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IMPLICATIONS OF CLIMATE CHANGE FOR EMERGENCY SERVICES OPERATIONS

Insights from the literature

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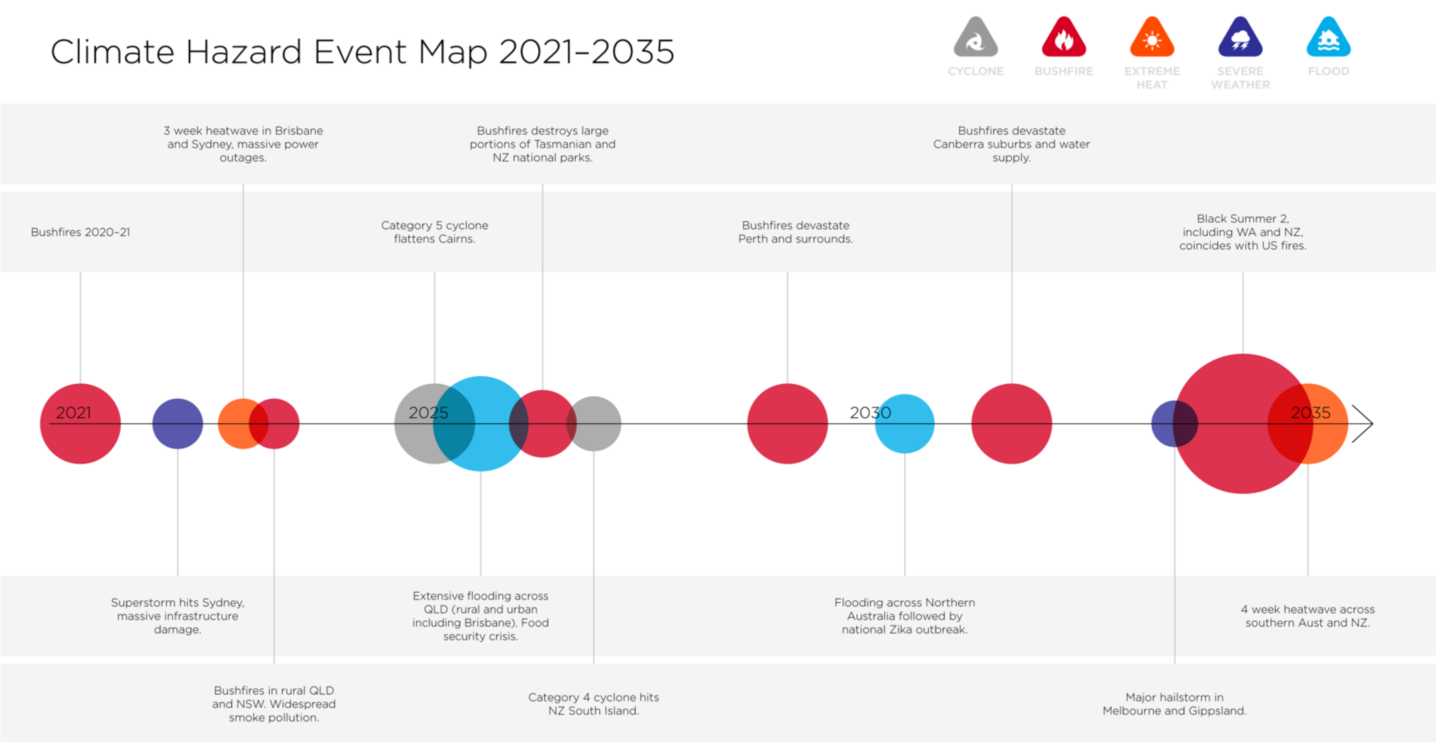

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Cover: Climate Hazard Event Map, produced for project scenario process. Source: Adriana Keating and Steve Atkinson; Design: Friedo Ligthart

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EXECUTIVE SUMMARY

Greenhouse gas emissions to date and existing pledges for emissions reduction from national governments suggest that the world is tracking a medium emissions future at best, and possibly a high emission one. This report consolidates available knowledge of the potential impacts of climate change on key issues that influence the (emergency management services (EMS) in Australia and New Zealand, through a systematic review of the literature (both peer reviewed and grey literature) combined with an analysis of relevant inquiries. It is an output of the BNHCRC project entitled *Preparing Emergency Services for a Climate-challenged World*.

For the EMS, one of the most immediate and visceral impacts of climate change is increasing frequency and severity of disaster-inducing natural hazards. Yet, it would be a mistake to assume that this is the extent of the challenge: interacting climatic, social, demographic and economic trends will result in transformations in our societies and way of life. For the EMS, the climate change adaptation challenge is more than just 'more of the same'. The increasingly significant impacts that climate change is having on the natural and human systems that support livelihoods and wellbeing in Australia and New Zealand present a profound challenge for all communities, businesses and services.

In the decades ahead, Australia is expected to experience increased warming across the whole of the continent with rainfall declines over much of the southern parts of the country very likely. These changes are not unfolding linearly. Already it is clear that the climate has altered over recent decades through a serious of step changes or 'breaks'. This means that current rates of change are an unreliable indicator of future rates of change.

Similarly, New Zealand is already registering warming and changing rainfall in some regions. These trends are expected to continue and include increasing average temperatures and more hot days for norther areas, significant shifts in rainfall patterns and more extreme rainfall, and profound increases in the time spent in drought by 2040. Sea level rise is also a major concern for the island nation, with sea level rise around New Zealand projected to be up to 10% higher than the global average.

For Australia and New Zealand, climate change means more heatwaves, more extreme precipitation events, more bushfire weather, more storms, fewer but more intense cyclones, and more landslides. It also means more compound events and cascading impacts, where multiple extreme events occur simultaneously – as was seen in Black Summer, where bushfires, heatwaves and floods were experienced during a long-term drought. Climate change is also increasing the risk that second and third order impacts of disasters, such as a disease outbreak following a flood, themselves cascade into another event of equal or greater severity.

Increasing frequency and severity of climatic hazards are intersecting with growing exposure and changing vulnerability patterns to drive disaster risk. Some of the desirable features of contemporary lifestyles – such as high levels of consumption and technology-dependent, centralised systems – are further increasing disaster risk. A no-regrets approach to climate change adaptation is

to build 'adaptive capacity', which is made up of five interlinked domains: assets, flexibility, social organisation, learning, and agency. Building adaptive capacity/reducing vulnerability requires looking beyond direct climate change impacts (e.g. managing heat) to address structural and systemic constraints on the ability of people and ecosystems to adapt to ongoing change, such as social inequalities, low environmental sustainability and poor governance.

Climate change adaptation incorporates a range of objectives and areas of effort. While it necessarily involves "coping" at any moment in time, it also extends far beyond just coping to also better "fit" emerging conditions and to proactively adjust to, and help positively shape, the future. Criteria of success of a climate change adaptation initiative include effectiveness, efficiency, equity, accounting for externalities, and having an extended time horizon. The inverse of good adaptation is maladaptation: actions that may lead to increased risk of adverse climate related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future.

Adaptation faces limits and barriers. As climate change worsens, it is likely impacts will exceed some systems' and groups' capacity to manage them. Uneven structural vulnerabilities and engrained issues such as downplaying climate change risks means some groups are continually or regularly unable to cope or adapt well. One of the risks of the "shared responsibility" paradigm of disaster risk management in Australia is that 'communities often are left to manage residual risks shifted towards individuals, whether or not they have the financial, physical, mental, or social capacity to manage them'. It is often assumed that a lack of climate change information or adaptation knowledge is the main barrier to effective and timely adaptation action. While knowledge and information are important, analysis of barriers to adaptation suggests that institutional barriers (e.g. lack of clear mandate, roles, responsibilities, willingness to act) are often more significant.

One of the enablers of good climate change adaptation is systems thinking – appreciating systemic relationships and how to manage them. When it comes to the EMS, a systems-based approach widens our understanding of the sector and the many implications of climate change for it. This report presents two frameworks that are useful for contextualising the EMS in a wider context, identifying how climate change might influence various elements of this system, and where the EMS can direct different types of adaptation strategies.

The academic literature provides some valuable insights into the drivers at work in the EMS context. However, very little research addresses the "question of the future" *per se* and that which does, does not do so in a comprehensive manner that incorporates climate change or challenges the assumption that existing trends will unfold linearly. We therefore need to bring together different insights in order to piece together what the future may entail for the EMS. One useful way to begin this process is to systematically consider the 'STEEP drivers' - that is, insights into Social, Technological, Environmental, Economic and Policy/Political drivers – and to then start thinking through how they may interact with climate change. In response to input from the scenarios team (the other part of this project), we have included a sixth category – legal – into the framework. This report provides examples of the types of changes and uncertainties the EMS may need to consider as it encounters the climate change adaptation undertaking.

We draw on the literature review to present analysis provided to the scenarios process. This includes a summary of biophysical impacts of climate change to 2035, including a plausible (but not predictive) climate hazard event map. We then summarise the likely flow-on effects to 2035 and finally the likely implications of those flow-on effects for water and environment, agriculture and aquaculture, infrastructure, human health and wellbeing, and society in general. Finally, we explore what adaptive capacity might look like under the four plausible futures developed by the scenarios team. In this way, the EMS has a comprehensive picture of what climate change impacts might influence them and what resources they might have to manage them.

INTRODUCTION: THE CLIMATE CHANGE ADAPTATION CHALLENGE

Even if humans were to halve all greenhouse emissions tomorrow, the climate would continue to change for decades, if not centuries. This is because the greenhouse gasses that have already accumulated in our atmosphere will persist and with them the 'greenhouse effect' of increased heat. Increased heat in our atmosphere is resulting in shifts in atmosphere systems and causing ocean warming, sea level rise and glacial melting

[1]. These climatic changes are already manifesting – in 2018 Australia's average temperature was 1.14°C above average.[2]

For the emergency management services (EMS) in Australia and New Zealand, one of the most immediate and visceral impacts of climate change is increasing frequency and severity of disaster-inducing natural hazards. Our experience with disasters to-date cannot be used as a guide for the future; as the final report of the 2009 Victorian Bushfires Royal Commission[3] stated:

It would be a mistake to treat Black Saturday as a 'one-off' event. With populations at the rural–urban interface growing and the impact of climate change, the risks associated with bushfire are likely to increase.

Yet, it would be a mistake to assume that this is the extent of the challenge: interacting climatic, social, demographic and economic trends will result in transformations in our societies and way of life. For the EMS, the climate change adaptation challenge is more than just 'more of the same'. The increasingly significant impacts that climate change is having on the natural and human systems that support livelihoods and wellbeing in Australia and New Zealand, present a profound challenge for all communities, businesses and services.

Climate change adaptation is not an outcome, but an ongoing process. Adaptation decisions need to consider long-term consequences and thus grapple with uncertainty. Climate change adaptation planning is decision-making under uncertainty, complexity, and contested values. While the EMS are experts at risk management, the multiple uncertainties that climate change introduces means that it is poorly suited to conventional risk management. How climate change will manifest globally and at finer scales, how different groups and systems adapt and how these factors intersect with other complex, social, ecological, and economic dynamics are all highly uncertain. These uncertainties can only partially be reduced through further modelling[4].

This means that planning for the future cannot rely on a 'most likely' climate change scenario or identifying an 'optimal' response. Relying on such approaches faces a high risk of failure and high likelihood of worsening underlying causes. What is needed is to test thinking and plans against *multiple* plausible futures in order to identify actions that:

- are robust - perform well across multiple possible futures;
- are flexible - can be changed and adapted over time, and do not lock-in or out particular options; and

- address the root drivers of risks and vulnerabilities, not just tackle the impacts.

As part of their efforts in tackling this challenge, emergency service agencies across Australia and New Zealand are seeking to build their knowledge and skills in testing their capabilities against a range of plausible futures to inform their strategic planning and associated preparedness activities. One component of this capability building is for these agencies to address the question: *How can fire and emergency service agencies develop and use forward-looking (and linked) climate and social change scenarios to best prepare their businesses so that they can continue to provide effective services in a climate-challenged world?*

To address this question, the Bushfire and Natural Hazards CRC (BNHCRC) established a project entitled *Preparing Emergency Services for a Climate-challenged World* in order to:

- Consolidate available knowledge of the potential impact(s) of climate change on key issues that influence emergency services agency operations;
- Develop a robust and tested methodology that can use that information to develop future scenarios, and to use that methodology to develop a set of plausible climate change future scenarios; and
- Develop a guide to using such scenarios, including worked examples and capability building workshops, that can be used by emergency service agencies across Australia and New Zealand to aid their strategic planning and associated preparedness activities.

This report addresses that first point. It consolidates available knowledge of the potential impacts of climate change on key issues that influence the EMS through a systematic review of the literature (both peer reviewed and grey literature) combined with an analysis of relevant inquiries. Section 6 of this report presents inputs into the scenarios process and resulting guide (points 2 and 3) that were drawn from this research throughout the project.

FUTURE EMISSIONS AND CLIMATE SCENARIOS

The most recent work on emissions (which informs the forthcoming IPCC Working Group One Sixth Assessment Report) divides possible futures into four main types of climate-emissions scenario, ranging from very low emissions and a radiative forcing about 1.9 W/m^2 - consistent with containing average global warming to 1.5°C - to very high emissions and a radiative forcing of 6.0 W/m^2 - leading to average global warming of over 5°C, which is widely considered catastrophic (FIGURE 1).

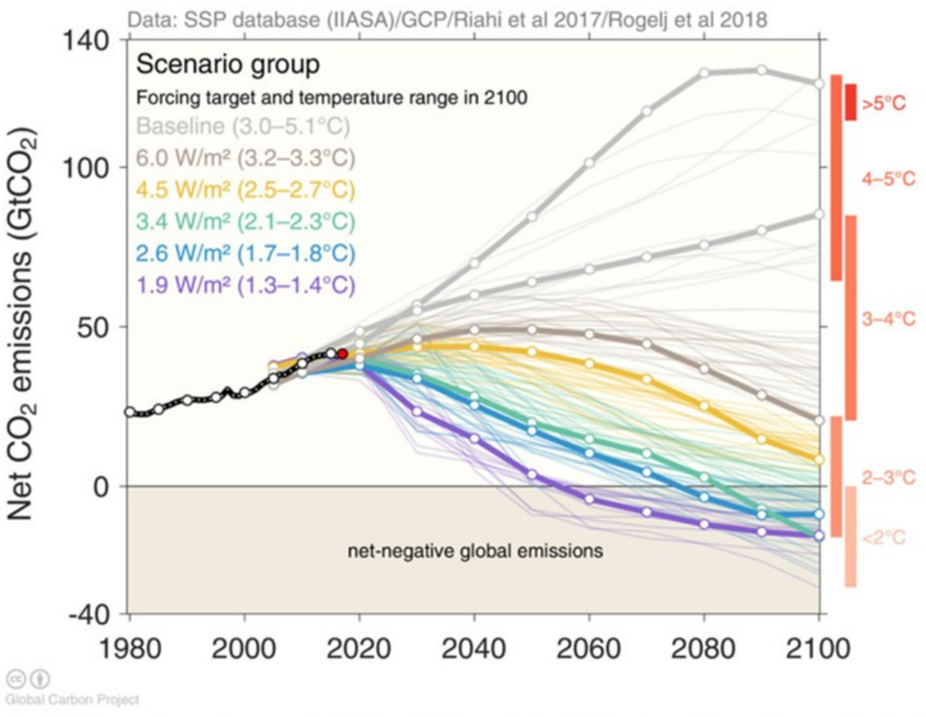

FIGURE 1: FOUR EMISSIONS SCENARIOS, RADIATIVE FORCING AND TEMPERATURE[5].

The wide range of temperature futures shown in FIGURE 1 highlights that the emissions scenario a climate model uses strongly determines what outcomes it will project. While projections for the next decade or two do not differ greatly, the longer the time frame, the more significant emissions outcomes are. The longer lasting and longer lead time a decision has, the more attention needs to be paid not just to climate projections but to what emissions scenarios are used to produce them.

Most existing climate projections (including those produced by the Australian government) do not use the scenarios approach described above but rely on a slightly different, older approach to understanding possible futures called Representative Concentration Pathways (RCPs). These represent different futures according to atmospheric concentrations of greenhouse gases. The main RCPs are categorised by the effective radiative forcing a given concentration level produces. The four main ones are forcing levels of 2.5, 4.5, 6 and 8.5 W/m^2 which correspond loosely to the four scenarios above. These are used to inform General Circulation Models (GCMs) of past and future climates for different parts of the world, including a set of projections for Australia produced by CSIRO and BOM and New Zealand by the Ministry for the Environment and NIWA.

Climate projections are inherently limited by the complexity of and competing analytical approaches to the systems they are modelling, gaps in the data record, and feedbacks from shifts already emerging. The resultant uncertainty means that they cannot be treated as robust predictions, even of worst-case scenarios. In particular, existing science has a limited capacity to predict 'compound events' – major climate-related events such as floods that result from the intersection of concurrent changes in climate (and sea level rise)[6]. This is illustrated by the compound event of the recent mega-fire in Southern Australia (Black Summer), which stemmed from a combination of drought and heat extremes and was followed by severe storms. It was not predicted by existing models[7].

The mega-fire may also prove to illustrate another increasingly apparent risk, which is positive feedbacks between land and climate, triggering systemic and potentially irreversible changes in natural systems. There is increasing concern that 'tipping points', such as large-scale forest, wetland or peat die back and burning, will emit large amounts of carbon dioxide and methane into the atmosphere[8]. Such outcomes are not factored into existing scenarios and have the potential to push global warming far beyond 5°C. For this and other reasons, climate projections should always be interpreted cautiously.

Emissions to date and existing pledges for emissions reduction from national governments suggest that the world is tracking a medium emissions future at best, and possibly a high emission one[9]. Combined with uncertainty in the models, this means that the climate projections used to inform adaptation should include the more extreme projections from high emissions scenarios.

STARTING POINT: CURRENT RESEARCH ON THE IMPACT OF CLIMATE CHANGE FOR THE EMS

The starting point for this literature review was to look at what work has already been done specifically on the potential impacts of climate change for the EMS in Australia and New Zealand. There are some significant pieces of research that support the EMS to plan for the impacts of climate change. Several key pieces of work are outlined below. In this literature review, our goal is to start from this point and extend it, drawing on a wider literature and approaches in order to further explore the challenge.

AFAC Discussion Paper: Climate Change and the Emergency Management Sector (Australasian Fire and Emergency Service Authorities Council, 2018).

