Implications of Climate Change for Future Disasters

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Introduction

The climate is changing, and human-caused emissions of greenhouse gasses are accelerating the rate of change. Already we are seeing an increase in average temperatures, rising sea levels and a range of disruptions to weather patterns that are affecting the human and non-human worlds. Perhaps one of the most poignant ways in which people will experience the effects of a changing climate will be through exposure to natural disasters; fires, floods, drought, and severe storms. These events can – and do – cause the loss of life, loved ones, and livelihoods. Societies have navigated disasters throughout history, sometimes more successfully than others, but the unprecedented climate change we are experiencing and continuing to cause in the present time will affect our ability to predict, prepare for, and withstand future disasters. Because of climate change, what came before cannot be used as a reliable guide for what we will face in the future. In this chapter, we outline what is known about climate change – its mechanics, causes, and impacts – and describe how climate change will affect disasters in Australia into the future.

Australia is no stranger to natural disasters. In 1893, a tropical cyclone around Rockhampton in Queensland brought extreme weather and heavy rain, killing 35 people, injuring over 300, and destroying two major bridges in Brisbane city (Australian Institute for Disaster Resilience, n.d.-a). Two years later the Federation Drought began, drying reaches of the Murray-Darling River system and causing devastating effects for the agricultural industry. By 1902 the drought had broken, but the losses to the wheat, cattle, and sheep industries persisted; many farmers abandoned their farms (Australian Institute for Disaster Resilience, n.d.-c). The 1939 Black Friday bushfires in Victoria were brought on by dry conditions and extreme heat. Temperatures in the 40s, with hot and strong winds carried bushfire through several towns, razing them to the ground along with large areas of forest, and killing over seventy people (Bureau of Meteorology, 2001b). The year of 1974 began with the Brisbane floods which killed 14 people and caused damage estimated at $200 million (over $1 billion in 2019 dollars) (Kitchener, 2011), and ended with Cyclone Tracy battering Darwin with extreme wind and rain (Bureau of Meteorology, 2001a). Cyclone Tracy killed 65 people, destroyed most built infrastructure in its path, and led to widespread evacuation.

More recently, in 2009 the Black Saturday bushfires followed an extreme heatwave in Victoria, killing 173 people and destroying over 2,000 homes, resulting in over $1 billion in damages (Australian Institute for Disaster Resilience, n.d.-b). Just 10 years ago, this was one of the worst natural disasters in Australia's recorded history. But we cannot expect it will be the last. As explained in the final report of the 2009 Victorian Bushfires Royal Commission (Victorian Bushfires Royal Commission, 2009) (emphasis added):

> "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."

Climate change: The fundamental physical mechanics

If we are to understand how climate change will affect future natural disasters, we must first understand the fundamental mechanics of our changing climate. Day to day we experience weather; states of rain, wind, heat, or snow that can change from hour to hour though adhere to broad patterns across the seasons. When we look at long-term patterns in weather, for example over 30 years or more, our attention turns away from weather and towards the climate. As such, when we talk about climate, we are discussing the long-term averages that describe the conditions of a place. So, it can help to think of climate as the long-term average, while weather patterns in a day-to-day sense are fluctuations around that average.

When we talk about climate change, we are discussing changes to those long-term averages. We can look at historical climate change, and view how the climate changed between warm periods and ice-ages. But in its most salient contemporary use, climate change describes a very specific phenomenon; that of human-caused emissions of greenhouse gases into the atmosphere, and the resulting disruptions to our climate.

Fundamentally, human-caused climate change results from the accumulation of greenhouse gases in our atmosphere. These greenhouse gases are emitted by human activities, such as: burning coal, oil and gas for electricity or transport; land use change; and growing livestock. These gases are long-lived so they remain in the atmosphere for upwards of thousands of years. Commonly we talk about carbon dioxide as it is one of the most prevalent greenhouse gases emitted by human activities, but there are other greenhouse gases emitted by human actions too, such as methane and nitrous oxide. Water vapour is a greenhouse gas, but because it persists in the atmosphere for only a short amount of time, it has minimal sustained impact on the climate. As is indicated by their name, greenhouse gases contribute to the ‘greenhouse effect’, the trapping of heat in the Earth system by the atmosphere. For life to survive on Earth, we need the greenhouse effect, but human-emitted greenhouse gases are increasing its strength, resulting in higher amounts of heat retained in the atmosphere, causing global warming. More heat in the atmosphere means more energy available to power atmospheric systems, leading to changes in the geographical distribution, frequency, and intensity of weather events. In addition, more heat in the atmosphere leads to more heat being transferred to the oceans, causing ocean warming and sea level rise as a result of thermal expansion of ocean waters and glaciers melting.

