Chapter 2

Australia's changing climate and its implications for the built environment

2.1 Australia has a significant amount of residential dwellings, other buildings and infrastructure. As the Australian Sustainable Built Environment Council (ASBEC) explained, 2015 figures indicate that there are almost 8 million buildings across the country, and that these buildings have a replacement cost of approximately $5.7 trillion. These buildings include:

- over 7.5 million residential buildings with a replacement value of $3.5 trillion;
- around 215,000 commercial buildings worth $1.8 trillion; and
- around 139,000 industrial buildings worth $0.3 trillion.[1]

2.2 Other essential infrastructure networks are also extensive and of high value, such as roads, railways and energy infrastructure.

2.3 These buildings and other infrastructure assets need to withstand the Australian climate. Australians are already familiar with extreme events such as heatwaves, cyclones, bushfires and floods that have caused extensive damage to cities and infrastructure and resulted in deaths and injuries. Due to climate change, however, many types of extreme events are expected to become more frequent or more intense. Coastal areas are also experiencing rising sea levels and more intense storm surges.

2.4 Damage from extreme events can already be significant, both in terms of human life and economic cost. To understand the implications for Australia's infrastructure, this chapter highlights the evidence received about recent changes to the climate system, terrestrial environment and the marine environment that are relevant when considering future challenges for housing, buildings and infrastructure.

2.5 Available evidence about projected changes is also discussed, noting that there is uncertainty about such projections and that future changes are dependent on the emissions pathway taken. In doing so, the report refers to the four emission pathways adopted in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The following extract from CSIRO's submission provides a useful explanation of the IPCC's emissions pathways framework:

> The magnitude and nature of multi-decadal to centennial climate change that the world is likely to experience depends strongly on actions to reduce the emissions of greenhouse gases. The Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) adopted four Representative Concentration Pathways (RCPs) to span the range of

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1 Australian Sustainable Built Environment Council (ASBEC), *Submission 26*, p. 2.

> possible future trajectories in terms of the resulting greenhouse gas concentrations in the atmosphere. The four RCPs are RCP2.6, RCP4.5, RCP6, and RCP8.5; these are named technically after future radiative forcing values, but basically range from very low to high emissions pathways, and include the effects of burning fossil fuels as well as greenhouse gas emissions from land use change and industrial processes such as concrete manufacturing. The Paris Agreement goals are consistent with a future concentration pathway that falls between RCP2.6 and RCP4.5; whereas current commitments by countries are more consistent with the RCP4.5 trajectory at least until 2030 or so…RCP4.5 is often referred to as an 'intermediate emissions scenario'. A continuation of historical emissions is more consistent with the RCP8.5 trajectory. Given there is not yet any certainty that the world will meet the Paris Agreement commitments, good risk management should consider this whole range of future climates.[2]

Sea level rises and coastal erosion

2.6 Sea levels have risen over the 20th century as a result of ocean thermal expansion[3] and an increase in water entering the ocean from melting glaciers and ice caps.[4] CSIRO submitted that between 1966 and 2009, the average rate of relative sea level rise from observations along the Australian coast was 1.4 ± 0.2 millimetres per year.[5] Globally, sea levels increased between 1993 and 2016 at 'an average rate of 2.6 to 2.9 millimetres per year, amounting to a total increase in the order of 7 centimetres over that period'.[6]

2.7 A joint submission from several Australian Government departments and agencies added that the overall trend in sea level rise is affected by variability, such as El Niño and La Niña events. The submission noted:

> A strong event, such as the 2015-16 El Niño or the 2010-11 La Niña, can result in fluctuations of 5 to 10 millimetres in global sea level over periods

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2 CSIRO, *Submission 45*, p. 7 (citation omitted).

3 As the ocean warms, its density decreases resulting in an increase in volume. See JA Church and JM Gregory et al, 'Changes in Sea Level' in *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, JT Houghton and Y Ding et al (eds), 2001, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 644.

4 CSIRO, *Submission 45*, p. 7; Climate Council of Australia, *Submission 40*, p. 3. For a detailed analysis of sea level change, see JA Church and PU Clark et al, 'Sea Level Change' in *Climate Change 2013: The Physical Science Basis—Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, TF Stocker and D Qin et al (eds), 2013, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

5 CSIRO, *Submission 45*, p. 7.

6 Department of the Environment and Energy, Bureau of Meteorology, Great Barrier Reef Marine Park Authority, Attorney-General's Department, Department of Agriculture and Water Resources, and Geoscience Australia, *Submission 39*, p. 13.

> of 6 to 12 months, with larger shifts on individual coastlines. (Sea levels in the western Pacific, including eastern and northern Australia, are generally lower during El Niño events and higher during La Niña events).[7]

2.8 Nevertheless, it is expected that by 2020 the Australian sea level will, on average, be 0.06 to 0.19 metres above the 1986–2005 level. The rate of increase is expected to be faster than that experienced over the 20th century, due to continued ocean thermal expansion and melting glaciers and ice caps, as well as the loss of mass from ice sheets, and changes in the mass of water stored on land.[8]

2.9 CSIRO added that whether a low or high emissions pathway is taken is expected to have only a limited impact on the committed amounts of sea level rise 'over the next decade or so'. However, CSIRO emphasised that future sea level rises later in this century will be sensitive to the amount of global greenhouse emissions. CSIRO submitted:

> By 2090, intermediate global emissions (RCP4.5) are likely to lead to a global sea-level rise of 0.27 to 0.66 m. High global emissions (RCP8.5) are likely to lead to a rise of 0.38 to 0.89 m. However, a collapse of the marine-based sectors of the Antarctic ice sheet could add several tenths of a metre to sea-level rise late in the century…[9]

2.10 It is widely accepted that climate change could result in increased numbers of coastal properties being damaged or lost due to storm surges, increased coastal erosion and higher sea levels. The ASBEC submitted that the impacts of these climate change-related developments 'are being seen already in many Australian coastal settlements'.[10] Local governments advised that coastal assets are already being affected, and that the cost to protect, upgrade and repair such assets is expected to increase with climate change and sea level rise.[11]

2.11 The Climate Council of Australia advised that the exposure of coastal assets to sea level rise 'is very large and the risks are set to increase'. The Climate Council submitted that, across Australia, more than $226 billion (2008$) in commercial, industrial, road and rail, and residential assets are potentially exposed to flooding and erosion hazards at the high-end scenario of 1.1 metres of sea level rise by 2100. This figure includes 5800 to 8600 commercial buildings, with an estimated replacement value of $58 billion–$81 billion; 3700 to 6200 light industrial buildings,

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7 Department of the Environment and Energy et al, *Submission 39*, p. 13.