[10] This paper identifies key risks and priorities for the EMS in relation to climate change. Key risks identified are:

- an increase in the frequency, severity and complexity of extreme weather and cascading events, intersecting with other stressors that require joint agency planning and interoperability;
- implications for security and stability;
- an increase in exposure and vulnerabilities of communities to disasters and amplifications of other stressors and shocks;
- an increasing of the economic cost of disasters, further stretching the resourcing of emergency services;
- an increase of health and safety risks for staff and volunteers, including fatigue and mental health;
- sustained consequences of ecosystem changes, including impacts on effectiveness of risk mitigation activities;
- supply chain vulnerabilities for the sector;

- an increased expectation across private and public sectors that emergency services have regard for and consider climate change risk across operations and service delivery;
- an increase in liability exposures for emergency services and impacts of insurance sector changes;
- changes in the financing of projects and critical infrastructure;
- failure of building codes and land use planning to adequately adapt; and
- an ineffective transition to low emissions technologies.

Planning and capability requirements for catastrophic and cascading disasters project (Risk Frontiers, Macquarie Uni, BNHCRC). This work includes the 'Emergency management capability maturity assessment tool', which "can be utilised by jurisdictions and organisations to better understand potential capability gaps in the context of severe-to-catastrophic disaster scenarios. Through utilisation funding provided by the Bushfire and Natural Hazards Cooperative Research Centre, this tool will be promoted for use across all jurisdictions".[11]

Improved decision support for natural hazard risk reduction project (Uni of Adelaide, BNHCRC). This project, called UNHaRMED, developed a decision-support framework: "This system allows for the dynamic understanding and assessment of all three components of risk; exposure, vulnerability and hazard, in line with recent recommendations from the World Bank's Global Facility for Disaster Reduction and Recovery (Fraser et al, 2016). UNHaRMED thus allows policy makers to better understand the drivers of risk and the impact of their policies on risk profiles now and into the future. This enables policy makers to account for climate change, urbanisation, population increases and future environmental conditions in risk assessments".[12]

Mapping and understanding bushfire and natural hazard vulnerability and risks at the institutional scale project (Victoria Uni, BNHCRC), which produced two frameworks. The 'Problem solution framework': "This document is designed as a framework to assist understanding of how to manage and implement actions in the context of continuous change, where risks and actions are complex and outcomes often are uncertain. Although it uses climate change as the focus, this framework can be applied to assist understanding in any area of practice requiring management of ongoing change and dynamic risk, in current and future contexts".[13] It also looked at risk ownership with the 'Risk ownership framework for emergency management policy and practice': "The purpose of this framework is to provide a companion process for current risk planning processes, in particular the National Emergency Risk Assessment Guidelines (NERAG), where key tasks can be integrated into current risk assessment and planning activities. Its aim is to support better strategic management of risks associated with natural hazards. It does this through providing a series of tasks that support the allocation of risk ownership as part of strategic planning activities. This framework is not intended to replace current risk processes, but to enhance and add value to what is already there".[14]

EFFECTS OF CLIMATE CHANGE ON CLIMATE AND OCEANS

EFFECTS OF CLIMATE CHANGE ON CLIMATE AND WEATHER

Overview

An extensive scientific literature on climatic extremes is summarised in major reports such as the IPCC's 2012 Special Report on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX)[15], CSIRO's recent (2020) *Climate and Disaster Resilience*[16] report to the Federal Government, the *Severe weather in a changing climate (2nd Ed.)* published by Insurance Australia Group (IAG)[17], the *State of the Climate 2020 report*[18] (see FIGURE 2) and for New Zealand the *Climate Change Projections for New Zealand*[33]. Key points are discussed in this section.

Climate change is altering the base climate and the magnitude and frequencies of extremes in temperature and precipitation. In the decades ahead, Australia is expected to experience increased warming across the whole of the continent with rainfall declines over much of the southern parts of the country very likely[19]. These changes are not unfolding linearly. Already it is clear that the climate has altered over recent decades through a serious of step changes or 'breaks'[4]. This means that current rates of change are an unreliable indicator of future rates of change. No climate variable – including average heat, extreme heat, extremes in extreme heat - should be presumed to unfold progressively in the future; they may arrive far more abruptly. Virtually no existing research on Australia's futures takes account of this possibility.

FIGURE 2: FUTURE CLIMATE PROJECTIONS AS OUTLINED IN THE STATE OF THE CLIMATE 2020 REPORT[18].

Similarly, New Zealand is already registering warming and changing rainfall in some regions. These trends are expected to continue and include increasing average temperatures and more hot days for northern areas, significant shifts in rainfall patterns and more extreme rainfall, and profound increases in the time spent in drought by 2040. Sea level rise is also a major concern for the island nation, with sea level rise around New Zealand projected to be up to 10% higher than the global average. Finally, fire danger is expected to dramatically increase by 2040 and continue to worsen.[20]

Increasing average temperatures

While the temperature trend is clear – warmer averages and far hotter extremes – the precipitation trend is more ambiguous and geographically variable. Australia's climate is already highly geographically variable. Climatic changes will likely vary over space, including altitude. The spatial distribution of different "climate envelopes" (relatively contained climatic areas) is also shifting under climate change. For instance, the tropical and subtropical zones are moving southward under climate change, bringing with them new climatic hazards, interactions and associated pests and diseases[21]. This includes higher average and extreme temperatures. Recent high-resolution simulations for Victoria point to the need to plan for a "hot case" scenario. For example, in the 2050s under a high emissions (RCP 8.5) scenario, in summer almost all of Victoria could reach at least 40°C in summer, with some parts reaching 55°C – a situation with no historical precedent (FIGURE 3).

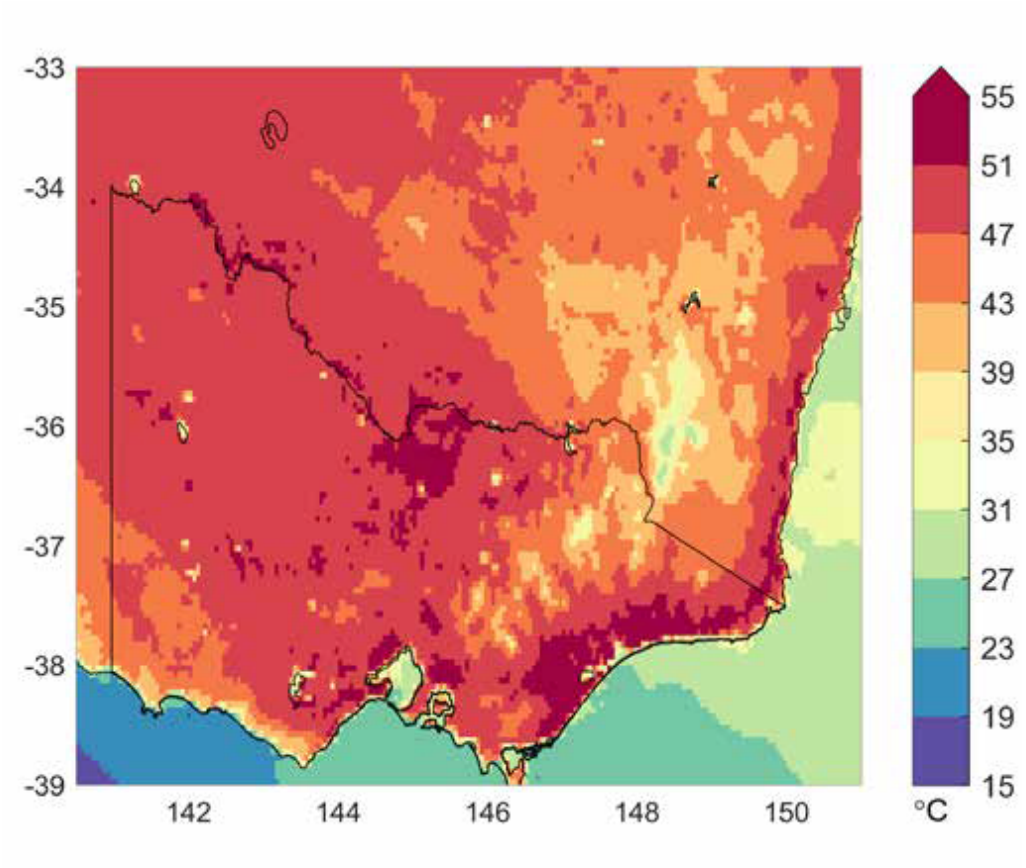

FIGURE 3: DAILY MAXIMUM TEMPERATURE FOR AN EXTREME SUMMER DAY SIMULATED UNDER RCP8.5[6].

Irrespective of the climate change scenario used, there is a shift towards higher extreme temperatures across Australia, particularly a significant increase in the number of warm nights[22]. In addition, extreme minimum night-time temperatures are projected to increase in frequency and severity until approximately 2030, after which time they will be overrun by the general trend in the opposite direction towards higher temperatures, meaning less frosts after this time.[23]

Extended periods of extreme heat (heatwaves) are also increasing[1]. The duration and intensity as well as frequency of heatwaves has already increased since 1950 for many parts of Australia, particularly in southern and eastern Australia[24]. The *State of the Climate 2020* report notes: 'Australia's climate has warmed on average by 1.44 ± 0.24 °C since national records began in 1910, leading to an increase in the frequency of extreme heat events.'[18] It is important to note that observed and projected increases in *average* temperature do not fully convey the increasing extreme heat. It is particularly northern Australia, however, that is projected to have more and more intense heatwaves in the future[25]. For example, downscaled future climate projections for Queensland suggest that heatwaves will further intensify over this century, with different climatic regions within Queensland responding differently[26]. What we have experienced in recent years as 'record heat' is projected to be considered mild or cool by 2035 in the majority of analysed models in high warming scenarios[27,1]. This depends on greenhouse gas mitigation though as projections of heatwaves are sensitive to average global warming, with the frequency of heatwaves increasing substantially if there is average warming of 2°C versus 1.5°C[28].

Heatwaves are Australia's most deadly natural hazard[29], affecting human health and labour capacity[30]. The 2009 heatwave over south eastern Australia killed 374 people, double that of the subsequent bushfire. High night time temperatures inhibit the ability of people to cool down and recuperate, allowing heat to accumulate in the body and pushing people to their biological limit, especially if they have pre-existing biological vulnerabilities or need to generate bodily heat through physical exertion. For similar reasons, the combination of high temperatures and high humidity especially stresses human bodies. Although there is a tendency to conflate high ambient temperatures with heat, without factoring in other variables[31] in the Wet Season (October to April) in tropical Australia (across Western Australia, Northern Territory and Queensland) thermal loads stem as much from humidity as temperature, where the former refers to the proportion of water vapour in ambient air compared to if the air was saturated. Those exposed to environmental heat outside or who work with hot machinery are especially susceptible. Mortality and morbidity increase even after only two days of extreme heat[32]. As discussed further below, heat also leads to a range of other direct and indirect health hazards. All of this poses real challenges for the emergency services.

Increasing temperatures are also a significant concern for New Zealand. FIGURE 4 shows observed and projected increases in average temperature in New Zealand. By 2040, mean temperature is expected to increase from 0.7-1.0°C and continue climbing from there. The number of hot days (where maximum temperature is 25°C or higher) is projected to increase by between 40-100% by 2040.[33] While the direction of this trend is consistent across New Zealand, the largest increases are projected to occur in the north of the North Island and in coastal Gisborne and Hawke's Bay.[33]

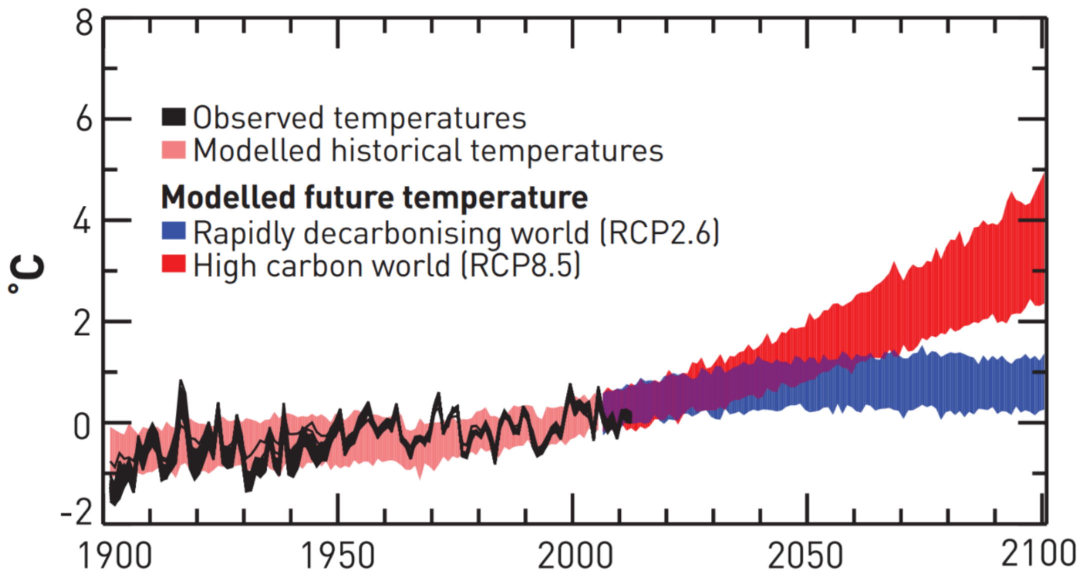

FIGURE 4: BASED ON IPCC WORKING GROUP II FIFTH ASSESSMENT REPORT CHAPTER 25 SOURCE: NEW ZEALAND CLIMATE CHANGE CENTRE[20].

Heatwaves are often called an invisible killer because they often occur behind closed doors and are dispersed throughout the community. They are in fact Australia's most deadly natural hazard[34], affecting human health and labour capacity[35]. The 2009 heatwave over south-eastern Australia killed 374 people in Victoria alone, double that of the concurrent 'Black Saturday' bushfire. High night-time temperatures inhibit the ability of people to cool down and recuperate, allowing heat to accumulate in the body and pushing people to their biological limit, especially if they have pre-existing biological vulnerabilities or need to generate bodily heat through physical exertion. For similar reasons, the combination of high temperatures and high humidity especially stresses human bodies. Although there is a tendency to conflate high ambient temperatures with heat, without factoring in other variables[36] in the Wet Season (October to April) in tropical Australia (across Western Australia, Northern Territory and Queensland) thermal loads stem as much from humidity as temperature, where the former refers to the proportion of water vapour in ambient air compared to if the air was saturated. Those exposed to environmental heat outside or who work with hot machinery are especially susceptible. Mortality and morbidity increase even after only two days of extreme heat[37]. As discussed further below, heat also leads to a range of other direct and indirect health hazards. All of this poses real challenges for the emergency services.

Shifts in precipitation

Projected precipitation changes vary widely across Australia and New Zealand. Northern Australia may get wetter, though there is a high level of uncertainty about its future rainfall trends.[18] Across New Zealand, projections are that the north and east of the North Island will experience a reduction in precipitation, with everywhere else experiencing increases – especially on the west coast of the South Island.[33] In Australia, the southward progression of the subtropical zone means that, on average, southern Australia is getting drier. Although projections are highly variable ranging from small increases (+3% under RCP 2.6 or +4% for RCP 8.5) to significant decreases (-15% under RCP 2.6 to -26% for RCP 8.5) for 2090 in southern Australia[38], there is broad agreement among models that mid-latitude storm tracks (which have historically brought cool-season rains) are moving poleward[39]. CSIRO (2020) [40] states that:

> *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. These long-term trends are expected to emerge amid high variability, with ongoing wet and dry years and seasons.*

In addition to a generally drier climate, southern Australia will likely experience more periods of extremely low precipitation ("meteorological droughts"). Although meteorological droughts are caused by the interaction of many factors including land-atmosphere feedbacks and ocean systems, making them especially hard to predict project[41], Southern Australia faces 'more time in drought' in the future[42], in keeping with projections of more extreme El Niño periods[43]. Similarly, New Zealand is projected to face increasing frequency and severity of drought, particularly in already dry regions.[33]

Rainfall is affected by multiple climatic changes in any one location and by the biophysical environment such as coastlines and mountain ranges on weather. The western regions of both the North and South Islands of New Zealand are projected to experience increasing rainfall, while the east and north face drier conditions.[33] In Australia,, the topography of the Alpine region means it will especially experience a decline in rainfall on its inland slopes, causing drier vegetation and worse fire risk on those slopes.

Rainfall also varies over different temporal scales. Projections of very high rainfall are superimposed on the general drying trend in southern Australia, though far less clearly than droughts. In terms of extended wet periods, there are few confident projections. There are some suggestions that changes in the ENSO weather system and sea surface temperatures may involve an increased magnitude, if not frequency, of La Niña events, increasing the distribution of heavy rainfall and chances of intense tropical cyclones in the northern Murray Darling Basin, propagating water throughout the drainage division and potentially causing flooding of the sort that occurred in 2010-11. As Colvin (2020) notes:

> *Australia faces […] extreme rainfall variability, a widespread drying trend, and projected increases in both aridity and variability in the future. This means the distribution of rainfall across the continent and over time will change—we may see some areas that have long dry spells broken by a serious deluge not dissimilar to that which was observed in Queensland in the summer of 2019.*[1]

At a finer temporal grain, heavy downpours are expected to increase. In southern Australia, the intensity of daily total rain in 2090 is projected to increase by 5-30% under RCP 8.5 and up to nearly 20% under RCP 4.5[38]. As Clarke et al. (2019) explains, while outcomes will be the result of many variables: 'A warmer atmosphere can hold more moisture, so with all else being equal, heavy rainfall at the scale of minutes to a day is expected to increase in most places and seasons…'.[4] This is the case despite the general reduction in rainfall. Clarke et al.

continue: 'The projections paint a picture of a drying climate but an increase in daily rainfall extremes'[4].

In New Zealand, precipitation changes across the Islands are expected but are uncertain (see FIGURE 5). Overall, daily precipitation extremes in terms of dry days are expected to increase in the north and east of the North Island in the winter and spring seasons. In terms of very wet days, the western regions and the south of the South Island are projected to see a more than 20% increase in 99th percentile of daily rainfall by 2090 (ERP 8.5). Very extreme precipitation events, which exceed the current 2-year recurrence interval are also expected to increase per degree of warming, from 5% for 5-day duration events to 14% for 1-hour duration events.[33]

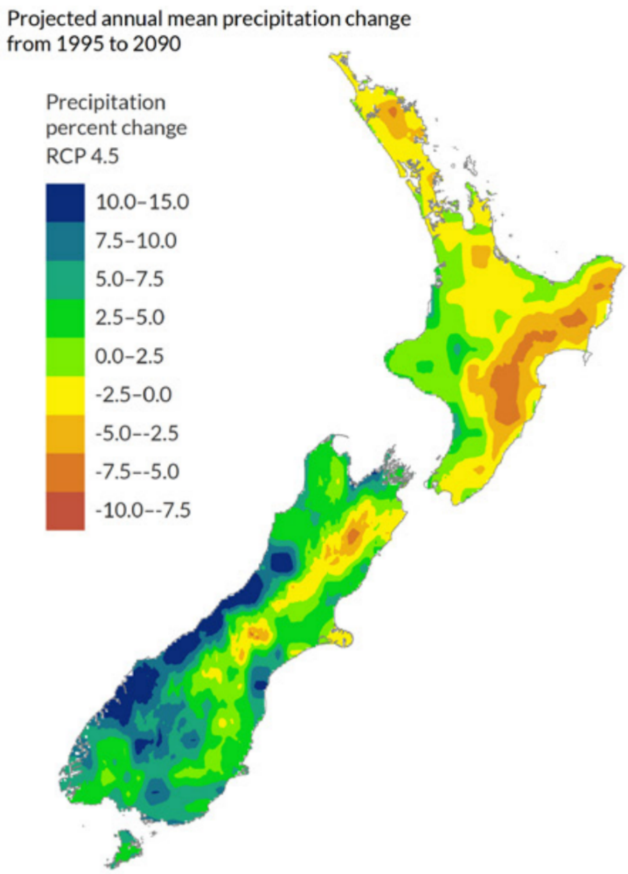

FIGURE 5: PRECIPITATION CLIMATE CHANGE PROJECTIONS FOR NEW ZEALAND, BASED ON IPCC REPRESENTATIVE CONCERTATION PATHWAY 4.5. SOURCE: MINISTRY FOR THE ENVIRONMENT & STATS NZ[44].