Future emissions reductions trajectories

As the increased accumulation of greenhouse gases in the atmosphere is the result of human activities, global efforts have been undertaken to engender a cooperative international effort to reduce emissions. In 2015 under the *Paris Agreement*, all nations committed to limiting future global warming to 2ºC above pre-industrial levels, and to pursue actions in accordance with a more ambitious 1.5ºC target (Althor et al., 2016). This is based on the recognition that every half a degree matters, and there is a substantial gain to be made by limiting warming as much as is possible. Even at 2ºC, we will see substantial deleterious effects on our human and natural systems (IPCC, 2018). At this point, our targets are to limit the extent of the negative impacts of climate change, not to prevent them.

However, the *Paris Agreement* is non-binding, and nations' pledged domestic emissions reductions targets are insufficient to limit warming even to 2ºC. Instead, we can expect average warming of 2.6–3.1ºC, assuming the pledges are met (Rogelj et al., 2016). What this tells us is that climate change will become ever more significant into the future. The failure to reduce emissions means that nations of large emitters – as well as private actors such as corporations – will be responsible for the consequences of climate change (Lewis et al., 2019), and those who contributed the least to the problem are most likely to be the most significantly impacted (Althor et al., 2016).

Australia's future under climate change

Climate change is not just a problem for the future, we are already living under conditions of human-caused global warming, and seeing the effects. In 2018, the average global temperature was 0.97ºC above the pre-industrial average; Australia was 1.14ºC above average (IPCC, 2018). Sea levels are rising by an average of 3.2cm per decade, and within Australia the greatest rate is seen in south-east and northern Australia (Bureau of Meteorology and CSIRO, 2018).

As a result, in 2018 Australia we saw extended drought conditions and what could be characterised as a fire *year* as opposed to a fire season. Despite overall low rainfall, there were rainfall events that yielded record rainfall and severe flooding (Bureau of Meteorology and CSIRO, 2018). In 2018 alone, over AUD $1.2 billion in insurance payouts were made following extreme weather events. Meanwhile, the cost of the drought to Australia exceeds $12.5 billion in 2018-19 (Insurance Council of Australia, 2018; cited in Steffen, Dean, et al., 2019), and that is not accounting for the non-monetary costs such as impacts on mental health & community wellbeing (e.g. Chan, 2019). This is at 1ºC of average warming, and we are tracking toward 3ºC. For the remainder of this chapter, we explore how climate change will affect disasters cross five areas: heatwaves, droughts, bushfires, and floods. We outline the intersection between climate change and disasters to lay the foundations for discussion on how justice matters for disasters, in the face of a changing climate.

Heatwaves

Heatwaves are broadly defined as periods of prolonged heat that are anomalous for that particular location (Perkins & Alexander, 2013). Heatwaves are measured by a suite of key characteristics of minimum, maximum or mean temperatures, such as the heatwave's intensity, duration and spatial extent of anomalies. There is no universally applicable definition of heatwaves, as varying measures are useful in different climatic regions and for different end-users and stakeholders. Studies of Australian heatwaves typically measure excess heat (relative to local climatological values) over three or more days (Perkins-Kirkpatrick et al., 2016), providing information specific to locations. Here we will discuss only atmospheric summertime heatwaves, although note that both out-of-season and marine heatwaves increasingly impact human and natural systems in Australia (Oliver et al., 2018).

Over Australia, the frequency and intensity of observed high maximum and minimum temperatures has increased (Alexander & Arblaster, 2017). The number of heatwaves, their duration and intensity has increased since 1950 for many parts of Australia and particularly in southern and eastern Australia (Perkins & Alexander, 2013). Heatwaves in Australia are associated with multiple physical drivers and mechanisms from within-year modes of variability (e.g. the El Nino-Southern Oscillation) to longer-term synoptic weather systems (Parker et al., 2014). Although heatwaves are naturally occurring phenomena, numerous studies have determined changes in Australian heatwave characteristics that are associated with human-caused climate change.

