Risk Information Portal developed by Geoscience Australia is a good example of consolidating authoritative flood maps and flood studies and other relevant information in a single online and accessible location.

Other improvements required include a system for the provision of consistent maps and map layers for use by first responders. For example, the development of an incident mapping on-line tool (IMOT) by the SA Department for Environment and Water facilitates rapid production of standard maps.

Post-event reviews have highlighted the importance and usefulness of FLIR and line-scan data, however resourcing is required to develop a common national communication and image receiving and processing systems for these complex data sets.

Improvements in the sharing and management of resources could be achieved by the development of an integrated, computerised inter-agency resource management and tracking system to improve awareness of locations of operational resources, gain an accurate reflection of both human and physical resources involved, especially for large complex incidents, and effectively track deployments and assigned tasks. This will require research into understanding how existing systems operate (see above) and how integration towards a national framework can be achieved. Improved coordination of interstate deployments could also be achieved with enhanced visualisation and mapping of intelligence.

Situational awareness could be improved by the integration and automation of existing systems. The harmonisation of systems across different agencies will improve the ability to share, analyse, interrogate and display information from disparate entities, particularly critical for large multi-agency coordinated incidents. An improvement in the connectivity and integration of technical systems is required and this could be facilitated by a data analytics and augmented intelligence approach.

The 2019/20 bushfire season highlighted the urgency for integrated communication technologies (e.g. radio networks) for first responders to ensure that reliable communication is established between agencies during cross-border emergency events. A national consistency in community messaging and warnings is also required to minimise confusion and support effective decision-making by the public. This has been a critical issue during the 2019/20 bushfires with fires burning across state borders.

6.7.5 Barriers to system integration

The greatest barriers to the integration of systems are technological, organisational and resourcing. Technological barriers can generally be addressed by research and development, requiring resources and expertise. Addressing technical barriers will improve connectivity and integration of technical systems. However, the harmonisation of systems across different agencies also requires the removal of organisational barriers. All jurisdictions need to be committed to be part of a national framework, and accordingly put time and effort into ensuring that likely requirements for system harmonisation are implemented and information is shared. As stated in the review from Cyclone Debbie, while there are "many barriers to introducing a common system across different agencies… the facts are that the current system is inefficient in its use of staff, contributes to sub-optimal information being presented to decision-makers, and is a cause of concern for practitioners at all levels" (Office of the Inspector-General Emergency Management 2017).

6.7.6 Capability

Capability could be enhanced by the improvement in staffing models and training used by many agencies. Appropriate training for operators and end users of incident information management systems and tools is key to unlocking the full potential of the technology in first response.

The Australian Defence Force can assist with logistics support to jurisdictions during disaster events (e.g. evacuation of remote communities affected by cyclones and large-scale floods). This support could be enhanced and be more effective by development of protocols for improved co-ordination between the Australian Defence Force and jurisdictions. Effectiveness of this approach is underpinned by the need for integrated systems and inter-operability.

6.8 Chapter 6 Acknowledgements

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6.10 Appendix State level incident management systems and situational awareness platforms

Multiple technology platforms are used in the various State Emergency Operations Centres (EOC) to manage emergency events (Table 8). These IT platforms assist emergency services to efficiently and effectively process, analyse and share a vast amount of complex data and intelligence for timely decision-making and achieve effective multi-agency emergency management coordination. This section summarises and describes the technology platforms used in various states and identifies opportunities for improvements.

New South Wales

The NSW RFS core operational system is ICON (Incident Control Online), a common operating IT platform for information and resource sharing. A GIS-based common operating platform (COP) system, online systems such as a spatial Fire Weather Portal and FBAn page are additional technology platforms used during emergency events.

Description

ICON is a multi-agency system that incorporates situation reports with succinct summary of incident status, incident action plans, resource allocation, incident warning levels, threat analysis including fire spread predictions and control strategies. The integration and sharing of intelligence and resources pertinent to the incident enable effective decision making. The system is accessible and shared with all stakeholders. Relevant training is needed for effective use of the system.

COP system is a GIS based situational awareness platform that includes weather data, satellite imagery, hotspot detection, line scan data, fire reporting and aircraft locations. It overlays the information to provide state-wide situational awareness. Pertinent information from adjoining states is also included in the COP system. The system is accessible by all stakeholders.

Opportunities for improvements

- Adoption of AVL technology

Queensland

Technology platforms used in Queensland for disaster management are the Queensland Disaster Management Arrangements (QDMA) data sharing group and the State Disaster Coordination Centre (SDCC) Situational awareness platform.

Description

QDMA Data Sharing Group has been created within ArcGIS Online for sharing of data relevant to disaster management activities between QFES and other stakeholders. Items in this group include data layers published by QFES and other stakeholders within the Queensland Disaster Management Arrangements.

The SDCC Situational awareness platform is a series of web maps and dashboards to support disaster management activities. It is a centralised source of disaster management-related spatial data from various stakeholders including QFES, BoM, local government authorities and state government departments and agencies. It contains two Situational Overview tabs, one for weather events and one for bushfire specific events. A series of layers help provide situational awareness in the lead up to and during an event. Dashboards show disaster management group status including public information, levels of warnings, and emergency alerts; provision of maps displaying current incidents, damage assessments, infrastructure, burnt areas; State emergency services tasks; QPWS bushfire data; BoM fire weather warnings and daily precipitation. The platform was widely used during the 2019 Queensland bushfires.

Opportunities for improvements

- Provision of consistent map layers, and consistent, standardised maps that are up to date
- Increase situational awareness by providing maps to local disaster management groups (LDMGs) and district disaster management groups (DDMGs). This could be encouraged through the uptake of the QFES situational awareness platform product.

South Australia

CRIIMSON is an electronic incident management system developed by the CFS to support emergency management and operations. It is used by the CFS and MFS to collate incident information and for internal agency communication. The development of the system is on-going to ensure that new processes are captured and to enhance operations and incident management activities, interagency communication and sharing of information across agencies.

SESIIMS is the SES Incident and Information Management System using WebEOC. It is a system to share and manage information and provide incident intelligence in near real time. It is integrated with a number of systems including Whispir (a cloud-based communication platform), AlertSA and GIS portal. External access to the system is provided to other users as needed.

The Incident Mapping On-line Tool (IMOT) is an on-line app that allows for quicker digitisation of fireline intelligence (e.g. line scans, air observation plots, hotspot data, ground observer reports) and the rapid production of standard maps required by IMTs. It links to both ArcMap and ArcGIS Pro software and allows on-line map sharing with a range of agencies using an ESRI Portal environment. The tool is only in its first version, with improvements planned for development in 2020/21. Within two years, changes to the ESRI Portal environment used will enable a more comprehensive data space for fire (and other hazard) intelligence which will enhance IMOTs ability to map more data from a wider range of sources. IMOT is currently operated by the SA Mapping Functional Support Group (a multi-agency group constituted under SA's State Emergency Management Plan) which supports all response agencies with mapping and spatial information support. Future versions may be used by a wider audience for viewing data.

Tasmania

The review of the Tasmanian bushfires of 2013 highlighted communication issues between different jurisdictions and recommended a more coordinated approach, which led to the implementation of WebEOC.

Description

WebEOC is a technology platform that has transitioned from the police sector into the emergency management sector. The WebEOC platform developed for Tasmania is a cross-agency, all hazard online incident support tool with a simple design. The incident management in WebEOC is divided into four Tasmanian regions, with a maximum of one incident reported per region. If there are multiple fires in one region, they appear as one incident in WebEOC. This set-up is to simplify the incident management and better manage an overwhelming level of information for large events.

The platform is used for strategic level management and interagency communications (e.g. file sharing and online discussion). It is not a resource management system.

Information in WebEOC includes situation reports, incident action plans, media releases, task management and resource requests, running logs to maintain situational awareness, mapping systems to assist with situational awareness and resource tracking by AVL and links to specific pages such as BoM weather updates and fire agency COP system.

TFS uses a GIS-based COP system as a tactical tool (resource tracking for fires).

Opportunities for improvements

- Better reporting capabilities
- Improved sharing of information
- On-going training provided to users to ensure effective use of the system
- One IT system that integrates WebEOC, COP and dispatch system; this would require resourcing and funding.

Victoria

EM-COP - Next-Generation Incident Command System (NICS)

Description

EM-COP is a technology platform that was developed with the aim to provide a common operating picture during an emergency event and enable effective decision-making. This is achieved by gathering comprehensive and up-to-date information pertinent to the emergency event, providing the tools that combine, process and analyse the information to produce timely and accurate intelligence, and sharing the information between jurisdictions. The platform is flexible and adaptable to allow it to evolve with technological advances and add extra modules and functionalities as required.

Western Australia

Bushfires in WA are managed by the Department of Fire and Emergency Services (DFES), the Department of Biodiversity Conservation and Attractions (DBCA) Parks and Wildlife Service (PWS) and local bushfire brigades which are the responsibility of local governments (LGs). Technology platforms used for incident management include WebEOC, spatial support system (SSS) developed by DBCA and FESMaps.

Description

WebEOC is the primary emergency management system for DEFS. It was implemented as the joint agency operating platform for Level 3 incidents during the 2018/19 bushfire season. WebEOC may be established as the agreed operating system for an incident before it is declared Level 3 and this is by agreement between DBCA and DFES.

WebEOC is an all-hazard incident management system aimed at enhancing transparency and visibility. It is set up as a web fusion to facilitate sharing of information between agencies. It feeds real-time information to provide enhanced situational awareness and effective incident management. Information in WebEOC include information logs, incident action plans, incident situation reports, public messaging and warnings and predictive fire outputs. A joint agency operating platform enables increased visibility of critical information at region and state levels. The log request allows for a streamlined approach between region and state levels and minimises inefficiencies in systems and processes.

Following a recommendation of the Special Inquiry into the Waroona fire 2016 to establish an information system to track resources, IRMS (Incident Resource Management System) was developed, and integrated into WebEOC. IRMS integrates data from the computer aided dispatch system and the DFES and DBCA incident personnel data. The integration of the different agencies' resource management systems significantly improves the inter-operability at multi-agency incidents. All available resources can be easily tracked and personnel fatigue can be managed more efficiently.

The Spatial Support System (SSS) is a GIS-based situational awareness platform used by DBCA for all level incidents both as an operational and planning tool. It is an evolving IT platform with added functionality as new technology becomes available. It is a DBCA system with some inter-operability functions that enable DFES vehicles and fire appliances and active fires to be visible on SSS. Access to SSS is available to other jurisdictions as required.

Information displayed in the SSS include fire reports acquired from spotter aircrafts, look-out towers, public reports or satellite imagery; fire maps updated about once or twice in a 12-hour shift depending on timeliness and quality of information (e.g. air observations, IR line scans); incident weather forecasts issued by the BoM; localised weather forecasts either from an established remote automatic weather station with telemetry capability or from field observations using a hand-held weather meter; and resource tracking.

FES Maps is a geospatial mapping platform used for bushfires, cyclones and floods. It sits parallel to WebEOC.

Opportunities for improvements

- Increased adoption of WebEOC for all level incidents
- Training to ensure effective use of technology platforms.

7 Practical relief measures to build community-level resilience following a natural disaster

Authors (CSIRO): Cathy Robinson, Dan Metcalfe, Kerry Collins, Liana Williams and Erin Bohensky

7.1 Summary

Australian communities are increasingly exposed to severe weather events, driven by population growth and economic development in areas that are at risk of natural disasters such as flooding and bushfires. The size, type and scale of disaster and the nature of damages will have an influence on the recovery choices that are made. Yet, practical lessons learned from natural disasters in Australia and overseas all highlight that affected communities depend on an effective and efficient process of recovery to manage the impact of these events and build community resilience to future natural disasters.

Holistic disaster recovery frameworks have been developed that emphasise the need to invest in the human behaviours, planning decisions and on-ground activities that create the exposure and vulnerability to natural disasters in the first place. These frameworks also advocate recovery responses that are informed by a nuanced understanding of the local context and empower affected communities to actively contribute to planning and implementing recovery and resilience building support measures. As the recovery effort following recent 2019-2020 bushfires highlights, Bega's local social and ecological communities are not the same as those on Kangaroo Island. The inter-relationships between individuals, businesses and communities in each region will also influence the immediate and longer-term impacts of a natural disaster and so recovery and resilience building efforts can vary from months to years.

This Chapter examines the local economic, social and environmental impacts of natural disasters, identifying key aspects of successful emergency relief and "second response" recovery phases that help to build resilient communities, businesses and environments. Drawing on lessons learned from recent bushfires, and insights from other natural disasters in Australia and around the world, practical actions are identified to guide short-term relief and build long-term resilience within communities in Australia.

Key findings include:

- Natural disasters damage different sectors of the community, the economy and surrounding environment at a variety of spatial and temporal scales. The effects of natural disasters can be felt at individual, community, regional, state level, and can impact an entire country. Recovery efforts are therefore a complex process and must adjust to the nature and the intensity of the disaster itself and the level of preparedness and resilience of the impacted communities.
- Natural disasters also affect individual mental health and well-being. Volunteers and residents in disaster affected communities often suffer from physical, mental and emotional impacts for months

and years following a natural disaster event. People exposed to natural disasters through social and other forms of media can also be traumatised.

- In the aftermath of a natural disaster the reliable supply of essential goods, groceries, pharmaceuticals and other critical items is often too great to manage. The plethora of donations and grants can be overwhelming, and it can be difficult to appropriately match available resources to local needs. It is often unclear who the decision-makers are in such circumstances, constraining efforts to deliver a coordinated response.
- Accurate, timely communication during and after a natural disaster is critical and difficult to manage. Community recovery centres provide an important focal area to share disaster impact and recovery support information while phone, power and commuter access is restored. The media also has an important role to play to ensure recovery efforts and community experiences are accurately and fairly reported during and after the event.
- Recovery to build community and ecological resilience is critical. Recovery support that encourages individuals and communities to do things differently, build back better, and enable ecological systems to rebound and flourish is critical to reduce the vulnerabilities and inequalities that are particularly exposed during and after a natural hazard event.

7.2 Opportunities for improvement

Understand the local context and empower local communities. Successfully engaging and empowering the community is core to successful recovery by ensuring local context and values are understood and best achieved when the affected community exercises a high degree of self-determination to guide timely, efficient and coordinated delivery of critically needed goods and services.

Manage overwhelming generosity. There is a need to enhance collaboration among relevant agencies and NGOs to best address the questions of ‘who can and should do what, where and when, and with what resources?’ to direct, focus and coordinate efforts of individual agencies around achieving common goals.

- This would rely on a holistic understanding of the critical nature of needs in each individual community; a coordinated program and schedule that ensures continuous supply and a mode of delivery that enable communities to access required goods; and a mechanism to avoid duplicate requests from communities.
- A decision-support platform that facilitates a coordinated and centralised disaster response to natural disasters across suppliers, industry, government and senior community leaders could help ensure the timely, efficient and cost-effective of critically needed goods and services to disaster affected communities.

Support health and mental well-being of individuals who have been impacted by a natural disaster event. The physical and mental health impacts of natural disasters are not well understood, especially when exposure is prolonged. Support for mental health and wellbeing is critical to disaster response and this support may need to continue for months and even years after an event. Social media can contribute to this distress and can extend the negative impact of natural disasters on people not directly affected by the event.

Design recovery to build long-term resilience. Successful recovery is responsive to the complex and dynamic nature of both emergencies and the community. While short-term recovery responses are vital, there is also a need to foster longer-term resilience and reduce industry and community exposure to natural disaster.

- Sharing responsibility for disaster risk preparation and response: Measures are likely to vary depending on the disaster, industry, sector, and geography, but there is scope to support cross-sectoral learning in the development of tailored responses. This includes mechanisms that address concerns about insurance availability and affordability to support community members to recover and build resilience measures in their business models and properties before and after a natural disaster event.

- To support small business: Small businesses including tourism must be viewed as critical social and economic nodes in communities, and their ability to survive following a disaster seen as an important factor in the broader recovery process. Support to restore financial viability and, in some cases, harness new approaches to business development, are critical to build economic resilience for small and medium businesses affected by natural disasters.
- To mitigate and manage agricultural impacts: Support rural landholders to prepare for natural disasters by identifying risk to farming businesses, being familiar with local community disaster plan, and developing an on-farm emergency plan for stock/crops and equipment. Support speedy recovery by pre-emptively calculating standardised reimbursement rates for addressing urgent needs in the agricultural sector (such as fencing and feed), and by making greater use of existing property identification systems. Support strong training and information programs that assist rural landholders in understanding the many tools for managing risk and provide the necessary data for these tools to be broadly applied. Uptake of such strategies are enhanced if attention is paid to the role of women who often play a vital role as financial record keepers, decision makers, and the source of off-farm income to the operations.
- Restoration of significant conservation and cultural assets and landscapes to build the resilience of disaster impacted landscapes:
  - Support to pre-emptively identify high priority conservation, heritage and sacred sites that hold significant community value, and develop potential strategies to mitigate this risk and/or restoration of these sites in the aftermath of a disaster.
  - Post-disaster restoration needs to focus on refuge areas that contain threatened and culturally significant species and habitats and also support landscape-scale management through weed and pest management, cultural burning and other land management practices which support ecological goals and their connections to social and cultural resilience and human health.
  - There has also been a concerted effort to bring together the data holdings of institutions and individuals to understand the distribution, sensitivities to the disturbance and traits of individual species which convey risk or resilience in the face of bushfires and other natural hazards. Building on the work focused on southern and eastern Australia this summer to build a national inventory would enable a faster and more coordinated response to future natural disasters.

7.3 Introduction

Australia's exposure to severe weather events that affect human settlements is increasing, as population growth leads to greater development in areas that are subject to events such as floods and bushfires (Deloitte Access Economics 2017). There is also growing evidence that the consequences of disasters are difficult to predict, understand or quantify (O'Connell et al. 2018). This highlights the importance of interventions that need to be made prior to natural hazard events to reduce the vulnerability and mitigate the risk of natural disasters. These prevention interventions need to complement recovery efforts and can be done at all levels of government, in business, organisations and households (Beller et al. 2018).

This Chapter reflects on the general principals of holistic approaches to natural disaster recovery management and resilience to identify practical measures to support the recovery of individual and community basic needs, including health and wellbeing (Section 7.4); respond to agricultural impacts, noting mixed negative and positive results by sector and also by season (Section 7.5); impacts on small and medium enterprises (including tourism) (Section 7.6); and restoration strategies to build the environmental and cultural resilience in landscapes (Section 7.7). Drawing on lessons learned from recent bushfires, and insights from other natural disasters in Australia and around the world, practical actions are identified to guide short-term relief and build long-term resilience within communities in Australia.

7.3.1 Holistic approaches to natural disaster recovery

Disaster recovery efforts are defined as “the coordinated efforts and processes to effect the immediate, medium- and long-term holistic regeneration of a community following a disaster” (New Zealand Government 2019). They rely on the developmental and remedial process to minimise the escalation of the consequence of the disaster; regenerate the social, emotional, economic and physical wellbeing of individuals and communities, and take opportunities to adapt to meet the social, economic, natural, built and environments’ future needs (AIDR 2018). Frameworks to understand and measure community resilience are core to recovery efforts and describe the sustained ability of a community to recover from adversity (Magis 2010). While each community and natural disaster is different, three key factors have been identified that enable resilience. These include:

- Physical characteristics of the community (e.g. local infrastructure and access to emergency and health services)
- Procedural characteristics of the community (e.g. existence of disaster policies and plans)
- Social characteristics of the community (such as community cohesion and strength and capacity of local leaders (see Australian Institute of Family Studies 2012).

Building community resilience is an important goal of disaster recovery efforts and recognises that changes to local social-ecological systems are interconnected and can change over time, both during and after a natural disaster (Brown and Westaway 2011). Consideration of how natural disasters affects community resilience can also provide important insights on how and why recovery programs and activities are successful – or not.

Holistic disaster recovery frameworks used in Australia and overseas highlight that affected communities depend on effective and efficient process of recovery (Federal Emergency Management Agency 2005; FRRR 2011; United Kingdom 2013; AIDR 2020). This is a complex process and is best achieved when the affected community exercises a high degree of self-determination. This also requires an understanding of community context, with each community having its own history, values and dynamics (NZCDEM 2005; Schwarb et al. 1998). Two elements are at the core of this holistic approach - every action must be considered with the community at the centre, and every community is different. This means that short and long-term management responses recognise that both communities and individuals have a wide and variable range of recovery needs, and that recovery is only successful where all are addressed when communities are empowered and supported in a coordinated way (Deeming et al. 2018).

Understanding key factors that enable community resilience following a natural disaster also highlights the need for recovery efforts to identify and respond to the total costs of natural disasters in Australia (Deloitte Access Economics 2017; Gow and Paton 2008; UNESCAP 2019). This looks beyond direct tangible costs (those incurred as a result of the hazard event and have a market value such as damage to private properties and infrastructure) to consider indirect tangible costs (the flow-on effects that are not directly caused by the natural disaster itself, but arise from the consequences of the damage and destruction such as business and network disruptions); and the intangible costs (direct and indirect damages that cannot be easily priced such as death and injury, impacts on community and environmental health, mental health and wellbeing, and community connectedness).

Assessing the tangible and intangible costs of natural disasters are complex and significant. Following the unprecedented number of floods, storms and bushfires that devastated life and property across Australia in recent years prior to 2012, an assessment of the economic cost of the social impact of natural disasters in

2016 showed the intangible social costs of natural disasters in 2015 were at least equal to the physical costs – if not greater. For example, the tangible costs of the Black Saturday fires reached A$3.1 billion (in 2015 dollars), while the intangible costs reached A$3.9 billion. Together, these costs totalled A$7 billion, which equates to A$7.6 billion in today's dollars (Deloitte 2016). The National Drought and North Queensland Flood Response and Recovery Agency took a holistic approach with government assistance directed at primary producers, small businesses, and families and communities following the significant flood event in the region in late January and early February 2019 (Australian Government 2019b).

