Chapter 25. Australasia

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Executive Summary

[Note: this is not an executive summary. Because of time constraints, we simply present a (lengthy) selection of key findings and conclusions from individual sections to assist with an overview of our rather lengthy draft.]

Observed and Projected Integrated Climate Change

- The region continues to demonstrate long term trends toward higher surface air and sea-surface temperatures, more hot extremes and fewer cold extremes, and increased sea-level *(very high confidence)*. These trends align with global trends, and research since the AR4 has more clearly established that the temperature trends are consistent with model simulations of the effect of anthropogenic climate change (*high confidence*).
- With some exceptions, regional trends in precipitation remain difficult to distinguish from decadal-scale natural fluctuations. Much research in Australia since the AR4 has established partial attribution to anthropogenic climate change in the case of declining rainfall in southwestern Australia *(high confidence)* and in the more recent trend to decreased rainfall in southeastern Australia *(medium confidence)*. In southeastern Australia, anthropogenic climate change is likely to have played a role in decreasing runoff and soil moisture, and increasing fire danger *(low to medium confidence*). The strong increase in rainfall in northwestern Australia remains poorly understood.
- We have *very high confidence* that warming will continue in the region through the 21st century, increasing by at around one degree over 1990 levels by 2030 and reaching warming late in the century of 1 – 5C, allowing for climate model and emission scenario uncertainty. There is also *very high confidence* that these trends will be associated with more frequent hot extremes and less frequent cold extremes.
- We have *high confidence* in projecting future annual decline in rainfall in southwestern Australia and medium confidence in projecting annual rainfall declines in southeastern Australia. In other areas of eastern Australia, and in northern Australia, the direction of future rainfall change is uncertain. In these regions and in southern Australia in summer, two broad scenarios need to be considered in vulnerability and adaptation research: a hotter drier climate and a warmer wetter climate. In New Zealand, we have medium confidence that rainfall will change with a pattern of greater rainfall in the south and west and less rainfall in the north and east.
- Research since the AR4 has further established likelihood of future increased drought in southern Australia *(high confidence)* and eastern New Zealand *(medium confidence*); increased fire danger and reduced snowcover in Australia (high confidence). Tropical cyclones are projected to increase in intensity but decrease in numbers *(low confidence*).

Socio-Economic Trends and Their Interactions with Vulnerability and Adaptive Capacity

- Australia and New Zealand are expected to undergo significant population growth over the next several decades in the absence of radical and sustained policy changes, significant ageing and increasing multi-culturalism (*very high confidence*). Populations are highly urbanised and mobile.
- Economies of both countries depend on international trade in commodities and tourism. Future economic growth is projected at between 2 and 3.5% per annum for the next few decades (*limited evidence, medium agreement*) but could be subject to significant short-term fluctuations.
- The use of socio-economic information, particularly from future scenarios, in climate change impacts and vulnerability studies has been very limited and no harmonised set of socio-economic scenarios exists at national or regional levels. This severely limits the confidence that can be assigned to overall conclusions about vulnerability and adaptive capacity to climate change in human systems.

Natural and Managed Resources and Systems, and Their Uses

Freshwater Resources

- South-east and south-west Australia are likely to be drier in the future (*high agreement and high confidence*). The decline in future water resources availability and increasing demand from competing uses will place tremendous pressure on existing water resources systems. Elsewhere in Australia and New Zealand, there is less certainty on the direction of change in future rainfall and runoff.
- The bigger (but less frequent) floods as a result of more intense extreme precipitation (*high agreement and high confidence*) will increase flood damages, place pressure on existing stormwater and wastewater infrastructures and increase erosion and sediment and nutrient delivery to waterways.
- Climate change adaptation in urban cities has focused on finding new water supplies (including desalinisation) and water conservation measures and water sensitive urban planning. Climate change adaptation in rural areas has focused on developing more equitable water sharing plans to cope with current and future climates and assisting rural communities adapt to a future scenario of reduced water availability.

Terrestrial and Inland Freshwater Ecosystems

- Freshwater and terrestrial ecosystems in Australia and New Zealand are subject to considerable stresses due to habitat clearing & fragmentation, invasive species, altered fire regimes, and redistribution of water resources. Climate change is likely to interact with and exacerbate many of these existing stresses (*high confidence*).
- There have been few observations of biodiversity change in New Zealand directly attributable to climate change but reports of changes in species ranges, life cycles, vegetation boundaries, productivity and mortality due to heat stress are being increasingly documented in Australia (*medium confidence*).
- Species distribution modeling consistently projects future declines in species ranges, although relatively few species have been modeled in Australia, and even fewer in New Zealand. The response of Australian and New Zealand species to elevated CO_2 has been investigated for only a few species, but it is likely that low soil fertility across much of the Australian continent will limit future responses of vegetation (*medium confidence*). Indirect interactions of climate change via changes in fire regimes is likely to exert significant impacts on most ecosystems in Australia (*high confidence*).
- The alpine regions, low-lying coastal areas, high altitude tropical rainforests and other montane areas in Australia are likely to be the most vulnerable areas to climate change (high confidence). Some alpine and freshwater species in New Zealand have been identified as being vulnerable, but the overall impact of invasive species on the New Zealand biota is likely to remain the most serious threat in the short to medium term (*medium confidence*).
- The adaptive capacity of terrestrial and freshwater ecosystems in Australia and New Zealand is highly likely to be limited by existing fragmentation of habits, high endemicity (with resulting narrow geographic and climatic ranges), the low topographic relief, and east-west orientation of many river systems (high confidence).

Coastal Systems and Low-Lying Areas

- The main climate-related vulnerabilities of the coastal zone are to sea level rise, extreme events, and changes in ocean temperature (*high confidence*).

- Coastal protection to sea level rise and storms is provided by a range of natural habitats, including reefs, mangroves, sand dunes, sea grass beds and macro-algal forests. There is little evidence to date of climate impacts on these coastal habitats.
- Loss of coastal habitats from sea level rise and extreme events will affect biodiversity and coastal protection (*high confidence*).
- Human modification of the coastal zone in Australia may have intensified the impact of several recent extreme events leading to loss of property (*medium confidence*).

Ocean Systems, including Fisheries

- Average climate zones have shifted more than 200 km south along the NE coast of Australia and about half that distance along the NW coast. If current trends continue, annual average sea surface temperatures in northern regions could be ~0.5°C warmer and those of more southern parts ~2.0°C warmer within the next 100 years. Warming rates are faster in southern Australia with a poleward advance of the East Australian Current and accompanying increases in salinity (*high confidence*).
- Observed impacts on marine species around Australia have been reported from a range of trophic levels, including southerly shifts in geographic ranges of pelagic species, changes in phytoplankton productivity, changes in timing of recruitment in commercial fish species, declining growth rates of fish, declining coral calcification rates and changes in composition of some marine communities. These responses are consistent with having a climate change signal (*medium confidence*) but few studies on specific attribution are available. Few examples of observed change have been documented for New Zealand.
- Climate change is expected to include both positive and negative impacts on abundance, distribution, physiology and phenology (*high confidence*) and reduce the profitability of both wild fisheries and aquaculture in Australian waters (*medium confidence*). NZ? Southern species on the continental shelf are considered vulnerable due to limited availability of suitable habitat elsewhere (*high confidence*).
- Adaptation options exist at both the landscape scale (such as marine park provision and management) and for individual species (such as translocation) but implementation is complicated by interacting non-climate stresses, including habitat degradation, coastal pollution and over-exploitation (*high confidence*).

Forestry and Biofuel Production

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Food and Fibre Production Systems

- Access to water will become increasingly important for agricultural enterprises in the south west and south east of Australia and eastern regions of New Zealand (*high confidence*).
- Areas that currently experience high climatic variability may not be the most vulnerable to increased future variability as they already have a high adaptive capacity.
- Reduced grain quality (especially protein) will require increased fertiliser application (*high confidence*).
- In Australia observed trends to earlier grape maturity (a response to a warming climate) are expected to continue resulting in reduced quality (*high confidence*) and may require changes in location

Human Settlements, Industry, and Infrastructure

Urban Areas

- Health impacts from climate change in the urban environment are dominated by temperature related issues. For example, when the mean daily temperature is more than 30°C in Melbourne, the average daily mortality of people aged 65 years or older is about 15-17% greater than usual.
- Impacts on the built environment from hazards such as coastal and river flooding include increased damage to energy/telecommunications infrastructure, goods and chattels, internal features (e.g. underfloor/wall insulation), internal plasterwork and refurbishments, roof damage and weathering damage. Enhanced climate adaptive capacity of the built environment requires improved design standards, regulation, planning processes, and maintenance.
- Energy modelling projections show the cooling load for Australian houses to triple by 2070 compared to current levels, while there is a noticeable decrease in heating load in cooler climate zones.

- Many cities in Australia and New Zealand are facing challenges of increasing temperature and reduced rainfall in addition to an increasing water demand. A potential adaptation response is more intensive use of greywater. In Adelaide, both rainwater and recycling water has been adopted with the level of water-self-sufficiency estimated at around 60%.
- Existing aging stormwater and wastewater infrastructure problems in many New Zealand and Australian cities such as cross contamination, low outfall head, inadequate pipe volume capacity and saltwater intrusion are likely to be exacerbated in the future due to projected increases in heavy rainfall events and sea level rise.
- In Australia, between 187,000 and 274,000 residential buildings (valued between AUD51 and AUD72 billion, based on 2008 figures) and between 5,800 and 8,600 commercial buildings (valued between AUD58 and AUD81 billion) are exposed to inundation and erosion at a sea level rise of 1.1m assuming a high end scenario for 2100, with Queensland and New South Wales most impacted.
- The main issues for land based transport in Australia and New Zealand due to climate change are sea level rise and the increased frequency and intensity of extreme weather events. Rail buckling events during very hot days in New Zealand are likely to become more frequent. In locations where rail track conditions are poor, the mean number of speed restriction days is predicted to double from a base year of 6 per year in 1990 to 13 days per year in 2040 and to 23 days per year by 2090.