Linking these observed events to human-caused climate change, though, is not a simple endeavour. Studies have applied a range of methodologies to assess the role of human-caused climate change in these measured changes in Australian heatwaves, i.e. studies of *attribution*. Examining trends in observed temperature extremes using models with and without anthropogenic greenhouse gases, Alexander and Arblaster (2009) determined that the observed changes to heatwaves were consistent with what would be expected as a response to climate change. Dittus et al. (2016) similarly show that the observed increased area of Australia experiencing high temperatures is attributable to human-caused climate change. Further studies use an event attribution approach to examine climate change impacts on specific observed extremes such as a notable heatwave. For example, Perkins et al. (2014) determined that human-caused climate change increased the probability of the intensity and frequency of observed heatwaves in 2013-14 in Australia. This record hot year of 2013 (Bureau of Meteorology, 2014) has been a target for multiple studies, which also confirm an anthropogenic signal in extreme summer temperatures (Lewis & Karoly, 2013). In summary, multiple studies have found a human-caused greenhouse gas influence in Australia’s observed increases in extremes, which is consistent with changes observed across much of the globe (Perkins, 2015).

Heatwave frequency and intensity is projected to increase throughout the 21st century with further climate change. Using global-scale climate model information for Australia, numerous studies show that as we look toward the future, the number of cold temperature extremes substantially reduces and the number of warm temperature extremes substantially increases, depending on the greenhouse emissions scenario employed (Alexander & Arblaster, 2017). These findings are supported by targeted regional models, where the number of heatwaves and their duration is projected to increase significantly, with greater increases in the north than south of Australia (Herold et al., 2018). Other approaches have focused on how current extreme events may change in future projections, either under different levels of global warming, in different scenarios or at different times in the future. In model simulations where warming is limited to 1.5°C, frequency of extreme heat events in Australia, like the 2013 record summer, are substantially less likely than at 2°C (King et al., 2017). Furthermore, 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 (Lewis et al., 2017).

Extreme heat already negatively impacts human and natural systems, infrastructure and industry in Australia. To date, heatwaves are Australia’s most deadly natural hazard (Coates et al., 2014), affecting human health and labour capacity (Zhang et al., 2018). Heatwaves are also an established stressor of key natural ecosystems such as coral reefs (Hughes et al., 2017) and native fauna (Welbergen et al., 2008). Further detrimental impacts of heatwaves on road and rail infrastructure, agriculture and aquaculture industries, and energy supply are well documented (see Perkins, 2015). While some human and natural systems have the ability to adapt to the changing characteristics of heatwaves we are seeing now, projected future changes in heatwaves likely pose further risk to natural systems (Lewis & Mallela, 2018), human health and industry. Herold et al. (2018) specifically examined such impacts, noting that as all Australia capital cities are projected to experience at least a tripling of heatwave days each year, increases in mortality and substantial decrease in wheat production are also projected.

Drought

Drought is a human construct; depending on the definition, it may be characterised by meteorological conditions, hydrological state, or its impacts. Drought has been notoriously hard to define given its impacts are biophysical, economic, social and environmental (Mishra & Singh, 2010; Wilhite & Glantz, 1985). In this vein, policies to manage the impacts of drought have been established to ensure farming businesses have an improved capability to manage business risks and the tools to implement sustainable and resilient risk management practices (Council of Australian Governments, 2018). For the purposes of this chapter, we refer to the broadly accepted definition of drought in Australia as "a prolonged, abnormally dry period when the amount of available water is insufficient to meet normal use" (Bureau of Meteorology and CSIRO, 2018). Likewise the severity of a drought can be measured in terms of rainfall deficiencies, defined as serious or severe if rainfall for the period in question is between the 10th and 5th percentile (serious) or below the 5th percentile (severe) (Bureau of Meteorology and CSIRO, 2018). These definitions, whilst critical to triggering local, state and/or federal action, have been found to be inadequate as they are static measures that do not account for the changing nature of extremes resulting from human-caused climate change.