7.3.2 Australia's resilience to natural disasters

In a 2016 review of disaster risk across the world, The Economist Intelligence Unit (EIU) rated Australia as "mature" for overall preparedness and economic and social resilience, and as "developed" for resilience of the physical environment (EIU 2016). Yet reviews of Australian bushfire seasons (both in 2019–20 and in previous years) suggest that disaster recovery remains a difficult challenge for Commonwealth, state and local governments. Cheatham et al. (2015) attribute some of the challenges to "heightened political pressure and public scrutiny" during and following a disaster, which can result in unrealistic expectations about recovery funding (including the amount available and the speed with which it can be disbursed). Many aspects of disaster recovery can also take time to implement, often due to factors beyond the control of state or local governments. In some cases, government leaders can be confronted with a "complexity of tasks" and can misjudge the resources and skills required to facilitate recovery. Effective recovery governance also requires "bold organisational changes," which leaders may be reluctant to make.

Some regions may also bear greater economic costs than others during and after a disaster, further complicating government responses. For example, the resilience of some communities affected by bushfires in 2019–20 was already affected by drought, and these communities are now facing the health and economic impacts of COVID-19. Weather and climate forecasts highlight different risk planning and decision-making is needed in different parts of Australia (Chapter 2). In remote regions of Northern Australia, sparsely settled areas are extremely vulnerable to a range of annual natural hazard impacts. In these areas, much of the population are Indigenous, with limited access to appropriate institutional support and, at times, different interpretations of the nature or impact of a given natural event (NZCDEM 2005; see also Chapter 4).

Table 16 Income change in Victoria's 2009 bushfire-affected areas, 2006 to 2011

Source: Beaini & Ulubasoglu 2018. Based on Australian Bureau of Statistics (ABS) Longitudinal Census Data (up to 2011).

INDUSTRY OF EMPLOYMENT	INCOME CHANGE
Agriculture, forestry and fishing	Decrease - 31%
Retail trade	Decrease - 13%
Health care and social assistance	Increase - 8%
Accommodation and food services	Decrease - 12%
Transport, postal and warehousing	Decrease - 30%
Professional, scientific and technical services	Decrease - 19%

Some people in communities may also be more vulnerable to the total economic costs of disasters. A review of floods in Queensland, for example, has prompted a more nuanced understanding of the consequence of these events on based on variable vulnerabilities of different regions, communities and industries (e.g. Queensland Chief Scientist 2011). Several vulnerability indicators have now been identified to identify people who would benefit from additional and targeted assistance to prepare for, respond to and recover from disasters (Australian Government 2018). An analysis of the period 2006 to 2011 of areas affected by the 2009 Victorian Black Saturday bushfires showed an adverse impact on people's incomes, with some people more affected than others (see Chapter 4). On average, women's income dropped by 14% compared to 9% among men, people on low incomes experienced a drop of 18%, and renters experienced a drop of 14%. The impacts on incomes of workers in different industries were also variable (see Table 16).

7.3.3 Inter-relationships between economic, social, health, and environmental impacts of disasters

Assessments of the impacts of past disasters highlight that emergency situations can exacerbate economic, health and wellbeing inequalities. Though they are discussed separately in this Chapter, it is worth noting the strong inter-relationships and reinforcing effects across economic, social, health, and environmental impacts from disasters (cf. Chapter 3). For example:

- Loss of incomes and assets can have a dramatic effect on mental health, which can in turn limit financial recovery.
- Effective disaster communication may prevent a disaster or lessen its impact, whereas ineffective disaster communication may cause a disaster or make its effects worse (Houston et al. 2015). Emerging and evolving communication technologies offer a pathway for improved communication but also expose more people to unfolding events and so media (including social media) needs careful management (Finch et al. 2016).
- Insurance access, availability and affordability can be a source of considerable stress to property and landholders during the recovery period. Suburb or regional level disaster risk assessments may also provide incentives/disincentives for property owners to adopt practical efforts to rebuild or improve land holdings or properties to increase resilience to future natural hazards and mitigate increasing insurance premiums (see Chapter 3). The results can lead to areas of high non-insurance, including in Indigenous communities (ACCC 2018; ACCC 2019). This in turn can limit recovery and longer-term resilience against future natural disasters.

Understanding differences in vulnerabilities and needs for recovery are central in ensuring that these vulnerabilities (and inequalities) are not further entrenched through rebuilding under business as usual approaches that fail to fundamentally build resilience and proactive disaster responses (Brown and Westaway 2011; Leitch and Bohensky 2014). The remainder of this Chapter considers human health and well-being as well as industry or sector and environmental specific impacts and responses for supporting recovery and building long-term resilience to disasters in more detail.

7.4 Practical measures to support the recovery of basic needs, and human health and mental wellbeing in the aftermath of natural disasters

Supporting the basic needs and intangible costs of health and mental wellbeing impacts requires an assessment of the capabilities and vulnerabilities of a community. Lessons learned from past recovery efforts highlight that both the disaster and the recovery process can have a significant impact on people's health and mental wellbeing. Table 17 summarises immediate recovery needs reported from previous natural disasters and possible solutions to support communities that have been identified from research and past inquiries. Some of these needs are focused on access to food, medicine, clothes and shelter. Other impacts relate to the impacts of aid that is uncoordinated and difficult to navigate, and the challenges of finding ways to take the first steps to pay bills and re-build lost or damaged homes.

Table 17 Immediate impacts facing people affected by a disaster and practical measures to support access to aid, food and support services

IMMEDIATE IMPACTS	PRACTIAL RECOVERY MEASURES
Lack of personal identification (e.g. passport, driver licence) makes it difficult to access personal banking, register for aid and support services.	**Find ways to verify identity and issue temporary ID cards**. Existing databases (e.g. driver licence databases) could be used to verify identities on site, enabling immediate registration for assistance, etc. (Price Waterhouse Coopers 2010). **Technology, including the use of disaster recovery online platforms** have started to be used to help agencies and individuals respond to emergencies in a more agile and coordinated way. For example, telemedicine was an effective tool to deliver immediate first aid and medical treatment during Hurricane Katrina and the Queensland Police Service social media team played critical role to correct rumours, provide updated information and pass on messages from other agencies during Queensland's Tropical Cyclone Yasi (Gibbs et al 2016). **Support community service hubs** so that individuals and communities are empowered to access and ask for the support they need. Community infrastructure such as community and school halls offer safe refuge and are key priorities to support this effort.
Delays in accessing emergency relief funds, grants and loans limit people's ability to access housing and basic supplies, begin rebuilding, etc. Red tape and bureaucracy delay disbursement of government funds (e.g. paperwork requirements, problems accessing Centrelink if no prior account/no recent account). Charities face delays in disbursing aid as they perform due diligence.	**Develop a framework to prioritise among urgent recovery needs**. This is critical because some needs are more pressing than others, and aid is usually disbursed gradually (Cheatham et al. 2015). **Resource temporary agency offices to help people access resources.** In the aftermath of the 2009 Victorian bushfires and 2012 Queensland floods, the state government assigned case managers to support individuals and families and work with government agencies on their behalf, reducing red tape and increasing the pace at which essential services and financial support were delivered (PWC 2010).
Damage to housing leaves affected individuals and families without safe shelter. Some people's homes may be destroyed or damaged beyond repair. Other people may be prevented from returning home for safety reasons. Their property may be unsafe, or it may be located in an area that remains at risk.	**Prioritise helping people who cannot return to their homes**. During the 2019–20 bushfires, Find A Bed on-line website was set up with the aim of "matching people who had spare beds with people who had been displaced" (Derwin 2020). People registered as either having or needing accommodation and were matched based on location, accessibility, and other factors (findabed.com.au/) **Mobilise to support rebuilding efforts**. After the 2009 Victorian bushfires, steps were taken to provide those affected with guidance from professionals such as builders, architects, etc (PWC 2010, p. 11). A similar approach was supported by the Minderoo Foundation and other aid organisations in to support farming

IMMEDIATE IMPACTS	PRACTIAL RECOVERY MEASURES
	communities rebuild after the 2019-2020 bushfires (https://www.minderoo.org/?s=fire).
Lack of basic supplies leaves families in need of food, clothing, toiletries, etc. In the immediate aftermath of a disaster, people are likely to need basic items such as food and clothing. As time passes, different items may be needed, such as household goods. Needs should be assessed at various stages.	**Create community service hubs**. In the aftermath of the 2009 Victorian bushfires, these hubs facilitated access to basic services and the people tasked with coordinating the distribution of donated supplies (PWC 2010). **Identify specific needs and seek donations of items to meet those needs**. Some regional systems and processes have been established to make it possible to quickly and accurately identify needs and manage donations (e.g. see https://www.minderoo.org/fire-fund/news/fire-fund-recovery-pods-making-a-difference-on-kangaroo-island/) but a more coordinated and targeted approach across regions and jurisdictions is needed.
Lack of access to prescription medicine disrupts continuity of care (NZCDEM 2005).	**Allow people to access standard supplies of essential medication without a prescription**. In January 2020, a public health emergency order enabled affected people to access essential medication in standard quantities (e.g. one month's supply) without a prescription (ANMJ 2020).
Damage to utilities/communication links leaves people without power, water, internet and phone services, etc.	**Prioritise the restoration of essential utilities**. This includes addressing issues such as sewage and garbage disposal (NZCDEM 2005). **Ensure access to telecommunications**. Prioritise rapidly restoring mobile technology (as landlines are often unavailable following a disaster) and find ways to provide people with access to laptops and the internet. In the aftermath of the 2009 Victorian bushfires, laptops were available in community hubs to help people register for services, etc. (PWC 2010).
Impacts on income/livelihoods make it difficult to meet financial obligations such as mortgage repayments, rental payments and other bills.	**Provide relief through measures such as freezes on rent increases and evictions, mortgage holidays, etc**. In the aftermath of 2019–20 fires, the Australian Bankers Association (ABA) announced measures to help people with home loans, personal loans, credit card bills, etc., such as waiving fees and charges, interest rate relief for credit cards, deferring loan repayments and restructuring loans.
People may have only partial insurance or no insurance for their homes, or may be underinsured, and may be unable to rebuild.	**Lack of insurance impedes household recovery.** The Insurance Council of Australia (ICA) suggests that New South Wales' Emergency Services Levy (where insurance companies are taxed to fund emergency services) deters people from insuring their homes by increasing the cost of policies.

7.4.1 Health and mental well-being impacts in the short and longer term

Health and mental well-being are also key issues that need to be incorporated into immediate and long-term recovery efforts. During the 2019–20 bushfire season, smoke posed a range of health risks, especially for those with pre-existing heart or lung conditions. The president of the Australian Medical Association, Dr Barton, warned that “the length and density of smoke exposure is a new and possibly fatal health risk that many people within our community have not previously had to face” (AMA 2020). The Australian Academy of Health and Medical Sciences noted that the health impacts of bushfires are not well understood and that there are gaps in our knowledge regarding impacts on first responders, affected communities and the wider population, especially when exposure is prolonged (AAHMS 2020). Air quality in some Sydney suburbs was more than 10 times worse than the hazardous rating, and even in Canberra, which was less directly affected by the bushfires, air quality was 22 times worse than the hazardous rating. During the 2019–20 bushfire season, insufficient health advice was available to the public, both because of a lack of evidence in some instances and because existing evidence had not been collated and synthesised. Clear, evidence-based health advice is needed, along with targeted advice and plans for vulnerable groups, including infants, children, the elderly, individuals with pre-existing conditions, pregnant women, and Aboriginal and Torres Strait Islander peoples and communities.

The recovery process also affects people’s mental wellbeing. Various institutions are now focused on the mental health and well-being supported needed around natural disasters in Australia (e.g. Beyond Blue 2020). $75 million of immediate mental health services was part of the recovery support offered for the 2019/20 fire affected communities. $5 million from the Medical Research Future Fund (MRFF) has been released under an open and competitive grant round, with $3 million for research into the physiological impacts of prolonged bushfire smoke exposure and $2 million for research into the mental health impacts of bushfires on affected communities. Research funded will include studies into the short- and long- term impacts of bushfires on children and their caregivers mental health; how to direct support for the ongoing wellbeing and resilience of Australia’s first responders following the 2019/20 bushfires; and support mental health through building resilience during and after bushfires; enhance social and emotional wellbeing healing through arts-based storytelling for Aboriginal communities of Northern Inland NSW bushfire affected areas; and build community resilience to promote mental health in bushfire-affected communities. The Australian Institute of Health and Welfare will publish the biennial Australia’s Health 2020 report this year, and it will include a focus on mental health (see AIHW 2020).

This investment is supported by growing evidence of the immediate and long-term mental health impacts of natural disasters (Lindell and Prater 2003). This includes studies that have shown the mental impacts caused by flood (FitzGerald et al. 2019), tsunami (Math et al. 2006), and bushfire (Gibbs et al. 2016; Jahnke et al 2016). A study of health and wellbeing impacts of the 2009 Victorian Bushfires, for example, emphasised support for mental health and wellbeing as critical to disaster response (Gibbs et al. 2016). Seeking to understand the “interplay between individual, social and community-level recovery,” Gibbs et al. (2016, p. 7) reported evidence of “progressive recovery at [the] community level over time” but also noted “delayed impacts on individual mental health and extended impacts at five years post-bushfires”:

“Three to four years after the [Victorian Black Saturday] bushfires … a significant minority [of study participants] were reporting symptoms which indicated mental health problems that were beyond levels likely to be manageable and may require professional support. This is approximately twice the level you would expect in a population not affected by disaster. … Five years after the fires, rates of mental health problems had significantly reduced to 21.9% in high-impact communities but were still higher than national levels” (Gibbs et al. 2016, p. 12).

Table 18 draws on lessons learned from past bushfires and insights from other natural disasters on the impacts and practical measures to support mental health and well-being..

Table 18 Mental health impacts of natural disasters and practical recovery measures to support individuals and families.

MENTAL HEALTH IMPACTS	PRACTIAL RECOVERY MEASURES
Individuals. There is an increase in mental health symptoms of people directly affected by natural disasters. This is influenced by the severity of the event, the level of disruption to essential services and infrastructure, and the vulnerability of community members (FitzGerald et al. 2019). Managing messages and exposure to media also can be traumatic, including those not directly affected by the event (Headspace 2020). Psychological problems following a natural disaster can vary and can persist over time (Gibbs et al. 2016; Jahnke et al. 2012). Members of a community can experience variable impacts and levels of depression and trauma (Lowe et al. 2015). For example, areas that have a high disaster impact also report higher rates of violence against women, contributing to poorer mental health outcomes (e.g. genderanddisaster.com.au). Volunteers supporting recovery efforts are also affected and require support (Dickman et al. 2020).	**Provide professional emotional support for members of a disaster affected community as well as to volunteers supporting recovery efforts**. This can include resourcing relevant volunteer associations to provide support for their members (e.g. see https://www.iafc.org/iCHIEFS/iCHIEFS-article/firefighter-mental-health). Training and support for medical health professionals to deal with disaster-related trauma and psychological problems is also important (Freedy et al. 1993).
Families. Families and family members sometimes experienced different responses to natural disasters. Loss of resources, daily routine, a sense of control and social support were identified as key features affecting families to recover from Hurricane Hugo (Freedy et al. 1992). Gibbs et al. (2016, p. 17) found that "measures to support one family member's needs sometimes conflicted with other family member's needs – e.g. the decision about whether to relocate out of the disaster-affected area" following the 2009 Victorian bushfires. This meant parents had to find "ways to manage children's trauma reactions," while also managing their own responses to trauma and the "demands of rebuilding and recovery".	**Help foster effective coping skills within families who are dealing with the aftermath of a disaster**. Support tools to support trauma facing families, including children are available (AIDR 2019). Funding and training support for health practitioners supporting children and families are also available (Palfrey and Roberts 2019).
Social networks. Social network support factors such as mobilisation of actual receipt of health, sense of togetherness and also the impact of the deterioration of social support and sense of community are key aspects affecting emotional distress (Kaniasty 2004). People who chose to remain in affected communities in the aftermath of natural disasters are more likely to experience depression if members of their social networks had relocated (Richardson et al. 2020; Bryant et al. 2017). There is also a risk of poorer mental health outcomes if individuals are separated from family members (Richardson et al. 2020).	**Face-to- face and on-line platforms** have been critical mechanisms to address the loneliness caused by social isolation caused by a disaster event (see Robards et al. 2020). Providing long-term support is critical to build long-term mental and well-being resilience for individuals, families and communities affected by a natural disaster event.
Ecological grief and restoration. There are mental health implications of natural disasters and climate change (Cunsolo and Ellis 2018) including impacts caused by a disruption to a sense of place and identity (Chamlee and Storr 2009; Ellis et al. 2017).	**Restoring the natural environment positively affects people's health and wellbeing** . Richardson et al. (2020) report that "a strong attachment to the environment led to reduced psychological distress, fewer symptoms of major depression and fire-related PTSD, and higher levels of resilience, post traumatic growth and life satisfaction". Investments in Indigenous land management also show that conservation efforts can contribute to social goals (Burgess et al. 2009; Davies et al. 2011). Conservation responses can be successfully coordinated with other community restoration programs.

7.5 Practical measures to manage agricultural impacts of natural disasters

Analysis of extreme weather events shows similar mixed negative and positive results by sector but also by season which can help target disaster risk-mitigation more effectively (Ulubasoglu et al. 2017). It raises questions of how to address effects which continue into the year after a disaster — in particular for agriculture and whether these effects differ between crop and livestock operations. Preparedness mechanisms that allow businesses to mitigate these effects and allow them to return more fully to operation in the year after the disaster has been the focus of numerous programs and guidelines (Queensland Government 2020).

In 2012, the National Rural Advisory Council (NRAC) addressed this question in part with a study of insurance products for weather-related production risks available to Australian agricultural producers. NRAC found “farmers have access to a wide range of market risk options … and this range is continuing to grow”. One possibility are index-based insurance products which provide payouts based on a measure related to the disaster such as weather data, rather than actual farm damages. For example, a farmer receives a payout when rainfall falls below an agreed threshold. This helps reduce the cost of insurance, as providers do not need to do detailed farm assessments or ongoing monitoring (Hughes 2019). As a result, index-based insurance shows potential for uptake in Australia with a recommendation to include these products in the above-mentioned training and information programs as well as in the collection of data upon which the indices are based.

Business interruption insurance which replaces income in the event that business is stopped for some reason, such as fire, is also available (Kagan 2020; Venning 2020). It generally is attached to another policy and covers items like operating expenses, payroll, taxes, loan payments, and a move to temporary premises, if required. It may also apply if government actions cause operation to cease temporarily. It does not apply in the event of human disease officially listed under the Biosecurity Act such as COVID-19. If training included an exercise estimating financial needs in the initial weeks of a disaster, farmers can consider their options related to business interruption insurance and personal emergency funds. Short term decision-making is greatly aided by even a minimum financial bridge to the release of government emergency funds.

7.5.1 Role of rural women in natural disaster planning

The National Rural Women’s Coalition (NRWC) released a kit in 2015 “*Weather the Storm*” which was prepared to support women in their planning for natural disasters and emergencies. This was in recognition that in the growing frequency of events, such as bushfires, cyclones and floods, “there is an urgent need to educate communities about how to prepare for disasters and emergencies and that women have specific needs and vulnerabilities during and after a disaster” (NRWC 2015). Strategies such as these recognise disaster preparation opportunities are enhanced if attention is paid to the role of women as financial record keepers, decision makers, and the source of off-farm income to the operations. Furthermore, that women in rural areas are particularly vulnerable due to their isolation and where natural disasters are more likely to occur (NRWC 2015). “Women’s perspectives are often missing from disaster risk and decision-making, yet they can provide a unique and vital contribution to preparation and recovery” (NRWC 2015).

The NWRC 2015 report highlights that women:

- Are often keen to participate but are sometimes discouraged or intimidated by the male domination of emergency services, thus they need specific opportunities to learn and participate
- Are more vulnerable to disasters because they are more likely to be caring for children or the elderly, maybe isolated for long periods, likely to have responsibility for household running and the functioning of the family after a disaster, and
- Often have great social networks, knowledge of their local community, and are key in community preparations and recovery.

7.5.2 Targeted and speedy delivery of aid

Preparedness to reduce the effects of disasters must be met with speed in delivery of aid. The most immediate needs in the agricultural sector include replacement fencing, attending injured and dead livestock, ability to move product, and the flow of emergency financial assistance. The speed of these operations is greatly enhanced by:

- Continuously updated knowledge of the locations and extent of agricultural holdings in databases
- prior calculations of standard reimbursement rates for product compensation but also for commonly involved items such as fencing and erosion control
- the ability to deliver partial payment quickly with final payment following confirmation of required mitigation and completion of paperwork, and
- use of case managers to provide a consistent point of contact for the affected property.

7.5.3 Property identification to assist targeted recovery response

In Australia, opportunities exist to build on current use of systems such as Property Identification Codes (PIC). As noted by Agriculture Victoria (2020), "PICs are a unique code allocated by a state government authority to identify a property used for agricultural purposes… . The PIC records data about property owners, property information, and the number and species of animal on the property. The system is used to provide information to assist the response during biosecurity events and natural disasters such as bush fires, cyclones and health events".

The Commonwealth Government through the National Traceability project (conducted by DAWR) identified that a single, national approach to property identification to include "all properties with terrestrial and aquatic animals, and plant production activities, is a fundamental first step to improving traceability and is aiming to implement a national property identification system by 2022" (Australian Government 2019a). There is also scope to assist in targeting a response to suit the features and location of a property during natural disasters. The ability to link into an identification system for quicker disaster payments provides an additional benefit to producers participating in the system and acts as an incentive to keep records up to date. It also provides case managers a start on providing necessary assistance before visiting the operation.

7.5.4 Practical measures to respond to impacts of natural disasters – insights from the 2019-2020 bushfires

Table 19 presents a summary of impacts of the 2019-2020 bushfires that were reported by agricultural sectors and short, intermediate and longer-term practical measures that were implemented to support immediate and long-term recovery.

Table 19 Impacts and practical measures to manage agricultural impacts of natural disasters.