Rural Areas

- Rural communities are vulnerable to climate variability and change for a complex set of environmental, economic and social reasons. Adaptation of rural communities to climate change will require approaches that devolve decision-making to the level where the knowledge for effective adaptation resides, utilising open communication, interaction and joint-planning between stakeholders.

Energy Supply, Transmission, and Mining

- Recent events have shown a high vulnerability of the Australian mining sector to climatic extremes, but the adaptive capacity of the sector to deal with changing frequency of extremes is considered high, based on preliminary and qualitative studies (*low confidence*).
- Energy generation in New Zealand is currently vulnerable to climate variability, in particular dry years; this vulnerability is expected to decrease over the next few decades doe to increased hydrolake inflows and reduced heating demand (*medium confidence*). Australian energy supply is less affected by climate variability but demand is more sensitive to increasing demand for air conditioning.
- Electricity transmission and distribution systems across Australasia are at increasing risk from changes in climate extremes (*very high confidence*).

Tourism

- Tourism in Australasia is highly exposed to climate variability and extremes, as evidence by a number of recent events. Skiing is the sector at highest risk in Australia (*high confidence*), which (based on *very limited evidence*) could have negative flow-on effects on regional economic activity.
- Adaptive capacity by the tourism sector appears to be high but may be constrained by lack of coordination and limited strategic planning within the sector (*limited evidence, robust agreement*).

Human Health, Well-Being, and Security

Human Health

- An increase in heatwaves is likely to be associated with an increase in both heat-related deaths and increased hospitalizations in Australia [NZ?], especially amongst the elderly (*high confidence*).
- Mental health impacts and suicide rates are likely to increase, especially in those rural communities where climate change places additional stresses on livelihoods (*high confidence*).
- Increasing temperatures could result in a southward expansion of the area suitable for dengue fever in Australia, but mosquito vectors may be more affected by changing distributions of water tanks in urban environments than directly by changing climate. However there is evidence that dengue vectors were once more widespread than they are currently and considerable uncertainty remains as to future distributions. The impacts of climate change

on Ross River virus and related arboviruses such as Barmah Forest virus are uncertain. Malaria is considered a low risk to both Australia and New Zealand (*medium confidence*).
- Water- and food-borne diseases have been projected to increase in the future but the complexity of the relationships of these issues to climate means there is *low confidence* in the projections.

Livelihoods, Immigration, Security
- There is no evidence to date that climate induced changes to date are driving internal migration in Australia or New Zealand, or into Australasia from outside those two countries.
- There is inadequate evidence to say with confidence that climate change is now causing violent conflict within any countries within East Asia and the Pacific. The regional security outlook for the region is not expected to change in the immediate future due to climate change although increasing problems associated with disasters, disease, and border control may entail an increase in operations other than war for the region's armed forces (*limited evidence, medium agreement*).

Indigenous Matters
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Cross-Sectoral Impacts and Adaptation Decisionmaking Frameworks

- Economic model studies of climate change impacts provide *limited evidence* but *high agreement* of significant vulnerability of the Australian economy to climate change, with one comprehensive study projecting a 7.6% loss of GNP in 2100 under an unmitigated emissions scenario, subject to significant assumptions and uncertainties. No comparable economy-wide study exists in New Zealand.
- An emerging literature on pscyhological dimensions of risk perceptions and adaptive capacity provides *limited evidence* but *high agreement* that some projected climate change impacts that are difficult to quantify in monetary terms nonetheless constitute significant losses to some parts of society, even if they and are not used in economic and quantitative risk analyses, and that adaptation options will be constrained in some sectors and locations by social and cultural norms and preferences.
- Adaptation decision-making is largely devolved to regional and local levels, with local government playing a crucial role in monitoring and regulating community-level adaptation options and decisions. Significant barriers to adaptation at the local level limit the effective application of the otherwise high adaptive capacity of the region (*high agreement, robust evidence*).
- Climate change adaptation is becoming increasingly mainstreamed in some sectors, particularly the management of water resources in urban and rural regions of Australia.

Interactions between Impacts, Adaptation, and Mitigation at Multiple Scales

- At local scales, adaptation responses can provide synergies or trade-offs with other adaptation responses within the same sector or other sectors, and can support or counteract greenhouse gas mitigation objectives (*very high confidence*), but strategic frameworks and regulatory support for prioritisation and decision-making to meet multiple objectives are limited.
- Both Australia and New Zealand are exposed and sensitive to flow-on effects from climate change impacts, adaptation and mitigation responses occurring outside the region. Understanding of these risks and opportunities is growing but still limited. Existing studies indicate that Australia would see negative domestic impacts compounded by international flow-on effects (*medium confidence*), whereas there is as yet *limited evidence* but *high agreement* that climate change impacts globally would counteract negative domestic impacts in New Zealand.
- A limited set of studies suggests that global mitigation could avoid significant damages from climate change in Australia, including some that would be very difficult to manage by adaptation (*high confidence*).

Multi-Sector Synthesis, Key Uncertainties, and Research and Data Gaps
[not considered for ZOD Executive Summary]

25.1. Introduction

Australasia is defined in this report as the lands, territories and the offshore waters of the exclusive economic zones of Australia and New Zealand. This includes tropical oceanic, mid-latitude and sub-Antarctic islands. It does not include any lands of the Antarctic mainland nor regions of Melanesia and the Sunda region considered as part of Australasia in some other contexts.

This chapter is organised as follows: 25.2 summarises major conclusions from the previous assessment, followed by an assessment of observed and projected future climate changes including attribution to human causes (25.3) and the current and future socio-economic context for climate-related impacts and adaptation options (25.4). Section 25.5 and subsections discuss in detail the observed and projected impacts of climate change and adaptation options for individual systems and sectors. The subsequent sections summarise and integrate issues across sectors and systems: section 25.6 gives an overview of cross-sectoral impacts, adaptation and decision-making frameworks including barriers and limits to adaptation; 25.7 covers interactions between various impacts, adaptation and mitigation responses locally, within the region and between the region and the rest of the world; 25.8 gives a multi-sector synthesis of key vulnerabilities and adaptation options. Section 25.9 concludes with an assessment of key research and data needs to address key uncertainties.

25.2. Major Conclusions from Previous Assessments

The principal findings of the IPCC Fourth Assessment Report (AR4; Hennessy et al. 2007) were as follows:

- The AR4 confirmed and extended the main findings from the Third Assessment Report
- Consistent with global trends, Australia and New Zealand had experienced warming of 0.4 to 0.7°C since 1950 with changed rainfall patterns and a sea-level rise of 70mm; there had also been a greater frequency and intensity of droughts and heat waves, reduced seasonal snow cover and glacial retreat
- Impacts from recent climate changes were evident in increasing stresses on water supply and agriculture, and changed natural ecosystems; some adaptation had also occurred in these sectors but vulnerability to extreme events such as fire, tropical cyclones, droughts, hail and floods remained high
- The climate of the 21st century would be warmer (virtually certain), with changes in extreme events including more intense and frequent heat waves, fire, floods, storm surges and droughts but less frequent frost and snow (high confidence), reduced soil moisture in large parts of Australian mainland and eastern New Zealand but more rain in western New Zealand (medium confidence)
- Significant advances had occurred in understanding of future impacts on water, ecosystems, Indigenous people and health together with an increased focus on adaptation; the AR4 noted that potential impacts of these changes would be substantial without further adaptation, in particular for water security and coastal development, loss of biodiversity, increased risks to major infrastructure, but more variable impacts on agriculture and forestry across the region including potential benefits in some areas
- Vulnerability would increase mainly due to an increase in extreme events, but the extent of this increase would depend on adaptive capacity: human system were regarded as having a higher adaptive capacity than natural systems.
- Hotspots of high vulnerability included, by 2050 under a medium emissions scenario:
    - Significant loss of biodiversity in areas such as but not restricted to alpine regions, the Wet Tropics, the Australian south-west, Kakadu wetlands, coral reefs and sub-Antarctic islands
    - Water security problems in the Murray-Darling basin, south-western Australia and eastern New Zealand
    - Potentially large losses to urban development in south-eastern Queensland and in New Zealand from Northland to the Bay of Plenty

25.3. Observed and Projected Integrated Climate Change

25.3.1. Observed Regional Changes

25.3.1.1. Temperature

While highly variable from year to year as a result of strong rainfall variability (Jones and Trewin 2000); (BoM 2011a), Australian temperatures show a warming trend over the past 100 years (1910-2010) of 1.0X ºC [*to be confirmed*] (Della-Marta et al. 2004; Trewin 2012) (see Figure 25-1). The 95% confidence interval on the trend is approximately ±0.3 °C/century. In the national average the warming has been most pronounced since 1950 averaging 0.2 °C /decade with each decade (1950-1959, 1960-1969, through 2000-2009) warmer than the previous one (Trewin 2012). Rates of warming have been greatest in subtropical inland parts, with less warming in coastal areas, the northern tropics and Tasmania. In parts of northwest Australia recent increases in rainfall have been associated with a cooling of daytime temperatures and only slight increases in mean temperature [*seeking reference from Doerte Jakob*] (Jakob et al. 20XX).The warming trend in sea surface temperatures in the Australian region has been 0.9 °C since 1900, with less interannual variability than is seen for Australian land surface temperatures (BoM 2011b). Warming has tended to be greatest near 40 °S on the southern margins of the subtropical ridge [*seeking better reference for this*], and in tropical areas. Particularly rapid warming is evident near the East Australian Current, extending as far south as Tasmania's east coast [*Climate Change in Australia, but need a better more up-to-date reference*]. Observations from remote islands sites to the west and east of Australia show warming, which is most pronounced at night with a warming of mean temperature of between 0.3 and 0.7°C since 1950 (Jovanovic et al. submitted).