As with the factors driving heatwaves, Australian rainfall variability is influenced by a range of drivers operating across timescales (King, 2014; Maher & Sherwood, 2014; Risbey et al., 2009). Within-years, the El Niño - Southern Oscillation (ENSO) phenomenon is a critical factor (Allan, 1988; Ashcroft et al., 2014; Partridge, 1991; Pittock, 1978; Power et al., 2006). During El Niño, when the eastern Pacific is anomalously warm, there is an increased chance of below-average rainfall across much of Australia. In contrast, during La Niña, when the eastern Pacific is anomalously cold, there is an increased chance of above-average rainfall across much of the eastern half of the continent. On multi-year but within-decade timescales, the Inter-decadal Pacific Oscillation (IPO) and Pacific Decadal Oscillation (PDO) affect Australian rainfall. Individually, these drivers account for between 20-40% of the year-to-year variability in rainfall, but it is their interactions that are critical in determining the length, frequency and severity of Australian droughts (King, 2014).

Given the human-caused changes occurring in the climate system there is uncertainty about the future trends in ENSO and IPO/PDO, and as a result, drought. Recent research has indicated that the historical warming of the climate has already contributed to a southerly shift in the atmospheric system that carries cold fronts across Australia, the sub-tropical ridge (Timbal et al., 2010; Whan et al., 2014). The result of this is that cold fronts are steered away resulting in rainfall declines in winter and spring and thus increasing the risk of drought conditions across southern Australia.

Australia has also experienced significant warming over the historical record, which in turn has increased evaporation and has both heightened and accelerated water stress when drought conditions occur. Research by Nicholls (2003) highlighted that whilst rainfall deficits in the Murray-Darling Basin were similar during the extreme drought years 1982, 1994 and 2002 mean maximum temperatures were in fact 1.3°C warmer in 2002. The significant temperature increase in 2002 compared to earlier drought years resulted in much greater drought stress and larger reported crop and livestock productivity losses. In 2018, much of NSW received approximately half its annual rainfall, combined maximum temperatures 2-2.5 ^{o}C above average, resulting in the third highest evaporation values since records began (1976) and some of the lowest soil moisture values on record.

Climate change will continue in the decades ahead, with warming across the whole of Australia and rainfall declines over much of the southern parts of the country very likely (Bureau of Meteorology and CSIRO, 2018). For a global increase in mean temperature of 1.5^{o}C above pre-industrial levels, the likelihood of Australian drought events similar to those experienced in 2006 occurring each year increases by between 3 and 7% (King, 2014).

Drought also contributed to the enforcement of water restrictions in most major cities, to increased electricity prices, and to major bushfire events in 2003 and 2009 (van Dijk et al., 2013). Changes in future drought frequency and severity will have a significant impact on our environment, health and wellbeing, built environment and economy. The Millennium Drought (late 1996 – mid 2010) (Bureau of Meteorology, 2015) was associated with fluctuations in water bird, fish and aquatic plant populations during the drought years in the Murray-Darling Basin (Colloff et al., 2015). The drought conditions in 2017-18 coupled with existing patterns of water utilisation in the Murray-Darling Basin have also contributed to a series of mass fish death events (Australian Academy of Science, 2019; Vertessy et al., 2019). The likely increase in the frequency of future droughts, coupled with the ongoing intensive use of water resources of the Murray-Darling Basin, is likely to result in an increase in the number and extent of mass fish death events in the future. Many ecosystems dependent upon river flows and floods are also likely to be negatively affected by future droughts, with further losses of iconic species such as the river red gums increasing in likelihood (Bond et al., 2008; Colloff et al., 2016).

A number of drought related human health impacts have already been observed. These include physiological impacts such as heat stress, dehydration, respiratory impacts due to drought-related dust storms as-well-as psychological impacts such as depression, hyper-tension and stress (Austin et al., 2018). Pre-existing health conditions such as heart disease, asthma and high blood pressure may also be exacerbated to during prolonged or extreme drought conditions, and in such times reductions in health can lead to reductions in people's adaptive capacity (Hanna & McIver, 2018). Declines in physical health are also prevalent amongst the elderly in drought-affected rural communities in Australia an increase in the frequency and severity of droughts coupled with an aging Australian population may result in greater clinical or hospital presentations (Horton et al., 2010).