8 CSIRO, *Submission 45*, pp. 7–8.

9 CSIRO, *Submission 45*, p. 8.

10 ASBEC, *Submission 26*, p. 2.

11 See Hobsons Bay City Council, *Submission 7*, p. 6.

with an estimated replacement value $4.2 billion–$6.7 billion; and 27,000 to 35,000 kilometres of roads and rail, with a replacement value of $51 billion–$67 billion.[12]

2.12 In 2006, it was estimated that approximately 3 per cent of addresses in Australia are within three kilometres of the shoreline in areas less than five metres above mean sea level.[13]

2.13 The committee received evidence of how sea level rises are expected to affect individual cities and communities. Examples include:

- Darwin—the Northern Territory Government advised that around 180 residential buildings in Greater Darwin are estimated to be at risk from a 1.1-metre sea level rise. In addition, '190 buildings within 110 metres of the high tide mark…are at risk from erosion'.[14] The Government added that the threat is particularly evident around Darwin 'because Darwin's coastal cliffs are comprised of erodible, soft rock necessitating continual remediation and reinforcement by local government'.[15]
- Collaroy-Narrabeen Beach—the committee was advised that this beach is the most vulnerable to erosion from coastal storms in northern Sydney (and is considered be the third most at risk area from coastal processes in Australia). The Environment Institute of Australia and New Zealand noted that in 2016 an estimated $30 million in damage was caused by severe storms that eroded away about 50 metres of beach and caused extensive property damage.[16]
- City of Lake Macquarie—the local council informed the committee that a 0.9-metre increase in relative sea level is expected to result in the permanent inundation of over 93 hectares of residential zoned land, along with the loss of public land and facilities.[17]

2.14 The National Climate Change Adaptation Research Facility (NCCARF) at Griffith University has published maps indicating how sea level rise place areas of Australia potentially at risk of inundation. The maps are indicative only, and do not take into account storm surge or wave height, nor do they take into account sea walls,

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12 All dollar figures are 2008$. Climate Council of Australia, *Submission 40*, p. 4 (citation omitted).

13 K Chen & KJ McAneney, 'High-resolution estimates of Australian coastal population', *Geophysical Research Letters*, 33, 2006; cited in B Cechet, P Taylor, C Griffin and M Hazelwood, 'Australia's coastline: adapting to climate change', *AusGeo News*, no. 101, March 2011, Geoscience Australia, www.ga.gov.au/ausgeonews/ausgeonews201103/climate.jsp (accessed 5 January 2018).

14 Northern Territory Government, *Submission 17*, p. 2.

15 Northern Territory Government, *Submission 17*, p. 2.

16 Environment Institute of Australia and New Zealand, *Submission 36*, p. 4.

17 Lake Macquarie City Council, *Submission 29*, p. 2.

barriers or erosion. Noting the limitations, the maps provide an accessible means for understanding the potential risks of sea level rise for particular communities.

2.15 The maps for Brisbane and the Gold Coast for 2100 under a low emissions scenario follow at Figure 2.1 (on page 10) and Figure 2.2 (on page 11).

Changes in temperature and extreme heat events

2.16 Along with sea level rises, change in temperature is perhaps the consequence most readily associated with climate change. The Climate Council provided the following explanation of how greenhouse gas emissions from human activities affects temperature and precipitation:

> As greenhouse gases increase in the atmosphere, primarily carbon dioxide from the combustion of fossil fuels (coal, oil and gas), the climate system is warming because these gases are trapping more heat. The oceans are also warming, especially at the surface, and this is driving higher evaporation rates that, in turn, increases the amount of water vapour. In addition, a warmer atmosphere can hold more water vapour, leading in turn to more intense rainfall. The 1°C temperature rise that has already occurred, together with increasing evaporation, has led to an increase of about 7% in the amount of water vapour in the atmosphere.[18]

Temperature

2.17 CSIRO submitted that Australia's mean land surface air temperature and surrounding sea surface temperature have both increased by around 1°C since 1910. CSIRO added that:

> In recent decades, months warmer than average occur more often than months colder than average. And since 2001, the number of heat records in Australia has outnumbered extreme cool records by about 3 to 1 for daytime maximum temperatures, and about 5 to 1 for night time minimum temperatures.[19]