[INSERT FIGURE 25-1 HERE
Figure 25-1: Title?]

Analysis of a long running 7-station New Zealand temperature series, first described in (Salinger 1981) and subsequently updated and revised (Mullan et al. 2010), shows a temperature trend over the past 100 years (1909-2009) for New Zealand of 0.91ºC. The 95% confidence interval on the trend is approximately ±0.3°C/century. The air temperature trend is slightly greater than the sea surface temperature trend for the New Zealand region for the same period (0.71°C), though the year-to-year variations are entirely consistent (Figure 25-2).

[INSERT FIGURE 25-2 HERE
Figure 25-2: Title?]

The warming in Australia since 1950 has been accompanied by a reduction in the number of cool extremes and an increase in the number of hot extremes for both maximum and minimum temperatures (Nicholls and Collins 2006); Gallant 2008) [n*eed to cross check to PhD thesis and possible publications*]. The increase in the number of hot days is overlaid on considerable interannual variability largely linked to the swings from wet to dry years. (Trewin and Vermont 2010) using daily data found that record highs are being set at much higher frequencies than record lows in recent years, consistent with the background warming trend. They also found that the time series of the difference between the numbers of high and low temperature records showed positive trends significant at the five per cent level for all cases examined.

Analysis of extreme daily temperature data from a selection of New Zealand sites shows a significant decrease in the frequency of cold nights of 10–20 days a year in many locations for the period 1951–1998 (Salinger and Griffiths 2001). For the more recent period 1972–2008, (Clark and Sturman 2009a) found that averaged over all of New Zealand, the number of frost days has decreased by only approximately 1 day per decade, and that there is large variation with strong positive and negative trends in frost occurrence over this 37-year period regionally.

In summary, we have *very high confidence* that land air temperature and sea surface temperature in the Australasian region demonstrate a significant warming trend. We also have *high confidence* that there has been decrease in the occurrence of daily cold extremes in air temperature over both Australia and New Zealand, and an increase in daily hot extremes over Australia.

25.3.1.2. Precipitation

Australian and New Zealand rainfall shows substantial interannual through decadal variability, being modulated by ENSO as well as variations in the Indian Ocean and the IPO (Ummenhofer et al. 2009b) (Ummenhofer et al. 2011) (Gallant and Gergis 2011; gergis et al. 2011a; Gergis et al. 2011b). A number of trends have emerged in rainfall since the 1950s, with a marked drying of southwest Australia since the 1960s and a decline in autumn/winter rainfall in the southeast, particularly since the mid 1990s (Hope et al. 2010). The decade from 2001 to 2010 witnessed record dry conditions in many parts of inland eastern Australia (Potter et al. 2010a) with the hydrological impacts exacerbated by record warm temperatures (Cai et al. 2009a) leading to record low river flows (Gallant and Gergis 2011). Long records from individual stations (Fawcett and Trewin 2009) [n*eed to confirm full reference*] and reconstructions from proxies suggest the recent severe drought is probably (p value <0.02) unprecedented in the last 200 years (Gergis et al. 2011b). In marked contrast, northwest Australia has experienced a wetting trend since the 1950s, largely confined to the summer monsoon season (Jones et al. 2009). Trends in daily rainfall extremes have tended to follow trends in mean rainfall (Alexander et al. 2007a; Gallant et al. 2007).

An increasing trend in mean annual rainfall over the period 1950-2004 is evident in the south and west of both islands in New Zealand, with a decreasing trend generally seen elsewhere (Griffiths 2007b). Trends in extreme rainfall indices for New Zealand show a zonal pattern of response, with the frequency of 1-day 95th percentile rainfall extremes decreasing in the north and east, and increasing in the west over 1951–1996 (Salinger and Griffiths 2001). A similar pattern is present in the extreme annual 24-hour rainfall over the periods 1930–2004 and 1950–2004 (Griffiths 2007b). For the period 1979–2006, the general decline in summer rainfall over much of New Zealand is related to trends in ENSO and the Southern Annular Mode (Ummenhofer et al. 2009b). Such results confirm that historic trends in extreme and mean rainfall in New Zealand are strongly linked to atmospheric circulation changes and the prevailing airflow (Clark and Sturman 2009a; MfE 2008a; Salinger and Griffiths 2001).

In summary, we have *very high confidence* that since the 1950s, northwestern Australia and southern and western New Zealand have become significantly wetter, while southwestern Australia and northern and eastern New Zealand has become significantly drier. We also know with *very high confidence* that conditions have been exceptionally dry in the southeast of Australian since the mid 1990s. Changes to extreme daily rainfall have mostly followed mean rainfall changes (*high confidence*).

25.3.1.3. Winds and Atmospheric Circulation

McVicar et al (2008) reported declines in 2 m mean wind speed over 88% of Australia (significant over 57% of the country) over 1975-2006 and positive trends over about 12% of the mainland interior and southern and eastern coastal regions including Tasmania. It was noted that these trends were of opposite sign to reanalysis winds over the region. However, Troccoli et al. (submitted) compare trend estimates in 2 m and 10 m winds and find that although 2 m winds have a mostly declining trend of $-0.10\pm0.03\%$ a-1 ($-0.36\pm0.04\%$ a-1) for the 1975-2006 (1989-2006) period, 10-m winds exhibit an increasing trend of $0.90\pm0.03\%$ a-1 ($0.69\pm0.04\%$ a-1) for the 1975-2006 (1989-2006) period. The trends for light (strong) 10 m winds are larger (smaller) than those for mean winds. It is suggested that the trends are not driven by long term climate change. Trends in extreme winds can also be inferred from trends in particular phenomena. Proxies for wind such as geostrophic winds calculated from triangles of pressure (geo-winds) have been used by (Alexander et al. 2011) to infer an overall decline in storm activity over southeastern Australia since about 1885.

Westerly wind-flow over New Zealand increased during the later part of the 20th century (1978–1998) associated with the positive phase of the IPO (Mullan et al. 2001). More frequent westerlies in the New Zealand region are also predicted by global climate models as a response to increases in atmospheric temperature (MfE 2008a). Related to changes in the mean wind-flow, the frequency and strength of extreme westerly wind episodes over the period 1960–2003 increased significantly to the south of New Zealand, but only slightly increased over New Zealand itself, while extreme easterly winds decreased over land areas (Salinger et al. 2005).

Since 1998, the IPO has shifted to a negative phase (Parker et al. 2007) which typically results in weaker westerlies than normal over New Zealand (Mullan et al. 2001). This circulation change may counteract the effects of climate change related increases to the frequency of westerlies in the New Zealand region. There has also been a trend to more southerlies over the country since 1960 (Dean and Stott 2009).

In summary, changes to windiness over Australia are difficult to identify with confidence due to conflicting results from available studies. For New Zealand, changes independent of those expected to IPO fluctuations have not been detected.

25.3.1.4. Sea Level

Sea level in the Australian region is modulated by variability in ENSO, meaning that trends are highly dependent on the start and end year for calculations Church et al. (2006) Over the period 1920 to 2000 the average relative sea level rise around Australia was 1.2 mm/year (Church et al. 2006), which has been manifested in an increased frequency of extreme sea level events. Satellite altimeter data from 1993 to 2009 [*expect to update*] show a mean rise in sea level of 5.9mm/yr, which is nearly two times the global average (Church and White 2011).This larger rate of rise is at least partly associated with the sequence of El Niño and La Niña events over this period (Power and Smith 2007). Lower rates of sea-level rise offshore from southern Queensland and faster rates of rise offshore from southern New South Wales are the result of changes in the East Australian Current, particularly its greater southward penetration (BoM 2010)

Sea-level rise (SLR) was relatively slow in New Zealand from the 1500s to the late 1800s at an estimated rise of 0.3±0.3 mm/yr (Gehrels et al. 2008). Over the past century (1900–2000), sea level rose at a higher rate, with an average relative SLR of 1.6±0.2 mm/yr across New Zealand's four main ports (Hannah 2004; MfE 2008b). The updated trend in relative sea-level rise to 2009 is 1.7±0.1 mm/yr, which is a 10-port average trend adding in a further six regional stations (Hannah and Bell submitted)(Hannah & Bell, submitted). Adding an estimated 0.5 mm/yr for crustal rebound in the New Zealand region (Hannah 2004) to the average relative SLR for New Zealand, yields an estimate of the absolute (eustatic) SLR in New Zealand of approximately 2.1 mm/yr.