Bushfire

Bushfires are a part of the Australian landscape. Evidence stretching from long-past, palaeo time-scales to the present demonstrates that fires have been a normal and important part of the Australian landscape, and we know the impacts of bushfires varied between ice ages and warm periods. Bushfires have shaped and been shaped by the characteristically Australian sclerophyll vegetation – the bush – and the fire management practices of First Nations, and the subsequent settler-colonial European fire management regimes (Kershaw et al., 2002; Lynch et al., 2007).

Recently, fire risk has also increased via greater amounts of more expensive infrastructure being located in highly exposed places. This risk would have occurred even in the absence of the changes to fire we are seeing as a result of global warming. Climate has always been a key driver of fire characteristics, with the palaeo record showing that the importance of fire is increased during periods when the climate is warming and especially in situations of greater climate variability (Bliege Bird et al., 2012; Lynch et al., 2007).

Unsurprisingly, given that the global temperature has already warmed about 1^{o}C above pre-industrial levels (IPCC, 2018), over the past decades there has been an increase in fire risk globally with fire seasons lengthening by about 20% across a quarter of Earth's vegetated surfaces, and with a doubling of the area prone to burning (Jolly et al., 2015). Similar increases in fire risk have been recorded for Australia with increases in the frequency of fire-prone conditions and increased length of the fire season (Clarke et al., 2013; Jolly et al., 2015). These trends are projected to continue into the future globally (Liu et al., 2010; Moriondo et al., 2006) and in Australia (e.g. Cary & Banks, 2000; Clarke et al., 2011; Fox-Hughes et al., 2014; Matthews et al., 2012; Pitman et al., 2007; Sullivan et al., 2012) with increases in fire danger index, number of fire ignition days, rate of fire spread and fire season length. These changes are likely to be greater for the southern parts of Australia, 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.

The increase in risk is particularly associated with increased temperature, reduced rainfall and decreased humidity. However, there is some indication it could also be influenced by changes in major regional drivers of climate or dominant synoptic systems including when the Pacific is in an El Niño-like state and when the Indian Ocean Dipole is positive, both of which conditions may increase in frequency with climate change (Cai et al., 2009; Verdon et al., 2004). Additionally, many intense fires in southeast Australia are associated with strong winds channelled ahead of powerful cold fronts with the winds drawn from the hot continental interior. The frequency of these frontal systems is projected to increase by up to a factor of four by the end of this century, though whether or not this reaches the worst case scenario is dependent on the rate at which we reduce emissions – action on climate change can avoid the worst of the projected future changes (Hasson et al., 2009).

A growing concern is that these changes in fire regimes at global scale will result in positive feedback 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).

Bushfires cause devastating loss of life, homes, and livelihoods, changing people and places irrevocably. Rationally, society should respond to the increasing risk of fire due to climate change. O’Neill and Handmer (O’Neill & Handmer, 2012) outline four key responses: 1) diminish the hazard through reduction of accidental and deliberate ignitions and through fuel reduction, 2) reduce the exposure of infrastructure and buildings and improving building codes to enhance fire resistance, 3) reduce the vulnerability of people via addressing individual vulnerabilities and engaging communities and other stakeholders in the fire planning, management and training and 4) increase the adaptive capacity of institutions via insurance and fire policies such as a focus on protection of lives and critical infrastructure in periods of extreme fire danger. These changes suggest a need for increased future resources both for pro-active fire management and for post-fire recovery efforts, as well as cultural change. However, some of these responses may be affected by institutional inertia, lack of good information and apathy as well as by ongoing demographic trends such as reduced volunteerism which impacts on the numbers of fire-fighters. Additionally, extreme fire danger periods and associated heatwaves will increasingly impact on the capacity and health of firefighters and householders, reducing their ability to respond to fire risk (O’Neill & Handmer, 2012).

Flood and coastal inundation

Australia is characterised as a dry continent with limited freshwater resources, and our rivers are characterised have relatively low and very variable flows. In spite of being the driest inhabited continent, 80% of Australia’s population can be found at or near coasts and rivers of major significance. The rate of water use in Australia is amongst the highest in the world (Department of Environment and Energy, 2011) and Australia faces challenges of a growing and urbanising population, of growing demand for water for food and fibre production, and of environmental sustainability, particularly in the face of climate change (Prosser, 2011). These challenges are not unique to Australia, but, unlike other developed nations, Australia faces the added complications of 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 (Thompson, 2019). Further, the concentration of human settlements along Australia’s coastlines means a large proportion of the population is exposed to the impacts of rising sea levels (Abel et al., 2011). These dual drivers – extreme rainfall and sea level rise – mean floods will be central to Australia’s climate changed future (Bureau of Meteorology and CSIRO, 2018).