2.18 Recorded temperature changes by region are depicted at Figure 2.3 (on page 12).

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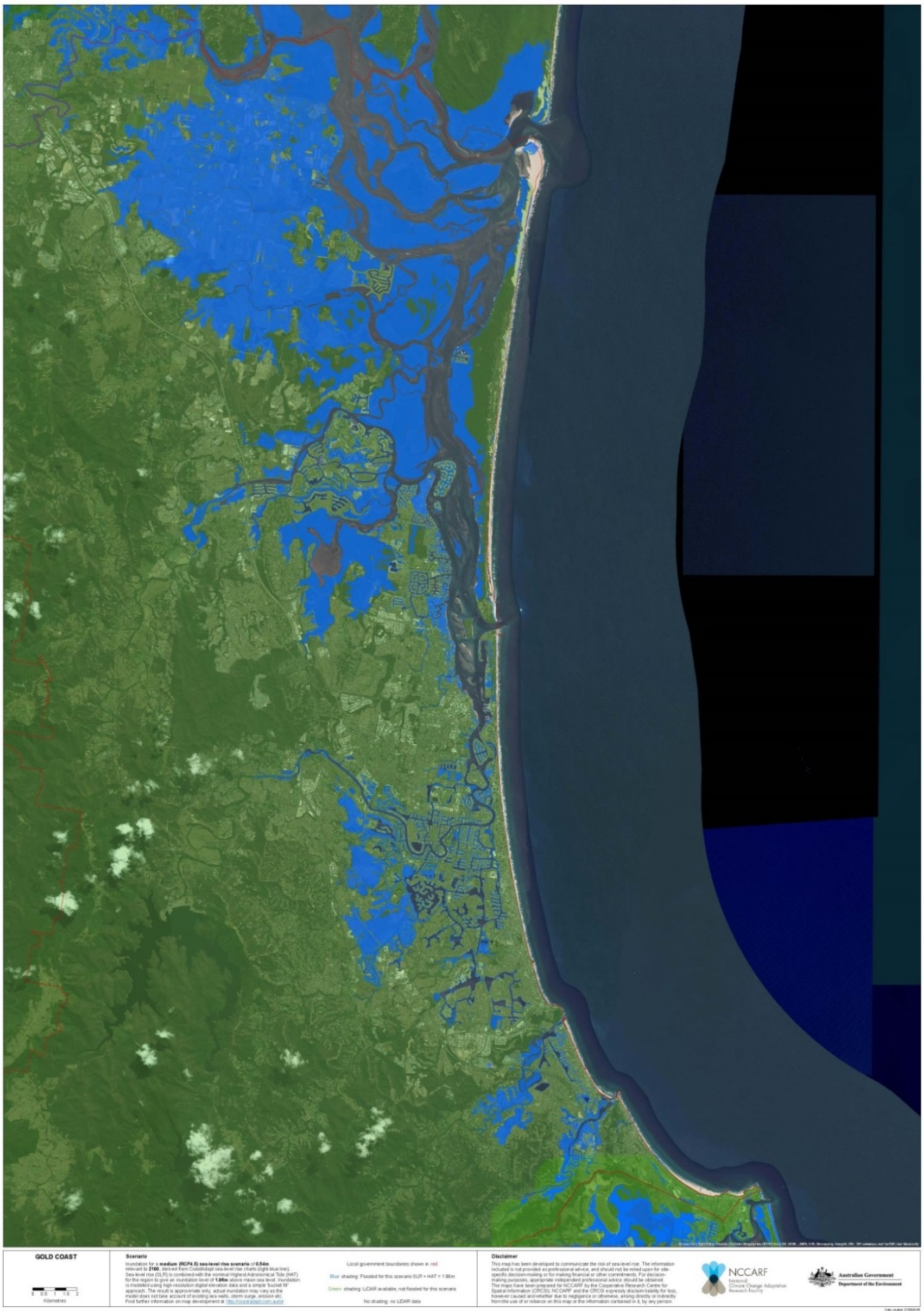
18 Climate Council of Australia, *Submission 40*, p. 8.

19 CSIRO, *Submission 45*, p. 8.

Figure 2.1: Brisbane, potential inundation in year 2100 under low greenhouse gas scenario (RCP4.5)

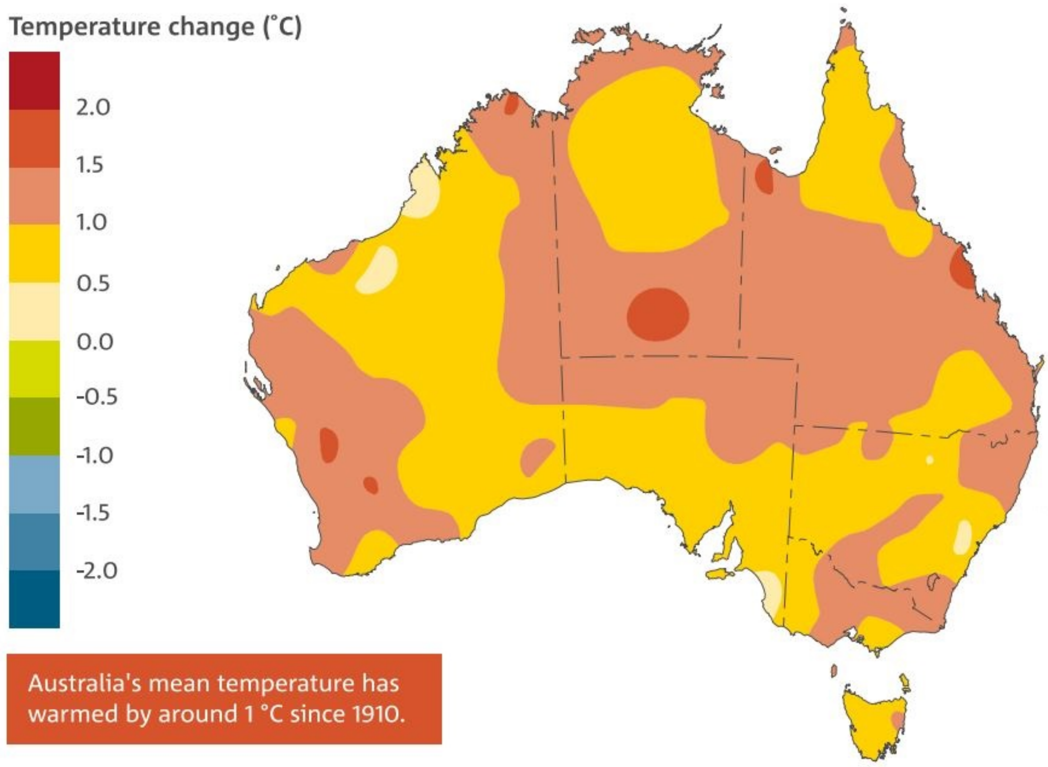
Figure 2.2: Gold Coast, inundation in year 2100 under low greenhouse gas scenario (RCP4.5)



Note: These maps illustrate a sea-level rise scenario of 0.54 metres relevant to 2100, derived from CoastAdapt sea-level rise charts, combined with the nominal highest astronomical tide that gives an inundation level of 1.96m above mean sea level. Inundation has been modelled using high-resolution digital elevation data and a simple 'bucket fill' approach. As noted above, the model does not take account features such as sea walls. Further information on how the maps have been developed is available at https://coastadapt.com.au/slr.