Changes in extreme sea levels were also analysed in tide gauge data of approximately 100 years at Sydney and Fremantle. At both locations a stronger positive trend was found in the sea level exceeded by 0.01 per cent of the observations than the median sea level, suggesting that in addition to mean sea level rise other modes of variability or climate change are contributing to the extremes. Trends in significant wave height were estimated by (Hemer et al. 2010) using satellite data over 1998–2001 relative to 1993–1996. These trends were positive only over the Southern Ocean south of 45°S whereas trends were positive across most of the Southern Hemisphere in the corrected ERA-40 reanalysis (C-ERA-40;(Hemer 2010b). (Hemer 2010a) found that the frequency of wave events exceeding the 98th percentile over the period 1985-2002 using data from a wave buoy situated on the west coast of Tasmania showed no statistically significant trend whereas a strong positive trend was found in equivalent fields of C-ERA-40 data.

In summary, we know with *very high confidence* that mean sea level has risen by around 1-2mm/year in the region over the past century. Changes to wave climate in the region have been examined but studies have failed to identify a consistent direction of change

25.3.1.5. Other Changes

Changes in Australian total cloud amount are mostly weak and non-significant, tending to be dominated by interannual variability associated with ENSO. Total cloudiness has shown declines in southern areas since the 1950s, particularly during autumn and winter (Jovanovic et al. submitted). Analyses of pan evaporation are limited by data availability with consistent measurements only dating back to the mid 1970s. These data reveal that negative trends dominate (Rayner 2007) though when averaged across Australia the trend is non-significant (Jovanovic et al. 2008).

Analyses of extreme events such as storms, tornadoes and tropical cyclones are affected by data availability and various biases due to changes in population and measurement quality, quantity and practice (e.g. Kuleshov et al. 2010; Mills 2004). Over the period of geostationary satellite coverage (1981-2007), (Kuleshov et al. 2010) found no significant change in the number of tropical cyclones in the Australia region, nor in the proportion of the most intense systems. There is, however, a trend to less frequent landfall of cyclones (Callaghan and Power 2011) and to more cyclones to the west of the Australia relative to the east (Hassim and Walsh 2008). Cause of the reduced landfall is not clear but may be related to a weaker Walker circulation and a shift to more frequent El Nino conditions (Callaghan and Power 2011).

Maximum winter snow depth (Nicholls 2005) at Spencers Creek in the Snowy Mountains of south-eastern Australia has decreased slightly since 1962, and the snow depth in spring has declined strongly (by about 40%). Data from four alpine sites from 1957- 2002 indicated a weak decline in maximum snow depths at three sites (Spencers Creek, Three Mile Dam and Deep Creek) and a moderate decline in mid-late season snow depths (August-September) at the same three sites (Hennessy et al. 2008a). Little is known about trends and interannual variability in snow cover extent and duration and snow depth in New Zealand (Clark et al. 2009)(Clark et al 2009).

We have *high confidence* that spring snow depth has significantly declined in Australia and medium confidence in a decline in cloudiness in southern Australia. Pan evaporation, total cloudiness (elsewhere in Australia) and tropical cyclones occurrence have not changed (*medium confidence*), although tropical cyclones making landfall in northern Australia have declined (*high confidence*).

25.3.2. Causes of Observed Changes

The AR4 assessment provides an excellent summary of relevant science up to 2004. (Nicholls 2006, 2007) adds an excellent and more extensive summary of science relevant to causes of Australian climatic trends. This topic has been a major research focus since the AR4 and the extensive literature is assessed here. The discussion here refers to trends in climate drivers such as the El Nino Southern Oscillation (ENSO), the Southern Annular Mode (SAM) and the Indian Ocean Dipole (IOD) and more information on these may be found in the relevant parts of the WGI assessment [*xxxx*]. For their regional relevance (Cai et al. 2009d; Cai et al. 2009e) on the IOD and Nicholls (2008) and Power and Smith (2007) on trends in the Southern Oscillation Index, are particularly noteworthy.

25.3.2.1. Temperature Changes

Australian regional warming was attributed to anthropogenic influence by the time of the AR4 (Karoly and Braganza 2005). Since then attention has focused more on changes to extreme temperatures. Trends in extreme temperatures in Australia have been broadly following trends in the mean (Alexander et al. 2007a) implying that they too may be attributed to anthropogenic influence (Nicholls 2006). An example is the observed frequency of record temperatures in Australia from 1957 to 2009 which has shown a pattern expected from the trend in the mean (low extremes early in the record, high extremes later) (Trewin and Vermont 2010). Trends in a range of temperature (and rainfall) extreme measures simulated in the 20th century simulations of the CMIP3 models have been compared with observations for 1957-1999 (Alexander and Arblaster 2009). Correspondence was good for most models, especially for the trend in warm nights. Observed increases in heatwaves were less spatially coherent than those simulated using a single coupled GCM over the period 1966-2003 (Tryhorn and Risbey 2006).

Some studies have shown that, in addition to greenhouse gas climate change, it is possible that land use change and direct CO2 effects may have affected changes in temperatures. Studies with the CSIRO Mk 3 climate model have shown that landcover change since European settlement has had a potential warming influence and the authors suggest that this may have helped to make recent droughts hotter (Deo et al. 2009; McAlpine et al. 2007). Deo et al also argues that reduced landscape roughness may have affected regional climate through increasing surface wind speeds, although other studies have noted windspeed decreases (Roderick et al. 2007). Droughts are also likely to have been be hotter due to CO2-driven reduced evapotranspiration, but an assessment for the 2002 drought shows the effect to have been relatively small (Cruz et al. 2010). The effect may be a more important consideration in future projections.

Studies have also shown that recent atmospheric circulation changes may have enhanced the observed warming over south-eastern Australian in winter but reduced it in summer (Hendon et al. 2007; Nicholls et al. 2010). Further, a relatively strong warming in sea surface temperatures (SST) in the Tasman sea region relative to other oceanic regions, has been attributed to a SAM-driven enhanced southern Hemisphere oceanic gyre which increases the strength of the East Australian current (Cai et al. 2006)

Atmospheric circulation changes affecting the strength and frequency of westerly and southerly airflow over New Zealand have a strong influence on regional climate trends. Such variability can either mask or accelerate human-induced warming in observed trends (Dean and Stott 2009). Removing the influence of the trend in southerly flow on New Zealand mean temperature enables the detection and attribution of anthropogenic influence on New Zealand warming (Dean and Stott 2009).

In summary, we have *high confidence* that the observed warming trends in both Australia and New Zealand can be attributed to anthropogenic influence. Trends in extreme temperature occurrence are mostly in line with expectations from the trend in mean temperature and are thus also, at least partially, attributable (*medium confidence*).

25.3.2.2. Causes of Precipitation and Other Moisture-Related Changes in Australia

Understanding recent Australian rainfall trends has been a very active area of research since the AR4. The primary focus has been on the decline in southern areas, but tropical changes have also been addressed. Drivers considered include mid-latitude circulation changes such as storm tracks, the subtropical ridge and the Southern annual mode, and (mainly tropical) SST modes such as the IOD. The role of tropical SSTs as drivers of change remains an area of disagreement.

The decline in winter rainfall in Southwestern Australia is clearly related to changes in synoptic circulation (Bates et al. 2008), particularly a marked reduction in troughs (Hope et al. 2006). It has been shown that these circulation changes are associated with a post-1975 reduction in cyclogenesis and southward deflection of storm tracks (Frederiksen and Frederiksen 2007). The possible relationship of these regional changes with the trend in a positive SAM index has also been considered, particularly given that an increasing SAM index is typically simulated under enhanced greenhouse conditions or with Antarctic Ozone depletion (Cai and Cowan 2006). Some authors have concluded that there was little relationship with SAM trends (Hendon et al. 2007; Meneghini et al. 2007), whereas others have implicated the (albeit weak) increasing winter trend in SAM (Cai and Cowan 2006; Nicholls 2010). Nicholls'use of a longer period of record may explain this difference. The actual SAM index was not always the same in these studies. (Cai and Cowan 2006) differed in using an empirical orthogonal function (EOF)-based index). Nevertheless, the role for enhanced greenhouse conditions in rainfall decline has been demonstrated using the CMIP3 models (Cai and Cowan 2006) (Hope et al. 2006). These studies simulated up to half of the observed decline when anthropogenic 20th century forcing was applied. Cai and Cowan (2006) further showed that ozone depletion was not a forcing factor in winter rainfall decline. Timbal et al. (2006), further, showed that fine resolution statistical downscaling improved simulation of the observed trends. More recently changes in stability and storm tracks seen by Frederiksen and Frederiksen (2007) have been shown to be well simulated in the twentieth century simulations by some of the CMIP5 models (Frederiksen et al. 2011a). These studies still fail to attribute up to half of the observed decline. The possible effect of natural variability and land use change appears likely to have made some contribution (Timbal and Arblaster 2006). The possible forcing effect of changing SST patterns in the Indian ocean has been raised in an idealised modelling study (Ummenhofer et al. 2008), although this is unlikely to be a large effect (Smith and Timbal 2010).