The relationship between precipitation, runoff and water availability is complex. Higher evapotranspiration under higher temperatures and shifts from winter to summer rainfall due to increased tropicality mean that stream runoff and water availability will likely decrease far more quickly than precipitation, adding to water scarcity in settlements reliant on surface water and increasing contestation between water users (e.g. mines vs irrigators vs towns). Risk to potable water supplies was identified as one of New Zealand's top ten most significant climate change risks.[17] For Australia, CSIRO projected a decrease in 2–22% in runoff as a result of 0–9 % decline in rainfall for each 1° C increase in annual global average temperature[39]. The spatial location of reduced precipitation will strongly affect its influence on runoff. For instance, in the Murray Darling Basin, approximately 12% of the basin (in the Alps) generates two-thirds of streamflow.[45] Water quality is also likely to decline due to high temperatures, storm runoff, dust storms and smoke and other factors, reducing the effective amount of water available. In 2019-2020 a number of Australian towns completely ran out of potable water for a period.

Changes in storms and cyclones

Sparse data on storms (especially from rural and remote areas), plus the erratic nature of storms and the complexity of modelling them, mean that historical trends are generally inconclusive. Dowdy (2020) suggests that thunderstorms have become more common over some regions of south-eastern Australia since 1979[46]. A significant type of storm that periodically affects far eastern Victoria is the East Coast Low – these are intense, slow-moving low-pressure systems (extra-tropical cyclones) that generate high winds and rainfalls. A particularly severe one in 2016 caused 20,000 homes to lose power. These lows often move in a south-easterly direction and impact New Zealand.[33] Severe hailstorms and dust storms are also familiar, with damaging examples of both being experienced in 2019 in Australia.

The frequency of storms in northern and southern parts of Australia as well as New Zealand is not expected to increase, however their intensity is expected to increase. Similarly, less frequent but more intense tropical cyclones are expected[18]. In Queensland, the Northern Territory, and Western Australia, cyclones are a major driver of floods, so larger floods are likely to be triggered by larger cyclones in these states[1].

Effects on fire weather

Together, higher temperatures and winds and more frequent lightning strikes will likely generate worse fire weather and more ignitions. Across Australia, extreme fire weather (Figure 26) and the length of the fire season is increasing[19]. The 2009 Black Saturday fires had the highest Forest Fire Danger Index (FFDI) at the time but this has been since surpassed by the February 2017 fires in NSW and then the 2019-2020 Black Summer fires. 2019 recorded the highest accumulative FFDI on record[47].

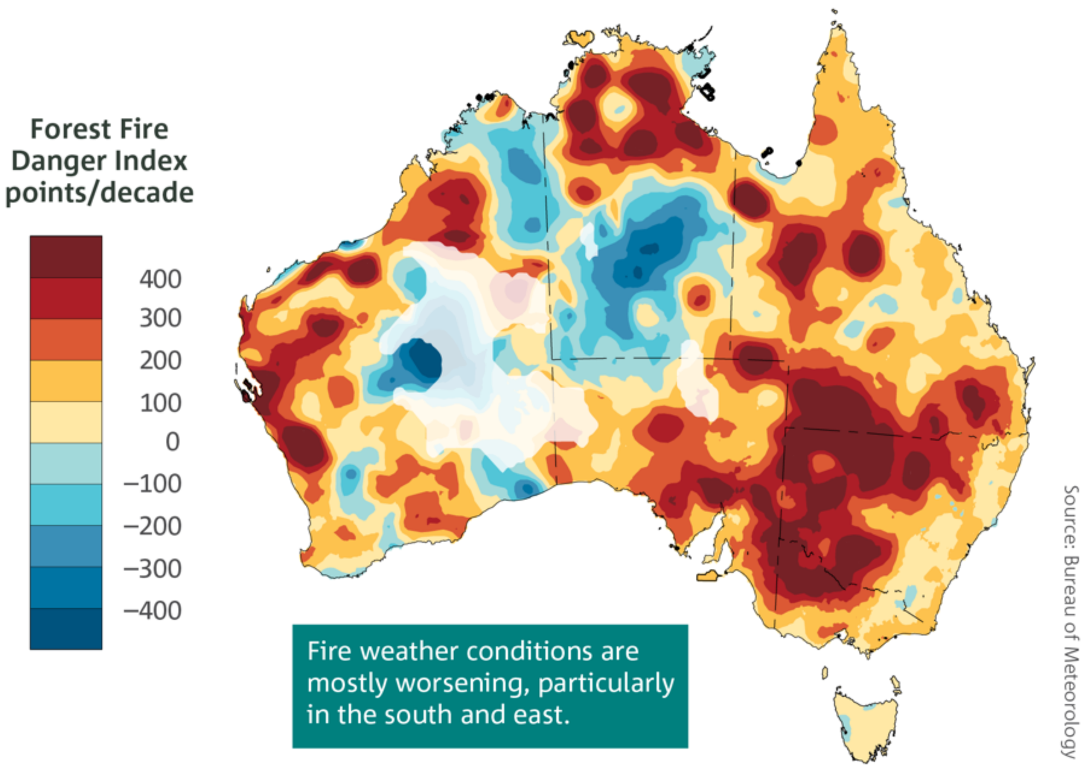

FIGURE 6. TRENDS FROM 1978 TO 2017 IN THE ANNUAL (JULY TO JUNE) SUM OF THE DAILY FOREST FIRE DANGER INDEX—AN INDICATOR OF THE SEVERITY OF FIRE WEATHER CONDITIONS[19].

In southern Australia, higher aridity and temperatures are progressively drying out the landscape and, combined with a greater number of lightning strikes, are contributing to more frequent fires[48]. In Victoria, for example, the number of fires increased by 171% between 1972 and 2014, though inter-annual variability is large and the total area burned did not rise, most likely because fire emergency responses improved[48]. In addition to management improvements, other variables mean that climate is not the main determining factor driving more frequent fires in Victoria, but it is becoming increasingly significant[48].

Wildfire risk is also increasing in New Zealand as a result of increasing fire weather (hotter, drier and windier) on top of longer-term declines in precipitation. The number of very high or extreme fire danger days is projected to increase by an average of 70% by 2040. Wellington and coastal Otago, which do not currently face regular fire risk, are set to experience the most substantial increases.[44]

Reflecting and exacerbating the catastrophic character of fire weather and flames are the "positive feedback" of the fires on weather conditions. Some recent fires in Australia have generated pyrocumulonimbus storms with extreme wind speeds that sent embers at least 33 km ahead of the fire front, igniting more fires. Of the pyrocumulonimbus storms studied, the largest stretched 15 km into the air and generated hundreds of lightning strikes up to 100 km ahead of the fire front, with the first lightning being generated in as little as five hours after the original fire ignition[49]. More fires can be ignited if strong winds break power transmission lines.[50]

The 2019-2020 Black Summer fires demonstrated the rapidly worsening fire risk in south-eastern Australia. As discussed further below, the fires represented a step change in fire intensity and extent. Burning an estimated 18.6 million hectares and involving an unprecedented number of pyrocumulonimbus storms, they exceeded the worst-case outcomes projected by current climate models[7]. Worsened by global warming[51] , the fires indicate that climate change is indeed unfolding in a swift, non-linear fashion.

EFFECTS OF CLIMATE CHANGE ON OCEANS

Climate change is affecting oceans and seas and their ecosystems in multiple ways, including:

- sea level rise caused by thermal expansion and ice melt,
- storms surges,
- marine heat waves,
- altered currents and dynamics,
- altered tides and waves, and
- ocean acidification.

The effects of climate change on oceans are not occurring evenly around the world. In Australia, sea level rise is occurring fastest in the north and northwest and southeast[19]. In terms of warming, the water around New Zealand has warmed by 0.2°C on average between 1981 and 2018:[44] the Tasman Sea off New Zealand and southeast Australia is an ocean warming "hot spot", with the sea around it heating at the rapid rate of 0.15-0.20 degree C per decade since 1950[19], continuing a trend of warming from around 13.8 degree C in 1900 to 14.8 degree C in 2019[52]. Marine heatwaves have been especially severe in the Tasman Sea, with one in 2015-2016 lasting for 308 days and one in 2017-2018 of unusual intensity, killing important kelp ecosystems[53][54]. Changing currents around Australia and New Zealand mean chlorophyll levels and net primary production of the southeast ocean marine bioregions of Australia and New Zealand are declining[55].

In addition to experiencing climate-related changes, the ocean is also acidifying as a side-effect of its absorption of CO_2 from the atmosphere (enhancing slow climate change). Since the 1880s, the average pH of surface waters has decreased by about 0.1, representing an increase of over 30%. Ocean acidification damages ocean biodiversity and marine health. This acidification is not evenly spread throughout the ocean and in Australian waters is concentrated in the Great Australian Bight.[56] In New Zealand, the subantarctic waters off Otago became 7% more acidic between 1998 and 2017 and this trend is expected to continue.[44]

For coastal ecosystems, the above changes are interacting with local factors to possible impacts include coastal erosion, altered coastal geomorphology, saline inundation of freshwater and changes to local pressure systems[1].

CLIMATE CHANGE IMPACTS AND RISKS

CONCEPTUALISING CLIMATE CHANGE RISK AND IMPACTS

Climate change works through multiple pathways – slow changes in systems, altering how they relate to each other, as well as altering 'natural hazards' both climatically and via other biophysical means. These altered climatic conditions will combine with numerous other dynamic factors to generate risks and impacts. As described above, how these risks and impacts will play out remain a source of significant uncertainty. This is because impacts only emerge when risks are actually realised (occur) and can then generate a wide range of flow-on effects (see below).

Risk is often understood as the intersection of a hazard (e.g. bushfire weather), exposure to the hazard (e.g. settlements in the urban-wildland interface), and pre- existing vulnerability (e.g. physical vulnerability such as susceptibility of structures to combustion, and social vulnerability such as socioeconomic disadvantage)[57]. FIGURE 7 represents this concept of risk together with climate and socioeconomic drivers that influence risks. Each one of these, especially vulnerability, is an emergent outcome of many dynamic factors. This means that identifying impacts in a given situation or projecting them in the future is full of uncertainty.

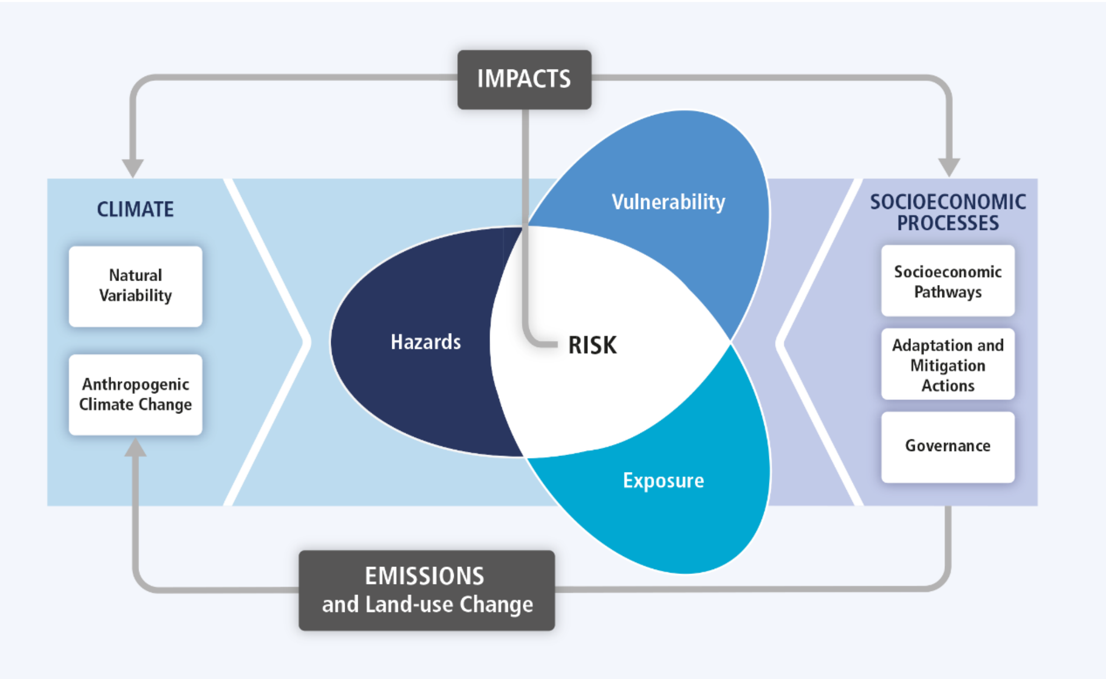

FIGURE 7: THE IPCC AR5 CONCEPTUAL FRAMEWORK WITH RISK AT THE CENTRE[57].

Risk: The likelihood, over a specified time, of severe alterations in the normal functioning of a community or a society due to hazardous physical events interactingwith vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery[10].

In addition to uncertainties, agreement on risk is also complicated by the fact that assessments of risk are based on subjective judgements about what is important, valued, and acceptable. For example, some people might see the habitat of an endangered species as highly valuable, while others might see infrastructure as more important. Because of this, while risk assessments might seem 'objective', possibly because of the use of biophysical or economic models, they are based on subjective judgements that may change over time[58]. This is a significant source of complexity and uncertainty in considering future outcomes as risk perceptions are likely to change under climate change.

The complex, systemic character of the world and climate change's interactions with it mean that it is also important to attend to first, second and third order risks and impacts, noting that the boundaries between these are loose.

- **First order risks and impacts are "direct" ones** and receive the most attention, particularly in disaster risk reduction work. This is about the most immediate, tangible and clearly causal relationships, such as the effects of increased temperatures on exposed humans, related increases in the prevalence of heat illnesses and associated pressure on emergency services.
- **Second order risks and impacts are "indirect" ones**, caused not by direct exposure to a hazard or climate change related problem such as sea level rise, but by its flow-on effects such as pressures on affected families and communities, over-burdening of the health system (affecting all those who need to use it or work in it), disruption of supply chains and longer term issues such as insurance in some areas becoming increasingly expensive or unavailable.
- **Third order risks and impacts are "distant" ones** that nevertheless have effects via influences on wider systems. This includes the effects of climate change on the national and global economy, social cohesion, environmental quality and the liveability of some regions and whole countries. It includes demands created by major disasters in distant localities, policy changes such as the increasing financial liability of organisational directors to disclose and responsibly manage climate risk, and the complex intersections of climate change and geopolitical relations, including increased competition over resources, possible conflicts and associated militarisation of society.

Holloway et al. (2015) and colleagues discuss the first, second and third order risks and impacts of climate change on the Australian Defence Force[59]. They note that as for other sectors such as EMS and universities that are expected to help enable others to cope with and adapt to climate change, climate change ushers in not just many direct challenges (i.e. first order risks and impacts), but also the second order impact of increased demands and expectations.

The effects of such impacts on "enabling sectors" are themselves intersecting. For example, increased demands on the military (e.g. due to more geopolitical conflicts in the region) may decrease their ability to assist EMS with disasters in Australia, while poor adaptation in the university sector (a real concern[60]) would undermine its ability to assist EMS with necessary research and training. Likewise, poor adaptation in the EMS will undermine virtually all other sectors, given its crucial role.

Hazards

Hazard: a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.[61]

The effects of climate change on some of the hazards facing Australia and New Zealand are outlined below. More on storms and cyclones and droughts is provided above, and more on extreme heat is provided in Section 2. While hazards are often thought of as the 'natural' element of risk, it is important to note that they are the outcome of human factors as well as climatic and other biophysical ones. Human shaping of the landscape, for example, helps generate bushfires, floods and landslides. What counts as a hazard is also shaped by human factors. A meteorological drought (significant period of low precipitation) matters as a drought for human populations when it results in water scarcity, which is determined not just by rainfall but access to other water sources (from distant locations or underground) and level of water demand. All of these human factors point to opportunities for climate change adaptation.

Bushfire

The observed trend of increasing fire risk[62,63] is projected to escalate under climate change[64,65,66,67,68]. This includes increases in the fire danger index, potential rates of fire spread, fire season lengths, number of fire ignition days, and fires that generate their own self-perpetuating storms[18]. These changes are likely to be greater for the southern parts of Australia during spring and summer, where rainfall declines are expected to be most pronounced, compared with the northern regions, where conditions are likely to remain the same as present, or become wetter[1]. One of the "second order" ways climate change is affecting bushfire hazard is via its effect on normal risk mitigation practices. Longer fire seasons are reducing the window for prescribed burning, while more extreme fire conditions are rendering prescribed burning less effective in reducing fire risk and more likely to escape control to turn into wildfires themselves. Finally, more fire and other events stretches EMS resources and reduces time for maintenance and recuperation.

Feedbacks between land and atmosphere are potentially worsening fire risk at multiple scales. At local and regional scales, increased fire frequency can encourage vegetation communities to alter to become more flammable. At a global scale feedbacks via the effect of smoke emissions on climate change and reduced carbon sequestration into vegetation and soil mean accelerates climate change. As Colvin et al (2020) note:

A growing concern is that these changes in fire regimes at global scale will result in positive feedbacks through increasing emissions of greenhouse gases leading to further climate change (Bowman et al., 2013). This concern is supported by analyses that show that when global fire weather seasons are longer-than-

normal or when long seasons lead to more global burnable area, net global terrestrial carbon uptake is reduced (Jolly et al., 2015; Liu et al., 2015).1

Smoke from bushfires is itself a hazard for the health of humans and other animals. Although less clear cut than the effects of flames, mortality and morbidity from smoke inhalation has already proved a serious climate change impact. Researchers estimate that the smoke pollution from the Black Summer bushfires, which brought the impact of the fires into the heart of capital city CBDs, caused around 417 additional deaths and over 1000 emergency-department admissions[69]. While much smaller, the bushfires in southwest Tasmania in the summer of 2018/19 resulted in evacuations of vulnerable people from regional towns not due to the threat from fire, but the threat from smoke. Evacuation managers grappled with the previously unrecognised need for air purifiers and sealable spaces to provide relief[70]. As research into the negative health effects of bushfire smoke progresses, it is likely this issue will feature more heavily in the disaster risk management discussion in Australia. It may impact public acceptance of prescribed burning. At the same time, recognition of the human and economic costs of smoke pollution may bolster the case for investment in risk reduction.