Source: NCCARF, 'Sea-level rise and future climate information for coastal councils', CoastAdapt, https://coastadapt.com.au/slr (accessed 9 January 2018).

Figure 2.3: Annual mean temperature changes across Australia since 1910



Source: Bureau of Meteorology; published in CSIRO and Bureau of Meteorology, 'Report at a glance' in *State of the Climate 2016*, www.bom.gov.au/state-of-the-climate/index.shtml (accessed 9 January 2018).

2.19 When considering future changes, CSIRO warned that there are two key uncertainties: future anthropogenic emission trajectories of greenhouse gases and the response of the Earth's climate system to those emissions.[20]

2.20 Notwithstanding this, CSIRO submitted that regional climate projections indicate that 'mean, daily minimum and daily maximum temperatures will continue to increase throughout this century for all parts of Australia'. CSIRO continued:

> The magnitude of the warming later in the century will depend on global emissions. By around 2030, Australian annual average temperature is projected to increase by 0.6-1.3 °C above the climate of 1986-2005 under intermediate global emissions (RCP4.5), with little difference in warming between different emission (i.e. RCP) scenarios. The projected temperature range by 2090 is 0.6 to 1.7 °C for low emissions, 1.4 to 2.7 °C for intermediate emissions and 2.8 to 5.1 °C for high emissions. Inland areas are likely to warm more than coastal areas.[21]

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20 CSIRO, *Submission 45*, p. 9.

21 CSIRO, *Submission 45*, p. 9.

Heatwaves

2.21 A heatwave event is a period of abnormally hot weather that lasts several days.[22]

2.22 Overall, the evidence received by the committee during this inquiry noted that the duration, frequency and intensity of heat events have increased significantly. For example, CSIRO submitted that attribution studies have identified that the 2013 and 2014 heatwave events in Australia were influenced by climate change.[23] Similar evidence was provided in the Climate Council's submission, which provided the following comments on the trend in extreme heat events:

> The incidence of extreme temperatures has increased markedly over the last 50 years, and heatwaves have become hotter, are lasting longer and occur more often…Ground-breaking scientific research that tells us how much influence climate change has on a single heatwave or heat record has shown that many of the most extreme weather events, such as Australia's record hot year in 2013, were virtually impossible without climate change…The 2016/2017 summer has been described as the "Angry Summer", highlighting the extraordinary number of weather records broken…This follows the long-term trend of rising global average temperature since the 1970s, increasing at a rate 170 times faster than the background rate over the past 7,000 years…[24]

2.23 Submissions commented on a wide range of projected changes in Australia's climate and extreme events. On temperature-related changes, CSIRO explained that projections indicate that heatwaves will 'become more frequent, hotter, and longer across Australia by the end of the 21st century'. More frequent and hotter hot days are expected, with the degree of change dependant on the emissions pathway taken.[25]

2.24 Projections for individual cities were provided, such as the following evidence from CSIRO regarding expected changes in Sydney's climate:

> Sydney currently has around 27 days each year where the maximum temperature exceeds 30°C. By 2090, under intermediate global emissions of greenhouse gases (RCP4.5), there are likely to be approximately 51 days each year exceeding 30°C; under high emissions (RCP8.5), this is projected to rise to 84 days. The average longest run of Sydney days with maximum temperature exceeding 30°C is currently around four per year. By 2090, under moderate (RCP4.5) emissions this will rise to around six days and under high (RCP8.5) emissions, nine days.[26]

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22 Bureau of Meteorology, 'Glossary', www.bom.gov.au/lam/glossary/hpagegl.shtml (accessed 9 January 2018).

23 CSIRO, *Submission 45*, p. 9.

24 Climate Council of Australia, *Submission 40*, p. 1 (citation omitted).

25 CSIRO, *Submission 45*, p. 9.

26 CSIRO, *Submission 45*, p. 9.

2.25 CSIRO and the Bureau of Meteorology have undertaken analysis to project how the number of hot days in Australian capital cities will increase over time under different emissions pathways. Results of this analysis are at Table 2.1.

Table 2.1: Actual and projected average number of days per year with the maximum temperature above 35°C for Australian capital cities

City	1995	2030	2090	
		RCP4.5	*RCP2.6*	*RCP8.5*
Adelaide	20	26	32	47
Brisbane	12	18	27	55
Canberra	7.1	12	13	29
Darwin	11	43	52	265
Hobart	1.6	2.0	2.0	4.2
Melbourne	11	13	14	24
Perth	28	36	37	63
Sydney	3.1	4.3	4.5	11

Note: The 1995 figures are averages of observations for 1981–2010. The 2030 and 2090 figures are from climate model projections under different RCP scenarios.

Source: CSIRO and Bureau of Meteorology, *Climate Change in Australia – Technical Report, 2015*; cited in Climate Council of Australia, *Submission 40*, p. 6.

2.26 In urban areas, rising temperatures and a greater number of hot days per year due to climate change could exacerbate the 'urban heat island'[27] effect that city residents already experience. The following evidence received during a previous inquiry into stormwater management illustrates how heat can be significantly higher in built areas compared to nearby green areas:

> …on an early March morning at break of dawn, the temperature over Adelaide's city centre was 10 degrees warmer than it was over the Parklands. That is because of the hard surface, the heat sink and everything else like that. That relates back to a suburban environment. If you have all house and hard space—all impervious area—in an urban environment, that one park at the end of every three or four streets, no matter how well it is manicured or preserved, is not going to provide that cooling effect. It needs to be done street by street.[28]

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27 The urban heat island effect describes the situation when an urban area is significantly warmer than the surrounding rural area. One of the explanations for this is because greenery, which provides a cooling effect, has been replaced with urban infrastructure to a significant extent. Waste heat from other human activities and a range of factors regarding the design of buildings and the urban environment also contribute to the heat island effect.