IMMEDIATE IMPACTS	PRACTICAL RECOVERY MEASURES
Emergency fodder and water is often the first requirement following a bushfire (Integrity Systems 2019).	State/territory agencies, along with state farming organisations and volunteers, may coordinate emergency fodder drops following natural disasters. After this initial assistance it becomes the responsibility of the livestock owner or their nominated representative to organise. Caution should be used due to the risks associated with purchasing from unfamiliar suppliers like chemical contamination, weed seed, etc. A Commodity Vendor Declaration should be requested, and records kept of all feed brought and the animals it was fed to (Integrity Systems 2019).
Livestock welfare - Treatment of sick, injured, or diseased animals must be provided at the first reasonable opportunity (Integrity Systems 2019) Ensure stock have the appropriate shelter, shade, good quality feed and water and unburnt ground, exposure to hot post-fire soil can cause further injury to hooves (Agriculture Victoria 2020a).	Producers initial mental state immediately after a major event tends to be one where they feel that they don't have the time, energy or resources to deal with injured livestock (Rogers et al. 2015). Support from state/territory agency staff/regional vets is a priority.
Disposal of dead livestock.	Appropriate carcass disposal methods and specific health risks in the local area to be identified and known by local councils (coordinate clean-up activities) and state authorities (advise about disposal needs of dead or injured animals, or any approvals required, e.g. in case of mass burials) (Agricultural Victoria 2020a) to assist landholders.
Uncertainly of livestock numbers that perished in a disaster.	The NLIS database can be used to reconcile livestock numbers and update the number of head on a producer's property. It can also be used to record the number of animals that dies on a property (Integrity Systems 2019). Need to ensure/encourage all property owners to have up to date PICs.
Assessment by authorities of the number of properties affected, their damage and stock losses. Until assessment conducted aid/emergency funding is limited. These assessments are conducted by state government primary industry departmental staff and include an initial rapid assessment, followed by a detailed damage assessment (Agriculture Victoria 2020a). These assessments are frequently slowed by the enormity of the task.	Assessments by state government authorities can be improved by: • Property owners ensuring their information is up to date within the PICs/NLIS databases prior to bushfire season/wet season (flood and cyclone risk regions). Authorities are able to use PICs to locate properties and owners when emergency events such as fires occur. This allows for state authorities to contact and visit all agricultural properties in the fire affected area to address any immediate animal welfare concerns, assess asset losses and guide other relief services to sites of high need. Having an up to date PIC is crucial to enabling authorities to carry out this work effectively (Agriculture Victoria 2020a, NSW Government 2020a). Thus, improving property owners understanding of this prior to the next season may be a key point of influence for improving the response. • State departments having enough staff trained and readily available for the task. Extension services strength lies within their pre-positioning, being readily available for deployment when skilled professionals are required, and their established existing networks (Hunt et al. 2011). Retention and strengthening of the core agricultural extension capacity and expertise should be a strategic objective for rural community stakeholders, and industry and government (Hunt et al. 2011).
Loss of fencing – replacing or repairing fencing to keep stock secure and safe.	The first priority when challenging with re-fencing after a fire or flood is the boundary fence (Agriculture Victoria 2019). Following that focus on fencing which aids care of livestock. After that, producers should use the opportunity to assess internal fencing and replan as part of a broader reassessment of the property (Agriculture Victoria 2019; NSW Government

IMMEDIATE IMPACTS	PRACTICAL RECOVERY MEASURES
	2017a). This pause may also assist in ensuring emergency funds can be utilised, save money in the longer term and improve future property management. Response times could be improved with the use of prior calculations of standard reimbursement rates for product compensation of commonly involved items, such as fencing, allowing for the delivery of a partial payment quickly with final payment following confirmation and completion of paperwork.
Loss of property machinery – may impact on a response due to not being able to perform basic tasks and repairs.	The loss of machinery may mean certain tasks become difficult to complete. For example, no machinery to unload or distribute livestock fodder, no pumps to water stock or crops.
Loss of property water infrastructure –impacts on stocks ability to access water and/or ability to irrigate crops (if rain doesn't fall).	After emergency water supply, repairing water infrastructure is another key priority for both livestock and crops. Fires may damage infrastructure (tanks, troughs, pumps, irrigation pipes), low dam water levels, and ash/soil/fire retardant may cause water quality issues (NSW Government 2020b). For certain crops, e.g. tree crops, grapes, it is vital that the irrigation infrastructure is replaced quickly (if rain doesn't fall) particularly if the soil is quite dry (Agriculture Victoria 2013a; Agriculture Victoria 2012).
Delivery of funds/aid.	Use the PICs to help delivery emergency aid and funding. Need to ensure/encourage all property owners to have up to date PICs. NSW already has requirements to submit an annual return of land and stock for all landholders who pay rates or have a PIC (NSW Government 2020a). This approach could be adopted (if not already) nationally to assist in improved emergency aid/funding delivery.
INTERMEDIATE IMPACTS	**PRACTICAL RECOVERY MEASURES**
Reassessment of damage – including of livestock, pastures and crops. Issues that may not have be obvious in the first 10 days - two weeks may appear.	Landholders need to recheck and reassess the damages after the first initial period as damage or injuries that weren't obvious may become more certain. It is a time when some producers will need more support. For example, those producers dealing with livestock in a hospital situation, where care is continuous and animals may need to be destroyed over a prolonged period, are likely to find the process mentally very hard (Rogers et al. 2015). Veterinary support from state/territory agency staff/regional vets will be important. It is also often a time when other livestock injuries become apparent (e.g. burnt hooves and udders) and a better understanding about the long-term survival of livestock can be gauged (Rogers et al. 2015). Crop wise, the extent of damage to some tree crops and vine crops will not be evident initially. Decision on how to move forward with crop damage is better left to after the immediate phase is over (Agriculture Victoria 2013a).
Agistment can provide relief in terms of stock feed and safety but the movement of livestock does pose added biosecurity risks.	Producers need to be aware of a number of key actions when agisting livestock – inspect the property or send a trusted rep; have a written agreement between agister and landowner; have a biosecurity plan that includes stock isolation when moving stock to and from agistment; record all stock movements between PICs in the NLIS database; if a LPA accredited producer then use a LPA accredited property, enquiry about contaminated sites or potential chemical exposure, and check if the PIC has any statuses assigned to it on the NLIS database (Integrity Systems 2019).
LONG TERM IMPACTS	**PRACTICAL RECOVERY MEASURES**
Restocking	Producers need to give careful consideration when sourcing stock (both livestock and planting materials) in the recovery phase from bushfires. Restocking after drought or fire increases the risk of introducing diseases, parasites, weeds and pests, requiring producer to have an appropriate biosecurity plan to manage them (NSW Government 2020c). Source from trusted sources, obtain health records, treatment records, segregate incoming stock, and seek advice from local state extension services if required.
Recovery - plan how to begin to recover and access help better from authorities and/or aid	Take the time and opportunity to replan and reflect on business direction (e.g. change fencing, reorganise livestock operations, paddock design, infrastructure) (NSW Government 2017a). Producers should consult with technical specialists and their insurance company when making decisions about long term block viability and possible replacement strategies of tree and vine crops (Agriculture Victoria 2013a; Agriculture Victoria 2013b; Agriculture Victoria 2012). Decisions should take into account the severity of the damage through the block, age, variety, rootstock and planting densities. Consideration should be given to the management

IMMEDIATE IMPACTS	PRACTICAL RECOVERY MEASURES
	required for the crop in the future, for example amount of work required to rejuvenate a mix of dead and sick vines needs to be weighed up against a total replant of a block (Agriculture Victoria 2012). This replanning stage also presents an opportunity to replace under-performing varieties or to change over to disease resistant, drought or salinity tolerant rootstocks (Agriculture Victoria 2012).
Planning for future adversity	A disaster management plan should be developed as part of an on-farm biosecurity plan (Integrity Systems 2019). This may include: Evacuation plans for people and livestock; plans for water provision if infrastructure is destroyed by fire; list of emergency contact details including fire brigade, local council, state department of primary industry, local vet, emergency animal disease hotline; proactive management of livestock (e.g. up to date NLIS identification, vaccinations and stock records); proactive management of environment (Integrity Systems 2019). Ensure that all agricultural enterprises have a PICs. The ability to link into an identification system for quicker disaster payments provides an additional benefit to producers participating in the system and acts as an incentive to keep records up to date. It also provides case managers a start on providing necessary assistance before visiting the operation.
Resilience	Rural extension services are a key mechanism in capacity-building and resilience in agricultural communities (Hunt et al. 2011). The benefits of their services in bushfire response efforts, as well as other natural disaster responses, has been demonstrated (e.g. NSW DPI 2017). Extension services strength lies within their pre-positioning, being readily available for deployment when skilled professionals are required, and established existing networks (Hunt et al. 2011). Extension services may also be a source of financial planning to help reduce risk.

7.6 Practical measures to manage the impacts on SMEs from natural disasters

Small businesses, or Small and Medium Enterprises (SME) are important economic contributors in Australia (Commonwealth of Australia 2018), and a vital socio-economic node in communities (Huang et al. 2018), but due to their size often lack the necessary resources to rebound from an event quickly. It is also important that disaster recovery for small businesses is understood as an iterative process involving interconnected decisions made by individuals, families, households and communities over time (Marshall and Schrank 2014; Madera 2017). Because of the great diversity in their features–for example, the nature of business, products or services, and location–disasters can have wide-ranging implications for small businesses. Impacts may be direct, and immediate, including damage to assets, loss of income, livelihoods and employment, and exposure to interrupted supply chains. Many of these impacts persist for long periods (Huang et al. 2018). Small businesses may also suffer from indirect impacts that are slower to eventuate and more diffuse, such as migration of residents away from the region, loss of economic and community vitality, and erosion of consumer confidence (CSIRO et al. 2020).

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An immediate objective of recovery for small businesses is restoring financial viability and enabling the business to get back on its feet. This needs to be supported, but the aspiration of small business owners to improve their adaptability and robustness to future disasters while they move through the longer-term recovery process demands equal attention (Marshall and Schrank 2014). This might entail re-assessing and changing ways of doing business and harnessing new approaches to business development. This is especially necessary for regional cities and communities where industries may need to cope and adapt against a background of changing demographics, unemployment and skills shortages, regional competition and distance from urban economic services (CSIRO et al. 2020). Where diversification or modification of the product, service, market or way of doing business in the immediate recovery period is possible, business agility also needs support. For example, food truck mobilisation is a key concept in disaster recovery, and small companies that can deliver mobile catering and other services may be able to continue to temporarily conduct a modified form of their business in the post-disaster environment.

A primary avenue for supporting small business recovery is through direct financial assistance in various forms. This includes recovery loans; for disaster-declared jurisdictions, disaster assistance can be activated for small businesses under the joint Commonwealth-State Disaster Recovery Funding Arrangements (DRFA). In Queensland, for example, Extraordinary Bushfire Assistance Loans have been made available as low-interest loans of up to $500,000 intended to help eligible small businesses pay for costs of repairing or replacing assets lost or damaged because of the disaster and to provide working capital to assist entities meet expenses for costs such as “repairing or replacing damaged plant, equipment or buildings, paying salaries or wages; creditors; rent and rates; buying goods, including fuel, for the purpose of carrying on the small business activities” (QRIDA 2020). However, while a range of loans and grants may be available, there is often a lack of coordination across levels of government and between jurisdictions, making the process of identifying assistance complex and challenging to navigate at local levels of government (ANAO 2015), which undermines the effectiveness of grants programs to assist individual small business owners. Better harmonisation of information flows around assistance is thus an imperative. Some businesses may also utilise informal or ‘bootstrapping’ financial assistance such as household resources or informal insurance (e.g. borrowing from family members or friends) (McDonald et al. 2014). It is important to recognise that while often a critical stop-gap measure, these forms of assistance come with boundaries and limits, and can potentially put undue pressure on the community networks associated with small businesses.

The connectedness of the small business sector to other parts of the economy and community also needs to be considered. Comprehensive research on disaster response indicates that the highly interconnected supply chains Australia depends on tend to optimise for efficiency, but at a cost to diversity and redundancy, and when disrupted can have cascading and amplifying effects (O’Connell et al. 2018). Thus, while it is vital to preserve supply chain integrity, it must be accompanied by building of flexibility and anticipation among small businesses and the broader community, so that they are prepared to cope with the loss of essential goods and services when supply chains are interrupted (O’Connell et al. 2018).

7.6.1 The example of tourism businesses

In June 2018 there were 302,520 tourism businesses in Australia, 95% of which are micro-small enterprises employing less than 20 people (Tourism Research Australia 2019). In 2018-19 the tourism industry contributed $60.8 billion to Australia’s GDP and accounted for 5% of employment (Tourism Research Australia 2019). The impact of disaster events on tourism – which often rely on natural assets such as national parks – span from direct damage to infrastructure and attractions, closure of services, damage to the image of an area, and the erosion of consumer confidence in the destination – all contributing to reduced visitor numbers (Mair et al. 2014). This has flow-on effects for other local businesses that rely on tourists to bolster their business. The recovery of tourism, beyond repair to basic infrastructure and resumption of travel, is often slower than other businesses because of the need to rebuild the image of the destination as safe and open for business (Mair et al. 2014). For example, marine-based tourism operators reported difficulty in attracting tourists back to the region after Tropical Cyclone Yasi due to negative media coverage that discouraged some would-be travellers – these indirect impacts of lost operating days were found to be more significant than direct impacts, and lasted for months (Marshall et al. 2013). Reduced visitor numbers due to perceptions of being 'closed for business' were also reported after tropical cyclone events in north Queensland in 2011 (Gooch et al. 2012).

Localised disaster events can affect the image of the region as a whole and may also divert visitors away from neighbouring (unaffected) regions (Mair et al. 2014). Tourism operators impacted by the 2003 fires in north east Victoria reported that sensationalist media coverage created a heightened sense of danger for would-be travellers, and created an image of mass devastation that dissuaded travel in areas that were not impacted by fires, or where the danger had passed (Cioccio and Michael 2007). In response to global coverage of the 2020 fires international tourists cancelled trips to affected and unaffected areas alike, with the Australian Chamber of Commerce estimating in January that international forward bookings had dropped 23% from the previous year (Australian Chamber of Commerce and Industry 2020).

Disaster management in the industry to date has tended to be reactionary, rather than proactive (Mair et al. 2014; Ritchie 2008). Short-term responses include communication and marketing campaigns to correct misperceptions about the scale and extent of a disaster and promoting a destination as 'open for business' (Mair et al. 2014). After the 2003 fires in north east Victoria, swift action by state and local governments to repair or replace physical infrastructure and funding/support for regional marketing campaigns, was viewed as important mechanisms to support tourism businesses (Cioccio and Michael 2007).

However, this type of short-term strategy assumes a rapid return to business, and doesn't account for compounding, large-scale disasters such as those experienced in 2020 (Quiggan 2020). After the 2020 fires, the industry was allocated a $76 million recovery package, of which $10 million was allocated to fund new events, festivals and attractions as part of rebuilding tourism in the worst affected areas; $61 million to Tourism Australia (to work with states and territories) on domestic and international marketing campaigns, hosting of international media and support for the Australian Tourism Exchange (a key business event) to rebuild Australia's image and attract more national and international visitors. Business and Tourism East Gippsland targeted a 'pay now, travel later' strategy towards domestic tourists to support businesses with cash flow while they rebuild (BTEG 2020). State and Commonwealth grants programs have also been dedicated to support local events and infrastructure as part of bringing people back into regions (e.g. Huf and Mclean 2020). The potential benefit of these measures have been undermined by the COVID-19 travel restrictions.

Analysing the preparedness and recovery of tourism operators in north-east Victoria after the 2003 fires, Cioccio and Michael (2007) found some businesses were better prepared than others due to mandatory/regulated requirements related to their business – for example, a caravan park leasing land from a national park was required to engage an external consultant each year to review their risk management strategy as part of retaining their lease. Another key strategy was insurance, though many tourism businesses were not insured for interruption to their business, while others had questioned the effectiveness of insurance compared to reinvesting (increasing) premiums into the business to manage (some) of the risks themselves (Cioccio and Michael 2007). The insurance industry plays an important role in incentivising improved risk management and preparedness – this is discussed in Chapter 3 (Frameworks and harmonisation).

Mair and colleagues (2014) argue it is vital that the industry increase its collaboration and knowledge sharing across the industry to learn from past disasters and foster greater understanding of how to support recovery. Scale is important here: Small enterprises (most Australian tourism businesses) are limited in how they can contribute to the rebuilding of the industry post-disaster. There is an important role for regional and state associations in coordinating and sharing across the industry and/or affected regions. Small enterprises are also often constrained in the financial and human resources they can allocate to contingency planning (Cioccio and Michael 2007), which may be more appropriately supported at a destination, regional or state-scale.

7.7 Recovery planning for small businesses

Recovery planning requires both short-term measures to address immediate impacts like cash-flow interruptions (discussed in more detail above) and longer-term strategies to increase resilience to future disasters. Table 20 summarises some of the measures relevant for small business.

Longer-term recovery planning priorities for the small business sector include training and capacity building, fostering social capital, and supporting networking, involving a suite of actors including non-government and non-profit entities. The Small and Medium Enterprise Association of Australia (SMEA) calls SMEs the “most important economic driver of Australia”, and supports small businesses through opportunities to help grow sales, identifying ways to save costs and to foster networks with other members (SMEA 2020). In the context of dynamic change in regions, Queensland’s Communities in Transition Program emphasises the need for “dynamic business and sector development”, sketching out four key areas for strategic effort: building collaborative industry clusters, creating a stronger innovation platform for emerging businesses, cohesive workforce forecasting and coordinated response and strengthening regional economic governance. Central to these is a focus on building relationships with a wide range of partners, including local councils, community and industry actors, and State Government (CSIRO et al. 2020).

These measures enable capacity building and fosters innovation through skills mobility and building greater connectivity and collaborative, supportive communities, which plays an essential role in the wake of disaster. Specifically, support may include providing mentorship programs and opportunities for training and education, boosting entrepreneurial skills, the creation of community groups that focus on local grass roots actions and establishment of co-working spaces (CSIRO et al. 2020).

Brisbane City Floods. Photo Andrew Kesper / CC BY (https://creativecommons.org/licenses/by/2.0)

Table 20 Impacts and practical measures for small and medium business affected by natural disasters

IMMEDIATE IMPACTS	PRACTICAL RECOVERY MEASURES
Reduced revenue and cash flow of business due to temporary closure, reduced visitor/customer numbers.	Increased support to access direct financial assistance such as grants, low interest loans, tax concessions, to support short-term recovery. Efforts across regional and state jurisdictions should be coordinated to ensure business owners are aware of opportunities. Increased support for business agility: post-event adaptation of product, service, provision or customer base.
Lack of insurance or under-insurance inhibiting capacity to rebuild or recover costs.	Insurance industry measures (e.g. through the Insurance Council of Australia) to work with communities on preparedness and risk mitigation. Support opportunities for regional tourism bodies to coordinate marketing/social media campaigns to rebuild image and mitigate negative perceptions about extent of damage and impact.
Building resilience to future disasters and disruptions, including impacts from cumulative, multiple and prolonged events.	Skills and capacity building to support longer-term resilience and adaptability of businesses to tap into multiple consumer engagement / outreach strategies. e.g. online and shopfront business. Fostering of networks and collaborative clusters to support mentoring, training and education across regions and sectors. Through insurance industry, incentivise mitigation and risk reduction – e.g. programs to reduce premiums where steps (e.g. infrastructure modifications) are taken to mitigate risk.
Visitors deterred from visiting area / damage to destination image. Visitors prevented from visiting an area due to safety concerns and/or compounding events.	Support opportunities for regional tourism bodies to coordinate marketing/social media campaigns to rebuild image and mitigate negative perceptions about extent of damage and impact. Regional tourism body collaborations with media to ensure coverage of recovery (not just disaster) Creative campaigns to allow visitors to explore regions remotely – eg. #greecefromhome – a collaboration with Google and the Greek National Tourism Organisation which enables ongoing tourism engagement *and* deliberately builds skills and capacity within the tourism industry.

7.8 Practical measures to manage the environmental and cultural heritage impacts of disasters

Natural hazards impact on our environment as well as on our lives, our wellbeing, our property and our communities. Fire management agencies focus primarily on saving life, then protecting property, and then on protecting the environment, in that order. However, environmental impacts can have long-lasting impacts effects on our natural and cultural assets, and also affect the wellbeing of people who value those assets or the services they provide.

This section will focus largely on the bushfires of the summer of 2019/20 but draw on examples from other natural disasters where appropriate. It is not intended to be comprehensive, but rather illustrate the scale of effects and impacts, and of the task to support recovery and where possible enhance resilience.

Over 10 million hectares burned during the 2019/20 Australian bushfire season. Early scientific assessments suggest that these fires had a devastating impact on biodiversity, including the loss of at least one billion birds, mammals and reptiles, adding further to the ongoing threats to species' survival (RMIT ABC Fact Check 2020), and threatening habitat both for remaining populations and for migrant species yet to return.

A Wildlife and Threatened Species Bushfire Recovery Expert Panel (https://www.environment.gov.au/biodiversity/bushfire-recovery/expert-panel), established by the Minister for the Environment, the Hon Sussan Ley MP, and chaired by the Threatened Species Commissioner, acknowledged that 'the recovery of native species, ecological communities, natural assets and their cultural values for Indigenous Australians [would] require a sustained and strategic long-term recovery effort'. The Panel identified four objectives to guide immediate recovery efforts:

- Prevent extinction and limit decline of native species.
- Reduce the immediate suffering of native animals directly impacted by the fires.
- Maximise the chances for long term recovery of native species and communities.
- Ensure learning and continual improvement is at the core of the response.

and five priority activities required to meet these objectives:

- Protecting unburnt areas within or adjacent to recently burnt ground that provide refugia.
- Feral predator and herbivore control to reduce the pressure on native species where appropriate.
- Emergency salvage of plant and animal species for ex-situ conservation or wild-to-wild translocation.
- Rapid on-ground assessment for species and communities of concern.
- Supplementary shelter, food, and water for animals where appropriate.

Species and community-level bushfire impact assessments were conducted by the Expert Panel in collaboration with Commonwealth, State and Territory government agencies and many taxon experts. Impact assessment considered

1. the conservation status of the species and communities before the fires
2. the proportion of the species' range or community's distribution potentially impacted in 2019/20, and
3. how vulnerable the species or community is likely to be to fire events based on recorded traits such as mode of reproduction, time to maturity, and ability to recolonise impacted areas.