Flood

Climate change is increasing the risk of all three types of floods:

- pluvial floods (caused by intense rainfall),
- fluvial floods (caused by rivers, dams or other water bodies breaking their banks), and
- coastal floods (caused by storm surge, especially if in combination with high tides and sea level rise).

Pluvial floods can lead to fluvial floods in other locations, as the 2010-2011 floods in the Murray Darling Basin demonstrated. Heavy rainfall events have already increased in Australia, particularly Northern Australia18. In southern Australia, the drying trend is projected to eventually reduce the peak magnitude, volume, frequency and duration of floods.[71] Dey et al. (2019) suggest that floods will increase until 2030 then decrease by 2070.[72] The frequency or return period of floods is especially uncertain under climate change, with projections varying from one to 5000 years[73,74,75]. Contributing to difficulties in projecting future flood risk is the fact that, as indicated above, floods are compound events generated by multiple factors such as sea level rise in addition to rainfall[4].

Currently, flooding is New Zealand's most frequent natural hazard event. Sea level rise and increasing extreme rainfall induced by climate change, together with urbanisation in exposed areas, is increasing New Zealand's flooding risk, although with regional variation. Paulik et al (2019) produced the first national, comprehensive pluvial and fluvial flood hazard area map for New Zealand. They then explored how flood exposure might change under different RCP scenarios. Their analysis found considerable regional variation in estimates of mean annual flood under climate change scenarios, yet their model was not able to capture changes in more extreme events[76]. In a companion report, Paulik et al (2019) looked at coastal flooding exposure under future sea-level rise for New Zealand.

They found that coastal flooding with a 1% annual exceedance probability will increase under climate change, with exposed coastal areas experiencing large and rare events more frequently[77].

Under high emissions scenarios, rainfall extremes are highly likely to far exceed those experienced to date, with 'the possibility that many regions [in Australia] could receive more than 150 mm in 24 hours' and 'daily rainfall in some areas of more than 300 mm' fairly frequently4. Even when intense rainfall events are only short, they can cause damaging flash flooding, especially in urban settings where water is trapped by impervious ground covers.*18* The intensity of rain generally means that the water is less accessible or beneficial, with a lot of it lost as runoff rather than soaking into the ground or captured in water storages, and the quality of the water reduced by debris, extending the impact of the rain event far beyond the reach of the rainfall or flood waters.

Landslide

Landscape factors such as geology, soil structure and human interventions can combine with heavy rainfall to trigger rapid and damaging landslides, including fatalities[78]. Multiple-occurrence regional landslide events (MORLEs), a landslide phenomenon where thousands of individual landslides occur almost simultaneously, occur on average two to three times per year in New Zealand. MORLEs are most often triggered by extreme rainfall[79]. Crozier (2010) argues that while the theoretical basis for increased landslide risk due to climate change, the mechanism by which this occurs is complex, since it is the result of changes to many elements within the complex geomorphological system that determines landslide hazard. He finds that while it is reasonable to state that climate change will increase landslide risk in New Zealand, understanding the multiple factors influencing risk, both climatic and social, is essential for risk management; this finding would likely apply to Australia as well.[80]

In Australia, climate change is expected to increase heavy rainfall in the eastern states, the same region most prone to landslides.[81] It is therefore reasonably likely that Australia will experience more landslides in the future. The 1997 Thredbo landslide is the most devastating in recent memory, killing 18 people and destroying two ski lodges and several vehicles[82]. It was primarily caused by unknown faults (due to poor risk management) in the construction of a road. Subsequent access to the alpine region and conditions posed a challenge for emergency management. Australia's landslide risk management is now of a high standard, largely revolving around regulations and guidelines[83]. However, as climate change increases the intensity of rainfall and stress on soils, it is possible that the risk profile will shift over time. It is possible that these changes may result in increase of risk to buildings and infrastructure that were built to codes suitable at the time of construction but unsuited to new conditions. Ongoing monitoring and emergency preparedness is therefore a challenge for the sector.

Compound events, compounding impacts, cascading impacts

In addition to the biophysical effects of climate change being caused by a combination of climatic and other non-climatic biophysical factors such as land condition, some extremes are 'compound events' where different extreme situations occur concurrently or in quick succession. Black Summer, where bushfires, heatwaves and floods were experienced during a long-term drought, illustrated the challenge of such events.

> **Compound events:** When extreme weather and climate events occur consecutively within a short timeframe of each other, or when multiple types of extreme events coincide, the impacts can compound in severity.[18]

In their systematic review of the emergency management literature, Oh and Lee[84] find that the last 10 years, the issue of complex and compound events has risen to the fore. Similarly, Bosomworth et al.'s[85] in-depth consultation with the EMS found many within EMS identify 'the increasing number and complexity of significant emergency events, driven by dynamic interactions between environmental, political, social, and technical changes' as a significant challenge.

> **Cascading impacts:** the dynamics present in disasters, in which the impact of a physical event or the development of an initial technological or human failure generates a sequence of events in human subsystems that result in physical, social oreconomic disruption. Thus, an initial impact can trigger other phenomena that lead to consequences with significant magnitudes.[86]
>
> **Cascading disasters:** Cascading disasters are extreme events, in which cascading effects increase in progression over time and generate unexpected secondary eventsof strong impact. nese tend to be at least as serious as the original event, and to contribute significantly to the overall duration of the disaster's effects.[86]

Above we describe direct, secondary and third order impacts of disasters, such as a disease outbreak following a flood. Climate change is also increasing the risk that these second and third order impacts themselves *cascade* into another event. Some of the most obvious cascading impacts are biophysical responses, such as disease and pest outbreaks in the aftermath of floods or other disasters that have disrupted normal sanitation and food safety practices. These second and then third order impacts can then compound initial impacts, by making flood waters unsafe for example.

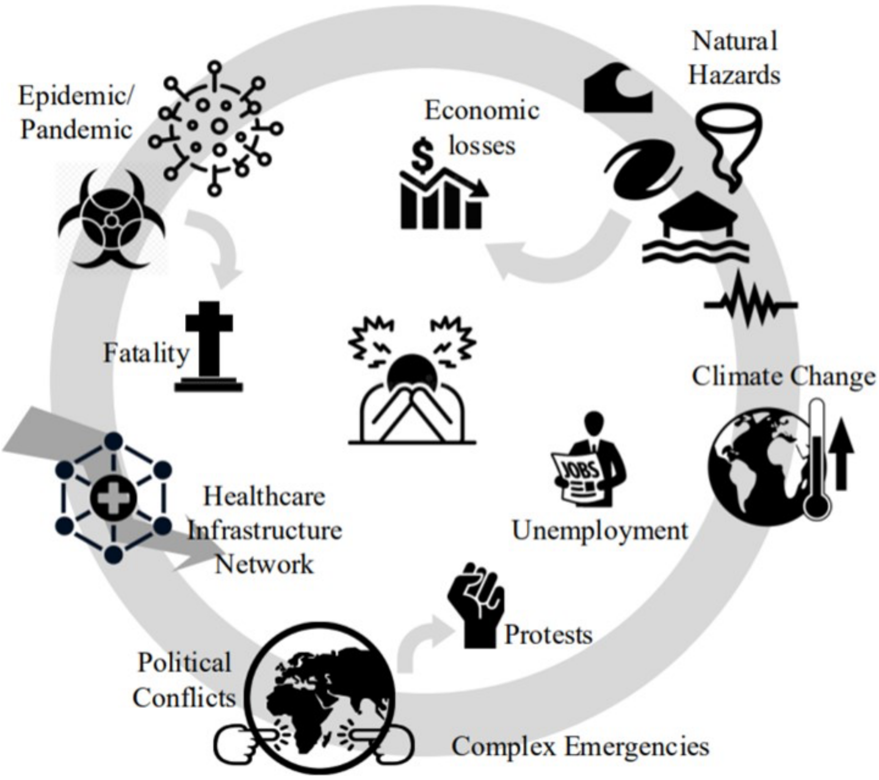

FIGURE 8: A MULTI-RISK CONDITION[87].

As discussed below in the section on Vulnerability, further compounding happens when hazards intersect with existing or co-occurring challenges, sometimes resulting in cascading disasters. This is starkly illustrated by the immense difficulties posed by COVID-19 pandemic and related policy responses on any disaster response. Hariri- Ardebili[87] explores the multi-risk condition faced by many societies (see FIGURE 8) and find that multi-hazard scenarios can have cascading effects that are largely unacknowledged in the literature.

Section 1: General biophysical impacts of climate change

Individually and in combination, the above changes in climatic conditions and Australia's freshwater and oceans are generating far-reaching bio-physical impacts. In addition to changes in soil, physical habitats (e.g. rocky coasts, stream beds), broad landscape features (e.g. due to floods and storms) and air quality (e.g. smoke pollution), this includes myriad impacts on non-human species, which are already beginning to alter in abundance, distribution and character as they respond autonomously to climate change and to interacting changes around them. Information about such changes is hampered by the lack of empirical research and research on not just chronic climate change, but extreme and combined climate change effects on natural systems. Impacts on non-human species are evident in terrestrial, freshwater and marine environments. Altered interactions between species have already caused cascading impacts on ecosystem structure and functioning. In the Southern Hemisphere, changes in species ranges are especially apparent due to the complicating effects of the ozone hole on regional climate conditions.[88]

	Terrestrial environment	Freshwater environment	Marine environment
Change in species abundance	Reduction in abundance of River Redgum communities along the Murray River during the Millennium Drought (Selwood et al 2019) Local extinction of Smoky Mouse due to bushfire smoke pollution and heat in ACT (ABC 2020).	Reduction in abundance of stream macroinvertebrates, especially those sensitive to low-flow conditions and poor water quality (Thomson et al. 2012). In the MDB blue-green algalblooms in the flowingsections of rivers arerare. But during theMillennium drought blooms were recordedin the River Murray in2003, 2007, 2009 and 2010 (Bowling et al.,2016). A bloom in 2016 spanned over 2,500 km of the River Murray and its distributaries in the Edward-Wakool (Bowling et al., 2018).	Disappearance of small, cool-temperate species as waters warm (Poloczanska et al., 2009).
Change in species distribution	Expansion of shrubs in the Victorian Alps at the expense of grasslands (Hoffmann et al., 2019). Expansion of mosquitoes and viruses they carry further southward into.	Invasive crayfish native to Murray Darling Basin more swiftly outcompetes other native crayfish in warmer temperatures (Cerato et al., 2019) and able to expand range.	Movement of the larvae of tropical lobster species down the East Australian Current and into temperate waters (Woodings et al., 2019). Expansion of mangroves at expense of saltmarshes with higher tides in Western Port Bay (Rogers et al., 2005). Expansion of Eastern Australian Current bringing tropical and sub-tropical species into temperate waters adjoining Victoria and Tasmania (Johnson et al., 2011).

TABLE 1. EXAMPLES OF HOW NON-HUMAN SPECIES ARE ALREADY CHANGING IN ABUNDANCE AND DISTRIBUTION AS A RESULT OF CLIMATE CHANGE, ACROSS TERRESTRIAL, FRESHWATER AND MARINE ENVIRONMENTS.

As different species alter in abundance and distribution, two main types of impact are generated for humans:

1. New problem ecologies – namely, new weed, pest and disease issues as species migrate in response to climate change and other drivers. Some of these may be ephemeral (e.g. algal blooms) and some may be long term (e.g. establishment of new viruses).
2. Reduced/lost ecological services – such as pollination, pest control or carbon storage. These losses are often overlooked but may be among the most significant climate change impacts for society, especially for sectors directly dependent on natural resources and processes.

An example of the first is vector borne diseases. Climate change-induced growth of mosquito populations, for instance, is a major public health issue[89, 90]. The Royal Australian College of Physicians identify warmer temperatures and heavy rain as increasing the risk of Ross River Virus and Dengue Fever in Australia. Modelling by Bambrick et al.[91] estimates that 'there could be an eight-fold increase in the number of people living in dengue prone regions in Australia by the end of the century.' A second order effect of vector borne disease is its impacts on the quality and usefulness of blood donations. Bambrick et al[91] highlight that vector-borne disease outbreaks severely threaten the donor blood supply in a region, as occurred in 2009 in Cairns and Townsville. If blood shortages coincide with a disaster event, they will compound the impact of the disaster.

An example of the latter - reduced/lost ecological services - is the impacts of more frequent, intense fires on Victoria's forests. While many forest species are adapted to fire, the intensity of contemporary fires and their rapid return period means many in affected areas have not had time to recover (FIGURE 9). Combined with the extension of fires into previously unburnt areas of fire-sensitive species (e.g. temperate rainforest), this is leading to the extinction of some species in some areas.[92, 93.]

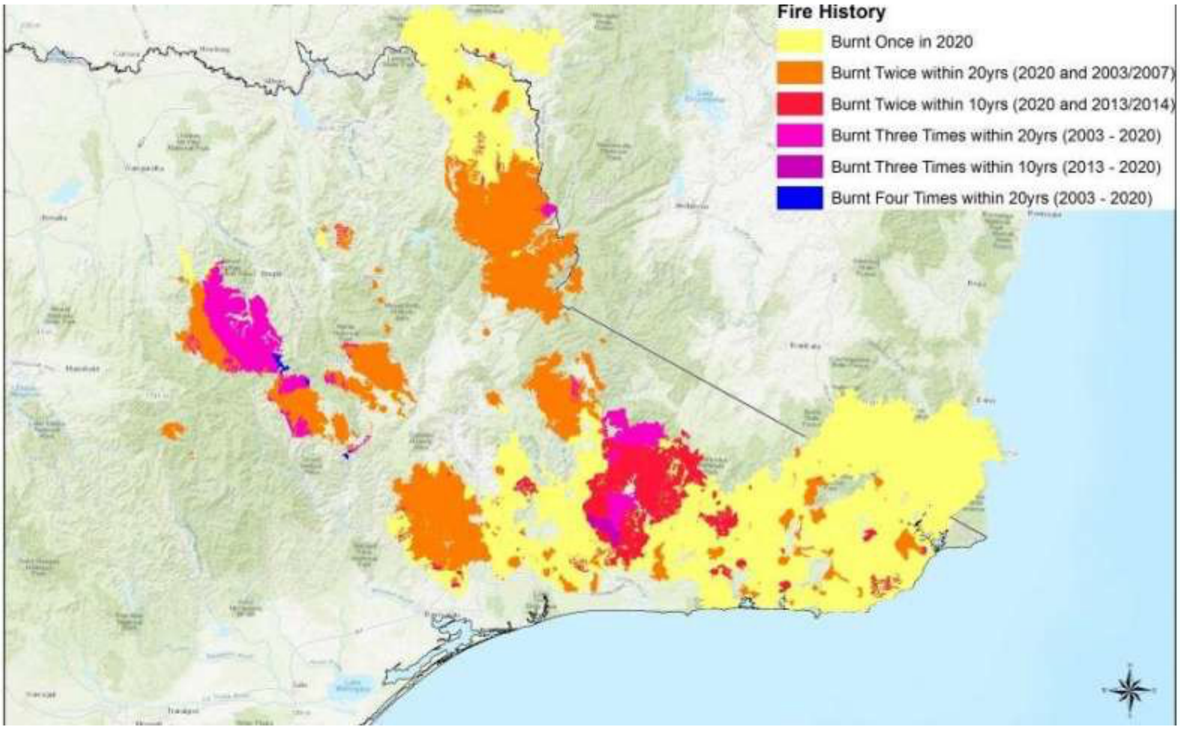

FIGURE 9. FREQUENCY OF FIRES IN EASTERN VICTORIA SINCE 2000, INDICATING REPEATED BURNING OF SOME AREAS (BENNETT ET AL. 2020).

Exposure

> **Exposure:** The presence of people, livelihoods, species or ecosystems, environmentalfunctions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected[61].

The Australian population is already highly exposed to a wide range of hazards thanks to its broad geographic distribution and concentration along coasts and in cities.1 As the Australian population and economy grows, so too does its spatial exposure to hazards. Trends of urbanisation and coastal development, for example, are continuing to place new settlements and other assets in hazard-prone areas. Some new developments (e.g. housing estates on flood plains) can increase the likelihood of hazards such as floods by reducing drainage, causing flow-on effects for others. Traditional spatial planning is generally ill-equipped to manage the risks of climate change hazard exposure due to the power vested in applicants and its conventional focus on individual development applications and short term impacts rather than cumulative impacts and long-term needs. A recent RMIT report concludes that:

> *This is particularly problematic in peri-urban areas where over time, the piecemeal mediation of competing agricultural, conservation and rural residential interests tends to create a largely unregulated patchwork of land uses characterised by high resource use, increased vulnerability to bushfires and other environmental consequences.*[94]

As exposure increases, resident and community expectations about the level of protection the EMS can provide have not adjusted. In the study by Bosomworth et al. (2016), members of the EMS 'consistently described community expectations as increasingly unrealistic and argued that, as a consequence, community disaster resilience had declined'.[85]

Exposure to hazards also occurs in more temporary ways due to the movement of people. The most obvious example of this is the large scale movement of holiday makers to coastal and regional tourist destinations over summer. Many of these locations are high amenity but particularly high risk. Visitors are also often especially vulnerable (see Vulnerability section below) due to their lack of local knowledge and other factors. At finer scales, exposure is a function of what shelter people and animals can access and their level of mobility (capacity to evacuate out of the path of danger). Again, holiday makers tend to be highly exposed at this scale.

In addition to exposure to hazards, exposure to second and third order effects is an important consideration. For example, the Black Saturday fires demonstrated how people can be impacted by failures in the centralised systems such as electricity, fuel distribution and water they normally depend on, compounding other impacts such as smoke and heat and disrupting normal responses such as evacuation. Section 2 outlines the many issues associated with direct and indirect exposure to heat, including the exposure of heat-sensitive equipment such as air-conditioners and electricity grids.

Managing these far-reaching effects is a major area for climate change adaptation attention. As Bosomworth et al. conclude:

> *The mounting frequency and intensity of natural hazards, alongside growing interdependencies between social-technical and ecological systems, are placing increased pressure on emergency management. This is particularly true at the strategic level of emergency management, which involves planning for and managing non-routine, high-consequence events.'*[85].

Section 2: The many dimensions of heat and its compounding factors

Rising temperatures are commonly underestimated as a serious climate change impact, but they are already having far-reaching effects at the scale of individuals, families, organisations, communities, regions and nations. This Section focuses on the particularly challenging impacts of increasing heat in Australia's Monsoon Tropics. It looks in turn at effects on health and wider systems.