The causes of the more recent decline (mainly post-1995) in rainfall in south-eastern Australia have been addressed in a number of studies. The likelihood that anthropogenic climate change is playing a role has been demonstrated using 20th century climate model simulations (Timbal 2010b) but the observed changes are substantially larger prompting the conclusion that the model response is too small or that natural variability has amplified the trend (Timbal 2010b). The CMIP3 models also strongly show future decline in cool season rainfall for this region (Suppiah et al. 2007) and when these models are statistically downscaled (Timbal and Jones 2008), but with smaller rate of decline than has been observed recently. The observed drying is strongest in autumn which conflicts with the model results, but the occurrence of some recent dry winters and springs are reducing this discrepancy raising the possibility that it may have arisen due to natural variability (Timbal 2010a). This dry period has been strongly linked to an intensification of the subtropical ridge (STR) in eastern Australian longitudes (Larsen and Nicholls 2009),(Timbal and Jones 2008); (Murphy and Timbal 2008a); (Cai et al. in prep; Timbal 2010b) combined with anomalously low precipitable water in one study (Timbal and Jones 2008). Otherobservational and modelling studies have highlighted Indian ocean SSTs (including the IOD) as a significant driver (Ummenhofer et al. 2009a); (Cai and Cowan 2008a); (Cai et al. 2009c); (Ummenhofer et al. 2009c). Nicholls (2010) and Smith and Timbal (2010) rejected the primary forcing role of tropical SSTs and instead attribute the strengthening of the STR and the rainfall decline to the positive trend in SAM which is not driven by regional SSTs (links to Hadley cell change? Ref?). Watterson's (2010) modeling study found strong coincident relationships between Indian Ocean SST anomalies and Victorian Autumn rainfall, but little evidence of these SSTs being a primary driver or being capable of causing anything but a small fraction of recent rainfall decline. Other recent studies have continued to argue for a possible primary role for Indian ocean SST with regard to the spring and winter changes (Cai et al. 2009c; Cai et al. 2009d; Cai et al. in prep), with SSTs possibly driving rainfall through its impact on the STR(Cai et al. in prep). So, at present, the primary mechanism behind the recent south-eastern Australian rainfall decline remains unclear, although it now appears that Indian ocean SSTs are unlikely to have played a forcing role in the Autumn change (the largest component). No recent author has rejected the idea that rainfall decline is linked to human actions and, therefore, is likely to continue.

Causes of the increasing rainfall trend in northern Australia remain unknown. No twentieth century simulations of the CMIP3 archive simulate such a large increase - indeed many simulate decrease (Cai et al. 2011a). It is unlikely to be due to changes in ENSO (Smith et al. 2008a). The modelling study of Rotstayn et al. (2007) implicated the growth of northern hemisphere aerosols as a forcing factor, but the active process in the model was subsequently shown to be potentially unreliable (Shi et al. 2008) and also likely to be so in other CMIP3 models (Cai et al. 2011a). Rainfall reductions in SE Queensland are related locally to regional subsidence and reduced easterlies (Taschetto and England 2009). A large scale driver may be the IPO (Speer et al. 2011). In addition a possible link to basin-wide warming in the Indian ocean has been noted in a modelling study (Taschetto et al. 2011).

Australian trends in extreme rainfall occurrence show areas of increase and decrease which mostly follow the trends in mean rainfall discussed above (see (Alexander et al. 2007a; Gallant et al. 2007). Trends in extreme rainfall are not coherent spatially in the broader region (Choi et al. 2009). Notably, there is some evidence that the trend in the most extreme rainfalls in Australia is changing more rapidly than would be expected from the change in the mean (Alexander et al. 2007b). Alexander and Arblaster (2009) compared various rainfall extreme indices as simulated in the 20th century simulations of the CMIP3 models with observations for 1957-1999. Correspondence was not as good as it was in their temperature comparison, although the majority of models got the direction of change in the regionally averaged indices correct. In their study of combined temperature and rainfall extremes, Gallant and Karoly (2010) noted that the processes driving occurrence inter-annually could not explain the trends.

The impact of higher temperatures in exacerbating the effects of drought (Nicholls 2006) has been reinforced by studies showing that warming is a major contributing cause of reduced runoff in the Murray-Darling Basin (Cai; Cowan 2008b) and reduced soil moisture in the Southeastern Australia (Cai and Cowan 2008b; Cai et al. 2009a).

The observed decreases in pan evaporation in the Australian region are mainly driven by changes in wind-speed at the pan sites (Roderick et al. 2007). In addition, generally decreasing trends in calculated Penman potential evaporation over 1981-2006 are due to the effect of warming being more than offset by changes in other variables, particularly declining wind-speed (Donohue et al. 2010). However, and as the authors note, it is possible that the decline in wind-speed is an artifact of changes at the observation sites. With regard to positive trends in fire danger days in south-eastern Australia, Lucas et al. (2007d) concluded that climate change may have been a contributing factor. It has also been observed that years of large fires in south-eastern Australia are associated with positive IOD events and that these events have been more dominant recently (Cai et al. 2009c) - this trend may be related to greenhouse gas forcing (Cai et al. 2009e).

In summary, although the rainfall decline in southwestern Australia is not fully understood, we have *high confidence* that it is partially due to anthropogenic climate change, and *medium confidence* that this is causing at least half of the decline. Although studies disagree regarding the processes driving the rainfall decline in the southeast of Australia since 1996, there is agreement on anthropogenic climate change being a partial cause (*medium confidence*). Rainfall trends in northern Australian are not well enough understood to assign causes with any confidence. In southeastern Australia, anthropogenic climate change may also have played a role in decreasing runoff and soil moisture, and increasing fire danger (*low to medium confidence*).

25.3.3. Projections

There have been significant developments in our understanding of how climate is likely to change regionally in Australia and New Zealand. Recent work has provided more detail in projected climate change through application of high resolution downscaling techniques (Grose et al. 2010) and has provided further insight regarding changes to climatic extremes (Alexander and Arblaster 2009). There have been significant developments in methods used for regional projections and in our understanding of what processes drive regional climate changes simulated by the models.

25.3.3.1.Regional Model Evaluation and Development in Projection Methods

Many recent studies have assessed CMIP3 GCMs by evaluating their current simulations in the Australian region using differing model metrics (Perkins et al. 2007a; Smith and Chandler 2010) (Charles et al. 2007a; Kirono and Kent 2010; Moise and Hudson 2008); (Grose et al. 2010); (Vaze et al. 2011); (Chiew et al. 2009a; Suppiah et al. 2007; Watterson 2008); (Maxino et al. 2008); (Frederiksen et al. 2010). Many of these have aimed at narrowing uncertainty in projected climate change by only focussing on the better performing models. However, where comparisons have been made, there is considerable disagreement regarding the relative merits of the various models (e.g. (Chiew et al. 2009a; Smith and Chandler 2010) making it difficult to justify selection of a small set of models (Vaze et al. 2011). There is, however, some agreement on a small set of consistently poor performing models across a range of studies and metrics. Smith and Chandler (2010) identified such a set of models (GISS-AOM, CGCM3.1 – T47, GISS-EH, IPSL, PCM) across the range of studies that they reviewed. Other assessments not considered by them (e.g.(Vaze et al. 2011): (Cai et al. 2011b) (Frederiksen et al. 2011a)) do support their conclusion. Where researchers have selected a set of stronger models, the range of uncertainty in projections can be narrowed in a potentially robust way. Perkins et al. (2009), for example, found that the models with stronger skill according the metrics they used (see Perkins et al. 2007) showed significantly less warming than the full set of models. Further, Smith and Chandler (2010) found that the models which they assessed as having a more accurate simulation of current climate tended to show rainfall decrease in the Murray-Darling Basin significantly more strongly than the full set of models. This latter result needs to be contrasted with studies whose preferred models had simulated change biased more towards increase (Cai et al. 2011b; Pitman and Perkins 2008), and studies where model selection had limited impact on the range of projected changes (Chiew et al. 2009a; Kirono and Kent 2010)). Based on the outcome of this research, a number of authors are taking the view that use of most available GCMs in regional applications, rather than a performance-based selection, is the most appropriate course of action at present [s*eeking NZ angle*] (Kirono et al. 2011b); (Chiew et al. 2009a).

Probabilistic projections for Australia based on the CMIP3 model results have been prepared using the REA approach (Moise and Hudson 2008) and using a fitted Beta-distribution (Watterson 2008). Watterson's approach was the basis of the (CSIRO and BoM 2007)national climate change projections for a range of variables (see below). The approach has been further developed to include estimates of the effect of decadal-scale climate variability (Watterson and Whetton 2011), joint probabilities for multiple variables and time series (Watterson submitted; Watterson and Whetton in prep.; Watterson and Whetton submitted). An alternative way of presenting climate projection information has also been developed which casts the projection information as a set of categories of climate change with probabilities attached to these (Watterson in press; Whetton et al. 2010). This approach has a number of advantages particularly in simplifying the communication of climate change information.

Recent work has applied various high resolution dynamic and statistical downscaling techniques (e.g. (Charles et al. 2007a; Chiew et al. 2010; Timbal 2008, 2010b; Timbal et al. 2006; Timbal et al. 2009; Timbal et al. 2008; Timbal and Jones 2008); (Grose et al. 2010). These can provide further insight into aspects of climate change which are affected by local topographical forcing as well as providing locally relevant data for use in applications. Dynamically downscaled projections have had extensive recent use in climate change assessments in Tasmania (Grose et al. 2010). Notably, a number of these studies have reported that projected changes can differ between methods and reflecting the host GCM (Bates et al. 2008; Charles et al. 2007a; Chiew et al. 2010; Li and Smith 2009; Mpelasoka and Chiew 2009). The downscaling method used can affect assessments of runoff change quantitatively (but generally not qualitatively) (Chiew et al. 2010; Mpelasoka; Chiew 2009). Obtaining consistency between the projections from two statistical downscaling schemes and the host GCM required careful selection of the predictor variables. A commonly used very simple precipitation downscaling approach did not greatly bias results of a runoff assessment (Chiew et al. 2010)

25.3.3.2.Temperature Projections

Climate projections of (CSIRO and BoM 2007) provide temperature projections for Australia based on the CMIP5 models based on the methods of (Watterson 2008). These have been used widely in impact assessment. Annual projected warming above 1990 temperatures by 2030 is around 0.5 to 1.5°C across Australia under A1B (mid-emissions case), with less near the coast and more in inland areas. Projected warming by 2070 warming is 1.0 to 2.5°C (B1) and 2.2 to 5°C (A1FI). Probabilistic temperature projections have also been prepared using the REA method with broadly similar results (Moise and Hudson 2008). More recent work on temperature projections have mainly focused on aspects of extremes which are considered below. Figure 25-3 shows the probability of warming exceeding selected thresholds (from (CSIRO and BoM 2007).