This approach required accurate fire extent maps, accurate understandings of the distribution of species and communities, and an understanding of the traits that convey resilience or risk to species.

This type of coordinated response was also delivered after the February 2009 Victorian bushfires, bringing together Commonwealth and Victorian agencies, community groups and scientists, and led to the establishment by Department of Environment, Land, Water and Planning (DELWP) of a Natural Values Recovery Program. The legacy of this program includes proactive nature conservation activities in advance of the 2019-20 bushfires (DELWP 2020).

7.8.1 Impact mapping

In response to the 2019-20 bushfires a National Indicative Aggregated Fire Extent Dataset (NIAFED) was compiled by the Department of Agriculture, Water and the Environment (DAWE), being developed from the national Emergency Management Spatial Information Network Australia (EMSINA) data service, which shows current active fire incidents, and supplementing it from other sources. The published metadata for the dataset acknowledges the following data providers, emphasising both the good will of contributors seen broadly in the responses to the summer's extremes, but also the need for better integration: NSW Rural Fire Service; Northern Australian Fire Information (NAFI); Queensland Fire and Emergency Service; Queensland Department of Environment and Science; SA Country Fire Service; SA Department for Environment and Water; Tasmanian Fire Service; Tasmanian Department of Primary Industry, Parks, Water and Environment; Victorian Department of Environment, Land, Water & Planning; WA Department of Biodiversity, Conservation and Attractions (DAWE 2020a). The NIAFED is released on behalf of the Commonwealth Government and endorsed by the National Burnt Area Dataset Working Group, convened by the National Bushfire Recovery Agency.

A layer indicating fire intensity within that extent was developed by the Centre for Australian National Biodiversity Research, a joint venture between CSIRO and the Director of National Parks, for intersection with the plants distribution data. National fire severity mapping produced by DAWE developed using a modelled method developed by NSW Department of Planning, Industry, and Environment is being used to inform updates to the vertebrate and invertebrate priority lists.

By contrast, in order to estimate the area of forest affected by Severe Tropical Cyclone Yasi in 2011, the Bureau of Meteorology's storm track was intersected by the surface wind fields generated by the Hurricane Research Division of the National Oceanic and Atmospheric Administration to model surface wind data. These were then used to interpret tree mortality data inferred from pre- and post-cyclone Landsat and MODIS satellite images, combined with Vexcel hyperspectral aerial photographs, to estimate a mortality of in excess of 300 million trees across 9, 000 km2 of forest (Negrón-Juárez et al. 2014).

7.8.2 Distribution data

Distribution models are developed and maintained by DAWE for EPBC-listed species and communities. Following the 2019-20 bushfires these distributions were intersected with the NIAFED within a restricted Preliminary Analysis Area which covered bioregions that had been impacted by fires in south-west Western Australia, southern South Australia, Victoria, southern and eastern New South Wales, south-eastern Queensland and Tasmania. This intersection provided the Wildlife and Threatened Species Bushfire Recovery Expert Panel with indicative current national assessments of environmental values potentially affected by fires, which enabled the development of an initial list of protected species in bushfire affected areas, released on the Department's website on 20 January 2020. Ten bioregions in this area were significantly impacted.

Preliminary results indicated an initial list of threatened and migratory species which had had more than 10% of their known or predicted distribution in areas affected by bushfires in southern and eastern Australia from 1 August 2019 and 13 January 2020:

- 49 listed threatened species had more than 80% of their modelled likely or known distribution within the fire extent
- 65 listed threatened species had more than 50%, but less than 80%, of their modelled likely or known distribution within the fire extent
- 77 listed threatened species had more than 30%, but less than 50%, of their modelled likely or known distribution within the fire extent
- 136 listed threatened species and 4 listed migratory species had more than 10%, but less than 30%, of their modelled likely or known distribution within the fire extent.

Refinement of this initial list, to include non-EPBC listed species and to incorporate variation in species' vulnerability to fire, drew more heavily on States, Territories, herbaria and museum data, together with expert opinion. For non-EPBC listed species (according to Legge et al. 2020; Woinarski et al. 2020; Gallagher et al. 2020a):

- Mammal, frog and spiny crayfish distributions used quality filtered point records extracted from the DAWE sourced primarily from States, Territories, herbaria, museums and the Atlas of Living Australia (ALA)

- Reptile distributions drew from the species distribution polygons for reptiles compiled during the 2017 reptile assessment carried out by IUCN (Meiri et al. 2017) and modified by expert opinion
- Bird distributions based on gridded observation points analysis from records held by BirdLife Australia, and compared to a different fire extent map (see Legge et al. 2020)
- Freshwater fish distributions based on IUCN fish sub-catchment distributions, from data compiled during the 2019 IUCN Red List assessment for Australian freshwater fish (https://www.iucnredlist.org/)
- Distributional data for selected invertebrate species used quality filtered point records extracted from the DAWE sourced primarily from States, Territories, herbaria, museums and the ALA. Analyses mostly used a filtered subset of records, to include only those records post-dating 1995, and those with a precision of ca. 1 km. Note that for many (probably most) invertebrates there exist limited or no reasonable distributional data, so fire overlap was analysed instead for several invertebrate groups (butterflies, land snails and some beetle groups) for which some distributional data existed, and where there were known to be species susceptibility to fire
- For plants, records from the Australasian Virtual Herbarium were downloaded and filtered to exclude any records of taxa with no ratified name according to the Australian Plant Census or of non-native origin, or taxa with cultivated status, and/or flagged geographic issues in the ALA, and individual records lacking a vouchered specimen for verification and/or collected prior to 1950 were also excluded, leaving a total dataset of over 3 million records for 22,326 species.

The complexity of this undertaking, and the variety of approaches demonstrated, again indicates the good will of all parties, but also a need to agree on consistent data collection, aggregation, storage and sharing protocols. Such nationally agreed standards and distribution maps would support better planning, emergency responses and recovery actions.

7.8.3 Susceptibility to impacts of bushfire and other natural hazards on population recovery and resilience

Species and communities were reviewed against criteria to establish their likely susceptibility to population declines or local extinctions if they occurred within the spatial extent of the 2019-20 bushfires. This approach included a consideration of potential mechanisms of decline, where in the landscape those mechanisms were most likely to have an impact, and species-specific characteristics that increase exposure to those risks.

The review identified 20 mammal, 17 bird, 23 reptile, 16 frog, 16 fish, 212 invertebrate and 471 plant species, plus 19 threatened ecological communities as high priority for urgent management intervention; 147 species of invertebrate were identified as requiring further investigation and assessment; they are likely to have met the thresholds for prioritisation but paucity of information hinders final determination (Legge et al. 2020; Woinarski et al. 2020; Gallagher 2020b). Ongoing work suggests that more than 800 plant species have more than 50% of their records falling within the fire grounds; fewer than 10% of these species have formal Commonwealth legislative protection (Linda Broadhurst, personal communication).

Of particular concern are the potentially multiplicative effects of compounding threats. For example, some areas affected by 2019–20 bushfires were also experiencing lengthy droughts and extreme temperatures that have direct impacts on biodiversity and will have a major influence on the post-fire response of species and ecosystems. In some ecosystems, fires facilitate the entry and spread of disturbance-favoured invasive plants. For example, the Kosciuszko fires of 2002–03 catalysed the rapid and extensive spread of sweet vernal grass through a range of subalpine ecosystems (Verrall and Pickering 2019), while tropical cyclones are implicated in the establishment and spread of weeds in rainforest which is otherwise highly resistant to incursions (Murphy and Metcalfe 2016). In response to aggressive colonisation of burned areas after the

2009 Victorian Black Saturday bushfires, Zimmer et al. (2012) developed a post-fire weeds triage manual to help managers decide which species should be priorities for management to increase habitat recovery potential and enhance community resilience.

Feral animals also have a highly significant effect on post-event survival. For example, Sambar deer were greatly reduced in abundance during the Black Saturday fires in Victoria but had regained former levels of occupancy in Kinglake National Park 16-24 months later (Forsyth et al. 2011). Increased rates of herbivory on regenerating shoots of vulnerable species was highlighted as a concern following the 2019-20 bushfires, and significant investments have been made across multiple jurisdictions to control feral herbivores. Feral pigs were targeted in the North West Queensland Livestock Recovery Package as part of a $3 million weed and pest management package announced by Commonwealth and Queensland State Governments after the 2019 Northern Australia monsoonal floods. Pigs are generalist feeders which dig up roots, eat foliage, scavenge carcasses, predate small vertebrates, and are implicated in disease spread, including of the root-rot fungus *Phytophthora* (Commonwealth of Australia 2017).

Predation by mammalian carnivores is also a concern; in Victoria after the 2009 Black Saturday bushfires efforts were made to control feral cats (e.g. Johnston 2012) and foxes (Robley et al. 2012), and following the 2019-20 bushfires efforts have been made to erect cat-proof fences, bait and trap cats and foxes. Cats are likely to be responsible for greater mammal mortality than any other threatening process in Australia (Murphy et al. 2019), and at least in northern Australia, cats show a habitat preference for fire scars (Leahy et al. 2016; McGregor et al. 2016). Integrated approaches to reducing feral cat numbers, supporting native species recovery and management of habitat to build resilience for native species are key research foci (Hradsky 2020).

Case study: The globally significant Great Western Woodlands (GWW) of Western Australia suffered severe fires in the Norseman-Balladonia and Frank Hann NP areas over the summer of 2019-20, leading to closure of the Eyre Highway for about two weeks, and similarly severe fires occurred in other parts of the GWW in the two previous years. Outcomes of the research to date identify the ecological significance of old-growth fire sensitive woodlands and the need for targeted fire protection (Prober et al. 2016; Gosper et al. 2018). Characterisation of changes in their biodiversity with time-since-fire over 400-year periods showed higher values for birds, plants, and carbon storage in old growth woodlands, the latter taking at least 150-200 years to develop after fire. Of special concern are fires that burn relatively fire-resistant old-growth woodlands (in extreme conditions). These lead to regeneration of dense, young woodlands (pole stands) that are about five times more flammable than old-growth woodlands, with this phase lasting for more than 100 years. This fire-feedback makes it difficult to return to the valued old growth woodland state (characterised in the Australian Ecosystem Models framework, above, as obligate-seeder eucalypt woodlands), providing further impetus for suppressing fire in old-growth woodlands. Consequently, the research team is now working with the Ngadju people through the Ngadju Native Title Aboriginal Corporation to map remaining old growth woodlands (i.e. significant, fire sensitive habitat) using satellite imagery to enable Ngadju rangers and other fire managers to target them for mitigation and rapid suppression activities in future seasons where extreme conditions prevail.

7.8.4 Response

In January 2020, The Australian Government made an initial commitment of $50 million for emergency wildlife and habitat recovery, informed by the priority actions and species/communities identified by the Expert Panel.

On Tuesday 3 March the Australian Government announced an additional $2 million National Environmental Science Program (NESP) funding to the Threatened Species Recovery Hub (TSR) to deliver research and scientific advice to help support and guide wildlife recovery efforts and habitat rehabilitation strategies following Australia's bushfire crisis. The NESP TSR identified five priority research areas in the immediate response to the bushfires, which were endorsed by the Expert Panel for further development of projects:

- Assessment of impacts on species and ecosystems
- Prioritisation of actions for those species
- Priorities in bushfire recovery for Indigenous Australians
- Monitoring and investigation, and
- Lessons for the future.

A report compiled for the NESP TSR made extensive review of the published literature to highlight design considerations for conducting post-fire reconnaissance surveys to assess fire severity, habitat condition and threats in areas most vulnerable to the 2019-20 bushfires (Southwell 2020). Whilst not mandatory, the guidance was expected to support funded Wildlife and habitat recovery program projects, and inform others undertaking on-ground surveys.

In May, a further $150 million was committed to target on-ground activities to support recovery efforts, update conservation plans for threatened species and track the recovery effort. Individuals, communities, businesses, charitable organisations and the state and territory governments have also invested resources, time and effort into emergency responses, immediate relief and recovery efforts. Empowering local community efforts to regenerate the natural environment has been identified as critical to cultural and natural heritage management. Around 6400 Australian Defence Force personnel supported the 2019–20 bushfire recovery, and concerted efforts to work with local Aboriginal elders to guide bushfire recovery and landscape management efforts have been highlighted as a practical, best-practice example of community-led efforts (ADF 2020).

7.8.5 Recovery

Recovery beyond immediate emergency response will require long term commitment and planning. For some species genetic rescue or translocation for population management may be required, or seed-banking for plants or captive breeding for animals. Strategic feral animal control of predators and herbivores will also be required to facilitate recovery of burnt areas and limit pressures on unburnt refugia. Weed management will also be required to prevent weeds from dominating regrowth, suppressing natural regeneration or encouraging future fires (Mellend et al. 2008). Active revegetation and regeneration may be required in some areas, together with landscaping to reduce gully erosion and contamination of waterways. Coordinated responses and resourcing needs are widely discussed, for example by DELWP (2020), the communiques of the Wildlife and Threatened Species Bushfire Recovery Expert Panel and resources available from the NESP TSR (https://www.nespthreatenedspecies.edu.au/).

For example, long-term monitoring of flying-fox populations has allowed researchers to track the population-level consequences of significant weather events, such as tropical cyclones (Westcott et al. 2015). Extreme heat events are also major causes of mortality for EPBC-listed and other flying-fox species (as well as of other creatures). The National Flying-Fox Monitoring Program (http://www.environment.gov.au/biodiversity/threatened/species/flying-fox-monitoring) documented an extreme heat event in November 2018 in Far North Queensland that caused mortality of approximately one-third of the known population of the Spectacled Flying-Fox. CSIRO and the University of Melbourne have recently completed a project to understand the physiological responses of flying-foxes to extreme heat events and using this to predict the camp modifications/management that land managers could make to reduce mortality in the event of a future extreme heat event. National Flying-Fox Monitoring Program data also informs the University of Western Sydney's Heat Stress Forecaster (https://www.animalecologylab.org/ff-heat-stress-forecaster.html; see Ratanayake et al. 2019) which is used by state and local governments and community groups to predict and prepare for heat stress events.

New Zealand's holistic framework for disaster recovery offers recommendations regarding the natural environment, noting that "sound recovery practices" can reduce the impacts of disasters. The framework advocates for a "cooperative process led by specialist agencies, supported by local authorities and involving the wider community". It argues for a "holistic suite of measures … such as enhanced emergency feeding programs for [wildlife] by departments and the community; enhanced pest control in the affected areas; temporary bans on public access to fragile areas; temporary hunting bans … ; active relocation programs for threatened species; [and] community involvement in re-planting activities" (NZCDEM 2005).

7.8.6 Research to guide recovery efforts for ecological resilience

Across Australia's innovation sector, there is extensive and intensive research on Australia's unique biodiversity, including work targeting individual or groups of species, ecosystems, ecological processes and the management responses that relate to them. Natural disasters are but one of many pressures, and much of the work that is done has application to the preparation for or response to natural disasters, whilst not always being explicitly targeted solely at them. Virtually all such research is carried out with collaborators from across the research sector, with or for policy makers, land managers, non-governmental organisations and Indigenous or non-Indigenous community groups. And such work is typically additive, building bodies of work over years and decades.

For example, in order to provide better advice to land managers and decision makers, DAWE has funded a series of Biodiversity Knowledge Projects, including the Australian Ecosystem Models framework (Richards et al. in review). Developed through broad consultation amongst national vegetation experts, the Framework provides a continental set of dynamic ecosystem reference models and a method to consistently capture changes to ecosystem state and condition, relative to disturbance-driven changes in ecosystem attributes that do not impact ecosystem integrity, and providing a means to support national ecosystem health assessment and reporting, as well as integrated ecosystem management. Such approaches can demonstrate that significant ecosystem disruption caused by natural disasters such as tropical cyclones, bushfires and flooding are recognised as part of natural ecosystem dynamics, and thus provide land managers with an understanding of the natural regeneration process and how management interventions may support recovery, rather than treating such systems as 'lost' and bulldozing or otherwise removing them. The framework is currently being used to underpin the ecological interpretation of a set of experimental ecosystem accounts in two protected area case studies in Australia (the Gunbower-Koondrook-Perricoota forest icon site (on the Murray River west of Echuca) and Kakadu National Park) and incorporate additional understanding of ecosystem dynamics over time, including ecosystem responses to climate change.

There is also a need to build national information resources to manage Australia's unique natural assets. While the response of national and state and territory agencies, museums, herbaria and experts has been remarkable, the hurried activities clearly highlight that Australia needs to work towards nationally-agreed species distribution maps. These maps need to be active not passive, reflecting for example the retreat of species requiring running freshwater or humid habitats into limited and disjunct refugia under conditions of drought, when the coincident or consecutive occurrence of chronic and acute events such as drought, fire and flood can impact on significantly greater proportions of a species population than would be apparent from intersection of the entire historical range map with an event footprint.

The events of summer 2019/20 also highlighted a gap in Australia's understanding of the vulnerability of its biodiversity assets to natural disasters. Collaborative national resources need also be devoted to the complex issue of determining the degree of risk reduction that can be achieved per unit input of management and financial input. Risks to biodiversity assets should be explicitly built into and accounted for in the management of individual fires. For example, Victoria's Department of Environment, Land, Water and Planning are developing a framework to integrate ecological values into bushfire management planning. Such approaches also need to consider cultural heritage values.

DAWE's Threatened Species Scientific Committee will review and update the Conservation Advice documents of taxa affected by the 2019/20 fires, but Commonwealth and state listings need to have resources devoted to Recovery Plans, Action Statements or their equivalents so that the listings also come with management guidance. Similarly, for cultural heritage, recommendations on potentially deleterious fire-fighting techniques such as earthworks, and of appropriate post-disaster interventions, may also help to limit further damage to culturally important sites where possible.

7.8.7 Cultural heritage

The Australian Archaeological Association has made a series of recommendations for cultural heritage sites and has called for an audit of burned country, undertaken in consultation with affected Aboriginal and non-Aboriginal communities and heritage professionals (AAA 2020). This would have two main aims:

1. Visits to the locales of known sites and heritage places to identify what has been damaged or destroyed and to assess the condition of what survives. It is very likely that many hundreds, if not thousands, of sites will have been destroyed. Inappropriate rehabilitation could cause further damage to heritage places.
2. Surveys of burned country to identify previously unknown Aboriginal and non-Aboriginal sites and heritage places exposed by the lack of vegetation that may have survived the ravages of the fires. For example, although fire impacted much of the Budj Bim Cultural Landscape World Heritage Area, the burns also revealed cultural sites that were previously concealed beneath vegetation. With the approval of Traditional Custodians, these newly discovered sites can be placed onto heritage registers to protect them into the future. The communities can also be supported to incorporate these places into living heritage narratives.

These aims complement one of the recommendations from New Zealand's holistic framework for disaster recovery, which highlights that pre-identifying amenities, including culturally significant sites, that are important to "peoples' social and emotional recovery will help prioritise recovery activities" in the future (NZCDEM 2005).

COVID-19 restrictions are delaying assessment of damage to cultural heritage. NSW National Parks and Wildlife Service is planning to use drones to carry out initial assessments of some sites, after consultation with the community, to address concerns about bushfire impacts on culturally significant sites. These actions are in accord with its obligations under the NSW *National Parks and Wildlife Act 1974* and the Gundungurra Indigenous Land Use Agreement (DAWE 2020b).

7.9 Recovery measures to build community resilience to natural disasters

Successful recovery is responsive to the complex and dynamic nature of both emergencies and the community. It presents an important opportunity to ensure that efforts to support recovery also build resilience in the long term, especially in the context of compounding disasters. Practical measures need to be cognisant of systemic causes of disaster, even if they cannot address them in themselves, and must be designed robustly, with a 'no regrets' approach. These measures must also be designed to maintain possibilities to support transformative change when such opportunities arise. These measures must also empower disaster-affected communities to ensure local context and values are understood when providing recovery support and to guide timely, efficient and coordinated delivery of critically needed goods and services. Recovery support that encourages individuals and communities to do things differently, build back better, and enable ecological systems to rebound and flourish is also critical to reduce the vulnerabilities and inequalities that are particularly exposed during and after a natural hazard event.

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8 Improving Built Environment Resilience

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8.1 Infrastructure Resilience

8.1.1 Chapter 8 Summary

Australian governments recognise the importance of infrastructure resilience and acknowledge an expectation by the community that governments will safeguard its continued operation. The Australian approach to infrastructure resilience is progressed through a range of strategies and frameworks, with the NDRRF the key driver at the commonwealth level.

This Chapter focuses on decisions which impact the resilience of Australia's critical infrastructure. It explores the many stakeholders and groups involved in making these decisions (collectively termed 'actors'), and how they are informed.

Critical infrastructure is not limited to physical facilities and assets but includes networks, data and supply chains. Australia's infrastructure is under threat from both frequent and infrequent disaster events as well as changing risk profiles from slow-onset threats from natural or man-made hazards. While resilience is defined as the capacity for critical infrastructure to absorb the impact of events and recover to a normal state, resilient infrastructure is greater than an asset's capacity to simply withstand attack. When evaluated through the dimensions of impact on the physical, organisational, economic and social aspects of critical infrastructure, its resilience is only demonstrated where each dimension is resilient in its own right.

Australia's critical infrastructure, especially in relation to linear infrastructure networks such as roads and water, are multijurisdictional and traverse the boundaries of all three tiers of government. Further, many physical assets and networks are owned and operated by the private sector, including entities not based in Australia. In this complex system of ownership, applying resilient approaches to future infrastructure planning will require participation by a diverse range of actors, each with their own motivations and objectives. Therefore, strategies and frameworks to include resilient approaches to infrastructure planning should be applied under a paradigm that recognises both the multidimensional aspect of resilience and multijurisdictional nature of the participating actors and stakeholders.

The NDRRF recognises this complex paradigm, supporting all jurisdictions and non-government stakeholders to collectively prepare for the hazard, exposure, vulnerabilities and capacity to survive. Australia's Critical Infrastructure Resilience Strategy extends this framework with an aim to ensure the continued operation of critical infrastructure in the face of all hazards.