Floods are the most costly natural disaster for Australia. The average direct annual cost of flooding between 1967 and 1999 was estimated at $314 million (Bureau of Transport Economics, 2001). Costs vary considerably between flood events (depending on flood volumes and infrastructure affected); for example, the Brisbane floods of 1974 caused $700 million damage at that time, while the damage from the 2011 floods resulted in approximately $10 billion in damages (Prosser, 2011). Impacts of flooding also vary geographically with the economic cost of natural disasters for Queensland over the 2007 to 2016 period estimated at $11 billion per year, and floods contributing 60% of this cost. In comparison, in Western Australia in the same period natural disasters averaged $1 billion per year, with only 15% of that cost being due to floods (Deloitte Access Economics for Australian Business Roundtable for Disaster Resilience and Safer Communities, 2017).

At a national scale, statistical analysis of historical floods shows that decades of higher than average rainfall, such as the 1950s to 1970s, can have more extreme floods than would be expected under average rainfall conditions. During these wet decades, a once-in-a-100-year flood is likely to be twice as large as would be expected during drier times (Kiem et al., 2003). As the climate changes due to global warming, this will become ever more a pressing issue. Both warmer ocean temperatures and ambient atmospheric conditions are likely to enhance to moisture holding capacity of the atmosphere. This in turn will result in more intense rainfall events leading to more extensive flooding. Climate modelling also supports the likely increase in the intensity of cyclones as a result of warmer oceanic and atmospheric conditions (Johnson et al., 2016). In Queensland, the Northern Territory, and Western Australia, cyclones are a major driver of floods, so the future changes in flooding are likely to be large in these states.

Meanwhile, globally sea levels have already risen by 20cm since 1880, and this is expected to continue – and increase in the rate of rise – into the future (Bureau of Meteorology and CSIRO, 2018). Sea level rise impacts on human settlements and ecosystems will be affected, via a number of different processes including enhancements of astronomical tides, storm surges, and waves caused by wind, swell, local pressure systems, and coastal geographic features (McInnes et al., 2016). Around Australia, sea level rise has been most pronounced in the north-west, north, and south-east of the continent (Bureau of Meteorology and CSIRO, 2018). Sea level rise, therefore will not lead to impacts uniform in place and time, rather, coastal inundation will be a result of the combination of sea level, geography, and prevailing weather conditions.

In the absence of effective mitigation or adaptation, it is highly likely that insurance premiums will rise as does future flood risk. Currently, not all hazards are insurable. Hazards such as bushfires, riverine flooding and storm damage are generally covered, but events such as coastal inundation and erosion are not. More than $277 billion (in 2019 dollars) in commercial, industrial, road and rail, and residential assets are exposed to flooding and erosion hazards at a sea-level rise of 1.1m (Steffen, Mallon, et al., 2019). Whilst this scenario represents the upper limit of possible sea-level rise it is still plausible given the existing, inadequate, efforts to reduce emissions.

Australian coastal assets at risk from the combined impact of inundation and shoreline recession include: between 5,800 and 8,600 commercial buildings, with a value ranging from $58 to $81 billion (2008 replacement value); between 3,700 and 6,200 light industrial buildings, with a value of between $4.2 and $6.7 billion (2008 replacement value); and between 27,000 and 35,000 km of roads and rail, with a value of between $51 and $67 billion (2008 replacement value) (Department of Environment and Energy, 2011). Other national infrastructure within 200 meters of the coastline include: 120 ports, five power stations, 258 police, fire and ambulance stations, 75 hospitals and health services and 44 water and waste facilities (Department of Climate Change, 2009). All these sites critical for a well-functioning society will be threatened by floods in our climate changed future.

It is clear that due to rainfall extremes and sea level rise, both coastal flooding and riverine flooding risk will increase in the future, and this is especially critical to Australia given the concentration of our human settlements around rivers and the coasts. As the climate changes, the increased likelihood and severity of floods will amplify existing risks to Australian communities, including impacts on health and well-being, damage to coastal ecosystems and disruption to individual and community livelihoods. Beyond the impacts on people, the cost of repairing damage to infrastructure is large, and is likely to result in a high cost to local economies and the Australian economy generally.