Direct and indirect effects on human health

Direct heat effects on human health include:

- Heat stress, heat exhaustion, other heat-related illnesses and death
- Increased accidents (e.g. vehicular, weapons, occupational burns, wounds, lacerations, amputations)[95]
- Dehydration and associated kidney problems
- Impaired digestion and worsened gastrointestinal illnesses[96]
- Skin conditions (e.g. eczema)[97]
- Exacerbation of existing heart, kidney and respiratory problems[98]

- Mental, cognitive and behavioural disorders[99]
- Reduced reproductive and sexual health[35] Indirect effects include:
- Reduced food safety due to food deterioration and pathogens
- Reduced water quantity and quality
- Reduced ability to carry out important daily tasks including exercise[100]
- Increased alcohol consumption and revelry[29]
- Increased prevalence of violence[101]
- Increased prevalence of climate-sensitive infectious diseases
- Increased volatility and toxicity of some chemicals
- Increased air pollution, including ozone
- Lost income due to reduced labour capacity and productivity[102]
- More over-burdened health system
- Impaired local economic development and associated loss of services[103].

Even where personnel are acclimatised and actively managing physical work rates, consistently elevated core temperatures over a period of one or more days can contribute to heat illness, even if 'dangerous' threshold temperatures (environmental or core body temperature) are never reached[104]. The accumulation of thermal load over time means that even when OHS obligations are met in the workplace, personnel can still suffer the ill-effects of heat because they (inadvertently) 'top up' their heat exposure and resulting sensitivity through other activities and domains – both on and off-duty, in the workplace and at home. As a result, accounts of heat stress that spatially and temporally extend beyond occupational domains to broader social practices (family and civilian activities, including sport, recreation, nutrition habits) are needed to understand how heat stress emerges for people living in hot climates[105].

Strategies that problematise bodily heat stress as an acute and "exceptional" problem rather than as a 'chronic' – normal, ongoing and widespread – problem, overlook the realities of hotter climates. Their inadequacy at reducing heat risks may disproportionately disrupt operations and fail to be cost effective. In commercial settings, work:rest protocols designed to avoid workers overheating are regularly ignored because of the impost on productivity over the increasingly extended periods that ambient temperatures are too high[106].

The timing and frequency of extreme weather can compound heat stress effects by requiring high levels of exertion during hotter times of the year. Emergency and disaster response and recovery efforts are often required during events involving extreme temperatures (e.g. bushfires) or humidity (e.g. cyclones). Summertime is becoming a high risk period, disrupting holidays and rest periods. The Australian Defence Force - which has been increasingly called upon to respond to such disasters, domestically and internationally - is increasingly aware that 'No longer is the summer break considered a "stand-down" period of rest and relaxation – rather it has become part of the Australian defense operational rhythm'.[59] Rapidly shifting between different climates can also diminish bodily performance. If non-acclimatised people are called into hot areas to work their bodily endurance tends to be significantly less than those who are acclimatised[107].

Heat has other cascading and compounding effects. We discuss these now in terms of systems disruptions and wider systemic effects.

System disruptions caused by heat stress

Heat stress can itself trigger system failures. A lot of machinery, equipment and infrastructure - including those central to keeping us cool and functioning such as computers, ICT, air-conditioners and refrigerators - has its own thermal limits and is susceptible to malfunctioning under high temperatures. Heat stress can also trigger system failures by increasing the risk of human errors thanks to its impairing effect on our cognitive and physical functioning[108]. Such effects may play a role in disrupting critical infrastructure construction or maintenance work[107]. In turn, heat can delay repairs and maintenance work. Combined with effects of transport systems and associated supply chain disruptions, including related food insecurity, a community and organisations' operational capacity may be reduced.

Sectors highly susceptible to current and future heat stress impacts include agriculture and the food system; construction[109,106], transport, including ports[110] and energy[107]. In terms of the latter, many elements of energy production and distribution are highly sensitive to heat, with transmission lines sagging, conductors overheating and equipment buckling. Power failure resulting from equipment failure, human error, slow repair times or inadequate staffing can cause major cascading effects, especially if it affects the EMS.

'Systemic' impacts of heat stress

Disruptions to infrastructure either from heat stress, or hazards and heat stress, with slow repair-times may reduce the resilience of local socio-economic systems and put greater pressure on the EMS[59]. In more direct ways as well, heat stress has a major negative impact upon the productivity, workplace health and safety, and general health and wellbeing of the population. Nationally, Australia loses $6.9 Billion dollars a year in lost productivity to heat stress[111]. In the Monsoon Tropics, seasonal periods of heat and elevated humidity mean conditions are highly likely to exceed recommended environmental thresholds for much of year[106], and outdoor and/or manual workers regularly exceed ISO standards for core temperature, meaning they should trigger "stop work" periods[107]. Periods of hot weather not only amplify the risk of workers suffering a heat related illness, but increase the likelihood of workplace injuries more broadly, including burns, wounds, lacerations, and amputations[112]. This indicates that there are likely to be reductions in operational capacity across all sectors as a result of extreme heat.

Organisations can also be impacted in multiple ways longer term. Recent research indicates that the hot climate of the Monsoon Tropics in Australia hampers the recruitment and retention of staff across outdoor and labour intensive industries[113]. A nation-wide study of over 1,250 persons who had experienced heat stress found that people residing in northern Australia had an

86% higher probability of intending to move to a new location because of heat than people in southern Australia[111]. Related exits and fluxes in communities can in turn be demotivating for those who remain.

These issues are being magnified by climate change. Some predict that heat stress will be climate change's most expensive impact due to global productivity reductions, particularly in tropical regions[102]. Although widespread effects on regional economic resilience may be, for the EMS, a 'distant' impact[59] such effects may hamper preparedness and operational capability and capacity.

Overall, heat stress leads to multiple cascading impacts for organisations, affecting their plans and operations, training and testing processes, built and natural infrastructure, and acquisition and supply chains. Some of these potential impacts are outlined below (FIGURE 10).

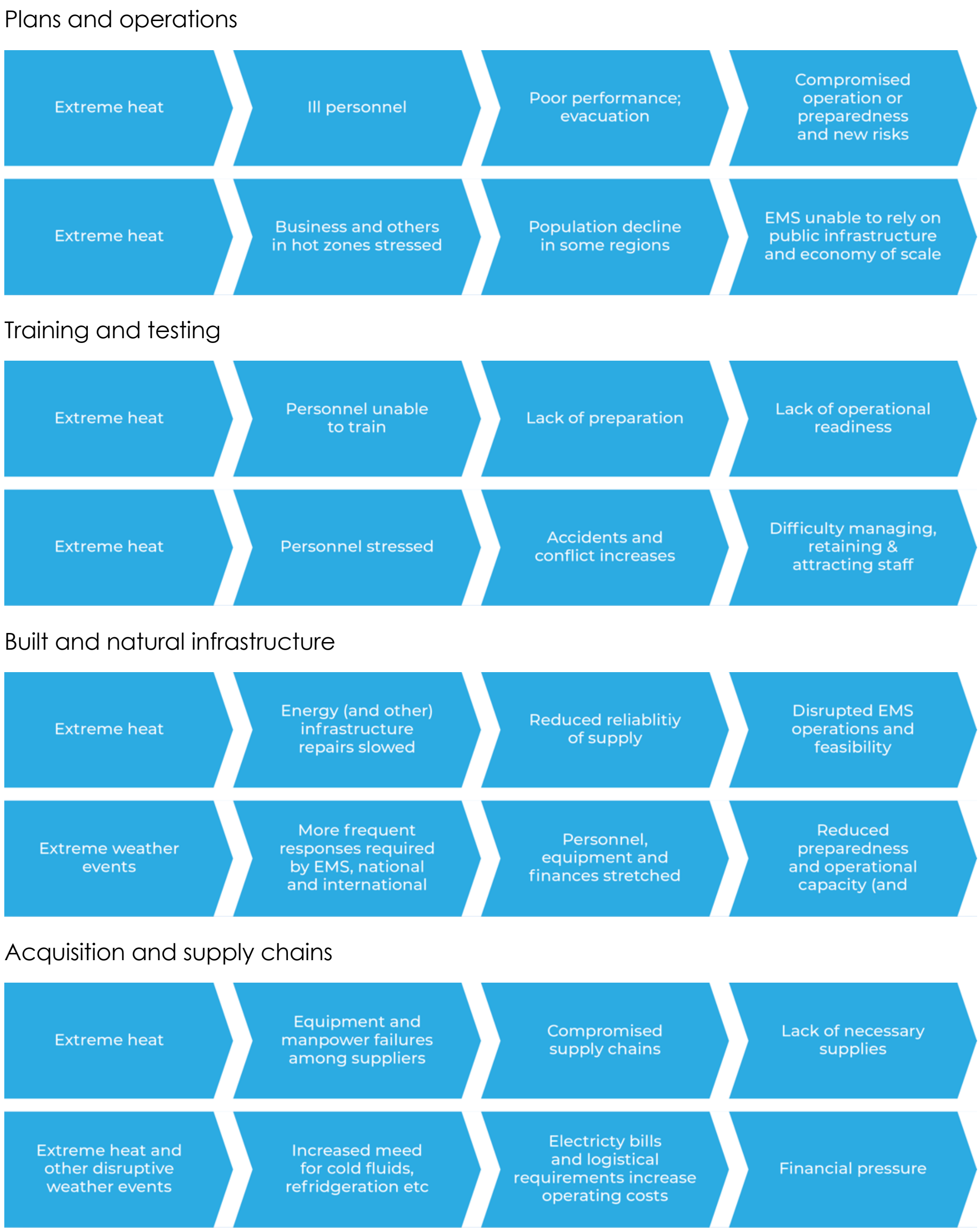

FIGURE 10. EXAMPLES OF CASCADING EFFECTS OF HEAT STRESS ON ORGANISATIONS IN THE EMS.

Vulnerability

Vulnerability: The 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 (UNISDR defused in AIDR report) including "root causes" such as social inequalities and environmental exploitation[114].

At any point, an individual or group is facing a range of challenges and has a range of capacities. The resultant variation in how exposure to hazards and other climate change stressors is referred to as vulnerability. It covers hazard or stressor-specific factors and more generic factors. Importantly, while some generic factors are statistically associated with lower or higher vulnerability (e.g. older age) these should not be taken as deterministic and there are many cases that prove them incorrect. Nevertheless, it is useful to appreciate that certain populations may be more or less badly affected by a given aspect or all aspects of climate change. Homeless populations for example suffer such severe disadvantage that they are likely to be amongst the worst affected in any given situation.

Climate change risks mean that some things presumed to be advantageous may prove disadvantageous in at least some situations. For example, high tech or centralised systems may improve capacity in many ways but can be a source of increased harm if and when they fail. High consumption lifestyles can seem desirable, but set people up for greater losses in the event of a disaster, particularly if people are unaware of the fragility of such systems. As Bosomworth et al. (2016) found:

> *The country's strategic emergency managers are also concerned that the growing interdependence between infrastructural, social, and technical systems is boosting vulnerabilities to hazards. Interdependencies between energy, transport, and food production systems, for instance, mean that the disaster impacts experienced in one community can affect many other communities (Boin and 't Hart, 2010)… Despite the sometimes fragile nature of essential critical infrastructure services during disaster events, industrialised societies expect that they will be available during extreme events*[85]

Some of the main skills and capacities needed for adaptation and disaster resilience are not those typically valued in society (e.g. resourcefulness). Vulnerability needs to be understood at different scales. Besides the individual and household scale, vulnerabilities exist at higher social and spatial scales such as shared utilities and other systems, and environmental qualities and risks such as falling soil productivity and biodiversity. Some of the drivers of vulnerability – dynamic pressures such as bureaucratic silos or political conflict and 'root causes' (see *FIGURE 11*) such as extraction-oriented economies and consumption- oriented lifestyles – require major collective efforts to overcome, pointing to the scope of climate adaptation[115].

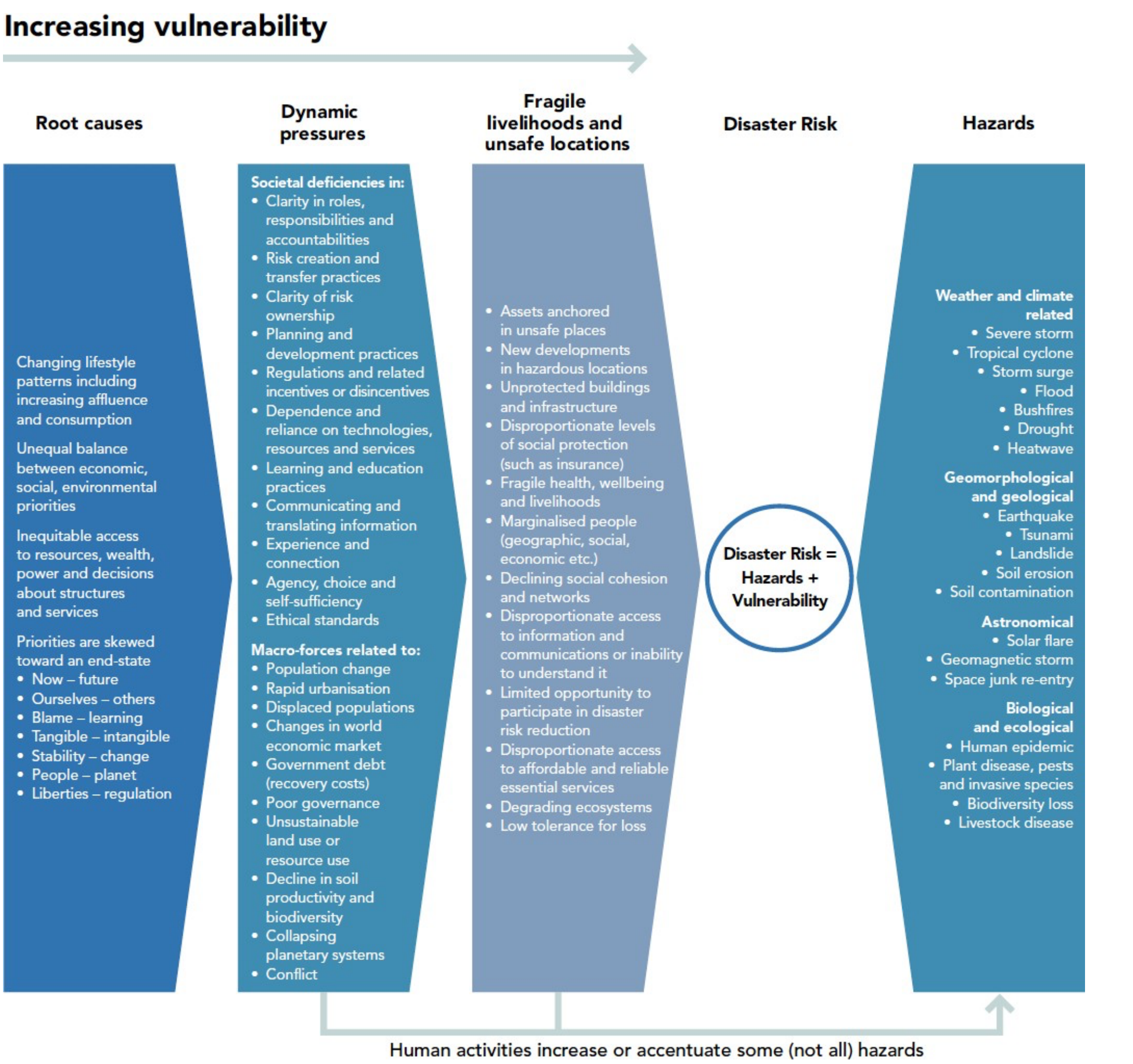

FIGURE 11: THE PROGRESSION OF VULNERABILITY, HIGHLIGHTING THE THINGS TO REDUCE OR THE THINGS TO AVOID. NOTE THIS DIAGRAM IS TO SERVE AS AN ILLUSTRATION OF THE CONCEPTS OF ADDRESSING SYSTEMIC VULNERABILITY AND IS NOT COMPREHENSIVE (SOURCE: ADAPTED FROM WISNER ET AL, 2011)[115].

ADAPTIVE CAPACITY

> **Adaptive capacity:** The ability of systems, institutions, humans and other organisms to adjust to acute and chronic climate change stresses and take advantage of opportunities.[116]

The inverse of vulnerability and a goal of adaptation is high adaptive capacity. Levels and sources or types of adaptive capacity vary greatly between individuals, communities, ecosystems, and sectors, and is shaped dynamically by ever altering contexts. There are many social and environmental variables that impact on adaptive capacities – e.g. access to services and infrastructure, as well as levels of social capital in the form of community cohesion, relationships, and trust.

Specific adaptive capacities include the ability to reduce the risk of hazards (e.g. having the resources to do fuel reduction burning), to reduce one's susceptibility and exposure to a particular event (e.g. having flood resistant buildings, having the capacity to evacuate), and to improve one's resilience or capacity to cope with a given disruption.

A no-regrets approach to climate change adaptation is to build 'adaptive capacity'. A recent Australian-based review identifies five interlinked domains of adaptive capacity[117] (FIGURE 12):

- Assets: the natural, financial, technological, and service (for example, health care) resources that people have access to, individually and as a group (introducing questions of equitability). Assets include public goods.
- Flexibility: opportunities for diversification and switching between options to respond to the shifting environment and improve adaptation outcomes. Requires monitoring, review, open-mindedness and nimbleness.
- Social organisation: how well society is set up, inter-connected and able to cooperate to achieve positive collective outcomes at various scales. Relies on good relationships.
- Learning: the capacity to detect, understand and apply new data and information at multiple scales, including about emergent shifts in the environment and feedbacks on past actions.
- Agency: the ability to enact a positive course of action despite constraints, mobilising the other domains of adaptive capacity, both as individuals and groups.

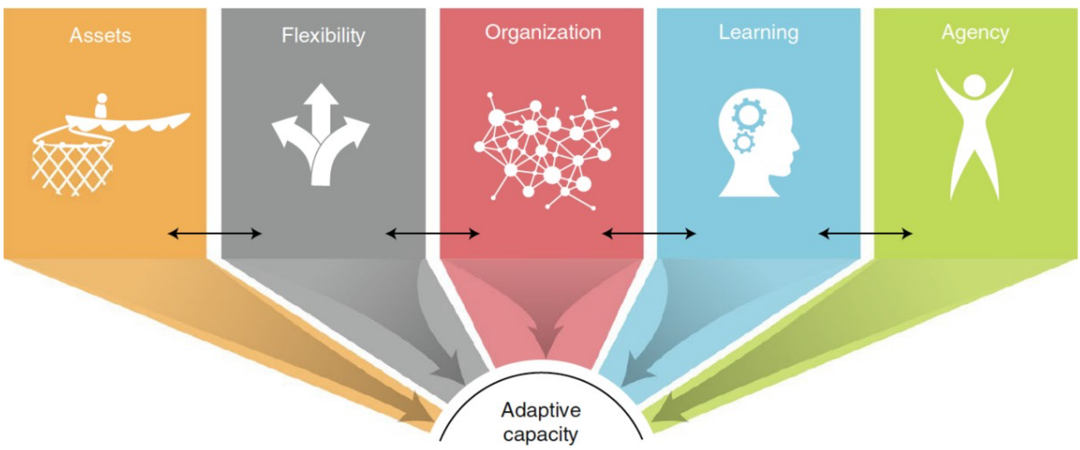

FIGURE 12. THE FIVE MAIN DOMAINS OF ADAPTIVE CAPACITY[117].