Notwithstanding these established frameworks, it is acknowledged internationally that the tools to support the implementation of disaster risk reduction are not available. As a result, operational imperatives are often prioritised over longer term resilience strategies. While Australia's current resilience frameworks recognise the important role of strategic decision making and acknowledge the role of information in supporting actors in the delivery of informed resilience choices, recent reports show that practitioners lack sufficient guidance in implementation. Shared cross-sectoral information can help to interpret the existing frameworks and unify potentially competing objectives across the diverse actors impacting infrastructure resilience.

Regulation, codes and standards establish minimum requirements with either a tenuous or direct link to resilience, while the assessment of resilience during infrastructure planning can demonstrate that building a higher level of resilience than is mandated can be cost-effective. The nature of information to guide resilient outcomes therefore needs to transition from the historical evidenced approaches traditionally used in development of regulatory codes and technical standards, to forward looking scenarios of future exposures and vulnerabilities. This information is required in a form that supports a diverse group of actors to make forward looking decisions. It is also noted that in order to avoid resilience frameworks being limited to protection-based paradigms, diversity and the inclusion of societal values is to be encouraged. This inclusion translates the approach from 'including resilience' towards 'balancing resilience', a concept that aligns with the Sendai framework's specific aim to include input from policy, scientific and societal sources.

The assessment of infrastructure resilience extends beyond planning and construction to evaluate the performance of assets and networks in operation. A forward looking approach to resilience not only covers future threats, but introduces aspects of maintenance, retrofitting and changing societal expectations.

It is generally accepted that Australia has agreed strategies and frameworks to encourage the delivery of resilient infrastructure. However, industry and academic research indicates difficulty in translating those frameworks to implementable actions. Information is identified as a key aspect to support successful implementation and steer competing objectives toward unified outcomes. Trusted and authoritative information to guide stakeholders and actors in decision making is therefore critical to underpin forward looking decisions. Information in a form suitable for a wide audience will facilitate a balance of scientific, societal and traditional participation in the implementation of Australia's risk reduction and resilience frameworks.

8.1.2 Australia's Approach to Infrastructure Resilience

Australia adopted the Sendai Framework for disaster risk reduction in 2015 (National Resilience Taskforce 2018a), with a goal to prevent new and reduce existing disaster risks. The approach integrates economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures. It addresses the exposure to hazards, as well as related vulnerabilities to disaster, increasing preparedness for response and recovery, and thus strengthening resilience (UNISDR 2015b).

The Sendai Framework sets four priorities for focused action (UNISDR 2015a):

- Understanding disaster risk
- Strengthening disaster risk governance to manage risk
- Investing in disaster risk reduction for resilience
- Enhancing disaster preparedness and 'Build Back Better' in recovery and rehabilitation.

Australia's National Disaster Risk Reduction Framework (NDRRF) translates the first three Sendai priorities into the Australian context, while the fourth - Build Back Better - is progressed through the Australian Disaster Preparedness Framework (National Resilience Taskforce 2018a).

NDRRF informs Australia's strategic governance, policy and investment for disaster preparedness, allowing all jurisdictions to collectively prepare for severe to catastrophic disasters. The framework is not limited to governments, and aims to provide information to support decisions on strategic capability requirements across governments, private, community and international sectors (Department of Home Affairs 2018).

NDRRF reflects the complex nature of disaster risk, recognising facets of hazard (the event), exposure, vulnerability and capacity to survive (National Resilience Taskforce 2018a). In relation to critical infrastructure, these four items can be described as the disaster event, the actions it applies to the infrastructure, the potential for the asset to be adversely impacted by those actions and the capacity for those assets to survive or adapt.

Australia's Critical Infrastructure Resilience Strategy (CIRS) sets the Government's approach to enhancing resilience of critical infrastructure to all hazards (Attorney General's Department 2010). Its aim is 'continued operation of critical infrastructure in the face of all hazards, as this critical infrastructure supports Australia's national defence and national security, and underpins our economic prosperity and social wellbeing' (Attorney General's Department 2010).

Technological, social, economic and environmental change will continue to impact on the resilience of Australia's critical infrastructure (Commonwealth of Australia 2015a), and the Australian Government has a strong interest in promoting an understanding of, and preparation for, severe national-scale crises (Commonwealth of Australia 2015a).

However, although it is acknowledged that 'governments and industry in particular must take coordinated action to reduce disaster risks within their control to limit adverse impacts on communities' (National Resilience Taskforce 2018a), strong demands on both time and resources mean that current operational imperatives are often prioritised over longer-term strategic challenges (Commonwealth of Australia 2015a). Critically, the tools which support coordinated action and inform priorities for strategic actions are not available. Infrastructure Australia (2019) has identified that 'anticipating and mitigating against ever-changing risks to infrastructure is becoming more difficult as assets and networks become more interdependent and complex'. At this current stage, Australia lacks comprehensive resilience strategies for its assets and networks (Infrastructure Australia 2019).

Importance of Resilient Infrastructure

When considering the resilience of infrastructure, it is also important to recognise the crucial role infrastructure plays in making communities more resilient overall (Deloitte Access Economics 2016). By helping communities to withstand and recover from natural disasters, resilient infrastructure can minimise impacts and speed recovery.

The nation is dependent on reliable food, water, energy, telecommunications and transport (road, rail, aviation and maritime) (National Resilience Taskforce 2018a). Protecting critical infrastructure and ensuring its resilience is paramount to governments, with the Attorney General's Department reflecting 'a strong expectation within the Australian community that governments will take all necessary action to safeguard our critical infrastructure and assure its continued operation' (Commonwealth of Australia 2015a).

Figure 23 Building resilience in communities, infrastructure and the natural environment requires an ongoing up-to-date and informed understanding of hazard, vulnerability and exposure to drive continual improvement, and needs to be strongly linked to land use planning

The functions of critical infrastructure also depend on each other. Networks which ensure supply of food, water and energy are the outcome of complex interactions between physical assets, technology, society, environment and finance (National Resilience Taskforce 2018a). Failures in one or more of these interconnected networks will cause wide-ranging disruption to communities and businesses, with flow on results to Australia’s economy (National Resilience Taskforce 2018a). The societal consequences leading from the loss of one or more of these critical services highlights Australia’s ‘vulnerability in dealing with and recovering from disruptions’ (National Resilience Taskforce 2018b). The recent societal upheaval witnessed with a lack of a simple commodity like toilet paper, as seen in the 2020 coronavirus event, highlights society’s reliance on continuity of key services.

In addition to the direct cost of infrastructure replacement or repair, infrastructure failure leads to broader economic impact. Disruption to businesses and communities ‘may also have indirect impacts such as a long-term loss of business confidence and psychological distress’ (Deloitte Access Economics 2016). Demonstrations of this impact are the $76 million government funding set aside for individual’s distress counselling and mental health support following the 2020 bushfires (Department of Health 2020a), along with $48 million for the COVID-19 mental health response plan (Department of Health 2020b).

Noting the criticality of disruption to infrastructure, the approach to assurance is ‘progressively moving away from a focus upon protection towards emphasising resilience’ (Coaffee and Clarke 2017), with acknowledgement that investment in resilience can deliver benefits beyond avoiding loss and suffering (National Resilience Taskforce 2018a).

Notwithstanding this recognition of the benefit from including resilience in infrastructure planning, Infrastructure Australia (2019) is still calling for an increased focus on sustainability, security and resilience expectations; and warn that ‘underdone planning and rushed procurement can lead to lasting shortcomings in infrastructure performance’.

The bushfire case studies in Sections 8.2 and 8.4 (below) explore the gap in knowledge identified by Infrastructure Australia (2019), highlighting the necessity for information which supports the inclusion of resilience into the planning and procurement of infrastructure at a holistic level. Additionally, the case studies identify the importance of applying this holistic approach to resilience when maintaining, modifying and upgrading infrastructure, where poor decisions can undermine the original planning and design. What type of information will best guide and support the diverse range of actors and stakeholders who translate the goals for resilient infrastructure into practice; and allow them to apply the NDRRF into policy, regulation and subsequent technical standards?

8.1.3 Definition of Infrastructure

Infrastructure Australia segments the broad heading of infrastructure into economic and social:

- Economic Infrastructure refers to assets which support economic activity including services in energy, transport, telecommunications, water and waste; and
- Social Infrastructure comprises assets, networks and services that support the quality of life and wellbeing of the community, including health, aged care, education, recreation, arts, social housing, justice and emergency services (Infrastructure Australia 2020).

Australia's National Resilience Taskforce positions infrastructure within a broader setting, with elements which overlap built, social, natural and economic environments (see Figure 24 below).

For the purposes of this Chapter, resilience will be considered in context to critical infrastructure. Commonwealth, state and territory governments share a common definition of critical infrastructure as: 'those physical facilities, supply chains, information technologies and communication networks which, if destroyed, degraded or rendered unavailable for an extended period, would significantly impact the social or economic wellbeing of the nation or affect Australia's ability to conduct national defence and ensure national security' (Attorney General's Department 2010).

It is highlighted that this definition of critical infrastructure extends beyond assets to include networks, services and even supply chains, such as the complex network from paddock to plate (Attorney General's Department 2010). Therefore, infrastructure traverses the boundaries of state, territory and local governments (Infrastructure Australia 2020). The resilience of that infrastructure is reliant on coordinated planning across sectors, coordination of operation and maintenance, plus an organisational culture with the ability to provide services during emergencies and disasters irrespective of jurisdictional boundaries (Attorney General's Department 2010).

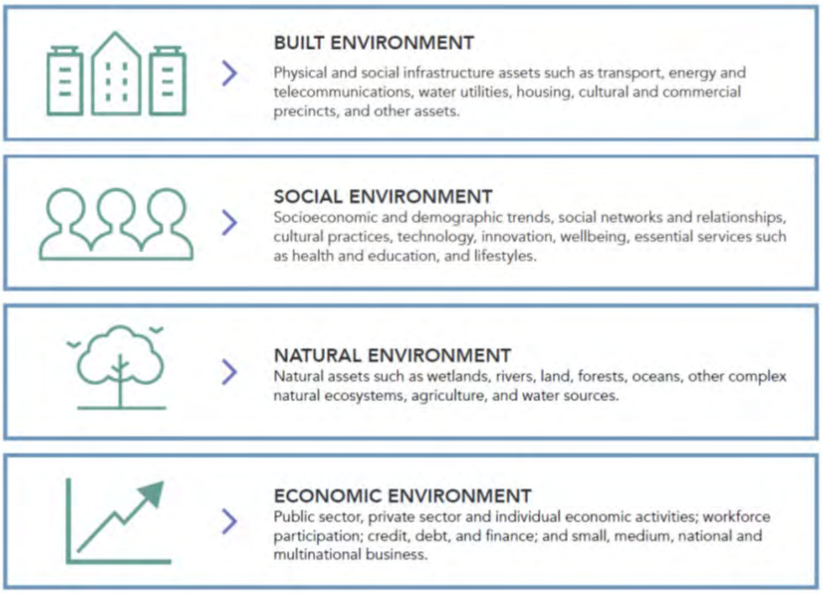

Figure 24 Broader environments around infrastructure Taken from National Disaster Risk Reduction Framework (National Resilience Taskforce, 2018a)

This multijurisdictional aspect requires an analysis of Australian infrastructure resilience to be undertaken in the context of Australia's federated system of government. Further much of Australia's critical infrastructure is privately owned or operated, adding the needs and impact of non-government actors into the equation. This steers the consideration of infrastructure resilience towards a broader and a more people-centred preventive approach, using risk reduction practices which are 'multi-hazard and multisectoral, inclusive and accessible (UNISDR 2015b).

Australia's population growth is driving infrastructure debate, with ageing assets being put under growing strain. Demand for roads and transport, social infrastructure, health and education (Infrastructure Australia 2019) will drive expenditure. Between 2016 and 2050, $1.1 trillion will be spent on critical infrastructure (Deloitte Access Economics 2016). This expenditure warrants effort to ensure critical infrastructure is developed within a resilience framework, and that Australia has the resilience strategies and information sets to support the implementation of that framework (Infrastructure Australia 2019).

Threats to Infrastructure

Resilience, in relation to infrastructure, has been defined as 'the ability of a system to prevent the occurrence of a crisis and the capacity to absorb the impact and recover to the normal state rapidly and efficiently when a crisis does occur (Labaka et al. 2016). In Australia, critical infrastructure is identified as not only highly vulnerable to, but also a major casualty of natural disasters (Deloitte Access Economics 2016).

Repairing or replacing infrastructure post disaster is costly, with Deloitte (2016) estimating that as an outcome of natural disaster damage, $17 billion (in present value terms) will be spent on the direct replacement of essential infrastructure between 2015 and 2050. In addition to replacement costs, the vulnerability of this infrastructure includes 'conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards' (National Resilience Taskforce 2018b). The impact of infrastructure losses can exacerbate the suffering of communities affected by disasters (Deloitte Access Economics 2016), reinforcing the requirement for infrastructure decision making to 'focus on people, their health and livelihoods' (UNISDR 2015b).

Chapter 1 of this report summarises Australia's increased risk of impacts from natural disasters, and the essential services relied on by the nation's communities are exposed to these increasing impacts (National Resilience Taskforce 2018a). However, threats to infrastructure are not limited to acute disaster events, with government frameworks also including risks from slow-onset events caused by natural or man-made hazards, as well as environmental, technological and biological risks (UNISDR 2015b). As climate risks are likely to pose a growing threat to Australia's infrastructure, the consideration of those risks in planning, design and operation of assets and networks 'can improve the resilience of services and reduce costs to future generations of users and taxpayers' (Infrastructure Australia 2019).

Characteristics of Resilience in relation to Infrastructure

Current literature on the resilience of critical infrastructure highlights the multidimensional understanding necessary for risk analysis and decision making through planning and ongoing operational phases. The simplest levels apply the concept of vulnerability as a combination of risk, susceptibility, resistance and the resilience level of the system (Labaka et al. 2016). Vulnerability is described as linking both the magnitude and exposure to a hazard, with the capacity of the system to resist and absorb the impact (McEntire 2001). More complex treatments segment the issue into components of vulnerability and adaptive capacity (Brunsdon and Dalziell 2005), highlighting that resilience is more than an absence of vulnerability. Bruneau et al (2003) apply similar complexity, identifying robustness, redundancy, resourcefulness, and rapidity as characteristics of resilience.

In addition to these specific characteristics Bruneau et al. (2003) defines four separate dimensions:

- Technical resilience focusing on the physical systems,
- Organizational resilience looking at management and decision making to either avoid or respond to crisis situations,
- Economic resilience covering the ability to face the extra costs that arise from a crisis, and
- Social resilience referring to society's capacity to lessen impact of a crisis.

The Bruneau et al. (2003) multidimensional approach to resilience aligns with the broad base of the Sendai framework (UNISDR 2015b), which underpins Australia's current approach to infrastructure resilience (National Resilience Taskforce 2018a). Accordingly, these paradigms, overlaid with the diverse range of participating actors, may be a useful lens through which to consider resilient approaches for Australia's critical infrastructure.

8.1.4 The role of information in standard setting and regulation

For critical infrastructure, what we build (and how we build it) is predominantly determined by various levels of regulatory and legislative output. Much of this is managed as an executive function of Australia's governments enacted through subsidiary legislation, rulemaking and standard setting by administrative agencies (Australian Government Solicitor 2014). Decision making in these public sector agencies, along with procurement, contracting models and risk evaluation, has significant impact on the functionality and efficiency of infrastructure (Infrastructure Australia 2019).

The outcomes of the rulemaking processes by administrative government are reliant on the information available to actors and stakeholders. The choices and decisions made now, and those made in previous generations will affect future generation's resilience to disaster (National Resilience Taskforce 2018b). Therefore, it is critical that those decision-making agencies have information to support and guide their decisions in a form that is not only usable by all actors but provides an understanding of the NDRRF strategies and encourages the inclusion of resilience in their processes.

Importance of including resilience in infrastructure decisions

Infrastructure resilience is critical to support communities to withstand and recover from natural disasters (Deloitte Access Economics 2016). But, although infrastructure networks are facing increased risk from climate change, Australia's resilience strategies provide insufficient guidance for future decision making (Infrastructure Australia 2019).

Although significant investment is made, Deloitte showed that governments and businesses do not consistently include resilience when making infrastructure investment decisions. More importantly, their report found that decision makers were not *required* to consider resilience (Deloitte Access Economics 2016). These observations contribute to Infrastructure Australia's (2019) view that Australia lacks comprehensive resilience strategies for its assets and networks, and a finding that governments 'often do not incorporate sustainability or resilience into their final infrastructure projects'.

Internationally, the need for governments to transition to a resilience approach when evaluating critical infrastructure (termed the 'resilience turn'), occurred in the early 2000s (Coaffee and Clarke 2017). Under this resilience umbrella, a range of assessment models and measures have been developed (Coaffee and Clarke 2017; Labaka et al. 2016). However, while clear parallels have been established linking critical infrastructure and resilience, the theory has not been connected or translated into practice at the implementation level (Coaffee and Clarke 2017).

Australian governments acknowledge the complexity of risks and have prioritised critical infrastructure resilience (Attorney General's Department 2010). As part of the growing awareness of this issue, a

Productivity Commission inquiry found that 'Governments overinvest in post-disaster reconstruction and underinvest in mitigation that would limit the impact of natural disasters in the first place' (Productivity Commission 2014). Citing this quote, the Australian Business Roundtable for Disaster Resilience raised concerns that 'there is currently no requirement for government or the private sector to consider resilience when making investment decisions, nor are there best practice principles to encourage its consideration' (Deloitte Access Economics 2016), and called for greater consideration of natural disaster risks and resilience when selecting projects and managing assets.

Recent reports into infrastructure resilience have agreed that improving the consideration of resilience in planning and risk analysis could 'prevent unnecessary disruption and generate significant reductions in disaster costs' (Deloitte Access Economics 2016), 'improve the resilience of services and reduce costs to future generations of users and taxpayers' (Infrastructure Australia 2019), and avoid replacement costs (Business Council of Australia 2013). However, while noting potentially better outcomes, resilient approaches will make planning and management of industry capacity more complex (Infrastructure Australia 2019). Part of this complexity is the diversity of actors (and their competing objectives) which are responsible for decisions which impact resilient infrastructure.

Diverse Actors and Competing Objectives

Owners of Australia's critical infrastructure, and therefore the actors involved in decisions which affect its resilience, include Australia's Commonwealth, state, territory and local governments, private Australian and international companies, plus Australian communities and individuals.

The Commonwealth Government notes that although the majority of critical infrastructure in Australia is owned or operated by states, territories, or the private sector, the Commonwealth Government has a complex set of roles, responsibilities and interests in its resilience (Attorney General's Department 2010). Depending on specifics, the Commonwealth Government can be:

- An owner and operator of critical infrastructure
- The regulator or industry regulator in some sectors (e.g. telecommunications, aviation and maritime)
- Responsible for operating the Trusted Information Sharing Network (TISN) for Critical Infrastructure Resilience
- The primary source of security threat assessments
- A source of research, scientific and technical advice relevant to the protection and resilience of critical infrastructure (Attorney General's Department 2010).

To achieve its objectives, the Australian Government generally takes a non-regulatory approach to critical infrastructure, recognising that the owners/operators in many cases are best placed to manage risks in relation to their operations and determine the most appropriate mitigation strategies (Attorney General's Department, 2010).

Under federation, different Australian governments have different responsibilities for critical infrastructure. State and Territory governments take responsibility for managing threats to life and property, as well as emergency response and law and order within their jurisdictions. While intergovernmental work on critical infrastructure does occur on a cooperative basis, each State and Territory government have their own critical infrastructure programs which vary according to the environment and arrangements for each jurisdiction (Commonwealth of Australia 2015a). Below Federal and State governments, private industry also play a role in 'self-governance' of various aspect of infrastructure design, maintenance and reinstatement.

Facilitating the voice for Australian communities in resilience decision making is explored further in Section 8.7 below. This segment includes it own competing objectives, balancing desired resilience outcomes against the ability or willingness to pay for that infrastructure. This community voice has been identified as important in delivering resilience while avoiding gold plating critical infrastructure.

The complexity which stems from a large number of actors in the decision making network is demonstrated diagrammatically by the Intergovernmental Panel on Climate Change (2014). Reproduced in Figure 25Figure 25 Opportunity space and climate resilient pathways. Adapted from IPCC climate change 2014, summary for policymakers (Intergovernmental Panel on Climate Change, 2014)

, the IPCC show how multiple actors and decision points, without consistent strategic information, can result in a range of possible futures.

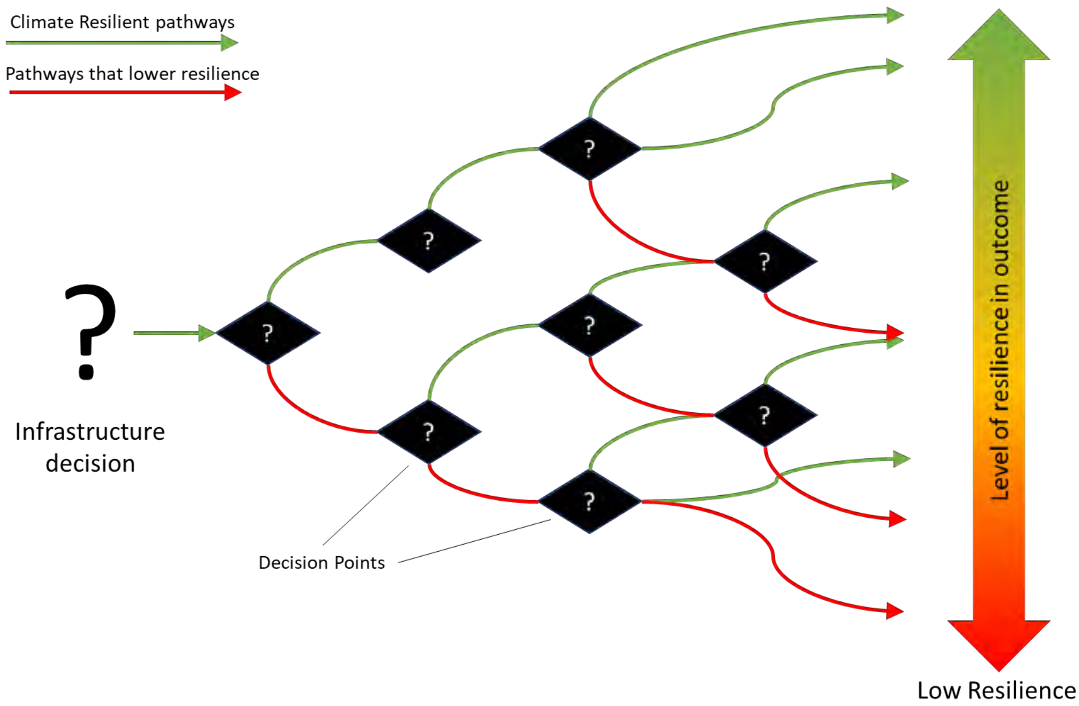

Figure 25 Opportunity space and climate resilient pathways. Adapted from IPCC climate change 2014, summary for policymakers (Intergovernmental Panel on Climate Change, 2014)

The diversification and competing objectives amongst those actors who affect decisions on the resilience of critical infrastructure impacts the successful implementation of strategies and frameworks described in Australia's approach to disaster resilience. The NDRRF's aim to support strategic decisions with sound, trusted and authoritative information (National Resilience Taskforce 2018a) highlights the key role information can play as a tool to unify actors and stakeholders in Figure 25 towards a common strategy, and higher resilience future.