[INSERT FIGURE 25-3 HERE
Figure 25-3: Title?]

In New Zealand, mean annual temperature is projected to increase by 0.2–2.0°C by 2040 and by 0.7–5.1°C by 2090, compared with 1990 (based on 12 CMIP3 models and all six SRES illustrative emission scenarios;(MfE 2008a)). The 12-model average (or 'best estimate') temperature change based on the A1B scenario for New Zealand is 0.9°C and 2.1°C for 2040 and 2090, respectively. The rate of warming accelerates over time, with the warming by 2090 more than double the warming by 2040. The pattern of warming is fairly uniform over the country.

In a comprehensive study of extreme events in the CMIP5 GCM ensemble, Alexander and Arblaster (2009) identified a strong projected increase in warm nights (90th percentile of Tmin), fewer frosts (below 0°C), and longer heat-wave duration (periods of at least five consecutive days with Tmax at least 5°C above the 1961-90 mean (see Figure 25-4 for more details of their results). This result is consistent with earlier results using fewer models and other methods (CSIRO and BoM 2007) (Tryhorn and Risbey 2006). Perkins et al. (2009) considered rarer extremes by using a generalized extreme value distribution fitted to CMIP3 GCM data and found more extremely high temperatures (1 in 20 annual daily events) and fewer extremely low temperatures were projected for Australia. This is consistent with the changes in the less severe extremes considered by Alexander and Arblaster (2009). In a study applying dynamic downscaling, Watterson et al. (2008) found that extreme high temperatures were projected to increase more than the mean change is some southern coastal areas. This was due to a faster rate of warming inland and the effect of this on weather types that bring hot weather to the coast. With regard to frost occurrence, (CSIRO and BoM 2007) noted that the simulated rate of future decline in frost occurrence in the GCMs and in downscaled results was less rapid than would be deduced from mean temperature. This result has relevance to simple downscaling approaches used in many impact assessments.

[INSERT FIGURE 25-4 HERE
Figure 25-4: Time series of areally averaged extremes indices between 1870 and 2099.]

Extreme daily temperatures are projected to increase in New Zealand, corresponding to the projected increases in mean temperature(Griffiths et al. 2005). Based on scaled mean temperature projections from a global climate model using an emissions scenario including sulphate aerosols and 1% per annum compounding CO2 concentration increase, the percent of New Zealand's frost-free land area in spring and autumn is projected to increase by 3.6–5.2% by 2020–2049 and by 15.9–16.7% by 2070–2099, compared with 1974–2003 (Tait 2008). The number of days with temperatures above 25°C is projected to increase by 40–60 days by 2080–2099 in already warm northern locations in New Zealand compared with 1980–1999, based on a regional climate model using the B2 and A2 emissions scenarios (MfE 2008a).

In summary, we have *very high confidence* in projected future warming for Australia and New Zealand. For Australia this warming is *likely* to be the range of 1.0 to 2.5°C (B1) and 2.2 to 5°C (A1FI) by 2070, and for New Zealand 0.7–5.1°C by 2090, across all emission scenarios. We also have *very high confidence* that these warmings will be associated with large increases in the occurrence of hot days and nights and decreases in the frequency of cold days and cold nights.

25.3.3.3. Precipitation Projections

Based on the CMIP3 ensemble, (CSIRO and BoM 2007) projected a reduction in annual rainfall for southern areas of Australia, especially in winter, and in southern and eastern areas in spring. Future changes in summer rainfall in northern and eastern Australia were uncertain with individual results ranging from substantial decrease through to substantial increases (see Figure 25-5). The magnitude of projected rainfall change by 2030 (relative to 1990) is around -15% to +10% in northern areas and -10% to little change in southern areas, with these results little affected by the assumed emission scenario. Winter and spring changes range from decreases of around 15% to little change in southern areas of the south-east of the continent, decreases of 20% to little change in the south-west, and decreases of around 15% to possible increases of 5% in eastern areas . A range of around -15% to +10% applies throughout in summer and autumn. The magnitude of the 2070 changes projected under the B1 is around twice as large as those projected for 2030, whereas under the A1FI scenario they are substantially larger still. In that case, the range of annual precipitation change is -30% to +20% in central, eastern and northern areas. The range of change in southern areas is from -30% to +5%. Seasonal changes may be larger, with the projected decreases in the south-west of at least 40%. Proposed explanations of the projected rainfall changes are similar to those discussed above in explaining observed changes and include the positive trend in SAM, southward shift in storm-tracks and the effect of simulated trends in tropical Pacific and Indian ocean SSTs (Cai and Cowan 2006; Cai et al. 2011b; Frederiksen et al. 2011b; Frederiksen et al. 2011a; Watterson in press). Improved understanding of modelled and observed responses of storm tracks, in particular, has increased our confidence in the projected rainfall decreases along the southern edge of Australia.

[INSERT FIGURE 25-5 HERE
Figure 25-5: Title?]

Other studies have made regional rainfall projections for Australia based on CMIP3 using a subset of models (Pitman and Perkins 2008; Smith and Chandler 2010) or through the application of statistical (Timbal et al. 2008) or dynamical downscaling (Grose et al. 2010) In the latter case, climate change projections for Tasmania at 14 km resolution were prepared using the CCAM stretch grid model to downscale six of the CMIP3 global climate models. This technique is particularly relevant to Tasmania as the global models do not represent adequately its topographical variations in climate and the high resolution approach did indeed reveal detail in projected rainfall change not discernible in the GCM results, such as a pattern of increased rainfall over the coastal regions, and reduced rainfall over central Tasmania and in the north-west.

The projected annual average rainfall change for New Zealand shows a distinct spatial structure of wetter in the west (up to 5% by 2040 and 10% by 2090) and drier in the east and north (exceeding 5% in places by 2090;(MfE 2008a)), based on 12 CMIP3 models and all six SRES illustrative emission scenarios. This annual pattern is driven by changes in winter and spring (Figure 25-6). In summer and autumn the pattern is different, though the percent changes are smaller than the winter and spring seasons.

[INSERT FIGURE 25-6 HERE
Figure 25-6: Title?]

The projected changes in mean annual and seasonal rainfall are strongly associated with the expected changes in mean wind-flow over New Zealand. Averaged over 12 CMIP3 models and six emission scenarios, the annual mean westerly component of flow is projected to increase by approximately 10% by 2040 and 2090, compared with 1990 (MfE 2008a). Seasonal changes vary substantially, with increases in the mean westerly component of greater than 50% projected for winter, 20% in spring, and decreases of 5–20% in autumn and summer.

(CSIRO and BoM 2007) noted that the most intense rainfall events in most locations will become more extreme, driven by a warmer, wetter atmosphere. Alexander and Arblaster (2009) identified a significant tendency in the CMIP3 ensemble for increased daily rainfall intensity, the contribution of very heavy precipitation, and consecutive dry days, which they concluded represented a future of longer dry spells but heavy precipitation events. Some other measures of extreme rainfall showed no significant trends. Rafter and Abbs (2009a) used extreme value theory to examine changes in the intensity of extreme daily rainfall, with return periods of 10 to 50 years in eleven of the CMIP3 GCMs. They showed a tendency for increases in all regions in most models for 2055 and 2090 with smaller increases in the south of Australia and larger increases in the north. Fine-scale regional climate modelling has been performed for several locations (Abbs and Rafter 2009) showing significant fine-scale spatial variability in change, and a tendency for short duration (sub-daily) rainfall to change more rapidly than longer duration (daily and multi-day) rainfall. In a study based on a single GCM, an increase to 2050 in conditions suitable for severe hail in Sydney was simulated (Leslie et al. 2008).

Increases to extreme rainfall for New Zealand of approximately 8% are projected for each 1°C increase in temperature (MfE 2008a). Consequently, a present-day 24-hour extreme rainfall with a 100-year return period is projected to occur about twice as often by 2080–2099 (based on the average of 12 CMIP3 models and the A1B emission scenario), compared with 1980–1999. Regional model runs based on the B2 and A2 emissions scenarios for 2071–2100 show substantial regional variation to the 8% increase per degree warming projection resulting from run-specific variations in the modeled storm tracks and localized topographic influences (Carey-Smith et al. 2010; MfE 2008b).

(Hennessy et al. 2008b) assessed how climate change may affect the occurrence of 1-in-20 year exceptionally hot or dry years in future for seven regions over Australia using the output of 13 CMIP3 GCMs. Critical thresholds were defined for the 20th-century simulation from each GCM and then projections (up to 2030) were constructed relative to these thresholds. Exceptionally dry years are likely to occur more often and over larger areas in the south and south-west (i.e. south-west of Western Australia and Victoria and Tasmania regions) with little detectable change in other regions for 2010-2040. Years with exceptionally low soil moisture are likely to occur more often, particularly in these same regions. (Kirono and Kent 2010) (Kirono et al. 2011a) examined drought in the CMIP3 models out to 2070 (A1B) using two drought indices. Consistent with Hennessy et al., they found projected changes in southeast and south-west of the continent ranging from little change to five times more frequent than current rates. Changes in the north ranged between a halving and around 2-3 times greater in occurrence.