These five domains affect each other and apply at any scale, from an individual to a nation. In the real world they constantly change as the physical and social environment changes and as (mal)adaptation is put into practice. In any one situation, their presence or absence largely determines how vulnerable the system in question is and thus how impactful a given climate change hazard is likely to be.

Building adaptive capacity/reducing vulnerability requires looking beyond direct climate change impacts (e.g. managing heat) to address structural and systemic constraints on the ability of people and ecosystems to adapt to ongoing change, such as social inequalities, low environmental sustainability and poor governance.[118] Ideally, experience at adaptation means that adaptive capacity grows over time and does not reinforce bad habits or dangerous situations.

Adaptive capacity does not translate automatically into adaptation action or positive outcomes, as illustrated by ongoing adaptation inaction among groups with high adaptive capacity (e.g. Mortreux and Barnett 2017[119]). How 'willing to adapt' an individual or group is depends on various factors. An Australian-based review identifies six key mediating factors:

- risk attitudes
- personal experience
- trust in and expectations of authorities
- place attachment
- competing concerns, and
- household composition and dynamics including gender.[119]

Different opinions on how and when to adapt underline the fact that adaptation is an art as much as a science. It is also political, calling to the fore power dynamics, different interests and trade-offs.[120] Being able to gather diverse views, accommodate difference and negotiate acceptable compromises is a further crucial enabler of good adaptation.

CLIMATE CHANGE ADAPTATION

Climate change adaptation: The process of active adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.[57]

WHAT IS (GOOD) ADAPTATION?

Climate change adaptation incorporates a range of objectives and areas of effort. While it necessarily involves "coping" at any moment in time, it also extends far beyond just coping to also better "fit" emerging conditions and to proactively adjust to, and help positively shape, the future.

In terms of Disaster Risk Management, adaptation can be considered to involves:

- Better disaster preparation and response to cope with more frequent and worse hazards
- More emphasis on continuous improvement, including disaster prevention and recovery
- Concurrently addressing slow and chronic changes such as sea level rise and increasing background temperatures
- Reducing existing vulnerabilities, not just hazards and exposure
- Addressing "root causes" of vulnerability, hazards and exposure such as poor land use planning and social inequalities
- Generating positive outcomes (co-benefits) above and beyond a reduction in negatives.

In many senses, adaptation is about building on DRR to not only help communities achieve safe locations and sustainable livelihoods, but also reduce dynamic pressures through better governance and planning, and redress root causes by improving the equitability of resource allocation and decision making (*FIGURE 13*). Climate adaptation also requires that we improve the resilience of our systems by applying the now tried-and-tested principles of resilience science in a collaborative learning-oriented manner, as an ongoing regional resilience project in the Goulburn Murray Region of Victoria[121] is doing (*FIGURE 14*).

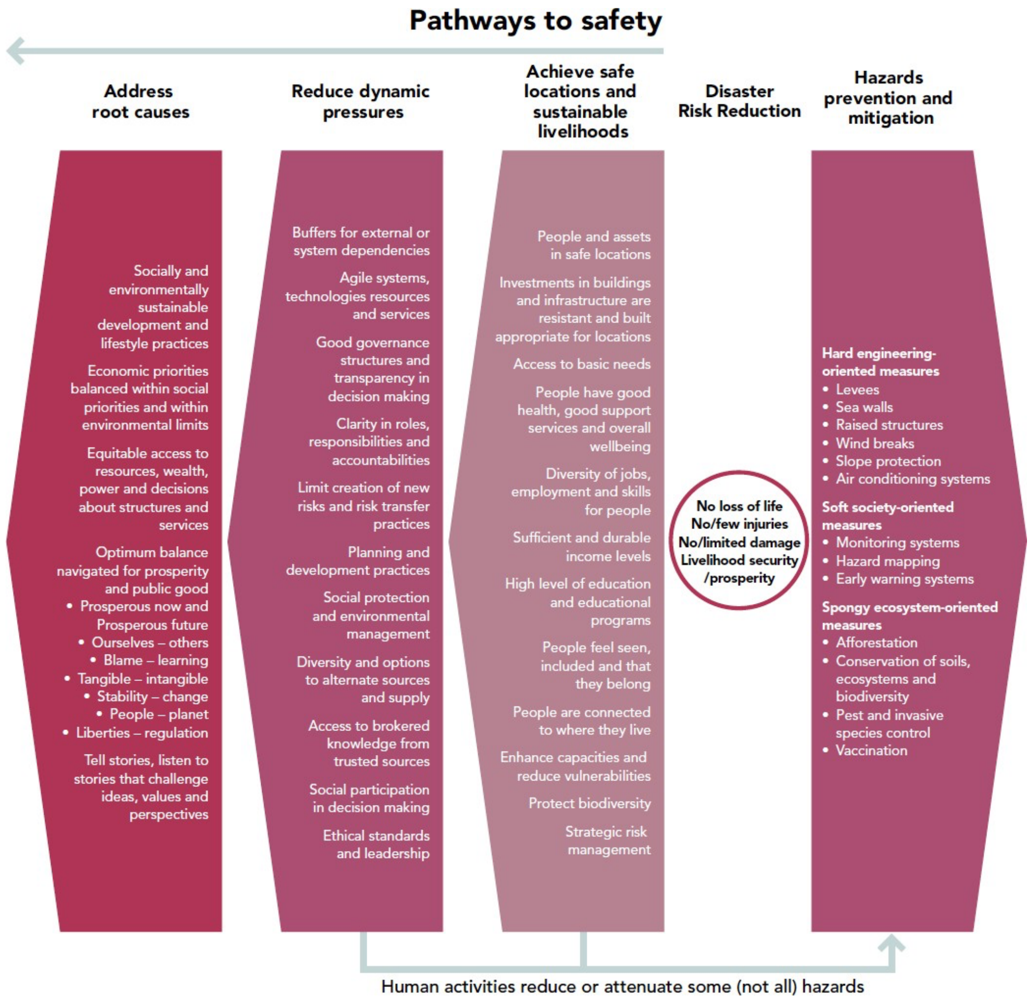

FIGURE 13: THE PATHWAY TO SAFETY, HIGHLIGHTING THE THINGS TO ENHANCE OR THE THINGS TO INCREASE. NOTE THIS DIAGRAM IS TO SERVE AS AN ILLUSTRATION OF THE CONCEPTS OF ADDRESSING SYSTEMIC VULNERABILITY AND IS NOT COMPREHENSIVE (SOURCE: ADAPTED FROM WISNER ET AL, 2011).

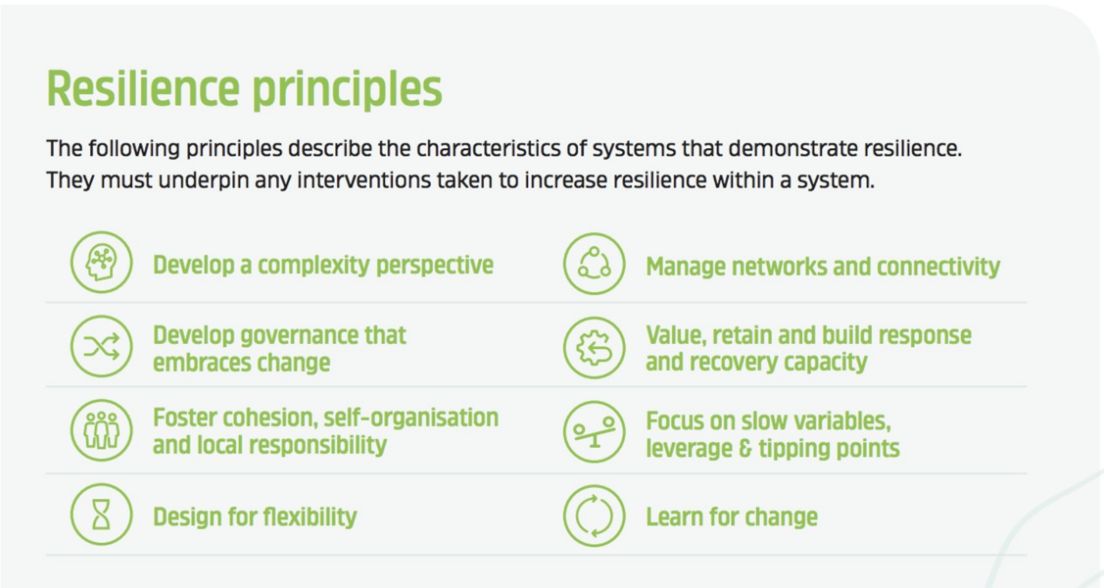

FIGURE 14: RESILIENCE PRINCIPLES[121].

The existence of principles for good adaptation underline that climate adaptation is not a simple switch or just about doing anything. Like DRR, it can be done well or poorly. Criteria of success include the following 5E's:[122]:

- **Effectiveness**: how effective was the intervention at reducing potential harm?
- **Efficiency**: what time, effort and resources were needed? Could the same outcome have been achieved more efficiently?
- **Equity:** who and what were advantaged or disadvantaged? How inclusive and equitable were the process and outcomes?
- **Externalities**: what risks and harms were generated (e.g. greenhouse gas emissions, biodiversity losses, community or staff stress and conflict)?
- **Extended time horizon**: to what extent does the intervention help adapt a system to not just the near term but the long term future? Does it place the system on the right "adaptation pathway"?

In terms of effectiveness, adaptation is never perfect or cost-free. The more severe a climatic impact or flow-on effect, the less likely adaptation will be able to fully avoid or neutralise the harms involved. Adaptation always leaves a 'residual risk'[123], which is often then the responsibility of the EMS to manage. Already it is apparent that even "well managed" extreme events often involve human fatalities and other losses given the scale and character of the event[85]. Losses and successes also alter over time. Adaptation is the process of continuously anticipating and adjusting to dynamic conditions. This means that what seems successful at one point in time may prove not to be successful in the future. Similarly, what seems successful at one spatial or social scale (e.g. a national scale, an individual scale) may be problematic at other spatial or social scales. For instance, nationalising OHS standards in thermal thresholds seems appealing, but proposed measures are based only on ambient temperature and overlook the fact that in tropical Australia, lower temperatures are dangerous due to the interacting effects of humidity, and individuals' bodily tolerance for heat varies, including over time.31

Adaptation takes effort and resources and comes with an opportunity cost. Yet these costs are relative. Adaptation will reduce the far larger costs and constraints of inaction, including the cost of dealing with future disasters in the absence of adaptation. In 2050 the total cost of disasters in Australia per annum is estimated to jump to $33 billion (up from $9 billion in 2015), unless steps are taken to reduce risk, increase resilience and adapt to long term changes.[124] These costs are substantially larger again when far-reaching indirect losses are included. Future extreme disaster costs may in themselves create second and third order impacts. Hochrainer et al. argue that in the future financial costs of disasters in Australia may threaten government fiscal stability and medium to long-term economic growth.[125]

Not all adaptations to climate change impacts are not necessarily 'good' and may instead perpetuate, for instance, social vulnerabilities, climate change, or loss of ecological services. Climate change adaptation actions are unlikely to benefit different groups or environments in the same way[126]. Inequitable access to adaptations within a community can worsen inequalities. For example, some efforts to provide farmers with access to seasonal climate forecasts to help them manage increased climatic variability have inadvertently deepened gender and class inequities in some farming communities.[127] This means that social and ecological justice are central to all adaptation decision-making. Adaptation also needs to look 'beyond simple cause-and-effect relationships, to identify and address economic, political, social, and technological drivers of current challenges'.[128] It also means that large adaptation decisions need to negotiate different perspectives and values.

Overall, as Moser and Boykoff put it:

> *Clearly, the question of success is not simply to be decided on scientific, rational, objective, or procedural grounds, bit is in important ways normative, historically contingent and context-specific. Some dimensions of success will be outcome-based yet in many instances, success on all outcome dimensions cannot be achieved simultaneously (or ever). The question then arises how to adjudicate among goals, how to assess and negotiate trade-offs, prioritize goals and strategies, and move a process along that many be socially and politically deeply contested.*[129]

The inverse of good adaptation is maladaptation: actions that may lead to increased risk of adverse climate related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future.[130]. Different types of maladaptation are described in TABLE 2.

Maladaptation Type	Explanation	Examples
Actions that increase greenhouse gas emissions	Actions that are energy-intensive and increase greenhouse gas emissions, perpetuate the problem of climate change. This increases vulnerability and the need for greater adaptation in the future.	Increased use of energy-intensive air-conditioners in response to the heat-waves.[131]
Actions that disproportionately burden the most vulnerable	Actions that meet the needs of one sector or group but increase the vulnerability of others, particularly those most at risk, such as minority groups or low-income households.	Seawalls may cause erosion beyond the spatial extent of the wall over the medium to long-term. This creates cascading demand for the extension of seawalls along the coast.[132]
Actions with high opportunity costs	Actions with high economic, social, or environmental costs relative to alternatives.	Increased upstream water harvesting to cope with reduced rainfall may harm and reduce the opportunities for communities downstream to manage their own risks of reduced water availability.[133]

Actions that reduce incentives to adapt	Actions that do not consider the broader context and impacts of their implementation. They may appear beneficial in the short-term but will increase vulnerability to hazards in thelong-term. Short-term adjustments that people make to deal with climate stressors or extreme events may reduce incentives to make necessarylong-term and transformative changes.	Construction of well-engineered climate-resilient roads designed to withstand current and future climate extremes may foster new settlement into areas highly exposed to the impacts of future climates.[123]
Actions that set paths that limit the choices for future generations	Actions that create path dependencies and that are inflexible, reduce the portfolio of future options decreased flexibility to respond to unforeseen changes in climatic, environmental, economic and social conditions.	Hard coastal defences encourage higher-density development within the protected area, increasing values of the defended assets and thereby skewing the cost–benefit equation, locking in seawalls as the preferred option for coastal protection.
Combinations of the above	Maladaptation arises not only from inadvertent poorly planned adaptation actions, but also from deliberate decisions where wider considerations place greater emphasis on short-term outcomes ahead of longer-term threats, or that discount or fail to consider the full range of interactions arising from the planned actions. In some situations, what may seem to be successful adaptation initiative from one sector has negative consequences for other social and environmental systems or sectors.	The avoidance of potential maladaptation becomes a barrier to effective implementation of adaptation. In the construction of a well-engineered road (example above) the immediate and multiple benefits to the community of a reliable road system (including as evacuation route in floods, etc.) might be judged as outweighing the longer-term risk of inappropriate settlements patterns. [135] The true maladaptation in this case would be the failure to implement appropriate incentives or regulations to avoid vulnerable settlements in the highly exposed areas.[123]

TABLE 2. TYPES OF MALADAPTATION.

The "solution space" for good adaptation (FIGURE 15). refers to 'the space within which opportunities and constraints determine why, how, when, and who adapts to climate risks'.[136] It is bounded by the realities of external climate change, its evolving impacts (e.g. sea level rise) and other biophysical constraints, as well as social constraints such as laws and regulations and what is considered necessary, reasonable and desirable in terms of avoiding maladaptation and pursuing good adaptation. Social and technological innovations can expand the solution space by generating or making acceptable new adaptation options. The ideal is that adaptation experience and learning helps expand the solution space over time faster than constraints such as extreme heat or social conflict reduce what is possible. Extreme events can expand the solution space by creating "windows of opportunity" for political and public acceptance of major adaptations such as "managed retreat" from high risk areas to reduce exposure. Some adaptations (e.g. altering land use planning, widespread education on adaptation) have a long lead time[137] and failure to commence them now may mean that the opportunity to pursue them is lost, especially if adaptive capacity is eroded over time and people are forced into reactionary coping mode.

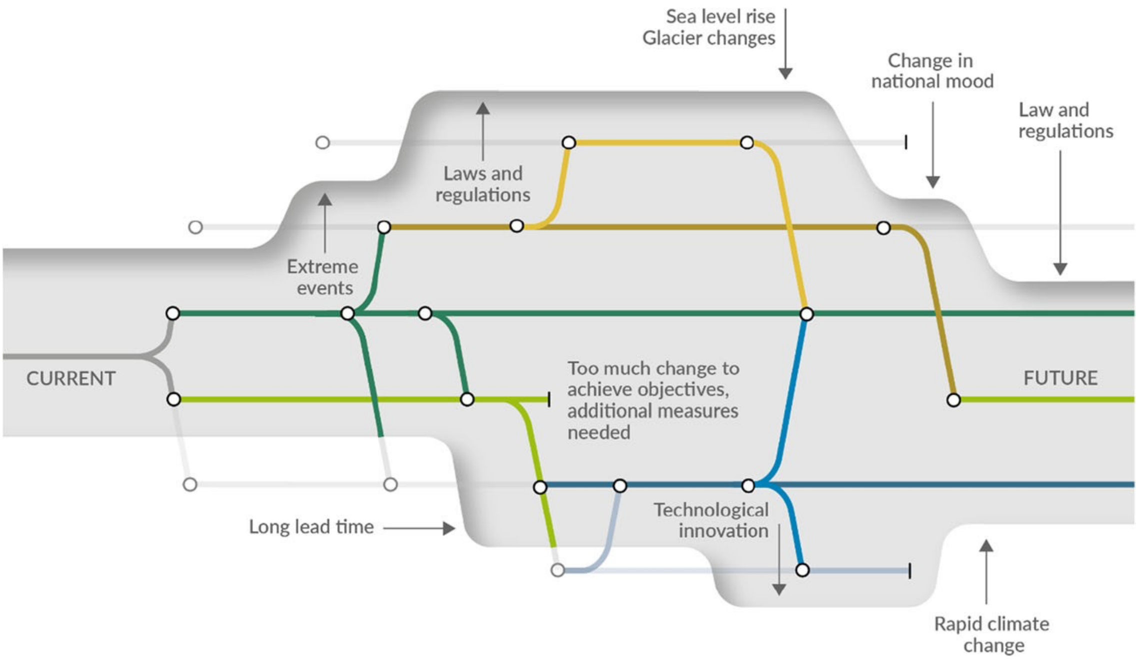

FIGURE 15. CONCEPTUALISATION OF ADAPTATION PATHWAYS (COLOURED LINES) WITHIN A SOLUTION SPACE (THE GREY SPACE). ARROWS INDICATE FACTORS EXPANDING OR CONSTRAINING THE SPACE.[136].