Information as a unifying factor

Australia's *Climate Resistance and Adaptation Strategy* (Commonwealth of Australia 2015b) identifies that a range of actors – government, business, communities and individuals - have complementary roles in managing climate risks. A key role for governments is to support those actors to deliver informed choices in response to climate risks, 'by providing authoritative climate information and effective regulatory systems' (Commonwealth of Australia 2015b). This strategic position aligns with the first priority in the Sendai framework, which promotes improved understanding of disaster risk. 'Policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment' (UNISDR 2015b).

The Sendai framework's approach to risk highlights the challenge of collecting information which is representative of and relevant to the range of actors. Forest and Wood Products Australia's fire engineering methodology to justifying disaster resilience of housing construction incorporates analysis outside of construction methods and materials (England 2020). Their approach incorporates hazard reduction, land management, evacuation and firefighting strategies along with analysis of codes and standards. This multi-disciplinary approach demonstrates that the application of resilience to even a narrow topic like the family home requires participation and information from a wide variety of sources.

Determining appropriate resilience measures prior to construction of infrastructure, and long before a disaster event occurs is challenging and requires detailed assessment of likelihood, along with analysis of resilience options and mitigations (Deloitte Access Economics 2016). Accordingly, decision-makers need access to 'trusted and authoritative disaster risk information, and the expertise to help them navigate through increasingly uncertain, ambiguous and dynamic environments' (National Resilience Taskforce 2018b). The transmission line case study in Section 8.5 provides insight to the development of information to support those assessments.

This reliance on information is recognised in research on government rulemaking by Croley, who observes that while electoral votes may be the currency of elected officials, 'information is the currency of administrative decision making' (Croley 2008). The importance of information is reflected in Australia's Climate Resistance and Adaptation Strategy, which notes the 'Australian Government will provide the greatest possible value to all stakeholders by harnessing opportunities to implement the Strategy more effectively', which includes more effective information sharing, particularly with regard to cross-sectoral information (Commonwealth of Australia 2015a).

Applying Forward Looking Information

At the construction phase of critical infrastructure, what is built is controlled by the regulatory environment and the various codes and standards which underpin that environment. Resilience is not often included in infrastructure planning with an 'implicit assumption that land use planning, building codes and standards provide adequate requirements (Deloitte Access Economics 2016). However, the content of these codes and standards tend to be developed based on past experience and accepted practice, rather than looking forward to consider potential future exposures (National Resilience Taskforce 2018b). The development of codes and standards are also susceptible to influence from interest groups, industry preferences and the momentum of conventional practices. They can also be developed in isolation to related regulatory instruments defining a convenient scope of considerations rather than a holistic resilience focus.

It is accepted that the codes and standards which enact regulation are developed to establish minimum, rather than aspirational requirements (Office of Best Practice Regulation 2007). Counter to this minimum approach, the assessment of resilience during evaluation of an infrastructure project, especially within the structure of a cost benefit analysis, may demonstrate that it is cost-effective to build a higher level of resilience than is mandated (Deloitte Access Economics 2016). Unfortunately, the information needed by the many actors who perform these evaluations and influence resilient outcomes 'may not be available in a form in which it can be used, reinforcing layers of systemic vulnerability' (National Resilience Taskforce 2018b).

Cyclones – Retrofitting for resilience

In 2018, based on research conducted by James Cook University supported by the Bushfire and Natural Hazards CRC, the Queensland Government introduced its Household Resilience Program. This program provides grants for up to 75% of the cost of cyclone proofing homes built between Bundaberg and Cooktown before 1984, when the current cyclone building code was introduced in the aftermath of Cyclone Tracy. To date 1,749 Queensland households between Bundaberg and Cooktown have seen their insurance premiums reduced by an average of $310 due to improvements made under the program. In May 2020 a renewal of the program supported by both Queensland and Commonwealth governments was announced as part of the Queensland Government's *Unite and Recover for Queensland Jobs* stimulus package designed to address the economic impact of the COVID-19 pandemic.

In their critique of current resilience frameworks, Labaka, Hernantes & Sarriegi (2016) note that 'validation is mostly based on feedback from experts and historical data, which might not reflect the reality of the future' (p22). Protection-based paradigms for critical infrastructure, rather than forward-looking resilience approaches, are driven by the application of risk management from an engineering context. This context excludes social and human factors from decision making and creates 'a very different reality from what is increasingly becoming known as resilience management' (Coaffee and Clarke 2017).

Information to guide resilient outcomes

An impetus to include both societal and science-based input into infrastructure resilience decisions is evidenced in the Sendai framework, which states 'disaster risk reduction requires a multi-hazard approach and inclusive risk-informed decision-making based on the open exchange and dissemination of disaggregated data, including by sex, age and disability, as well as on easily accessible, up-to-date, comprehensible, science-based, non-sensitive risk information, complemented by traditional knowledge' (UNISDR 2015b). Importantly, the Sendai Framework extends the concept of societal information to also include traditional knowledge; an aspect explored in Chapter 4 of this report in relation to Indigenous leadership in cultural burning and landscape management.

It is well established that decision-making should be informed by a balance between expert and values-based viewpoints (Rayner and Cantor 1987; Slovic et al. 2004; Sundlof 2000), but achieving this in practice is not straightforward. It has been demonstrated that participants with expert or technical knowledge are privileged in many areas of administrative decision making (Yackee and Yackee 2006), and those groups with credible information to offer have greater opportunities to exert influence (Croley 2008). This can leave societal views or traditional knowledge with a quieter voice. The challenge to balance scientific judgement and evidence with societal expectations and values was a difficult question faced by governments and regulators two decades ago (Pidgeon 1998) and appears similarly difficult in today's decisions on infrastructure resilience (Deloitte Access Economics 2016). Findings from the Launceston flood assessment (see case study below) demonstrate the importance of inclusiveness in resilience decisions. Actual community benefits of flood mitigation are greater than could be assessed economically. More holistic assessments which include intangible measures were highlighted.

The need for information to support decision making by a broader range of actors is reflected by Australia's National Resilience Taskforce observation that 'we do not have a good baseline understanding of the root causes of disaster and processes influencing how places and people are vulnerable and how this leads to disaster' (National Resilience Taskforce 2018b). They find that 'there is an urgent and growing demand for trusted and authoritative disaster risk information and services to inform operational and strategic decisions' (National Resilience Taskforce 2018a).

Review of current viewpoints indicates that there is a clear absence of information to guide future resilience decisions. However, the nature of the required information should not be taken for granted or assumed to only reside in the domains of science and engineering. To encourage the inclusion of resilience as a parameter of infrastructure decision making will require extending the range of participating actors beyond those traditionally involved and providing those actors with forward-looking information. This information should include a balance of science, societal and traditional sources, prepared and distributed in a way which informs – rather than directs – decision makers.

Difficulties putting frameworks into practice

As noted above, existing standards and codes are predominantly informed by historical experience, while the concept of resilient infrastructure requires an understanding of future scenarios in a potentially changing environment. The challenge of 'preventing and preparing for something which is unexpected is almost impossible since nobody knows when or how a crisis will occur or what would be affected by the crisis' (Labaka et al. 2016). Notwithstanding this challenge, the Sendai Framework (UNISDR 2015b) prioritises strengthening technical and scientific capacity to consolidate knowledge and develop models to assess disaster risks, vulnerabilities and exposure to all hazards.

Creation of this information set has been underway for some time in Australia. Examples of Commonwealth, state and private knowledge sources and sharing arrangements include:

- The Trusted Information Sharing Network (TISN). Established by the Australian Government in 2003, TISN provides a secure environment in which critical infrastructure owners and operators across seven sector groups (banking and finance, communications, energy, food and grocery, health, transport and water services) meet to share information and cooperate within and across sectors (Commonwealth of Australia 2015a)
- The Victorian Government's register of critical infrastructure (vital, major and significant), where owners and operators of vital infrastructure participate in a four-state resilience improvement cycle (Deloitte Access Economics 2016)
- The Infrastructure Sustainability Council of Australia (ISCA https://www.isca.org.au/) rating scheme for evaluation of transport, water, energy and communications infrastructure projects and assets against sustainability criteria including environmental, social and governance aspects (currently being updated with a greater focus on resilience to natural disasters) (Deloitte Access Economics 2016)
- Infrastructure Australia reports on infrastructure priorities (Infrastructure Australia 2019) and a method for infrastructure assessment (Infrastructure Australia 2018).

Internationally, a broad set of principles and frameworks have been promulgated, supported by documentation to translate these into practice. The Words into Action series by UNDRR are an example, which aims to 'offer specific advice on the steps suggested to implement a feasible and people-centred approach in accordance with the Sendai Framework' (UNDRR 2020).

While progress towards implementation has begun, at a general level the current literature finds resilience frameworks to be theoretical in nature, with difficulties reported when implementing them in practice (Labaka et al. 2016). A similar disconnect between publicly available guidance and the management of future resilience is observed in Australia (Infrastructure Australia 2019). The transmission line case study in Section 8.5 demonstrates both the collaborative effort required to develop practical information for complex networks threatened by multiple threats, and the importance of that information to future decision making.

The Australian government acknowledges and annunciates the importance of information in leading change in a diversified and fragmented decision-making environment. The Critical Infrastructure Resilience Strategy (CIRS) 'recognises that the best way to enhance the resilience of critical infrastructure is to partner with owners and operators to share information, raise the awareness of dependencies and vulnerabilities, and facilitate collaboration' (Attorney General's Department 2010). Established under the CIRS, the Trusted Information Sharing Network (TISN) for Critical Infrastructure Resilience has a primary role to build a partnership approach between business and government for critical infrastructure (Attorney General's Department 2010). The CIRS includes strategic imperatives to partner with critical infrastructure owners and operators, develop common understanding of organisational resilience, assist owners/operators of critical infrastructure to identify, analyse and manage cross-sectoral dependencies, and provide timely policy advice (Attorney General's Department 2010).

Notwithstanding past initiatives, Infrastructure Australia's (2019) position is that the nation's infrastructure sector lacks clear, publicly available information which guides stakeholders on how to plan, procure, construct and manage for greater resilience. They find that 'planning for resilience requires an understanding of the full scope of risks, their likelihood and the potential economic, social and environmental costs of outages, damage, disruption or failure' (Infrastructure Australia 2019).

Infrastructure Australia (2019) identifies that we often fail to approach risk and resilience using whole-of-life benefits, leading to ineffective designs and operating procedures. This is reflected by the Australian Business Roundtable for Disaster Resilience who found limited guidance on how to incorporate resilience into cost-benefit analysis (CBA), with only three of Australia's twelve CBA guidelines having reference to resilience (Deloitte Access Economics 2016).

Throughout much of the writing on this topic, whether in the academic literature or Australian government reports, we see a recurrence of terms such as guidance, support, and common understanding. This terminology is important when considering the types of information needed to support resilience decisions made within Australia's environment of multi-layer government and a predominantly privatised critical infrastructure ecosystem. Figure 26 (from Deloitte Access Economics report to the Business Roundtable for Disaster Resilience), highlights the role of research as a connector between the empirical evidence on hazards and impact, and the end-user decision makers. However, this assumes that the output of the research community is in a form that is both readily accessible and meaningful for those diversified decision makers.

Slovic et al. (2004) found that risk in the modern world is either dealt with as 'risk as feelings' applying instinct and intuition, or 'risk as analysis', using analysis and scientific deliberation. A clash of outcomes between those two approaches leads to 'risk as politics'. They conclude that 'we cannot assume that an intelligent person can understand the meaning of and properly act upon even the simplest of numbers such as amounts of money or numbers of lives at risk, not to mention more esoteric measures or statistics pertaining to risk, unless these numbers are infused with affect' (Slovic et al. 2004).

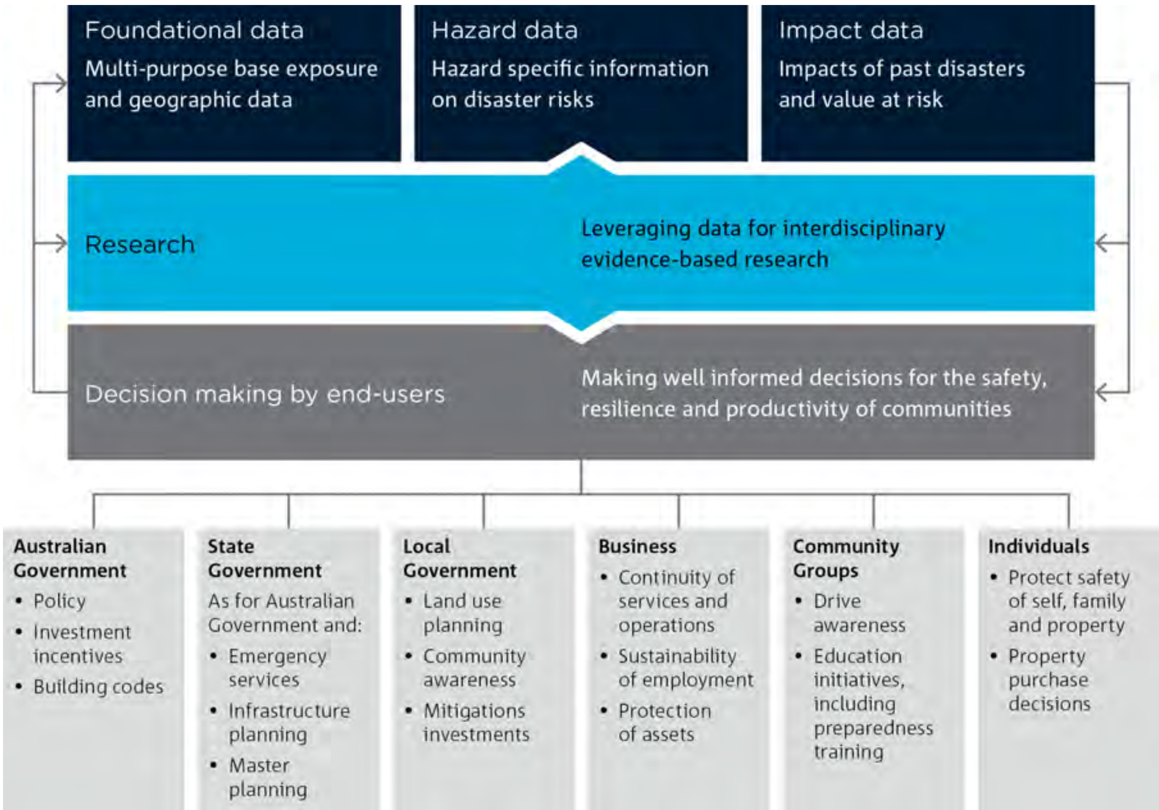

Figure 26 Inputs for decision making on infrastructure investments. From Building Resilient Infrastructure (redrawn from Deloitte Access Economics, 2016)

Reviewing Figure 26 in context to Slovic et al.'s (2000) findings highlights the role of the research community in guiding and supporting decision makers towards common understanding, minimising the gaps between feelings and analysis, and thereby minimising the potential for 'risk as politics'. It is this transition towards common understanding amongst participating actors that can underpin the implementation of resilience frameworks. The following case studies explore the importance of developing and sharing guidance information in a holistic form which is meaningful to the diverse range of actors who influence the resilience of Australia's infrastructure.

8.2 Case Study: Wye River Bushfire 2015

This case study highlights how the combined outcomes of planning and building policy objectives which aim to manage life safety in bushfires can translate poorly to certain settlement circumstances. It also highlights how building resilience is not a default outcome from building and planning policies that principally focuses on compliance at the time of initial occupancy with a life safety focus. The consideration of resilience measures and their effectiveness of lifetime of the building are worthy of deeper consideration both in terms of regulation and community engagement. This is highly relevant in both the rebuild process and ongoing urban maintenance, offering a holistic solution to these shortcomings.

8.2.1 Introduction and context

On 19 December 2015, lightning ignited a bushfire in the Otway Ranges National Park near Lorne (Vic Emergency 2015). Early on 25 December, severe fire weather conditions, including a strong northerly wind, led to the fire jumping containment lines and impacting numerous communities along the Great Ocean Road. The fire continued to burn for several weeks in steep, difficult and heavily-treed terrain (Vic

Emergency 2015). By the morning of 26 December, overnight rain and cooler conditions had slowed the fire. A total of 116 houses were lost during the fire: 98 in Wye River and 18 in Separation Creek (ABC 2015).

Post incident surveys were carried out from 6 to 8 January 2016 to examine the remains of the destroyed, partially damaged and unaffected houses as well as their surroundings within the fire perimeter. The surveys aimed to provide a better understanding of the mechanisms of house failure or house survival.

Wye River and Separation Creek are Victorian coastal towns in the Colac Otway Shire, around 155 km west of Melbourne. The towns are adjacent to the native forests of the Otway Ranges National Park, with native bushland coalescing into urban development from the steep ridges to the north-west, all the way to the coast at the south-eastern border of the townships.

The vegetation of the broader Otway Ranges National Park includes moist rainforest gullies, drier inland forests, and heathlands and woodlands along with coastline. No distinct border exists between the forests and urban areas of the townships. Rather, houses embrace the native vegetation, with tall forest canopies extending throughout most of the residential zone properties. Mature native trees provide important land stabilisation, shade and wind attenuation to the township. However, they also deposit extensive leaf, bark and twig debris on buildings and the surrounding landscape. This litter, in combination with cured grasses, provides a near continuous surface fuel layer, broken only by areas of hard surfacing or roadways where wind, run off and/or local traffic shifts the surface fuels.

Both Wye River and Separation Creek are built on steep south-eastern facing slopes. The townships extend from the coast up these slopes. The ridges are covered predominantly by native bushland. Some housed areas of Wye River and Separation Creek reach gradients higher than 30 degrees. Because of the steep terrain, many road and driveway cuttings require extensive land stabilisation. House and other building access is typically via narrow gravel roads and driveways, which makes access for fire suppression and rapid egress difficult.

Land stabilisation includes extensive use of retaining walls throughout the fire-affected areas. Some walls are built using non-combustible materials such as concrete. However, most walls are constructed of combustible materials such as Chromated Copper Arsenate (CCA) treated timber which readily ignited during the fire event.

Given the steep slopes, a large proportion of the houses within the fire-impacted area (including those built to more recent bushfire regulatory standards) project out from ground level with exposed subfloors. This creates the opportunity for residents to store heavy fuels such as plastic water tanks, building materials, small garden sheds, boats and kayaks. Sheds underneath houses are common because of the steep slopes.

The township has a small proportion of permanent residents. Most houses are owned as a secondary residence, such as holiday houses or investment properties. During the summer period, some houses may be vacant or occupied by a non-owner. Early on 25 December, warnings encouraged residents of Wye River and Separation Creek to evacuate. It is understood that impacted houses were vacated prior to the arrival of the fire and no lives were lost during the fire event.

8.2.2 Weather context

The preceding condition to the fire event provided low soil moisture levels which were qualified by a Keetch–Byram Drought Index (KBDI) (Keetch and George 1968) of 80 at Aireys Inlet (weather station 90180) and 83 at Cape Otway (weather station 90015) on the day of the fire. These levels are considered ‘serious’ with respect to surface fuel ignition potential and would provide low moisture contents in timber elements which are located near to or contacting the ground.

On 25 December, the temperature in the Wye River area reached approximately 36°C at around 16:30, with a relative humidity of 17%. Wind was blowing from a north/north-westerly direction with gusts of nearly

33 km/h (measured at 10 m above ground level) (BoM 2015). Based on temperature, relative humidity, wind speed and KBDI data, the forest fire danger index (FFDI) reached a peak at 16:30 of 49 in Aireys Inlet and 43 in Cape Otway. At a FFDI of 49 the weather condition is considered to be at a fire danger rating of 'Very High'. This level is typically considered well beyond a fire crews' ability to directly attack and arrest a running head fire. The Victorian building standards use an FFDI of 100 as a worst-case fire weather assumption for the purposes of determining fire arrival severity (Blanchi 2010).

8.2.3 Fire arrival and spread to houses

The bushfire burned towards Wye River in native bushland to the north-west. The first evidence of fire arrival experienced by the township was the arrival of embers which sporadically ignited surface fuels a few hundred meters within the township. Even though the winds responsible for driving the fire towards the township on the day of the fire came from the north or north-east, surveys did not reveal any evidence of a fire front arriving from this direction and interacting directly with structures. It appears that terrain and coastal wind effects around the township meant that spotting ahead of the approaching fire fronts ignited and burnt back upslope towards the approaching fire, reaching the perimeters of the townships before the approaching fire front. Generally, the solid body flame height appears to have been up to 0.4 m from these surface fuels.