Adaptation responses to both flooding and inundation are broad but are likely to be costly. In many instances these options include infrastructure “hardening”, such as development of sea walls, flood gates, or raising structures, “accommodation” which includes actions such as developing pumps and raising footpaths, and “retreat” which involves the relocation of residents from areas that are likely to become inundated or flooded (Fletcher et al., 2013). These questions, though, are values-laden, and the process by which different approaches to adapting to future floods are selected will need to be managed carefully to ensure the voice of all people is heard in the decision-making process.

Interactions in the real world

When examining the implication of climate change on natural disasters, emphasis is often placed on changes in individual climate variables, such as rainfall. However, historically significant weather and climate events are often the result of the combined influence of extremes in multiple variables occurring simultaneously. This is often referred to as the compounding effect of climate extremes and whilst it is harder to determine the severity or frequency of such compound events, understanding the interactions and aggregated impacts provides a much more realistic estimate of future impacts.

Compound extreme events can occur in various ways (Coburn, 2014), for example an extreme coastal storm surge may occur in conjunction with extreme rainfall, resulting in large scale coastal inundation through a combination of surge and related overland flooding. Similarly, extreme rainfall and extreme high wind events along the New South Wales coast are often associated with the simultaneous occurrence of an intense low pressure system, cold front and thunderstorms (Bureau of Meteorology and CSIRO, 2018). Drought can often coincide with extreme heatwave events or record high daily temperatures— an occurrence which typically results in large impacts on agriculture, human health, fire weather and infrastructure.

Climate change can have a significant influence on the frequency, magnitude and impact of some types of compound events. For example, the coincidence of background warming trends, background drying trends and extreme heat and low rainfall across Tasmania during the spring, summer and autumn of 2015–2016. October 2015 saw the third highest mean monthly maximum temperature on record for the state, record low monthly rainfall and record high fire danger (Bureau of Meteorology and CSIRO, 2018).

As climate change continues, the combination of increases in heavy rainfall and rising sea levels means that coastal and estuarine environments may experience increased flood risk, similarly the coincidence of drought and extreme heatwave conditions is very likely in the future. Understanding the frequency and resultant severity of future compound extreme events is a significant scientific challenge, but extremely important for effective disaster risk mitigation and strategic adaption (Mora et al., 2018).

Looking toward disaster justice to a climate changed future

In this chapter, we have explored the way in which Australia’s future disasters will be affected by a changing climate. Although Australia has a history of natural disasters – fires, floods, storms, heatwaves – the past cannot be presumed to predict the future due to the influence of human-caused climate change. In the most general terms, climate change will take the disasters Australia already experiences, and make them more severe and less predictable. Heatwaves, the most deadly of Australia’s natural disasters, will be more frequent, protracted, and hotter. Drought too will see people and the natural environment deprived of water more often and to greater extremes. Drought takes a toll on people not just through the physical impacts of the lack of water but through substantial mental health impacts, too. Severe drought can destroy livelihoods and agricultural communities. We have seen the devastation of bushfire in Australia, no more profoundly than in the 2009 Black Saturday Victorian bushfires. Current understandings of the fire-climate relationships suggest that we may experience reinforcing feedbacks in the future, where fires exacerbate global warming, which in turn raises the risk of fire. Flooding and coastal inundation will affect many Australians in our settlements concentrated around rivers and coasts.

Even under the most optimistic scenarios for emissions reductions we are still going to see the effects of climate change on natural disasters. We must consider how we can best adapt to this climate changed future (Conway et al., 2019; Howden et al., 2007; IPCC, 2014). This brings us to the question of justice, which will be examined by others in this book. Climate change is a problem caused by human choices and actions. The burning of fossil fuels and the clearing of land has created vast wealth for some people, but not all (Althor et al., 2016). And we know that the effects of climate change will hit the hardest on those who benefitted the least from the economic development that brought on climate change (Lewis et al., 2019) often in complex and insidious ways (e.g. Althor et al., 2018). The fact that we, as a species, have built for ourselves a climate changed future means that questions of disaster justice can become only more critical.

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