28 Mr Andrew King, Chair, Stormwater South Australia, *Committee Hansard*, 26 August 2015, p. 30; Senate Environment and Communications References Committee, *Stormwater management in Australia*, December 2015, p. 17.

2.27 Several submitters commented on the urban heat island effect during this inquiry. For example, the Northern Territory Government advised that it is aware that the Darwin central business district 'is consistently hotter than surrounding areas, largely due to planning outcomes and building designs that collectively contribute to the creation of a significant heat sink and source in today's climate'.[29]

2.28 The urban heat island effect is discussed further in Chapter 4. Heatwaves also have implications for the health of building occupants, which is discussed in Chapter 6.

Bushfires

2.29 Submissions commented on fire weather. Since the 1970s, longer fire seasons across large parts of Australia have been encountered.[30] CSIRO added:

> Projected warming and drying in southern and eastern Australia will lead to fuels that are drier and readier to burn, with increases in the average forest fire danger index and a greater number of days with severe fire danger…[31]

2.30 It was emphasised, however, that the influence of climate change on the amount and condition of the fuel needed for bushfires is 'complex'. To illustrate, the Climate Council noted that 'increases in rainfall may dampen the bushfire risk in one year by keeping the fuel load wetter, but increase the risk in subsequent years by enhancing vegetation growth and thus increasing the fuel load in the longer term'. Notwithstanding the complexity in assessing the implications of a changing climate for bushfire risk, the Climate Council observed that 'it is clear…that climate change is driving up the likelihood of dangerous fire weather'. The Climate Council explained:

> At higher temperatures, fuel is 'desiccated' and is more likely to ignite and to continue to burn…In addition, fires are more likely to break out on days that are very hot, with low humidity and high winds—that, is high fire danger weather…Heatwaves are becoming hotter, longer and more frequent, which is contributing to an increase in dangerous bushfire weather. Also, over the past several decades in the southeast and southwest of Australia, there has been a drying trend characterised by declining rainfall and soil moisture. Contributing to this drying trend is a southward shift of fronts that bring rain to southern Australia in the cooler months of the year…In very dry conditions, with relative humidity less than around 20%, fuel dries out and becomes more flammable…Jolly et al. 2015 and

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29 Northern Territory Government, *Submission 17*, p. 3.

30 CSIRO, *Submission 45*, p. 8. Fire weather is measured using the Forest Fire Danger Index (FFDI), which estimates the fire danger on a given day based on observations of temperature, humidity, wind speed and rainfall. The 'annual 90th percentile of daily FFDI points has increased since 1974 across Australia, especially in southern and eastern Australia, and the fire season has lengthened'. CSIRO and Bureau of Meteorology, 'Australia's changing climate' in *State of the Climate 2016*, www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml (accessed 9 January 2018).

31 CSIRO, *Submission 45*, p. 10.

> Williamson et al. 2016 highlighted that the combination of droughts and heatwaves contribute significantly to particularly bad fire seasons in Australia's southeast. A study into forested regions of Australia found that, in the majority of cases, years with drought conditions resulted in a greater area of burned land…[32]

2.31 The implications of bushfires for infrastructure are already significant under current conditions. The Climate Council submitted that Deloitte Access Economics has estimated that bushfires result in annual costs of approximately $380 million on average.[33] Australia's worst bushfire disaster—the 2009 Black Saturday bushfires in Victoria—caused the loss of 173 lives and resulted in estimated damage totalling $4.4 billion.[34]

2.32 Victoria has been particularly susceptible to damage from bushfire, sustaining around 50 per cent of economic damage despite only comprising 3 per cent of Australia's total landmass.[35]

2.33 Like other natural disasters, bushfires can damage a wide range of infrastructure, including water supplies, roads and bridges, and electricity infrastructure. The Climate Council provided the following overview of how bushfires can affect essential infrastructure:

> Large-scale, high intensity fires that remove vegetation expose top soils to erosion and increased runoff after subsequent rainfall…This can increase sediment and nutrient concentrations in nearby waterways, potentially making water supplies unfit for human consumption…During the Black Saturday fires in 2009, 10 billion litres of Melbourne's drinking water were pumped to safer storage locations because of fears it would be contaminated…These bushfires affected about 30% of the catchments that supply Melbourne's drinking water. Melbourne Water estimated the post-fire recovery costs, including water monitoring programs, to be more than $2 billion…The 2016 Tasmanian wilderness fire caused more than $130 million in damages to roads, hydro-electric infrastructure and bridges…[36]

32 Climate Council of Australia, *Submission 40*, pp. 6–7 (citations omitted).

33 Climate Council of Australia, *Submission 40*, p. 7.

34 ASBEC, *Submission 26*, p. 4.

35 Climate Council of Australia, *Submission 40*, p. 7 (citation omitted).

36 Climate Council of Australia, *Submission 40*, p. 7 (citations omitted).

Precipitation, storms, cyclones and flooding

2.34 This section examines the implications of climate change for precipitation and a variety of storm and water-related risks to coastal and non-coastal areas.