These surface fires which consumed the fine surface litter fuels were the primary ignition source leading to house ignition. These surface fires either ignited near-surface combustible elements belonging to the house or other combustible elements near ground level that developed to the extent to which they ignited the houses (this process is termed 'consequential fire'). In many cases house fires then developed to the extent to which they were able to ignite adjacent houses. The distance to which this appeared to be possible was up to 12 m (Leonard et al. 2016).

Consequential fire sources were prolific in the township. Treated pine retaining walls were prolifically burnt out providing both a fire threat to proximal houses and a toxic ash exposure to the surrounding area. Fire in the heavier fuels stored under and adjacent to the house's subfloor area such as plastic water tanks, building materials, small garden sheds, boats and kayaks, also appears to have been a significant factor in many of the losses.

While extensive surface litter provided a near continuous flammable fuel bed, the built elements within the township represented most of the fuel load. Some of these built elements were ignited by the initial spread of fire through surface litter fuels. The built elements then continued to burn for many hours, igniting other built elements. The extensive number of houses burning in the fire affected area would have meant that these areas would have been life threatening for any residents present as well as fire fighters.

It is interesting to note that localised ember spread within the townships was not as prevalent as in other surveyed bushfire events which involve house losses of more than 100 houses. This may be due to the relatively low wind speeds within the townships at the time of fire activity. The low wind speeds also appeared to exacerbate the prevalence of house-to-house ignitions at distances previously considered sufficient. These spread mechanisms supported the initial progression of fire within the townships and provided flame contact as follows:

- interaction between fine surface fuels and heavy fuel elements adjacent to houses
- interaction between fine surface fuels and combustible elements on the houses themselves
- interaction between fine surface fuels and LPG pressure vessels providing the potential for gas flares and explosions.

Heavy fuel elements then interacted with each other in the advanced stage of fire development within the township through the following mechanisms:

- flame contact from one heavy fuel element to another
- radiant heat transfer from burning heavy fuel elements to other nearby elements, e.g. retaining walls, fences or house cladding
- flame or radiant heat transfer to LPG pressure vessels providing the potential for gas flares and explosions.

The interaction of fire with established tall trees also increased the risk of tree and branch strike because fire weakens knots and flaws in trees. Branch or tree strike, either on buildings or across roadways, is a common risk during and after bushfire arrival. While there was no direct evidence of tree strike onto houses subject to recent regulatory standards, evidence of direct tree strike was apparent with some houses.

8.2.4 Implications for planning and building regulations

The fire event raises a range of questions around risks to life if there is insufficient warning for building occupants, or they are disinclined to evacuate. While survival from low-level surface fire spread can be provided by sheltering in buildings, the risk of loss of life for those that need to evacuate past other burning buildings and heavy fuel elements is high. This suggests that additional building and planning controls are required in order to limit the likelihood of house loss to an appropriate threshold and the prevalence of combustible heavy fuel elements along the egress routes in the townships.

Building regulations

The National Construction Code recognises two acceptable construction manuals for construction of houses in bushfire prone areas, AS 3959 and National Association of Steelframed Housing (NASH) (Australian Building Codes Board 2019). AS 3959 was significantly reviewed in the period following the Victorian Black Saturday fires (England 2020) and the NASH standard adopted into the NCC in 2014 (Australian Building Codes Board 2019). Accordingly, the date of construction and relevant Australian Standards used for construction are of particular interest to post event surveys.

There were approximately 80 planning referrals to the CFA in Wye River and Separation Creek, from as early April 2003. Both building and planning requirements have evolved significantly from 2003 to the present. There is a reasonable level of complexity in categorising these referrals to determine whether they resulted in an actual building and/or planning outcome. The nature and stringency of these outcomes has evolved over time, ranging from the requirement for stored water supplies to integrated sets of building and planning requirements.

These requirements can be broadly categorised into two categories: those that were built since the introduction of AS3959-2009 revisions and those prior. To gauge the relative effectiveness of the two categories, a review of past building approvals was undertaken to determine which houses were completely built or upgraded to meet these regulatory standards. The review identified seven houses built to the AS3959-2009 standard. Other houses may have been largely complete but are not included in the analysis as minor construction details can have a major impact on building performance in bushfires.

Of the seven impacted houses that were found to have been built to AS3959-2009 and had been issues an occupancy permit 4 were lost in the fire and 3 survived. Although this sample is too small to provide a statically significant result it does indicate that the performance of houses built to AS3959-2009 performed better than the 80% house loss rate experienced across the fire-affected area within the township.

The research study highlights a range of specific weaknesses in the near-ground material and design specifications of current the AS3959 regulatory standard, which for bushfire attack levels (BAL) up to and including BAL-29 allow combustible stumps, bearers, flooring, decking, stair and balustrades within close proximity to the ground. These elements were either directly threatened by fire spread through typical levels of fine fuel and grasses within the townships or ignited by typical heavy fuel elements that resided under or adjacent to the buildings. The typical elements included retaining walls, stored materials, vegetation, plastic water tanks and vehicles.

Planning controls

The Wye River and Separation Creek townships have terrain and tree coverage factors that introduce additional risks to life and property; specifically, the build-up of dead vegetation fuels. These factors combine to increase the likelihood of house loss and reduce the likelihood of survival outside a building during a fire event. Of specific note is the lack of planning provision which could limit:

- the materials used and proximity of retaining walls to buildings
- structure-to-structure fire spread and a structure ability to hamper egress along key roadways
- the distance to reach a place of relative safety. This may be in the form of either personal or public fire shelters.

8.2.5 Post Event Surveys

Understanding fire behaviour and the actions of bushfire attack at Wye River was the outcome of a formal post event survey methodology developed by CSIRO. These scientific surveys were first implemented following the Victorian Beaumaris fires in 1944 (Barrow, 1945), and have been undertaken following many significant fire events across Australia. Much of the process has now been formalised, using digital solutions to support field staff in the collection of accurate and objective data.

Undertaking post event surveys aligns with the Sendai framework's priority to understand disaster risk, with the specific aim to 'systematically evaluate, record, share and publicly account for disaster losses…' (UNISDR 2015b). This case study also demonstrates the importance of communicating the findings from those surveys in formats appropriate to those who will use that knowledge, allowing it to be applied toward both policy development and resilience decision making. In the case of Wye River, survey outcomes have and will continue to inform planning controls and building regulation. The Sendai framework captures this through its aim to 'facilitate a science-policy interface for effective decision making in disaster risk management' and 'to build the knowledge of government officials at all levels, civil society, communities and volunteers, as well as the private sector' (UNISDR 2015b).

8.2.6 Conclusions from Bushfire Case Study

This study found seven examples of houses that were impacted by fire and built AS 3959 following its revision after the Black Saturday fires in 2009. Of these, four were lost to fire and three survived. Although the number of buildings in this sample is small, these buildings have a higher survival rate than the 80% loss rate experienced across the region affected by this fire event.

The townships of Wye River and Separation Creek experienced a broad scale surface fire spread through a combination of dried grasses and litter fuels originating from extensive established tree coverage. The main impact of the fire on houses was through ignition of heavy fuel elements that were adjacent to or under buildings. These include adjacent houses (house-to-house ignition), combustible decking and retaining walls, vehicles, stored equipment, plastic water tanks and firewood. Forest and Wood Products Australia acknowledge the role of these non-building impacts, suggesting that there is opportunity for improved resilience through improvements in the scope and alignment of building standards, planning polices and maintenance practices(England, 2020). Buildings built to the regulatory standards as well as buildings that were not built to the regulatory standards were subject to these heavy (domestic) fuels, and many were not capable of withstanding the radiant heat or flame contact when the fuels were ignited. This appears to be a key reason why such a large house loss rate was experienced despite low intensity fire spread within the township. There were few examples of fire spread that were sufficiently intense to provide radiation exposure levels capable of compromising houses.

The steep terrain and challenging access within the township meant that risk to life of occupants that did not evacuate early would have been high. Roadways cut into steep slopes and house access via steep driveways meant that any egress during the fire by foot or by vehicle would be difficult. No clear areas for refuge were found within the fire-affected areas of the townships. Despite these difficulties, no lives were lost, which is testament to the timely warnings given to occupants prior to the arrival of the fire.

There are a number of clear directions from which building, planning and community support initiatives can be improved to address resilience to bushfire hazards facing townships such as Wye River, and for houses built in bushfire prone areas across the nation. A detailed description of possible prescriptions is provided in (Leonard and Short 2016). Much of these identified shortcomings would be effectively identified with a detailed performance review of building regulations and their relationship with planning regulation in achieve efficient and effective life and property risk mitigation. Providing this information in a form which can be used by policy makers, society and the experts who develop Australia's building regulations would influence the views of each and assist common agreement.

When observing this case study through a resilience lens it raises the question of what an acceptable level of loss extent and frequency is? Renewal of buildings under existing regulatory frameworks offers a seemingly insignificant improvement to ongoing loss outcomes. As noted in Chapter 2 of this report, climate projections suggest an increase in the frequency of fire weather events that can support uncontrollable fire arrival to settlements such as Wye River. How will governments and the community influence the initiative to implement resilience frameworks and transition to a resilient settlement outcomes? How can these initiatives transition from reactive responses to changes in threat frequency towards proactive forward-looking models?

Wye River Credit Russell Chartres www.flickr.com https://creativecommons.org/licenses/by/2.0

8.3 Case Study: Launceston Flood Risk Mitigation

CSIRO acknowledges Mark Edwards, Geoscience Australia, for the preparation of this case study. While covering a number of aspects relating to cost benefit analysis and funding models, this case study highlighted that the community benefits of these flood mitigation works were greater than could be assessed economically. When coupled with the observation that the economic viability of some mitigation works changed when considered from a broader perspective, the case study reinforces the necessity for holistic assessment of intangibles when applying Australia's frameworks for resilient infrastructure.

8.3.1 Background

Many Australian communities have been developed on flood prone land. This has often been the result of the nation's colonial past in which preferred development areas were fertile flood plains close to navigable waterways. Launceston is an example located within the Tamar River floodplain at the confluence of the Tamar, North Esk and South Esk Rivers in Tasmania. The city has been flooded numerous times and this led to the construction of flood protection works in the 1960's that were subsequently raised and strengthened between 2009 and 2016. These new structures performed well in the floods of June 2016 showing clear benefit to the community. However, were the improvements a sound investment of public funds in the context of the significant inflation of upgrade costs experienced and the capital cost of mitigation funds? Further, would a broader consideration of the benefits achieved through a more holistic assessment of avoided impacts provide a more informative evaluation of risk reduction?

The construction of these improved levees has influenced land development and the price of land. Significant development on land now having improved flood protection has occurred, including the relocation behind the new levees of a University of Tasmania campus and associated student accommodation. This has been accompanied by an increased population exposed behind the levees that has caused concerns for local emergency management which may need to evacuate people in a severe flood. What is the residual risk and how might this inform future development and mitigation priorities on partially protected land?

A project led by Geoscience Australia (GA) funded under the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) investigated these issues.

8.3.2 Project Objectives

The project aimed to assess:

- The avoided damage cost to Launceston in the June 2016 floods as a result of the new mitigation works
- The number of people who would be displaced due to inundation of homes for flood events ranging from the 20-year Annual Recurrence Interval (ARI) up to the Probable Maximum Flood (PMF) and the expected time for them to return before and after the new mitigation works
- The long-term cost to Launceston from flood hazard prior to the new mitigation works
- The long-term cost to Launceston from flood hazard following the new mitigation works
- A cost benefit analysis of the flood mitigation investment to upgrade the levees
- The economic viability of an extension of the Launceston levees to protect the suburb of Newstead including intangible benefits.

8.3.3 Collaborators/Stakeholders

The project was a collaboration with the Launceston City Council (LCC) with support from consultants BMT WBM. Project stakeholders included the BNHCRC, Tasmanian Department of Premier and Cabinet, Tasmanian State Emergency Service, Launceston Flood Authority and Northern Midlands Council.

8.3.4 Approach and Outcomes

The project took a quantitative approach based on combining hazard, exposure and vulnerability. Activities contributing to the project included:

- Supplementing existing flood study work held by LCC to cover a broader range of flood likelihoods (up to the PMF) with engagement of BMT WBM. Figure 27 shows flood heights above ground floor level for the 1,000-year ARI event
- Augmenting GA's building exposure information held in the NEXIS database (Geoscience Australia, 2020) to develop a detailed building exposure database covering a range of uses. Floor height was a key attribute provided by the LCC while other necessary attributes were obtained through a desktop survey exercise
- Mapping of GA's flood vulnerability models to buildings (and contents) in the exposure database
- Assessing the avoided impacts due to the mitigation measures across a number of sources in the residential and non-residential sectors (see Table 21)
- Considering climate change influences on tail water levels due to sea level rise in the Tamar River
- Assessing the benefit versus cost of the mitigation measures using a range of discount rates (Table 22)
- Addressing a broader range of measures of avoided impact for the suburb of Newstead to develop a more comprehensive understanding of the benefits accrued. These measures included intangible impacts such as social disruption, mental health, ecosystem damage, water quality and recreation.

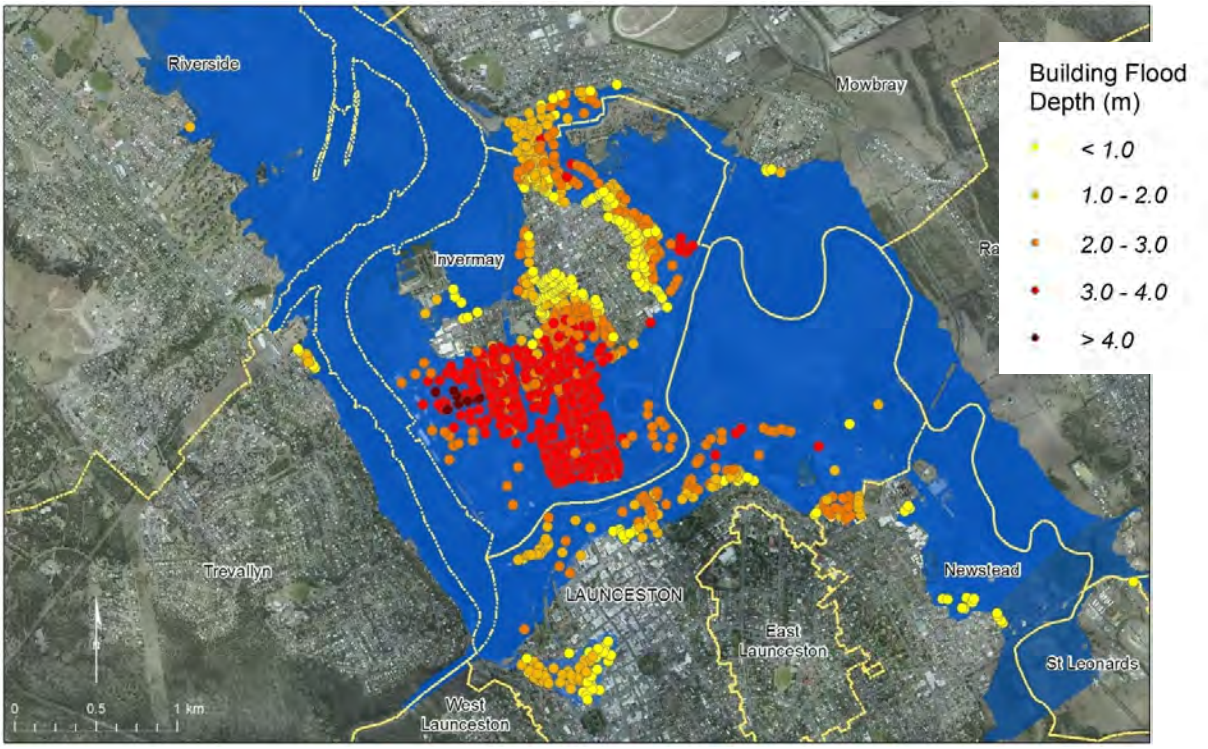

Figure 27 Launceston inundation depth above ground floor for 1000 year annual recurrence interval flood provided by Geosciences Australia from their systems

Table 21 Sources of estimated loss for residential and non-residential sectors

RESIDENTIAL SECTOR	NON-RESIDENTIAL SECTOR
Building repair/rebuild cost	Building repair/rebuild cost
Contents damage cost	Clean-up cost
Loss of rental income	Loss of inventory/equipment
Clean-up cost	Loss of stock
Loss due to fatalities	Loss of income: proprietor's income
	Loss of income: turnover
	Loss of income: wage/salary

Table 22 Assessment of the benefit cost ration at a range of discount rates

COST BASIS	TOTAL INVESTMENT (2016 $M)	AVOIDED LOSSES					BENEFIT COST RATIO (BCR)				
		3%	4%	5%	6%	7%	3%	4%	5%	6%	7%
Actual Cost	58.4*	88.0	69.7	57.1	48.1	41.4	1.51	1.19	0.98	0.82	0.71
Estimated Cost	27.9	88.0	69.7	57.1	48.1	41.4	3.15	2.49	2.04	1.72	1.48

Key findings of the study include:

- The investment in building the new flood levee system in Launceston was a sound economic decision based on the estimated costs at the time of decision making and the benefits assessed in the study (Maqsood et al. 2017a)
- That the price placed on capital funds for mitigation has a significant effect on investment viability
- Actual benefits of these mitigation works to the community are greater than could be assessed economically and would further support the investment in mitigation. The move to more holistic assessments that include intangible measures was highlighted
- Mitigation options were found to be economically unviable for the suburb of Newstead as an incremental improvement in flood protection (Maqsood et al. 2017b). If these works were considered as part of the combined Launceston levee upgrade, instead of in isolation, the overall benefit cost ratio would be positive
- The evacuation logistics assessed support strategies of the LCC to limit future increases in residential populations on land with improved flood protection.

8.3.5 Current Work and Next Steps

GA's work with the BNHCRC continues and currently involves applying a variety of flood mitigation measures in a virtual retrofit to buildings in flood prone areas of Launceston. The research targets the most effective measures to the appropriate flood environment. This work considers multiple rates of retrofit uptake, thereby providing a suite of credible outcomes for decision makers.

The base research and framework can enable the incorporation of a variety of climate futures and further mitigation options for Launceston as a logical next step.

8.4 Case Study: Bushfires and the Power Distribution Network

CSIRO acknowledges the research of Simon Dunstall which forms a key part of this case study which reviews the current Australian approach to the interrelationship between bushfires and the power distribution network. It explores how a more holistic approach, aligned with the NDRRF framework can be applied to inform investment decisions and support an ongoing transition to a more resilient critical infrastructure network.

8.4.1 Overview

Bushfire (wildfire) is a prominent element of the Australian landscape and thousands of fires occur annually as a result of human-induced and natural causes. Electricity powerlines and associated equipment cause several hundred fires annually across Australia. Excluding the sub-tropical areas of the country, the majority of these occur during the bushfire season (i.e. late spring, summer and early autumn) and have the potential to cause major blazes. During the season, approximately 2% of fire ignitions are attributed to the electricity system. Estimates of this proportion of electrical fires amongst other causes do vary by study and by region. Two constants, however, are that the proportion of electrically ignited fires increases as the fire danger worsens, and that electrically ignited fires are disproportionally associated with major fires that are large and cause fatalities (Blanchi et al. 2012).

That the proportion of electrically ignited fires increases as the fire weather severity worsens is overwhelmingly due to the primary environmental factors of wind speed and ambient temperature. High wind and high temperature bring about greater fire danger because they dry out vegetation fuels and make them more readily and rapidly combustible. The wind also accelerates the rate of spread of a fire. These same factors increase the ignition rate from electrical assets primarily because they directly impart physical loads and stresses on the assets, and the wind can cause vegetation to sway, break and/or become airborne and contact the electrical assets.

The potential for bushfires to cause both life and house loss is also strongly correlated with fire weather severity. The majority of Australian life and house loss occurs in the small number of bushfire events in which the fire weather severity exceeded an FFDI of 100 (fire danger rating of catastrophic). These factors go some way towards explaining why electrically ignited fires are disproportionally associated with the fires in Australia's past that have led to fatalities and major infrastructure losses, but a complete explanation of the scale of this disproportionality remains elusive.

The recent 2019/2020 bushfire season has also highlighted the vulnerability of the electrical distribution network to bushfire attack with extensive loss of supply across many areas that persisted in some cases for many months due to challenges related to the sheer extent of network infrastructure loss. This loss has had impacts relating to safety of life during these events and in the recovery phase after these events.

8.4.2 Investment following Black Saturday 2009 bushfires

In 2011 a $750 million powerline bushfire safety program (PBSP) was announced. This 10-year program aimed to deliver on many of the recommendations from the 2009 Victorian Bushfire Royal Commission, following the Black Saturday bushfires. This program aims to reduce the risk of bushfires associated with electrical assets without affecting electricity reliability. The program:

- Funded new electrical protection equipment (Rapid Earth Fault Current Limiters (REFCL) which can detect energy discharge before a fire is ignited)
- Overhead powerline replacement with underground cables in high-risk areas
- Backup generators at important in rural areas

- Compensation of customers for reduced supply reliability due to increased electrical protection sensitivity, and
- Provided funds for research and development into risk reduction technologies and procedures.

This investment provided a significant and important contribution to the reduction of the risk of bushfire incidence caused by the power distribution network.

In addition to this investment in 2015 the Victorian Government put in place a scheme commonly known as F-Factor. This is a financial mechanism administered by Energy Safe Victoria (the state electrical safety regulator) where each electricity distributor is provided with a target for bushfire ignitions. The distributor is financially rewarded if the ignitions fall under this target and penalized if the target is exceeded. The target is expressed in terms of risk units which have a translation into dollar values. In the most extreme case, a fire starting in a Bushfire Prone Area on a day of total fire ban (i.e. severe, extreme or catastrophic/code-red fire danger) earns the Distribution Network Service Provider (DNSP) risk units equating to an AUD$1 million penalty. The targets for each year are set by the relevant Government Minister, and generally are reduced from year-to-year so as to reflect the expected positive effect from consumer-funded and government-funded bushfire risk reduction projects including the undergrounding of highest-risk powerlines and the rollout of REFCL. In three out of the past four years, the Victorian Distribution Network Service Providers in aggregate have been rewarded for accumulating less than the target amount of risk units. The implementation of these programs involved detailed spatial analysis of the relevant infrastructure and its spatial relationship with existing and modified vegetation extents in order to prioritise investment and investment strategy.