Changes to potential evaporation are also important to drought occurrence. (CSIRO and BoM 2007) projected significant increases in potential evaporation across Australia using the Morton method. Questions regarding the reliability of this projection, partly based on a small observed trend to decreased pan evaporation (Roderick and Farquhar 2004), have been addressed in a study by Kirono et al. (2009) who found that calculated past (and projected future) potential evaporation was not inconsistent with observed trends in pan evaporation. However, a more recent study concluded that other methods of calculating changes to potential evaporation (e.g. Penman) were likely to be more reliable under changing climate conditions than Morton (Donohue et al. 2010)

Eastern areas of New Zealand are projected to have around ten percent additional time spent in drought by 2080–2099, compared with 1980–1999 (Clark et al. 2011). Upper and lower drought scenarios (using 12 CMIP3 models and the B1, A1B and A2 SRES emission scenarios) for the coming century range from: a strong shift toward an arid climate over most agricultural regions with well over a doubling of time spent in drought across most of New Zealand to an environment of minimal increases from current levels isolated to eastern agricultural regions (Clark et al. 2011).

In summary we have *high confidence* in projecting future annual decline in rainfall in southwestern Australia and *medium confidence* in projecting annual rainfall declines in southeastern Australia. In other areas of eastern Australia, and in northern Australia, the direction of future rainfall change is uncertain, with large changes in either direction being plausible. In New Zealand, we have *medium confidence* that rainfall will change with a pattern of greater rainfall in the west and less rainfall in the east.

Increases the intensity of daily extreme rainfall, or in the proportion of total rainfall in the extreme categories is projected to increase in most regions (*high confidence*) and drought is projected to increase in frequency and duration in southern areas of Australia and in eastern New Zealand (*high confidence*).

25.3.3.4. Winds and Atmospheric Circulation Projections

Wind changes have the potential to influence a range of terrestrial based processes (e.g. water supply, droughts e.g.(McVicar et al. 2008)) and oceanic processes e.g.(McInnes et al. 2011a). Changes in mean wind speed and direction for 2081-2100 relative to 1981-2000 were presented in McInnes et al. (2011a) based on a 19 member multi-model ensemble. For JJA these showed multimodel agreement (>66%) for increase in mean winds north of 30°S and across Bass Strait and Tasmania and decrease across much of the mainland coastline south of 30°S. These changes are consistent with a southward movement of the storm tracks (Frederiksen et al. 2011a).

Atmospheric blocking frequency is projected to decrease in winter (and much less so in summer) in the Australia-New Zealand region by 2075–2099 (using a high resolution Atmospheric GCM and the A1B emission scenario), compared with 1979–2003, with the possibility that blocking events greater than 13 days will be extremely rare in the future (Matsueda et al. 2010). Specific to the New Zealand region, blocking-type pressure patterns (to the east of the country) are projected to increase in summer by 3–4%, while trough and zonal-type pressure patterns are projected to become more frequent in winter (by 1–4%) and less frequent in summer (by 2–3%) by 2081–2100 (based on regional model runs using the A1B and A2 scenarios), compared with 1961–2000 (Mullan et al. 2001)

Extreme winds in New Zealand are often associated with trough and zonal-type pressure patterns, and are not often associated with blocking-type patterns (Mullan et al. 2011). Thus, the frequency of extreme winds (particularly over the South Island and southern North Island) is projected to increase (by 1–4%) in winter and decrease by a similar amount in summer, based on the model runs above.

Sub-tropical or mid-latitude low pressure system tracks are projected to shift poleward by 2081–2100 (based on 10 climate models and the B1, A1B and A2 emission scenarios) compared with 1961–2000. In winter, this results in fewer of these systems projected to pass over the North Island and an increased frequency to the south of the country (Mullan et al. 2011). Indices of severe weather calculated from a control (1970–2000) run and a future (2070–2100, A2 scenario) run of a regional climate model show that severe weather systems are projected to increase by 3–6% over most of New Zealand between these periods (Mullan et al. 2011).

In winter mean winds north of 30°S and across Bass Strait and Tasmania are *likely* to increase but decrease elsewhere (medium confidence). Extreme winds are projected to increase over the South Island and southern North Island in winter and decrease in summer (*medium confidence*).

25.3.3.5. Sea Level Projections

[*add mean sea level rise discussion for Australia*]

Projected changes to extreme sea levels have been assessed over some parts of Australia. Over southeastern Australia, (McInnes et al. 2011b; McInnes et al. 2009) found that a 10% increase in wind speeds, consistent with the upper end of the range under an A1FI scenario from a multi-model ensemble for 2070 together with an A1FI sea level rise scenario, would produce extreme sea levels that were 12 to 15% higher than those including the A1FI sea level rise projection alone leading to the conclusion that sea level rise and not meteorological changes had the greater potential to increase extreme sea levels in the future in these locations. Recent studies on the tropical east coast of Australia reported in Harper et al. (2009) show that the impact of a 10% increase in tropical cyclone intensity on the 1 in 100 year storm tide (the combined sea level due to the storm surge and tide), is small compared to projected mean sea level rise.

Waves play a significant role in shaping a coastline by transporting energy from remote areas of the ocean to the coast and severe waves can pose a threat to safety and destroy coastal and marine infrastructure. Future changes to wave climate on Australia's east coast have been evaluated by Hemer et al (2010) using wind forcing from 3 downscaled GCM simulations under an IPCC SRES A2 emission scenario. Over the period 2081-2100 relative to 1981-2000, a small (<0.2 m) but robust decrease in mean and storm waves (waves greater than 3 m) is found along the east Australian coast. Mean waves undergo a small (<5°) anticlockwise rotation (i.e. waves becoming more easterly). Storm waves undergo a small (~5°) clockwise rotation (i.e. waves becoming more southerly). However, they conclude that uncertainties arising from the method by which climate model winds were applied to wave model simulations (e.g., by applying bias-correction to winds or perturbing current climate winds with wind changes derived from climate models) made a larger contribution to the spread of climate model projections than the forcing from different GCMs or emission scenarios (Hemer et al. submitted)

Sea level rise for the New Zealand region is projected to be 0.2–0.6 m relative to the 1980–1999 average, by 2090–2099 (MfE 2008b). For risk assessment purposes, a SLR range of 0.5–0.8 m is recommended (MfE 2008b). For longer planning and decision timeframes beyond the end of this century, an additional allowance for sea-level rise of 10 mm per year beyond 2100 is suggested (MfE 2008b). Sea surface temperature increases in the New Zealand region are expected to be similar to the projected changes to mean air temperature (MfE 2008a).

[*Add summary statement of SLR*]

25.3.3.6. Other Projections

Lucas et al. (2007d) examined fire-weather risk in Australia using various climate model results. Simulations showed that the number of days with very high fire danger ratings is likely to increase by 2% to 30% by 2020 and by 5% to 100% by 2050. The number of days with extreme fire danger ratings is projected to increases between 5% and 65% by 2020 and between 10% and 300% by 2050. In other studies relevant to southeastern Australia, Hasson et al. (2009) using ten models from the CMIP3 archive identified large future increases in the synoptic conditions suitable for fire occurrence, and Cai et al. (2009c) suggested that fire occurrence will increase due projected increased positive IOD events. [NZ Fire weather – what has happened with the Scion study? emailed Grant Pearce 23/4/2011]

With regard to other aspects of future regional climate change (Hennessy et al. 2008a) modelled the impact of projected climate change on snow cover in the Australian Alps using a low impact (least warming, greatest precipitation increase) and high impact (greatest warming, greatest precipitation decrease) scenarios for 2020 and 2050 consistent with the (CSIRO 2001) projections. They found that the area with an average annual snowcover of at least one day declined by 10 to 39% by 2020, and by 22 to 85% by 2050. Using results from four of the CMIP3 GCMs and a risk diagnostic approach, the risk of cool season tornadoes was found to decrease in southern Australia due to increased atmospheric stability (Timbal et al. 2010).

Winter snow volume is projected to decrease by up to 50% in mountainous regions of New Zealand, based on the difference between a regional model control run (1980–1999) and a simulation under the A2 emission scenario (2080–2099;(MfE 2008a)). Based on theory, snowline elevations are expected to be higher (Fitzharris 2004) and the duration of days with snow lying at low elevations in New Zealand is expected to decrease (MfE 2008a) as the climate warms.

Abbs (2009a) examined regional climate model outputs which imply changes in tropical cyclone (TC) occurrence in the Australian region. The simulations showed on average an approximately 50% decrease in occurrence of TCs for the Australian region for the period 2051-2090 relative to 1971- 2000. They also reported a likely small decrease in the duration of any given cyclone and a southward movement of 100 km in the genesis and decay regions. Five of the seven simulations showed statistically significant decreases in TC occurrence. Application of empirical indices, such as those used by Camargo et al. (2007) to GCM outputs agreed with the projection of a decrease in the frequency of occurrence of TCs in the Australia-Pacific region. An analysis of likely changes in precipitation change showed an average increase of 17% in TC-related rainfall occurring within 300 km of the TC centre. There were no changes projected in the seasonality of TCs. Further downscaling of a sample of individual TCs showed a distinct shift towards deeper pressures and a flattening of the maximum wind speed distribution, with a larger percentage of TCs producing higher wind speeds in the 2070 climate than either the 1980 or 2030 climates. These findings are consistent with recently published international studies (Bender et al. 2010; Knutson et al. 2010).