Precipitation

2.35 CSIRO advised that rainfall patterns have changed. Examples put forward by CSIRO include:

- the 19 per cent reduction of May–July rainfall in the south-western region of Western Australia since 1970;
- reductions in rainfall during April–October (the growing season) in the continental south-east of Australia;
- increases in rainfall since the 1970s in parts of northern Australia; and
- decreases in average snow depths 'at a number of Australian sites since the 1950s'.[37]

2.36 In their contribution to the joint departmental and agency submission, the Bureau of Meteorology and the Great Barrier Reef Marine Park Authority (GBRMPA) explained that 'evidence for significant observed changes in extreme high rainfall is mostly inconclusive'. Notwithstanding this, it was noted that in the decades since the 1950s some parts of Australia 'do show a tendency…towards a higher proportion of rainfall falling from extreme events'.[38]

2.37 On future projections for precipitation, the joint submission explained that climate models 'generally indicate a higher proportion of total rainfall coming from extreme events, with more extreme rainfall events projected even in those regions where total rainfall is expected to decrease'.[39] CSIRO provided the following summary of expected precipitation changes based on information currently available:

> In southern Australia, winter and spring rainfall is projected to decrease, though increases are projected for Tasmania in winter…The winter decline may be as great as 50 per cent in south-western Australia under high emissions by 2090. The direction of change in summer and autumn rainfall in southern Australia is uncertain, but there is medium confidence in a decrease in south-western Victoria in autumn and in western Tasmania in summer. There is medium confidence in a winter rainfall decrease across eastern Australia by 2090. In northern Australia and northern inland areas, there is low confidence in the direction of future rainfall change by 2090,

37 CSIRO, *Submission 45*, p. 8.

38 Department of the Environment and Energy et al, *Submission 39*, p. 14.

39 *Submission 39*, p. 14.

> but substantial changes to wet-season and annual rainfall cannot be dismissed.[40]

2.38 As a result of the projected precipitation changes, southern Australia is expected to encounter increased time in drought 'with a greater frequency of severe droughts'. This is related to 'the southward shift of the fronts from the Southern Ocean that bring rain across southern Australia during the cool months of the year (winter and spring)'.[41]

Storm surges and tropical cyclones

2.39 Storm surges[42] and tropical cyclones attracted significant comment. These can be interlinked, as storm surges 'accompany tropical cyclones as they make landfall'[43] and 'the most extreme storm surges are normally associated with cyclones'.[44] However, storm surges 'can also be formed by intense low pressure systems in non-tropical areas, such as east coast lows in the Tasman Sea'.[45]

2.40 In modern Australian history, Tropical Cyclone Tracy, which devastated Darwin in 1974, is the standout example of the destruction cyclones can cause in Australia. Sixty-six people died from Cyclone Tracy (53 on land and 13 at sea) and approximately 35,000 residents (out of a population of 48,000) were evacuated in its aftermath.[46]

2.41 Cyclones that have occurred more recently have also caused significant damage. The ASBEC noted that Cyclone Yasi (2011) 'was estimated to have caused over $3.5 billion in damage and lost business in Queensland'.[47] Cyclone Debbie (2017) resulted in estimated insurance losses of over $1.6 billion.[48]

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40 CSIRO, *Submission 45*, p. 9. See also Climate Council of Australia, *Submission 40*, p. 8.

41 Climate Council of Australia, *Submission 40*, pp. 1, 10. See also CSIRO, *Submission 45*, p. 10.

42 Storm surges are 'a rise above the normal sea level resulting from strong, mainly onshore winds and/or reduced atmospheric pressure'. They can result in extensive flooding of coastal areas, particularly in low-lying areas. Climate Council of Australia, *Submission 40*, p. 3.

43 Climate Council of Australia, *Submission 40*, p. 3.

44 Department of the Environment and Energy et al, *Submission 39*, p. 13.

45 Climate Council of Australia, *Submission 40*, p. 3.

46 Department of Tourism and Culture (NT), 'Cyclone Tracy', https://dtc.nt.gov.au/arts-and-museums/northern-territory-library/nt-history/cyclone-tracy (accessed 9 January 2018).

47 ASBEC, *Submission 26*, p. 4.

48 National Insurance Brokers Association of Australia, *Submission 8*, p. 2.

2.42 Modelling work commissioned by the Northern Australia Insurance Premiums Taskforce estimated that the long-term future losses from cyclones in northern Australia are expected to be, on average, around $285 million per year.[49]

2.43 It was acknowledged that trends in tropical cyclone frequency and intensity 'are difficult to discern for the Australian region due to the short observational records, as well as high year-to-year variability'.[50] Nevertheless, it is projected that tropical cyclones will 'become less frequent with a greater proportion of high intensity storms (those with stronger winds and greater rainfall)'.[51] The Climate Council provided the following overview of the implications of climate change for tropical cyclones:

> Climate change is likely to affect tropical cyclone behaviour in two ways. First, the formation of tropical cyclones most readily occurs when there are very warm conditions at the ocean surface and when the vertical gradient is strong. As the climate continues to warm, the difference between the temperature near the surface of the Earth and the temperature higher up in the atmosphere, is likely to decrease as the atmosphere continues to warm. As this vertical gradient weakens, it is likely that fewer tropical cyclones will form…Second, the increasing temperature of the surface ocean affects the intensity of cyclones (along with changes in upper atmosphere conditions), both in terms of maximum wind speeds and in the intensity of rainfall that occurs in association with the cyclone. This is because the storms draw energy from the surface waters of the ocean, and as more heat (energy) is stored in these upper waters, the cyclones have a larger source of energy on which to draw…[52]

2.44 As noted in another of the committee's reports on climate change, in the southern Great Barrier Reef region the incidence of strong tropical cyclones is projected to increase from one every 25 or more years at present to one every 6–12 years. Between the Pilbara and southern Kimberley regions, the incidence of strong cyclones is projected to increase from one every 10 years to one every 7.5 years.[53]

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49 The Treasury, *Northern Australia Insurance Premiums Taskforce: Final Report*, November 2015, p. 30.

50 Climate Council of Australia, *Submission 40*, p. 9. See also Department of the Environment and Energy et al, *Submission 39*, p. 15.

51 CSIRO, *Submission 45*, p. 10. See also Department of the Environment and Energy et al, *Submission 39*, p. 15.

52 Climate Council of Australia, *Submission 40*, p. 9 (citations omitted).

53 Senate Environment and Communications References Committee, *In hot water: the impacts of climate change on marine fisheries and biodiversity*, December 2017, p. 14 (based on evidence from the Australian Institute of Marine Science).