8.4.3 Network Reliability

The reliability of the electrical network is of upmost importance, and electricity distributors pay large penalties when supply is interrupted for their customers. The penalties are calculated according to an approach known as Service Target Performance Incentive Scheme (STPIS) and often referred to as S-factor. This creates financial incentive for distribution businesses to invest in asset condition maintenance and improvements which mitigate threats, e.g., barriers and covers that stop animals and birds from contacting live equipment. Conversely, maximum bushfire mitigation can call for electrical protection systems and settings which increase the number and/or duration of outages, and therefore trade-off fire safety against reliability.

The conflict between fire mitigation and S-factor becomes less important under the more dangerous levels of bushfire conditions, because the strong economic signal from the S-factor penalties is counterbalanced with the potential losses and liabilities associated with a fire ignition. In lower fire danger scenarios, the economics of supply become dominant. In an overall sense the supply reliability economics are enough to drive major investments whereas the economics of bushfire mitigation are often weaker.

8.4.4 Consideration of the risk of fire hazards to networks

Bushfires can impact on power networks and this is an effect that is of interest to industry players. Up until the major bushfire events of late 2019 and early 2020, the impact of fire on the network was not considered with the same gravity as fires caused by the network, except in the case of electricity transmission where the loss of availability of an electrical line can have major consequences.

A notable event occurred in 2007 when a main transmission interconnector between New South Wales and Victoria went offline due to bushfire activity. The fire front passed close to lines, but it was electrical protection systems at a substation being activated by smoke that is believed to have caused the actual outage. Large parts of Victoria were affected by blackout as a result. Black Saturday 2009 fires also threatened major interconnectors, but in this case did not cause a shutdown. In March 2019, a fire in South-Eastern Victoria threatened one of the main transmission corridors between power generation in the Latrobe Valley and the rest of the state. On this occasion, power supply was not lost, and this was in part due to the prevailing standards for vegetation clearance in transmission line corridors. The 2019-2020 bushfires in Australia impacted millions of hectares and caused major electrical distribution network failures. In NSW over 5000 poles were destroyed requiring replacement (as of 30 January 2020). In Victoria, several thousand distribution system poles were directly impacted by fires in East Gippsland. Portable High Voltage generation equipment was used to ensure supply in major townships, but a prolonged period of loss of supply was experienced in the region. The supply of replacement poles in Australia remains a current concern for the industry, because of the widespread destruction of timber resources, coupled with limits on the national production capacity for poles constructed from concrete, fibreglass and steel.

The cost incurred by network down time after these major bushfire events focuses effort for timely reinstatement of the systems over the need to reinstate a system that is inherently more resilient than the one that was heavy impacted.

8.4.5 A broader framing of network resilience

Government intervention to provide funds, legal frameworks, policies and incentive schemes has been of critical importance to this point in the process. This has directly funded major network physical changes and has also communicated clearly to stakeholders and market regulators about the community's bushfire risk tolerance, i.e., the trade-off between network investment costs, community safety, and expected bushfire losses.

However, these funds tend to specifically target either a reduction of likelihood of ignitions caused by the network or, improve network resilience when impacted by bushfire. The obvious question remains as to what the potential benefits may be if both initiatives are considered within holistic resilience framework capable of determining the synergies and trade-offs of various design upgrade option that influence both aspects.

A holistic resilience framework could underpin investment decision support for a wide range of potential design upgrades either as a retrofit or replace when impacted, e.g.:

- Cost: benefit for undergrounding of power lines
- Cost: benefit of various power pole types and protection systems
- Cost: benefit of localised generation (solar, battery) for remote locations that are serviced by either risky or at-risk supply lines
- Cost: benefit of a decentralised generation and distribution for semi remote communities.

There is enough understanding to build and operate a holistic resilience framework for power distribution and its relationship to transmission and generations networks. Both the NDRISC and related NBIC bushfire frameworks can offer the necessary bushfire context to support the approach.

8.5 Case Study: Transmission Line Vulnerability

The authors acknowledges Mark Edwards (Geoscience Australia) and Steve Martin (Powerlink Queensland) for the preparation of this case study. This assessment of the vulnerability of Powerlink transmission lines in the context of present and future climate provides an insight into the actions of combined resilience threats onto complex networks. The study highlights the value in diversified stakeholders across government and the private sector collaborating to develop information which will support future resilience decisions.

The electricity transmission network of Queensland is managed by Powerlink and much of the system has an exposure to tropical cyclone and severe thunderstorm winds. Some parts of the network have higher concentrations of older assets that have been designed and constructed using design standards that have subsequently been improved. Further, the service conditions of some of these assets have been in the more corrosive environments that are characteristic of the warm and humid coastal tropics. There is also a risk that climate change may change the intensity of cyclones and severe thunderstorms making asset losses more likely in the future. As a consequence of these factors, some assets within the transmission system are more vulnerable to severe wind with system implications if towers along multiple connectors fail in a single cyclone event.

In a concluding collaborative project between Powerlink and Geoscience Australia, an improved understanding of network vulnerability is being developed in the Townsville region. It has involved modelling by Geoscience Australia of the wind gusts generated at the location of each of approximately 1,000 towers for a suite of eight tropical cyclone events. The selected events included those with eyewall wind speeds significantly above the current Australian Standards. The work also benefitted from an assessment of as-built tower wind loading capacity by Powerlink structural engineers. Using both inputs, the number of tower failures resulting from each event was assessed along with the uncertainty of the losses due to tower performance and a range of cascading failure mechanisms. Significantly it has entailed a sharing of specific asset information by Powerlink to derive losses that are as representative as possible. An example scenario impact is presented in Figure 28 showing both the local wind field and the tower failures expected across the network. The effects of terrain roughness and topography on local wind speeds can be clearly seen along with the more vulnerable tower assets.

Finally, commentary is being provided on how severe wind and associated impacts may change into the future based on current climate science.

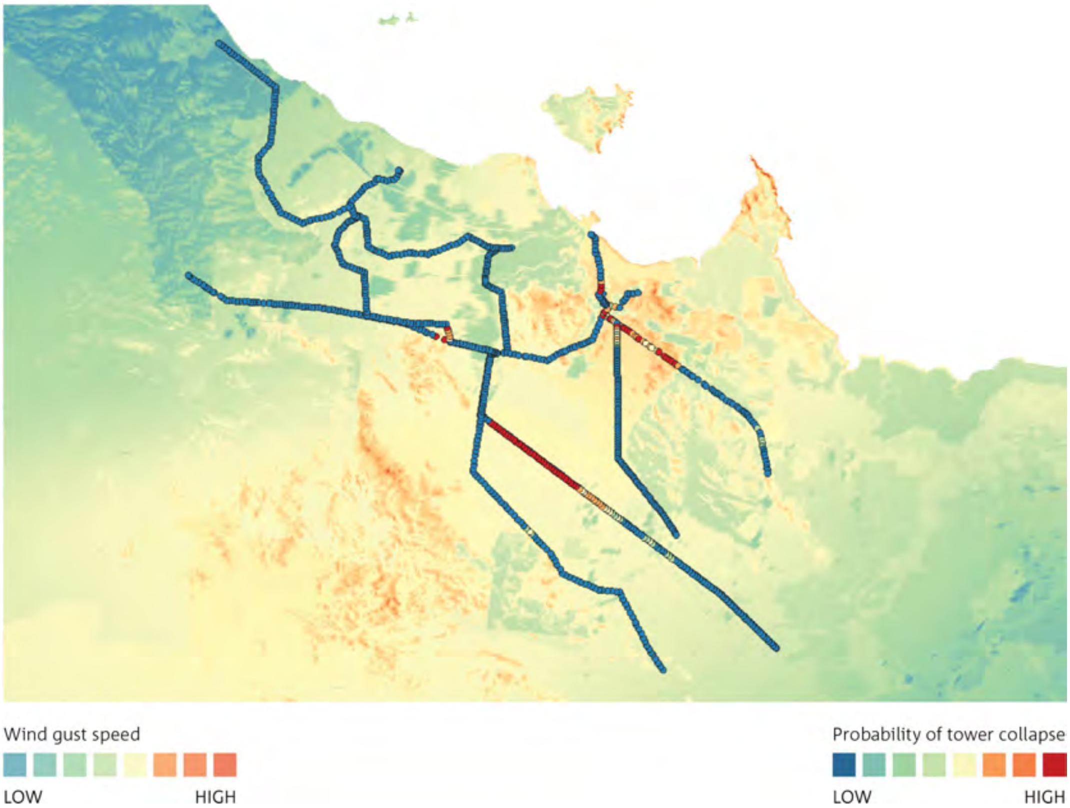

Figure 28 Impact results for a selected scenario event showing local gust wind speed and the probability of tower collapse across the transmission system.

The project has integrated hazard science, industry data, specialist industry expertise and engineering vulnerability modelling to derive information that could not be developed independently. Fundamentally it has recognised that the industry is the expert on the nature and operation of its utility system. The outcomes are providing industry with insights into potential system losses so that recovery needs can be assessed, and mitigation opportunities identified. It has also highlighted information needs in developing a quantitative understanding of the influence of future climate on severe wind. The need to better understand asset vulnerability and the effects of age and corrosion is also highlighted. Further, the need to translate event impacts to the assessment of system risk and resilience through a consideration of the full range of severe wind events is also noted. A system approach of this kind would consider both the present wind hazard environment and how the tropical cyclone and thunderstorm hazard environments may change due to climate change within the life of the assets.

8.6 Complexity of combined threats

Combined hazards and events (both natural and otherwise) carry the implication that the overall impact of the combined event can be significantly greater than the sum of the impacts from each individual hazard. These hazards may either occur at the same time or implicate the same region in close enough succession that recovery from the initial hazard is still under way.

Interactions across infrastructure are complex making it difficult to predict how an event impacting a piece of infrastructure will affect other parts of the network (Labaka et al. 2016). Knowledge of these complex systems is not well established in either decision-makers or the public and events can ‘create systemic shocks that disrupt these systems and quickly cascade to overwhelm the capacity of social, economic and natural systems to cope’ (National Resilience Taskforce 2018b). Previous studies on these interdependencies have suffered from a lack of data causing them to restrict scope to a small amount of related infrastructure (Labaka et al. 2016).

Determining the likelihood of these hazards combining can range from simple to complex according to the level of dependence of the drivers that cause the natural hazard to occur. Some natural hazards have drivers that are mutually exclusive, meaning that it is impossible for certain natural hazard to occur concurrently. Some natural hazards have drivers that are independent, meaning that their risk of co-occurrence is determined by the multiplication of the likelihoods of each. Some natural hazards have drivers that are partially or highly dependent, meaning that their likelihood of co-occurrence is significantly higher than the simple multiplication of their individual likelihoods.

Much can be done to more deeply analyse the likelihood and implications of co-occurrence of natural hazards within the context of changes in the geographic, frequency and intensity of natural hazard drivers in the context of a changing climate.

Extreme bushfire and heat wave have highly dependent drivers. An example of magnified impact from highly dependent events is the loss of power supply on a major scale during a bushfire event. This can cause power blackouts to cities or regions at a time when building climate control is critical for a vulnerable demographic.

It is important to note that some elements of critical infrastructure are not independent assets, but in fact networks or supply chains. For example, bringing food from the paddock to the plate is dependent not only on physical facilities, but also on a network of producers, processors, manufacturers, distributors and retailers (Attorney General’s Department 2010). These network nodes, and the infrastructure supporting them, can all be impacted by a bushfire event.

Extreme bushfire and flash flooding would generally be considered mutually exclusive, but this is not the case in certain regions. Firefighter deaths occurred in flash flood events on Ash Wednesday 1983. The weather profile that brought extreme fire weather to South Australia and Victoria on days such as Ash Wednesday 1983 and Black Saturday 2009 involved a high-pressure weather system followed by an aggressive cold front which not only brought 90-degree wind change but also localised rains.

Extreme Drought and Bushfire have highly dependent drivers. Drought conditions can exacerbate the impact of a bushfire by the drying out of building infrastructure making them more readily ignitable, while also reducing accessibility to water for suppression. Similarly, apparently minor sea-level changes are magnified during king-tides or storm-surge events resulting in significantly greater inundation potential (Fletcher et al. 2016).

Land-use planning, zonation and resilience building activities thus all benefit from development of integrated climate and disaster-risk scenarios, underpinned by a minimum set of commonly agreed underlying climate trajectories and timelines.

8.7 Implementation of Resilient Frameworks in a Societal Context

The inclusion of resilience as a factor in critical infrastructure decision making is recognised as important in Australia and internationally. The Productivity Commission (2014) and Infrastructure Australia (Infrastructure Australia 2018) recognise the need for greater consideration of natural disaster risks and resilience when selecting projects and managing assets.

However, there seems to be limited practical guidance on the incorporation of resilience into cost benefit analysis processes, with only three of the twelve Australian guidelines reviewed by Deloitte's (2016) study, referencing resilience. While a number of Australian Government departments have policies and strategies which aim to build resilience, the associated documentation is mostly at the higher level and does not consider how resilience can be achieved (Deloitte Access Economics 2016).

At the practical level, the Wye River case in Section 8.2 above has demonstrated the learnings available from multidisciplined post-disaster surveys. It highlights the importance for these learnings to also incorporate societal questions; thresholds for decisions to evacuate in a bushfire, or the complex trade-offs between encouraging communities to better maintain their houses compared to building more resilient homes that can tolerate an expected level of stored materials, degradation and modification. This demonstrates the challenges in the uptake of learnings and their application towards forward-looking approaches of what we build and where we build. The need to embed this more holistic approach amongst practitioners is supported by Deloitte's findings that 'design and architecture courses in Australia allocate little time to covering natural disaster risks or the resilience of buildings in future urban centres…and architecture schools in Australia offer very few, if any, courses that include training on how to consider resilience' (Deloitte Access Economics 2016).

Deloitte argues that resilience should be incorporated into tertiary studies for engineers and designers, reasoning that this approach will place infrastructure top-of-mind in future infrastructure design. However, without the addition of societal context, these technical actors will continue to apply resilience frameworks from a protection-based paradigm. Raynor and Cantor's (1987) work in risk management transitions the engineering question 'how safe is safe enough' towards the more balanced question 'how fair is safe enough'? They argue that 'while assessments of probabilities and magnitudes of undesired outcomes are essential to making engineering decisions' they are less relevant to societal choices of technical solutions (Raynor and Cantor 1987). Applying this to resilient frameworks translates the approach from 'including resilience' towards 'balancing resilience'.

The review of Australia's disaster risk reduction and resilience strategies in relation to critical infrastructure has found a complex structure of policies, strategies and resultant frameworks. While this Chapter has noted that the implementation of those frameworks involves a diverse range of actors in both government and private domains, it has also been found that there is a disconnect between government policy concerns and their translation into implemented practice (Coaffee and Clarke 2017).

This report has recommended that forward-looking information is essential to support the implementation of existing resilience frameworks to critical infrastructure decisions. Trusted information can also support the inclusion of societal expectations into what have traditionally been engineering or financially based decisions. This societal context aligns with the Sendai framework and may represent one of the factors which guide the implementation of resilience frameworks in Australia.

8.8 Chapter 8 Acknowledgments

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9 Glossary of acronyms

ACRONYM	MEANING
ABC	Australian Broadcasting Corporation
ACCESS	Australian Community Climate and Earth System Simulator
ACT	Australian Capital Territory
AFAC	Australasian Fire and Emergency Service Authorities Council
AFDRS	Australian Fire Danger Rating System
AI	Augmented Intelligence or Artificial Intelligence
AIDR	Australian Institute for Disaster Resilience
ANZEMC	Australia-New Zealand Emergency Management Committee
APRA	Australian Prudential Regulatory Authority
AQFx	Air Quality Forecasting system
ASFI	Australian Sustainable Finance Initiative
AVL	Automatic Vehicle Location
BNHCRC	Bushfire & Natural Hazards Cooperative Research Centre
BoM	Bureau of Meteorology
CFA	Country Fire Authority (Victoria)
CFS	Country Fire Service (South Australia)
CI	Confidence Interval
CIRS	Critical Infrastructure Resilience Strategy
CMIP	WCRP Coupled Model Intercomparison Project
COAG	(former) Council of Australian Governments
COP	Common Operating Picture
COVID-19	2019 Novel Coronavirus
CRC	Cooperative Research Centre
CRIIMSON	Critical Resource Incident Information Management System Online Network
CSIRO	Commonwealth Scientific Industrial Research Organisation
DAWE	Department of Agriculture, Water and Environment
DBCA	Department of Biodiversity, Conservation and Attractions (Western Australia)
DELWP	Department of Environment, Land, Water and Planning (Victoria)
DFES	Department of Fire and Emergency Services
EMA	Emergency Management Australia
ESM	Earth System Model
EU	European Union
FBAn	Fire Behaviour Analysts
FFDI	The Forest Fire Danger Index
FLIR	Forward Looking Infra-Red
GA	Geoscience Australia
GAR	Global Assessment Report by the United Nations Office for Disaster Risk Reduction
GIS	Geographical Information System
ICC	Incident Control Centre
IMOS	Integrated Marine Observing System
IMOT	Incident Mapping On-line Tool

ACRONYM	MEANING
IMT	Incident Management Team
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red
KBDI	Keetch–Byram Drought Index
LiDAR	Light Detection and Ranging
MFS	South Australian Metropolitan Fire Service
MODIS	Moderate Resolution Imaging Spectroradiometer
NAFC	National Aerial Firefighting Centre
NBIC	National Bushfire Intelligence Capability
NDRISC	National Disaster Risk Information and Services Capability
NDRRF	National Disaster Risk Reduction Framework
NESP	National Environmental Science Program
NESP ESCC	National Environmental Science Program Earth Systems and Climate Change Hub
NESP TSR	National Environmental Science Program Threatened Species Research Hub
NGOs	Non Government Organisations
NPWS	National Parks and Wildlife Service
NRSC	National Resource Sharing Centre
NSW	New South Wales
NSWOEH	State of New South Wales and Office of Environment and Heritage
PES	Payment for Ecosystem Services Agreements
PLACARD	PLAtform for Climate Adaptation and Risk reDuction
PM	Particulate Matter
QFES	Queensland Fire and Emergency Services
Qld	Queensland
LGAQ	Local Government Association of Queensland
QPWS	Queensland Parks and Wildlife Service
R&D	Research and Development
RCM	Regional Climate Model
RFS	NSW Rural Fire Service
RIEL	Research Institute for the Environment and Livelihoods
RPA	Remotely Piloted Aircraft
SCC	State Control Centre
SDGs	Sustainable Development Goals
Sendai	Sendai framework for disaster risk reduction
SES	State Emergency Service
SESIIMS	SES Incident Information Management System
SSS	Spatial Support System
SSTAARS	Sea Surface Temperature Atlas of Australian Regional Seas
TAS	Tasmania
TCFD	Taskforce on Climate-related Financial Disclosures
UK	United Kingdom
UTAS	The University of Tasmania
VIC	Victoria
WA	Western Australia

10 Relevant key reports being delivered in parallel

The reports and activities below consider some of the issues outlined in this report.

REPORT/ACTIVITY	LEAD AGENCY	AREAS RELATED TO THIS REPORT
Report of the Royal Commission into National Natural Disaster Arrangements, 2020	Office of the Royal Commission	Review of recommendations of previous reports and inquiries, and their implementation; community engagement to assess first and second-response effectiveness
National Bushfire Recovery Plan	National Bushfire Recovery Agency	National response to the 2019/20 bushfires
Australia's Health 2020	Australian Institute of Health and Welfare	Long-term impacts of natural disasters on mental health and chronic diseases
The Preliminary Report into the Appropriateness, Efficacy and Identified Gaps in the Government's Drought Response *and* 2019 Queensland Monsoon Trough. After the Flood: A Strategy for Long-Term Recovery	National Drought and North Queensland Flood Response and Recovery Agency	Responses to Drought and Flood
Policy Papers on Pandemic, Cyber and Natural Hazard Resilience	Infrastructure Australia and Infrastructure NSW	Work on infrastructure risk and resilience
Inquiry into the 2019-20 fire season	Victorian Inspector General for Emergency Management	Climate impacts on fire
Independent review (SA 2019/20 Bushfires)	South Australian Fire and Emergency Services Commission	2019/20 bushfire season with a focus on the Kangaroo Island and Cudlee Creek bushfires
Northern Australia Insurance Inquiry	Australian Competition and Consumer Commission	Insurability, enhanced resilience
NSW Bushfire Inquiry	NSW Government independent review	Causes of, preparation for and response to the 2019-20 bushfires in NSW
Australia's Health 2020	Australian Institute of Health and Welfare	Impact of disasters on health
Lessons to be learned in relation to the Australian bushfire season 2019-20	Senate Standing Committee on Finance and Public Administration	Preparation and planning for, response to and recovery efforts following the 2019-20 Australian bushfire season
Minister Andrews' Bushfire Science Roundtable	Department of Industry Science, Energy and Resources	
Wildlife and threatened species bushfire recovery expert panel	Office of the Threatened Species Commissioner, DAWE	

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11.1Photo credits

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11.2 Stakeholder meetings

Various topic-specific meetings and interactions informed the development of chapters of the Technical Report on Climate and Disaster Resilience. Key meetings which informed the development of this report included:

ORGANISATION	PARTICIPANTS
Australasian Fire and Emergency Service Authorities Council	Stuart Ellis, Noreen Krusel, Richard Alder, Amanda Leck, Paul Considine, Greg Esnouf, Simon Heemstra
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ORGANISATION	PARTICIPANTS
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Queensland Government	Minister Leeanne Enoch, Jamie Merrick, Karen Hussey
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South Australian Government	Premier Stephen Marshall and Courtney Morcombe
South Australian Department for Environment and Water	Mike Wouters
Tasmanian Government	Premier Peter Gutwein, Andrew Finch, Craig Limkin, Perry Jackson
Tasmanian Police	Ricki Eaves
Tasmania Fire Service	Bruce Byatt
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Western Australian Department of Fire and Emergency Services	Jon Broomhall, Danny Mosconi

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