TYPES OF ADAPTATION

There are innumerable adaptation options available. Some changes are already apparent. Most of these are incremental (minor changes) and reactive (in response to observed shifts in conditions). But some adaptations (e.g. the relocation of mainland wineries to cooler climates in Tasmania) are more transformational (major changes) and anticipatory (initiated prior to the manifestation of possible impacts). The emergence of transformational adaptations points to the sort of spatial reorganisation and landscape changes that climate change impacts and anticipatory and reactive responses to them is likely to generate. FIGURE 16 outlines a schematic of some of types of adaptation in terms of level of adaptation and its relationship to observed impacts.

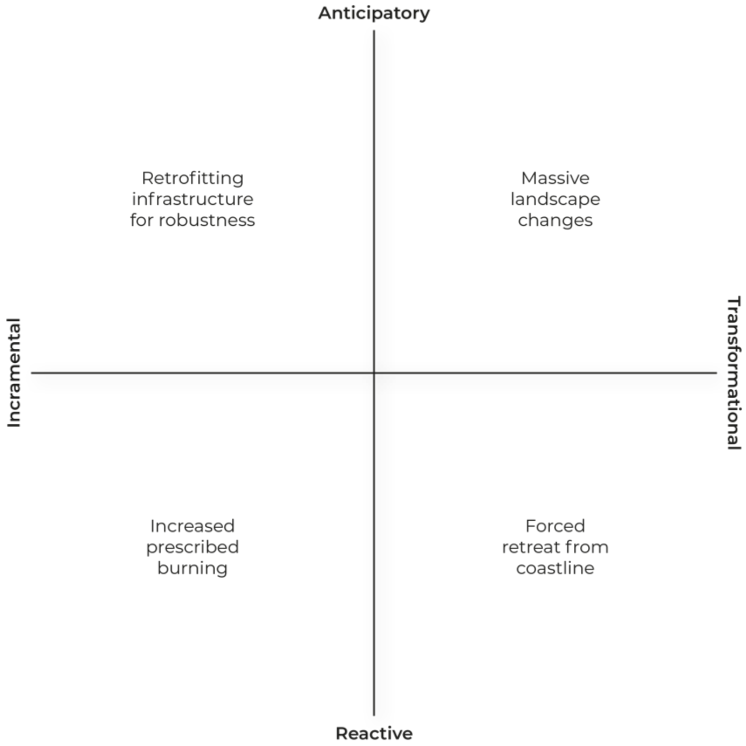

FIGURE 16: TYPES OF ADAPTATION ON TWO AXES. SOURCE: AUTHORS.

Other types of adaptation include hard adaptations (physical changes, notably protective structures such as dams or tougher buildings) and soft adaptations ("social" changes such as alterations in policies, ambitions and relationships, including new building codes, improved collaboration and new ways of thinking).[138] Some adaptations build "specific" resilience (the capacity to cope with a given (climatic) impact such as fire) while others build "generic resilience" (the capacity to cope with any disruption or stressor).[139]

The three components of climate change risk and impacts, plus the different orders of impacts, are a good starting point for thinking about adaptation approaches available. In addition to wider changes, adaptation can aim to:

- Reduce the risk of one or more hazards emerging (e.g. fuel reduction burning to reduce fire risk, river management to reduce flood risk)
- Reduce exposure to one or more hazards
- Reduce vulnerability to one or more hazards
    - Susceptibility to specific hazards – e.g. flammability
    - Vulnerability, or capacity to cope with and adapt to, any hazards or stressors

In addition to risk reduction and vulnerability reduction, adaptation requires we increase the resilience of our systems.[140] While resilience is interpreted in many ways, here we use it to refer to 'resilience thinking', which is about setting ourselves up to cope with and thrive in amongst volatility and change.[141] Resilience thinking acknowledges that the future is increasingly unpredictable.

Therefore, while there are many things we know we can do, and need to do, to reduce risk and vulnerability, we also need to be prepared to manage unavoidable disruptions and variability. This requires agility, adaptability and the flexibility mentioned above.

ADAPTATION LIMITS AND BARRIERS

Adaptation also faces limits. As climate change worsens, it is likely impacts will exceed some systems' and groups' capacity to manage them. For example, some ecosystems may fundamentally alter as species go locally extinct due to an inability to move or evolve quickly enough, and humans face biological thermal thresholds as discussed above.[136] Any individuals' or groups' capacity to cope at any one moment varies over time, dependent on circumstances. Uneven structural vulnerabilities and engrained issues such as downplaying climate change risks means some groups are continually or regularly unable to cope or adapt well. One of the risks of the "shared responsibility" paradigm of disaster risk management in Australia is that 'communities often are left to manage residual risks shifted towards individuals, whether or not they have the financial, physical, mental, or social capacity to manage them'.[85].

> **Adaptation limits:** The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions. Hard adaptation limit: No adaptive actions are possible to avoid intolerable risks. Softadaptation limit: Options are currently not available to avoid intolerable risks through adaptive action.[57]

Adaptation also faces barriers.[142] It is often assumed that a lack of climate change information or adaptation knowledge is the main barrier to effective and timely adaptation action. While knowledge and information are important, analysis of barriers to adaptation suggests that institutional barriers (e.g. lack of clear mandate, roles, responsibilities, willingness to act) are often more significant.[143] Enablers of good quality adaptation include:

- Systems thinking – appreciating systemic relationships and how to manage them
- Futures thinking – appreciating that futures are uncertain and will differ from the past
- Critical thinking – appreciating the need to consider which perspectives and groups are included in and advantaged by decision making or not
- A learning orientation – appreciating the need to continually learn and adapt as situations change.

A learning orientation needs to focus on successes as well as failures. It is best fostered by open exploration, as opposed to the blame mentality that can characterise post-disaster inquiries[144, 145]. Useful in this regard are the sort of internal reflective inquiries that some EMS agencies have used in place of or to follow formal inquiries. For example, after Tropical Cyclone Debbie and related flooding the Queensland Fire and Rescue Service complemented the formal review by Inspector-General of Emergency Management (Queensland) with its own review based on the principles of appreciative inquiry (identifying strengths and what worked well and why) that allowed it to draw out important lessons for the future.[146] Embedding such lessons into organisational processes and culture takes sustained effort. Research suggest that organisations need to consciously try to "learn how to learn" and attend to the whole learning cycle.[146].

ADAPTATION IN THE EMERGENCY MANAGEMENT SERVICES

MAPPING THE EMERGENCY MANAGEMENT SECTOR

Systems thinking: Systems approaches are holistic and dynamic ways of lookingat a situation or problem. They emphasise that the world does not operate as isolated components or silos. Although there are many different systems approaches, they commonly seek to articulate and understand how or why systems function the way they do. Systems approaches focus on the components of a system, their connections, dynamics and function as well as external drivers[147]. Systems thinking in climate change adaptation planning helpsto think holistically and see interrelationships and dynamics that flow on from a climate change impact or a policy intervention.

When it comes to the EMS, a systems-based approach improves our understanding of the sector and the many implications of climate change for it. FIGURE 17 and FIGURE 18 present two frameworks that are useful for taking a systems approach to climate change adaptation in the EMS. FIGURE 17 shows the three domains of strategy; this framework can be used to position actors within the EMS as the central domain of control and explore their relationship to inter-actors in the middle 'domain of influence' and contextual factors in the outer 'domain of appreciation'.

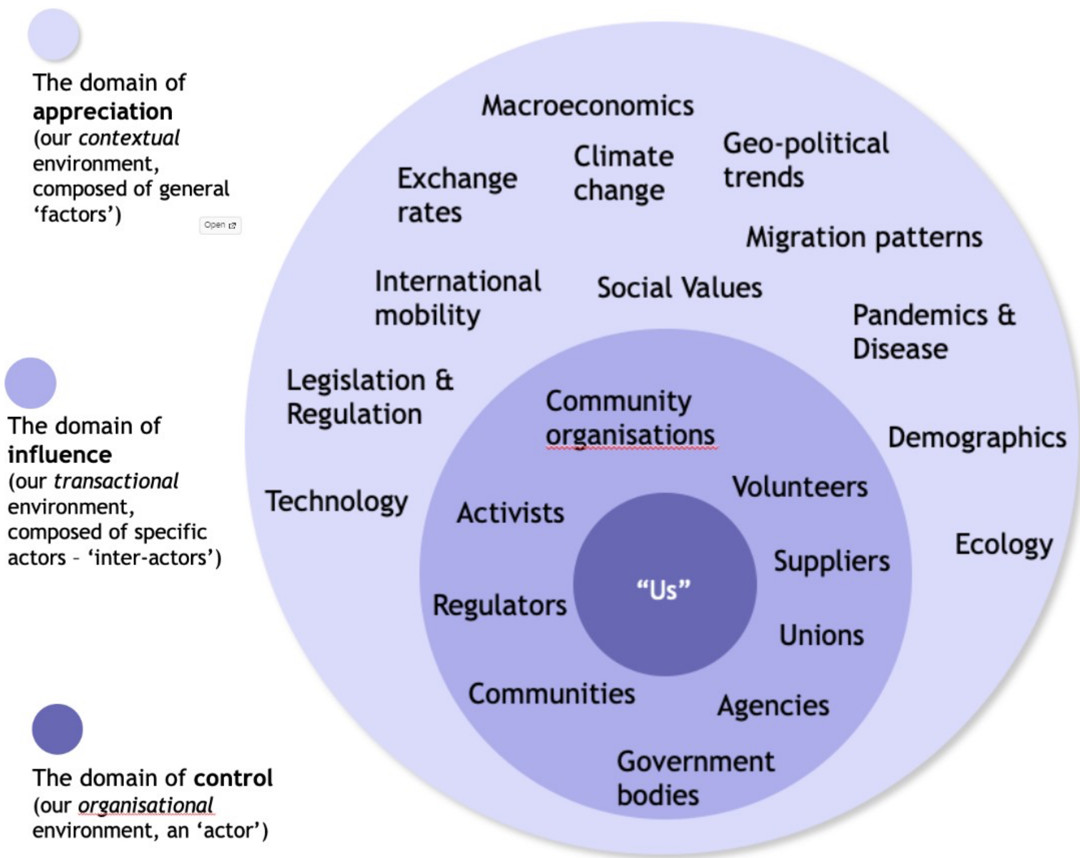

FIGURE 17: THE THREE DOMAINS OF STRATEGY. SOURCE: VAN DER HEIJDEN.

FIGURE 18 presents a sample system-map of the EMS that aims at capturing the key elements and relationships under a changing climate. The large box labelled 'Disaster resilience system' maps the key interactions between disaster risk, disaster risk management and emergency services, and community and economic development. The top boxes are the driving forces or enabling conditions that impact on that system. Climate change works through all of the other factors; although in its own box it is not separate to everything else, as the separate listing in the domains of strategy could imply.

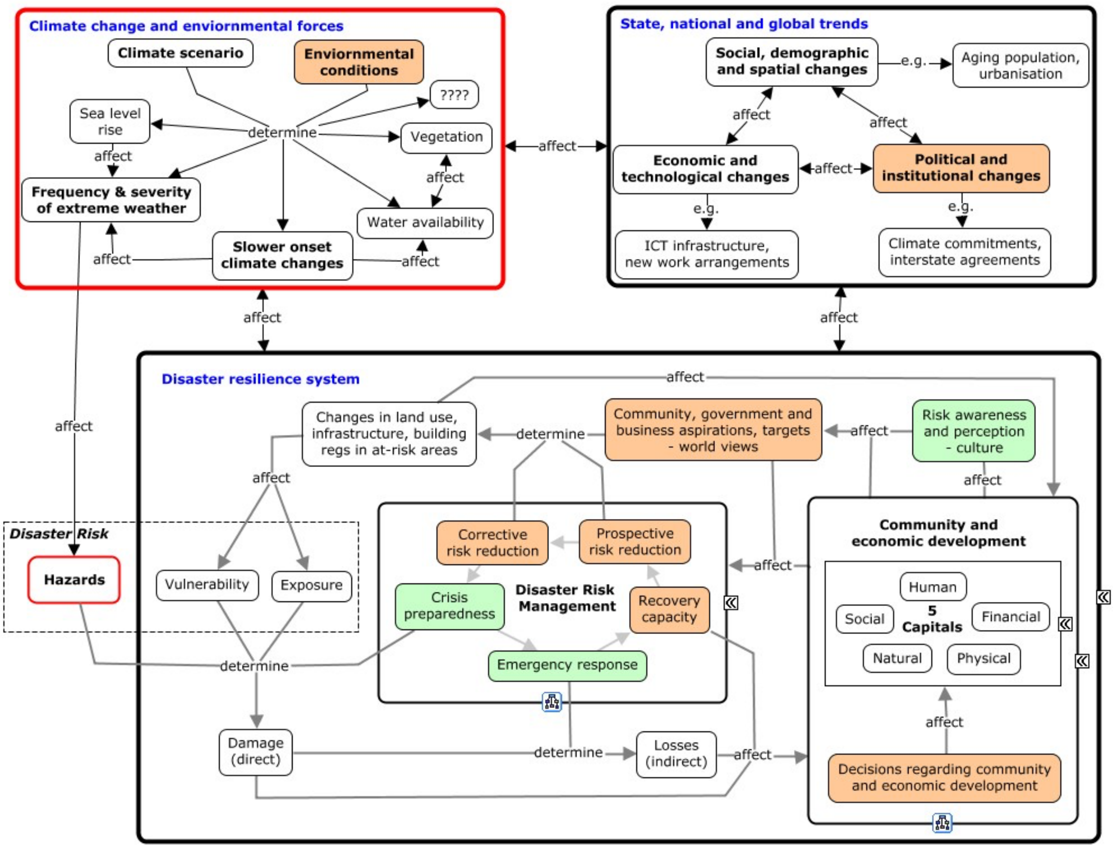

FIGURE 18: SYSTEMS MAP OF THE ADAPTATION CONTEXT FOR THE EMERGENCY MANAGEMENT SECTOR GREEN CONCEPTS ARE WHERE THE EM SECTOR IS IN THE LEAD AND HAS SIGNIFICANT INFLUENCE. ORANGE REPRESENTS OPPORTUNITIES OR ENTRY POINTS FOR THE SECTOR TO COORDINATE WITH OTHERS IN ADAPTATION PLANNING. SOURCE: AUTHORS. THE DIAGRAM IS BUILT USING THE CONCEPT MAP METHOD[148].

The systems map underlines that the EMS operates in a wider context. How climate change and other drivers affect this context is vital to understanding the future adaptation challenge for emergency services. Taking the language of the three domains of strategy, we note that the orange boxes might be considered the current domain of control, the green boxes are the domain of influence, while the rest of the system is the domain of appreciation.

Many emergency managers are aware that the ongoing efficacy of emergency management (the green boxes 'emergency response', 'crisis preparedness' and public 'risk awareness and perception') depends on the efficacy of the wider field of Disaster Risk Management (the central box). Climate change adaptation broadens the field again. Under climate change, the efficacy of emergency management depends on what we have called the wider Disaster Resilience System and its interactions climate change and other environmental forces, and wider state, national and global factors such as demographic changes.

This means that the EMS needs to not only adapt how it works within its current domain of control (green), but that it can work with others to within its domain of influence (orange boxes) to reduce risk and vulnerabilities, while demonstrating a sophisticated understanding of the other factors (the white boxes) within its domain of appreciation. In practise, this means engaging more deliberately and consistently with issues of risk reduction, land-use planning and building regulations, building back better, and informing community and economic development to be more risk-informed and climate-smart.

STEE(L)P DRIVERS AND THEIR INTERSECTION WITH CLIMATE CHANGE

The academic literature provides some valuable insights into the drivers at work in the EMS context. However, very little research addresses the "question of the future" *per se* and that which does, does not do so in a comprehensive manner that incorporates climate change or challenges the assumption that existing trends will unfold linearly. Nor is much research focused on the EMS context as we have mapped it out.

We therefore need to bring together different insights in order to piece together what the future may entail for the EMS. One useful way to begin this process is to systematically consider the 'STEEP drivers' - that is, insights into Social, Technological, Environmental, Economic and Policy/Political drivers – and to then start thinking through how they may interact with climate change. In response to input from the scenarios team, we have included a sixth category – legal – into the framework. TABLE 3 provides some examples of the types of changes and uncertainties the EMS may need to consider as it encounters the climate change adaptation undertaking. It synthesises insights from a wide range of academic and grey literature.