2.45 Storm surges were also discussed extensively during this inquiry, with stakeholders focused on the relationship between storm surges and the sea level in particular. CSIRO submitted that the rising sea level 'amplifies the effects of high tides and storm surges'.[54] To illustrate, CSIRO discussed a preliminary assessment of the implications of sea level rise in southeast Queensland. Two key findings of the assessment are as follows:

- Without taking into account an expected population increase, the number of buildings in the area at risk of inundation from a 1-in-100-year storm tide could increase from 227,000 at present to 245,100 by 2030 and to 273,000 by 2070. CSIRO noted that the population in the region is expected to increase to 4 million by 2030, which would compound climate change effects 'if the population remains at its current pattern of settlement'.
- With an additional 0.2 metre rise in sea level and unchanged planning and building regulations, by 2030 it is projected that the number of residential buildings at risk from a storm tide of 2.5 metres will increase from 35,200 to about 61,500 (and approximately 121,000 residential buildings by 2070).[55]

2.46 The Climate Council commented:

> As the sea level continues to rise, these storm surges are riding on a higher base sea level and thus becoming more damaging as they are able to penetrate further inland. Some of the most devastating coastal flooding events are caused by a "double whammy" of concurrent high sea-level events and heavy rainfall events in the catchments inland of coastal settlements. That is, coastal settlements can be inundated by water from both i) a storm surge, a high tide and a higher sea level, and ii) flooding rivers from the catchments behind the settlements.[56]

2.47 Likewise, the Bureau of Meteorology and the GBRMPA noted that, even if the severity of storm surges does not change, rising sea levels would result in increased frequency of flooding from storm surges. This is because 'an increase in the baseline sea level component will lead to an increase in sea levels at any specific time even if all other components are constant'.[57]

2.48 Given the relationship between cyclones and storm surges, and the projection regarding the increased intensity of cyclones due to climate change, it is considered there will be a greater risk of extreme storm surges.[58] In considering the implications of these events, the Australian Local Government Association (ALGA) emphasised that inland communities can also be affected by these coastal events. ALGA noted that

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54 CSIRO, *Submission 45*, p. 7.

55 CSIRO, *Submission 45*, pp. 11–12 (citation omitted).

56 Climate Council of Australia, *Submission 40*, pp. 3–4.

57 Department of the Environment and Energy et al, *Submission 39*, p. 13.

58 Department of the Environment and Energy et al, *Submission 39*, p. 13.

'much of the flooding from Cyclone Debbie was experienced beyond the coastal zone'.[59]

Extreme rainfall events and flooding

2.49 The Climate Council of Australia submitted that a 2°C increase in average temperatures globally 'could result in a 10–30% increase in extreme downpours'.[60] It is expected that extreme rainfall events (the wettest day of the year and the wettest day in 20 years) will increase in intensity in Australia.[61] As noted at paragraph 2.36, it is expected that a higher proportion of total rainfall will come from extreme events, even in regions where total rainfall is expected to decrease.

2.50 Flooding from heavy rainfall is another area of concern. Flood events have caused significant damage previously: notable examples include the floods in 2010–11 in southeast Queensland, Victoria, and Tasmania, which were calculated to have caused $5.6 billion damage.[62] The Climate Council provided the following summary of the damage caused by the 2010–11 floods in Brisbane and elsewhere in southeast Queensland:

> The economic impacts of heavy rainfall can be devastating. One of the worst flooding events in recent times in Australia as a result of heavy rainfall was the Queensland 2010/2011 floods. Extreme and extended rainfall over large areas of Queensland from a strong La Niña event in the latter part of 2010 led to record breaking and very damaging flooding in Queensland in December 2010 and January 2011. December 2010 was Queensland's wettest December on record…Approximately 2.5 million people were affected and 29,000 homes and businesses experienced some form of flooding. The economic cost of the flooding was estimated to be in excess of $5 billion…with 18,000 homes inundated, damage to 28% of the Queensland rail network and damage to 19,000 km of roads and 3 ports…Around 300,000 homes and businesses lost power in Brisbane and Ipswich at some stage during the floods…[63]

2.51 As noted above, although precipitation levels may decrease in many parts of the country, the intensity of extreme rain events is projected to increase. This has particular implications for urban areas, where impervious surfaces and significant amounts of runoff are typical features of the built environment. As noted in the committee's 2015 report on stormwater management, future growth in Australia's urban centres and more frequent extreme weather events due to climate change may increase volumes of runoff in urban areas that will need to be absorbed in the

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59 Australian Local Government Association, *Submission 12*, p. 4.

60 Climate Council of Australia, *Submission 40*, p. 8 (citation omitted).

61 Climate Council of Australia, *Submission 40*, p. 8.

62 ASBEC, *Submission 26*, p. 4.

63 Climate Council of Australia, *Submission 40*, p. 8 (citations omitted).

environment or managed by stormwater infrastructure, or will otherwise result in flooding.[64]

2.52 The committee received evidence discussing analysis of flood risk in particular areas. For example, Lake Macquarie City Council submitted there are around 18,500 properties in its jurisdiction that are subject to lake and catchment flooding in a 1 per cent flood event. The Council provided the following evidence of the consequences of this in the face of climate change:

> Recent climate change projections for the region indicate that there will be an increase in the frequency of extreme rainfall events (95th percentile) in summer and autumn. Other projections for the region indicate that the maximum intensity of extreme rainfall events will increase by up to 20% by 2050 for a 24 hour event and by greater amounts for shorter duration events in the longer term (2080).
>
> As a consequence, greater numbers of people and infrastructure will be exposed to the direct impacts of flooding in the future and communities and systems that are already exposed to flooding will be exposed more frequently. Within the broader Hunter region, vulnerable groups including elderly and low socio-economic groups are disproportionately represented in areas subject to flooding.
>
> Infrastructure within the City that is exposed to flood hazards includes residential dwellings, public infrastructure including road and nationally significant transport links, utilities, community facilities, commercial and industrial areas. Intangible damages associated with flood hazards include impacts on mental and physical health, disruption of services, and disruption of economic activity.[65]

Natural defences

2.53 Certain types of ecosystems and natural features such as coral reefs, sand dunes, mangroves and wetlands can help protect Australia's coast from the worst impacts of extreme weather events. How climate change is affecting coral reefs, kelp and mangrove forests, and the marine environment generally, were discussed extensively in the committee's 2017 report on the impacts of climate change on marine fisheries and biodiversity.[66]

2.54 In summary, there is substantial evidence that warming ocean temperatures and ocean acidification have had significant ecological impacts in the Great Barrier Reef and in Western Australian reefs, such as coral bleaching and reductions in coral

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64 See Senate Environment and Communications References Committee, *Stormwater management in Australia*, December 2015.