Driver	Potential changes	Key uncertainties	Intersection with climate changes	Questions for CC adaptation
Social	Ageing population, particularly in rural and regional areas General growth in large urban centres in metropolitan and regional areas Declining number, size and social cohesion of rural centres, particularly those reliant on broadscale agriculture where more land is managed by less people New more localised settlement patterns and neighbourhoods reduced reliance on big cities or CBD Changing worldviews, social values and community expectations Increased international migration, including from Pacific nations impacted	Future global and national immigration trends International migration patterns within Australia Sustainability of small towns Implications of demographic shifts for infrastructure needs and viability (e.g. irrigation or road infrastructure), and influence of the latter on settlement patterns Extent and location of the move to re-localisation	Older population tends to be more vulnerable to climate change, increasing the potential severity of impacts Spatial exposure to climate changes and their flow-on-effects is a key component of climate change impacts; changes to these will alter what impacts eventuate Increased proportion of new arrivals, ethnic, cultural and language diversity	Where will people live in the future and how does this shape climate change risk and adaptation needs? How does the shifting location and characteristics of the population alter resources (e.g. volunteers) for EMS?

	by climate change Greater recognition of Indigenous sovereignty Changing media landscape/misinformation Mental health, physical health declines/events			
Technological	Greater (application of) automation technologies reduces need for human workforce in difficult environments Greater (use of) sensing technologies increases capacity to monitor and respond to emerging conditions Greater (use of) digital technologies increases boundary-crossing collaboration Cybersecurity issues Greater use of social media during emergencies High demand for accessible risk information to inform individual decision-making, as recommended by the Black Summer Royal Commission report	Extent to which and where automation technologies will be applied and what their flow-on effects for industries and communities will be How monitoring of certain environmental parameters will alter decision making Where and how collaboration will increase in practice and what the implications will be for decision making	As climatic conditions worsen in some localities, and so too do OHS issues, some industries and areas may be more inclined to turn to automated technologies (e.g. mining in central Australia) Environmental sensing will improve understanding of climate conditions and emergent impacts Improved information flows and communication will improve understanding of how climate change impacts cascade across boundaries and improve adaptation To what extent and in what ways are these technologies themselves vulnerable to climate change?	How will the intersection of labour force changes and climatic changes reduce or worsen the impacts of climate change and/or affect adaptive capacity? How can improved just-in- time environmental information be used to improve adaptation over time? How can improved information flows and collaboration be used to improve adaptation over time? What risks are created by an increased reliance on technological solutions that are themselves susceptible to acute and chronic climate change impacts?
Environmental	Increased environmental risks including disruptions to and loss of environmental services (eg blue green algae outbreaks undermining water quality) Reduced resource security due to environmental degradation (eg declines in food security due to soil loss and drought) Loss or massive shifts in ecosystem functioning increasing fire danger Increased environmental awareness and improved policies lead to restoration and regeneration of landscapes Infrastructure questions and reliability and implications for industries such as ag Land management questions Overlapping disaster/fire	How different environmental pressures interact and whether and where "tipping points" are reached that flip natural systems into a more dysfunctional state The extent to which resources are secure in terms of not just quantities but reliability of flows Whether environmental policy changes will eventuate and be adequate to reverse patterns of environmental decline	Reductions in environmental quality have the potential to alter the spatial distribution of hazards (e.g. flammability of vegetation, likelihood of local droughts or floods), exposure (as people and wildlife migrate away from low quality areas), and vulnerability (because environmental quality or 'natural capital' is an element of adaptive capacity). In essence, environmental pressures will worsen climate change impacts	How will changing environmental conditions affect the distribution and severity of climate change impacts and the capacity to adapt to them? How would changes to environmental policies affect adaptation options?

	seasons and increasing demands for assistance from Pacific, NZ, Nth America			
Economic	Greater inequality in wealth and incomes. Economic downturn Greater reliance on voluntary sector to provide basic services. Shift away from home ownership towards tenancies. Turn to simpler, less consumptive lifestyles (“downshifting”) leading to turn away from large houses, private vehicles and asset accumulation. Increased economic and financial volatility. Restricting of insurance products to risk-exposed businesses and homeowners. New economic paradigm – eg wellbeing measures, doughnut economics	Social and spatial distributions of wealth and incomes and effects on social structure and cohesion. In particular, effects for younger generation and prospects for home ownership. Financial viability of organisations and services. Extent of any downshifting trend and whether it is forced and/or voluntary. Extent, source and character of future economic and financial volatility.	More brutal triage in EMS? Near and long- term impacts of climate change on different socioeconomic groups, and the relationship between groups and localities. How different patterns in asset ownership and accumulation affect exposure to climate change impacts and adaptive capacity (eg desire to stay and defend, ability to evacuate). How potential financial insecurity and pressure affects voluntary organisations’, services’ and households’ vulnerability to climate change impacts, especially if combined with increased reliance on voluntary sector for emergency response. Greater prioritisation of recovery and care in keeping with greater value given to wellbeing	How can climate change adaptation avoid or help ameliorate economic and financial stressors? What adaptation needs and options are opened up, or closed down, by economic shifts including funding of public services and changing property ownership patterns? How might the role of the insurance sector be leveraged to enhance climate change adaptation and reduce negative impacts?
Legal	Liabilities for losses arising from damage compensation Legal actions against directors and companies Increased occupational health impacts from increased workload faced by the EMS Litigation against polluters and financiers	Whether and how the increased physical and economic risks posed by climate change will increase the liability risk faced by company directors. How legal rights such as private property rights may be altered as a result of climate change adaptation necessities.	EMS already faces legal risks. Climate change may increase these, or alter the legal landscape to help enable EMS to do its job under climate change.	How will legal roles and responsibilities alter as a result of future disasters and climate change adaptations?
Policy/Political	Increased role for the Australian Government and Defence Forces in emergency management, as recommended by the Black Summer Royal Commission report Decreased role for government in providing services Re-instated role for	Extent to which federal, state and local governments accept responsibility for risk management and service provision or encourage self-reliance by organisations and communities. Ambition and pace of climate change	Extent and ways in which climate change vulnerabilities and impacts may be exacerbated by lack of government support. Near and long term impacts of a loss of affordable insurance or credit in certain	How can good adaptation outcomes be protected in amongst shifting roles and responsibilities? What risks and opportunities do shifting policies pose for long- term transformational

	government in providing services and facilitating action Climate change policies introduced to substantially reduce greenhouse gas emissions across the economy, and increase sequestration across landscapes, with financial penalties for those who do not comply. Normalisation of climate change considerations into the core decision making of all organisations, increased standards around risk disclosure and management. Changing priorities from unions in regard to employment conditions. Insurance and credit providers from high risk areas and industries. Increased militarisation of society Permanently or regularly closed borders between states/nations Serious geopolitical conflict involving Australia	policies and therefore degree of future climate change. Flow-on effects for factors such as landscape management (e.g. afforestation?) Public, regulatory and employee responses to examples of poor climate risk management and role of law in translating such failures into a liability risk.	areas due to climate change risks, worsening impacts of extreme events in such areas and leading to possible tipping points in the population and settlement pattern. How acceptable climate risk management efforts are in the eyes of others, and the flow-on effects of perceived failures to manage risk adequately. Intersection of emissions reduction and climate change adaptation policies and pressures. Impacts of mitigation costs on organisations and implications for their adaptive capacity. Increased militarisation of EMS/blurred boundaries between EMS and military	adaptation? What do rising public expectations around adaptation and responsible climate risks management mean for voluntary organisations?

TABLE 3. EXAMPLE STEEP DRIVERS RELEVANT FOR THE EMS.

2021-2035 SCENARIOS PROCESS

This literature review is an input to the *Preparing Emergency Services for a Climate-challenged World* project, which looks specifically at emergency services operations between 2021-2035. This section draws on the review presented above and focuses in on this period in order to inform and support the scenarios process being undertaken in the project. The scenarios process involved a series of participatory workshops with a project scenario team to develop and pilot a methodology to create transformative scenarios. For further details see Atkinson et al[149].

BIOPHYSICAL IMPACTS TO 2035

Working from the framing of risk as a function of hazard, exposure and vulnerability (outlined in section 0) we now present projected changes in the hazard element of the risk equation. As outlined in the above section, the long-term biophysical impacts of climate change depend on the emissions scenario that ends up coming to fruition. However, regardless of the emissions scenario, some climate change is already locked in. In fact, the projected changes to 2035 are consistent regardless of the emissions scenario or the model used. Because of this consistency, we are able to present a relatively certain picture of the biophysical impacts of climate change in Australia and New Zealand to 2035.

Changes in averages are expected to occur, specifically:

- Warming / increasing average temperatures.
- Declining rainfall and drought (note this trend is less certain for northern Australia).
- Sea level rise and ocean acidification.

In terms of extremes, as outlined in detail above we expected to see increasing climate and weather variability, specifically:

- Longer fire seasons and more severe fire weather.
- More frequent and intense heatwaves.
- More intense storms and floods.

It is important to note that these changes are not expected to unfold linearly. Instead, they should be understood as trends over time with considerable variability over the period.

As an input into the scenarios process, the research team developed Figure 19, a series of disaster events, called a climate hazard event map, that is considered plausible under the future outlined above. The hazard event map is a heuristic tool; it is one plausible example of how future hazards could manifest and should not be considered predictive.

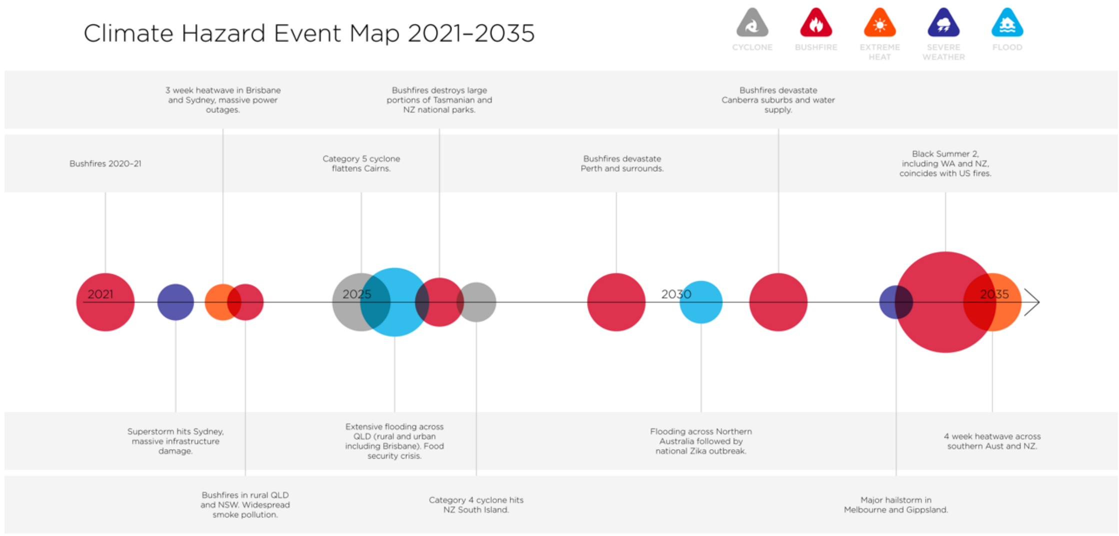

FIGURE 19: CLIMATE HAZARD EVENT MAP. SOURCE: AUTHORS.

FLOW-ON EFFECTS TO 2035

The biophysical changes outlined above will result in direct biophysical impacts as well as compounding climate change impacts. These are summarised in Table 4.

Climate change factor	Direct biophysical impacts	Compounding climatechange impacts
Sea level rise	• Seawater inundation > reduces quality of freshwater and soil • Coastal erosion > dangerous conditions, property damage	• Storms • Low rainfall > scarcity of freshwater to start with
Heat	• Human illness and death • Other animals and plants physically stressed • Physical equipment and infrastructure malfunctions including electricity grid	• Low rainfall > lack of water to cope • Storms and bushfire > infrastructure damage and lack of electricity to cope
Low rainfall	• If water demand exceeds supply, humans, other animals and plants will be severely dehydrated • Physical equipment and infrastructure degradation	• Heat > increased evaporation, increased risk of algal blooms, reduced water quality, increased water demand • Storms, fire, flood > runoff into water bodies reduces water quality

Heavy rainfall	• Human injuries and death • Damage to natural and built environment and infrastructure • Heavy runoff and flash flooding, causing further damage	• High winds during storms or cyclones • Prior drought or fire, leaving ground bare and increasing erosion and runoff into water bodies
Storms and cyclones	• Human injuries and death due to high winds • Damage to natural and built environment and infrastructure due to high winds	• Heavy rainfall before, during and after
Fires	• Human injuries, illness and death from flames and smoke • Damage to plants, animals, water bodies, and built environment and infrastructure	• Heat and high winds > adding to physical stress • Low rainfall > lack of water for response and recovery

TABLE 4: DIRECT AND COMPOUNDING CLIMATE CHANGE IMPACTS FROM VARIOUS CLIMATE CHANGE FACTORS.

LIKELY IMPLICATIONS OF FLOW-ON EFFECTS TO 2035

The implications of these flow-on effects are dependent on multiple, dynamic factors, as set out in section 0. These implications are not guaranteed, however, the literature review has identified several *likely* implications that are expected to be significant challenges in the next two decades. *In the absence of effective adaptation and mitigation,* climate change will profoundly impact our **water and environment**:

- Loss of species (biodiversity) and abundance; declining ecosystem services such as pollination and pest control.
- Reduction in water availability and quality; increase in cost.
- Increasing pests, weed and disease issues.
- Loss of iconic ecosystems including coral reefs, Kakadu National Park, snow fields.

This, in turn, will result in changes in **agriculture and aquaculture**:

- Declining agricultural and livestock yields.
- Declining (or complete collapse) of aquaculture industries.

Infrastructure will also be profoundly affected:

- Increased deterioration of key infrastructure including transport and energy infrastructure, due to more extremes.
- Significant risk to coastal buildings and infrastructure due to sea-level rise and storm surge.

These will compound impacts on **human health and wellbeing**:

- Declines in food security (quantity and quality) due to agricultural declines globally and quicker perishing.
- Vector borne diseases increase with growth of mosquito populations, which also compromise the blood supply.
- Further heat-related morbidity and mortality.

Over the long term, all industries, sectors, and parts of society will be affected by the above and aggregate systemic effects such as:

- reduced economic growth
- increased social stress
- flow-on effects of (mal)adaptation including major spatial reconfiguration of settlements, infrastructure and supply chains.

ADAPTIVE CAPACITY UNDER THE FOUR SCENARIOS

The scenarios process in the project identified key uncertainties in the driving forces behind the future, that could have substantive impact on the EMS. The team undertaking the process then developed four distinct yet plausible scenarios for the future, each with profound implications for the EMS. The scenarios are summarised in Figure 20:

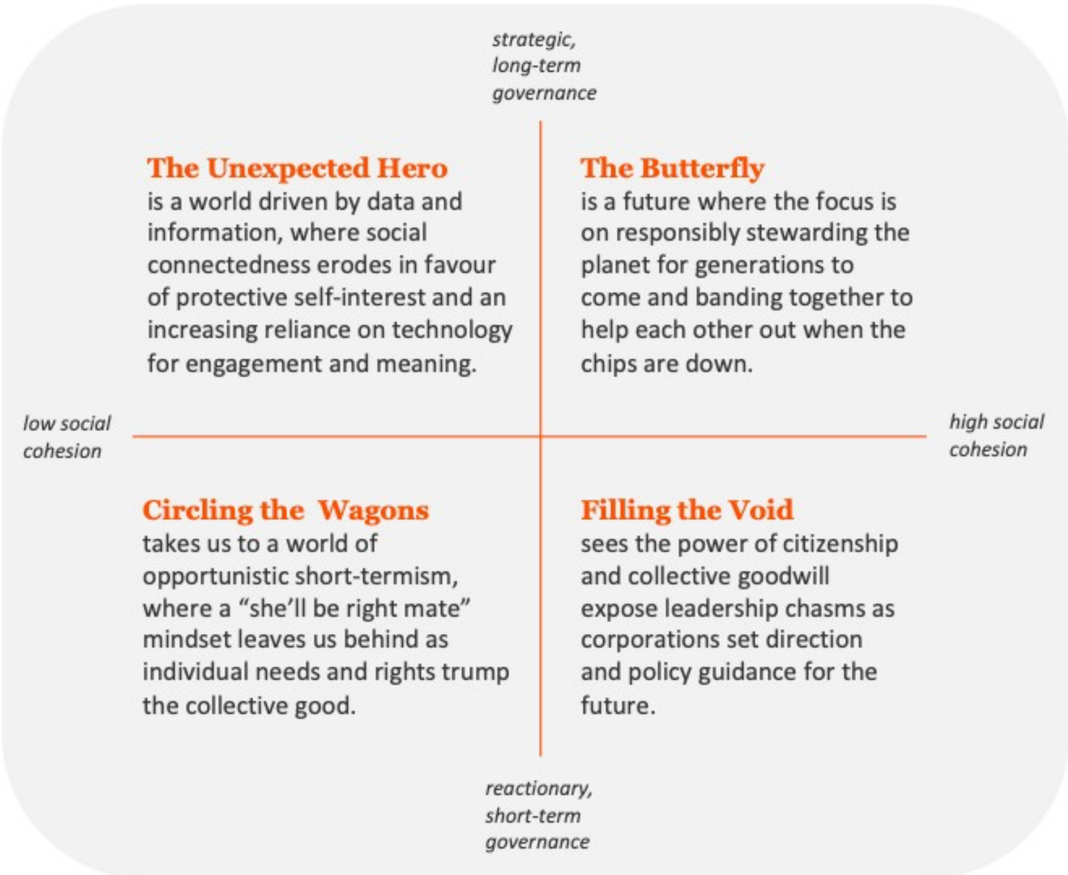

FIGURE 20: FOUR SCENARIOS DEVELOPED BY THE SCENARIOS TEAM. SOURCE: REOS[149].

Each scenario represents different levels and forms of adaptive capacity. In particular, each can be interpreted in terms of the five domains of adaptive capacity introduced above: assets, flexibility, social organisation, learning and agency[117]. This is shown in series of radar graphs presented in Figure 21:

FIGURE 21: ESTIMATED QUALITY OF THE FIVE DOMAINS OF ADAPTIVE CAPACITY IN EACH OF THE FOUR SCENARIOS. SOURCE: AUTHORS.

Although the scenarios were developed in a bottom-up manner by the participants, they broadly align with known determinants of adaptive capacity. Thus, despite using a novel process, the scenarios ultimately reinforce the fact that both strategic, long-term governance and high levels of social cohesion are important for effective climate change adaptation.

CONCLUSION

Climate change is altering the base climate and the magnitude and frequencies of extremes in temperature and precipitation. Australia and New Zealand are already facing and will continue to face increasing average temperatures and heatwaves, shifts in precipitation and water availability, changes in storms and cyclones, and effects on fire weather. Recent disasters, including those that have occurred concurrently with the covid-19 pandemic, show that the emergency management sector (EMS) is proactively tackling this challenge.

Multiple uncertainties mean that climate change adaptation is poorly suited to conventional risk management. Further modelling has only limited capacity to reduce uncertainties and predict 'compound events'. Therefore, planning cannot rely on 'most likely' climate change scenarios or identifying an 'optimal' response. Plans need to be tested against multiple plausible futures to identify actions that are robust, flexible, and address the root drivers of risks and vulnerabilities.

Enhanced disaster preparation and response to cope with more frequent and worse hazards is a crucial adaptation, already being pursued by the EMS. Furthermore, adaptation also involves: continuous improvement in disaster prevention and recovery; concurrently addressing slow and chronic changes; reducing existing vulnerabilities (e.g. social disadvantage), not just hazards (e.g. via better flood management planning) and exposure (e.g. via temporary or permanent relocation); addressing root causes of vulnerability, hazards and exposure; and generating positive outcomes (co-benefits).

Criteria of successful adaptation include effectiveness, efficiency, equity, externalities, and extended time horizon. Often the most significant barriers to adaptation action are institutional ones. Maladaptation – adaptation actions that increase greenhouse emissions, disproportionately burden the most vulnerable, have high opportunity costs, reduce incentives to adapt, or set paths that limit future choices – are an important concern.

A systems-thinking approach to adaptation has much potential for the challenges faced by the EMS. Systems-thinking helps decision-makers tease out complex interactions and interdependencies, understand driving forces, and thereby potentially identify more effective adaptation actions. We have drafted a system-map of the EMS to capture the key elements and relationships under a changing climate.

The academic literature provides some valuable insights into the drivers at work in the EMS system. However, very little research is focused on the EMS context *per se*. We therefore need to bring together different insights to piece together what the future may entail for the EMS. One useful way to begin this process is to consider the 'STEEP drivers' (Social, Technological, Environmental, Economic and Policy/Political drivers) and to then start thinking through how they may interact with climate change in the EMS system. In response to input from the scenarios team, we have included a sixth category – legal – into the framework.

Overall, it is clear that climate change is already underway and will continue to change for centuries. The implications of climate change for the EMS go well beyond increasing frequency and intensity of natural hazards. Australia and New

Zealand are highly likely to experience significant societal and environmental change, which will have far-reaching impacts on the EMS. These changes include a wide range of uncertainties and complexities, all of which point to the need to begin to face the climate change adaptation challenge and concertedly shift away from a simple framing of emergencies and disasters in

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