65 Lake Macquarie City Council, *Submission 29*, p. 3 (citations omitted).

66 See Senate Environment and Communications References Committee, *In hot water: the impacts of climate change on marine fisheries and biodiversity*, December 2017.

calcification and reproduction rates. Mangrove and kelp forest dieback has also occurred, such as the severe dieback of mangroves in the Gulf of Carpentaria.[67]

2.55 From an infrastructure perspective, the health of these natural coastal defence systems can be significant, particularly during extreme weather events. As Professor Damien Burrows noted during the committee's marine fisheries and biodiversity inquiry:

> Mangroves protect the coast by absorbing the energy of storm-driven waves and wind. The only two yachts undamaged by Cyclone Tracy in Darwin in 1974 were sheltered in a mangrove creek. In 2006, mangroves protected vessels and the coastline during Cyclone Larry in far north Queensland. The damage bill would have been much higher if it wasn't for the existence of intact mangrove forests.[68]

Need for a strong mitigation response

2.56 This report generally focuses on adaptation measures required in response to climate change. It is important, however, to address the need to reduce and curb greenhouse gas emissions, including the actions needed to meet Australia's obligations under the Paris Agreement.[69]

2.57 Several submitters emphasised the need for more action to be taken to address the consequences of human activities for the climate system. The Investor Group on Climate Change (IGCC) commented:

> Ultimately, the best defense against rising costs and the physical impacts of climate change is to meet the goals of the Paris Agreement and limit global warming to less than 2°C.[70]

2.58 To achieve this, the IGCC argued that Australia needs to be 'working to facilitate an economically efficient transition to a net zero emissions[71] economy in line

67 Senate Environment and Communications References Committee, *In hot water: the impacts of climate change on marine fisheries and biodiversity*, December 2017, pp. 29, 32.

68 Senate Environment and Communications References Committee, *In hot water*, p. 36.

69 The Paris Agreement is an international agreement reached in 2015 in response to the threat of climate change. The agreement seeks to keep global temperature rise in the 21st century 'well below' 2°C above pre-industrial levels and 'to pursue efforts to limit the temperature increase even further' to 1.5°C. In response to the Paris Agreement, in August 2015 the Australian Government committed to reduce emissions by 26 to 28 per cent below 2005 levels by 2030. United Nations Framework Convention on Climate Change, 'The Paris Agreement', http://unfccc.int/paris_agreement/items/9485.php (accessed 20 February 2018); Australian Government, *National Climate Resilience and Adaptation Strategy*, 2015, p. 13.

70 Investor Group on Climate Change, *Submission 55*, p. 15. See also IAG, *Submission 56*, p. 9.

71 An organisation, region or country can achieve net zero emissions by reducing greenhouse gas emissions and offsetting or sequestering other emissions so that their net emission reach zero.

with global commitments under the Paris Agreement', including by managing carbon risk as an economic and financial risk (this is discussed in Chapter 3).[72]

2.59 Governments and other stakeholders called on the Australian Government to strengthen its mitigation and adaptation efforts. For example, the Queensland Government submitted that it:

> …strongly advocates for the Australian Government to strengthen its climate change policy response in terms of its emissions reduction targets and a credible suite of mechanisms to achieve these targets, and its efforts in relation to climate adaptation.[73]

2.60 The need for a carbon pricing mechanism to change existing economic models and otherwise support the transition to a low-carbon economy was noted.[74]

2.61 Effective mitigation is critical due to the limits on the ability to adapt. Professor Lesley Hughes from the Climate Council of Australia warned that although Australia, as a developed country, is adapting to climate change 'reasonably well' at present, the ability to adapt 'even in a country like Australia, will become a larger and larger challenge'. Professor Hughes commented:

> Really, we need to fix the root cause of the problem so that we don't get a situation to which we simply cannot adapt. It's very clear from the climate science that we're heading for at least two degrees, probably more. We are not reducing emissions strongly enough to only get two degrees, so we're looking at more than two degrees in the second half of this century. The influence of that on extreme climate events will be massive. There will be many to which adaptation becomes increasingly unlikely.[75]

2.62 Professor Hughes added that the climate system has 'a very big lag time'. Professor Hughes explained that once 2°C of warming is reached, sea level rise will continue 'for centuries if not millennia'. The professor stated:

> When we get to two degrees, we are probably still in the range of adapting, but, beyond that, sea level rise is going to keep going up at least for centuries after that. So it really depends on the timescale at which you are thinking your infrastructure needs to adapt by. It's like turning off a tap, but the water keeps running for a few hundred years and you still have an overflowing bath tub.[76]

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72 Investor Group on Climate Change, *Submission 55*, p. 5.

73 Queensland Government, *Submission 58*, p. 1.

74 See Mr Andrew Petersen, Chief Executive Officer, Sustainable Business Australia, *Committee Hansard*, 23 November 2017, pp. 12, 13.

75 Professor Lesley Hughes, Councillor, Climate Council of Australia, *Committee Hansard*, 23 November 2017, p. 30.

76 Professor Lesley Hughes, Climate Council of Australia, *Committee Hansard*, 23 November 2017, p. 31.