Research since the AR4 has further established the likelihood of future increased drought in southern Australia (*high confidence*) and eastern New Zealand (*medium confidence*); increased fire danger and reduced snowcover in Australia (*high confidence*). Tropical cyclones are projected to increase in intensity but decrease in numbers (*low confidence*).

25.4. Socio-Economic Trends and their Interactions with Vulnerability and Adaptive Capacity

25.4.1. Overview

Socio-economic trends constitute important drivers of future changes in vulnerability and adaptive capacity (Fünfgeld 2010; Fünfgeld and McEvoy 2011; Hallegatte et al. 2011; Jones and Preston 2011; Preston et al. 2009) [*AR5 refs*]. The 'STEEP' model of scenario planning (Withers and Saliba 2009) identifies the following drivers of change: society, technology, economy, environment and politics. This section focuses on current knowledge and scenarios of future changes in society, economy and technology and assesses their implications for and use in climate change vulnerability studies. Future changes in political directions are amenable in principle to scenario-based analysis but are often driven by strong underlying value judgements and are not considered explicitly in this assessment. Non-climate driven environmental changes are considered where relevant in sectoral assessments of climate change impacts and adaptation options (see 25.5 and subsections).

25.4.2. Demographic Changes

Both Australia and New Zealand have experienced rapid population growth over recent decades, and in the absence of radical and sustained changes to current immigration policies this is projected to continue for at least the next several decades (*very high confidence*). By 2056, Australia's population is estimated to grow by between 40 and 90% from 22.4 million in 2010 to between 30.9 and 42.5 million, and to between 33.7 and 62.2 million by 2101 (ABS 2008). New Zealand's population is expected to grow at a slightly lower rate by between 11 and 52% from 4.4 million in 2010 to between 4.8 and 6.7 million in 2061 (Stats NZ 2011c). Differences in population gain between scenarios is due to alternative assumptions about future net inward migration, which are subject to changing policies and community preferences (Carr 2010; Hugo et al. 2010; Ridout et al. 2010), and differences in mortality and fertility rates (ABS 2008; Stats NZ 2011c). More than half of the recent population gain in Australia and more than 20% of the gain in New Zealand are due to permanent immigration (ABS 2008; Stats NZ 2010c).

Australia and New Zealand's populations are amongst the most urbanised in the world, with more than 85% living in urban areas and their satellite communities (ABS 2008; Stats NZ 2004). Most urban centres are located in coastal regions: 81% of the Australian population lives less than 50 km from the coast (DCC 2009), and 65% of the New Zealand population lives less than 5km from the coast (Stats NZ 2010b). The Australasian population is extremely dynamic with around half of the population moving house at least once every five years (ABS 2010b; Stats NZ 2006b). The trend towards urban concentration and reducing populations in remote rural areas is expected to continue even in the absence of climate change (Mendham and Curtis 2010; Stats NZ 2010d), but could be locally accelerated by climate change in some parts of Australia (25.5.3.3). Counteracting these broad urbanisation trends is significant population growth particularly in some non-urban coastal regions also referred to as ‘sea change’ movement (Freeman and Cheyne 2008; Gurran 2008). These locations could see further population increases due to retirement of baby boomers, increasing ICT development and structural change in the economy (Peters 2007; Stats NZ 2010d). In Australia, mining development could also have some impact on rural population distribution (Mendham and Curtis 2010; Peters 2007).

The population in both countries is expected to show significant ageing (*very high confidence*). Figure 25-7 shows the projected relative increase in different age groups in Australia. In both countries, the number of people aged 65 years and over will double in the next two decades and their percentage of the total population will increase substantially, resulting in changes in labour force participation, productivity impacts, increased pressure on health care and a declining ratio of workers to aged dependents (DOL 2010; Stats NZ 2006a, 2010a; Treasury 2010).

[INSERT FIGURE 25-7 HERE
Figure 25-7: Structural aging – Australia: Change by Age: 2006-11; 2031 (Series B) (ABS, 2008).]

[*Does the figure add anything? Could replace with population pyramids for different years (current and projected). Difficult to capture both countries (broad looks very similar), could do side-by-side comparison.*]

25.4.3. Economic Changes

Both Australia and New Zealand are developed and have export-lead economies largely dependent on natural resources, agriculture, minerals, manufacturing and tourism. Per capita GDP in 2008 was $38,638 in Australia and $27,036 in New Zealand (OECD 2011). The economies of Australia and New Zealand have undergone similar long-term structural changes, with declining contributions from agriculture and manufacturing since the 1980s and increasing contributions from service industries in both countries and, in Australia, mining and mineral extraction (ABARE and MAF 2006). Despite differences in the natural resource bases, both economies remain highly dependent on international trade in commodities albeit with different emphasis: Australia’s farm exports accounted for 11% and the mineral and energy resources sector for 54% of exports in 2009-10 (ABARES 2010), while for New Zealand, the agricultural and minerals and energy resources sectors accounted for 56% and 5%, respectively, of total exports in 2010 (Stats NZ 2011b).

In Australia, real GDP has grown by an average of 3.3% per annum between 1970 and 2010 and GDP per capita by 1.9%, while in New Zealand, real GDP has grown by an average of 2.4% per annum between 1970 and 2003 and GDP per capita by 1.3% (ABS 2011b; Stats NZ 2011a). Projections of future long-term economic growth are highly uncertain and subject to short-term fluctuations. Over the longer term to 2050, real GDP is projected to grow by 2.5-3.5% and about 1.9% per annum in Australia and New Zealand, respectively (Bell et al. 2010; Treasury 2010). Future projections indicate a further decline in the relative contribution to real GDP from agriculture in Australia from around 3.2% in 2005 to 2.5% in 2050, but a more steady contribution in New Zealand (Australian Government 2008) [*looking for NZ ref on relative share of agriculture*].

25.4.4. Social and Technological Change

Climate change impacts are generally expected to fall disproportionately on the poor and marginalised (25.3.3) [*AR5 refs*], but the measurement of poverty, inequality and exclusion is highly contested. Poverty in Australia has been measured at around 10 percent with a slight discernible increase in the 1997-2006 period. A comprehensive study of the multiple dimensions of social exclusion in Australia (Scutella et al. 2009) identified between 20 and 30 percent of the Australian population aged 15 years and over to be experiencing ‘marginal exclusion’ and 4 to 6 percent ‘deeply excluded’ and 1 percent ‘very deeply excluded’. However, anticipating future changes in income, poverty, income distribution, social exclusion and inequality is extremely difficult. The indigenous population currently constitutes about 2% (563,000) of the national population (ABS 2010a) and this proportion is expected to increase, with absolute numbers rising to about 1 million by 2040 (Biddle and Taylor 2009). The overseas-born population from varied cultural backgrounds is further increasing the diversity of the Australian population, which is expected to continue into the future. [*similar info from NZ to come*]

No studies could be identified that present region-specific scenarios of technological changes that would have informed impacts or adaptation studies in Australia or New Zealand.

25.4.5. Use of Socio-Economic Scenarios in Adaptive Capacity/Vulnerability Assessments

The above scenarios of demographic, economic and socio-cultural changes in Australasia are expected with *very high confidence* to alter socio-economic determinants of vulnerability and adaptation options and preferences at individual and community level (e.g. through distribution of age, gender, home ownership, economic resilience, labour force participation, access to information, participation in public life and political influence) (Edwards and al. 2011 - forthcoming; Fünfgeld and McEvoy 2011; Preston and Stafford-Smith 2009) [*Khan forthcoming*; *AR5 refs; could add generic refs from international literature but will wait to see what other AR5 chapters deliver*]. However, such information has been used only to a limited extent in Australia and is virtually absent in New Zealand studies of projected future impacts of and vulnerability to climate change.

Examples of studies that have used some aspects of socio-economic information to understand vulnerability or adaptive capacity to climate change, mostly at sub-regional and local scales, include a mapping project in the Sydney Coastal Councils Group (Preston et al. 2009; Preston et al. 2008), catchment-scale comparisons of vulnerability (Preston and Jones 2008), future scenarios for the Great Barrier Reef (Bohensky et al. in press), local-scale assessment of community vulnerability to flooding [*Khan, forthcoming*], regional assessments of adaptive capacity and response options for primary industry in south-west Victoria (Fitzsimons et al. 2010; Soste 2010; Tostovrsnik et al. 2010), and efforts to measure and enhance adaptive capacity in greater Sydney and south-east Queensland (Smith et al. 2008b; Smith et al. 2010). However, some of these studies used current rather than projected future socio-economic conditions, limited subsets of information and relied on postulated or observed correlations between socio-economic variables and vulnerability to climate change rather than detailed process modelling to capture dynamic changes.

A variety of mixed qualitative-quantitative scenario studies and tools have been designed to generate comprehensive scenarios of future environmental and socio-economic conditions, mostly to build strategic planning capacity at regional scales, in connection with but not exclusively for climate change (CSIRO 2006; Frame et al. 2007; Frame et al. 2009; Huser et al. 2009; Pettit et al. 2011; Pride et al. 2010; Taylor et al. 2011; van Delden et al. 2011) [*other qualitative big-picture socio-economic scenario exercises in Australia?*]. However, these scenarios appear not to have been used in any subsequent quantitative climate change impacts or vulnerability studies. No harmonised set of socio-economic scenarios exists that would ensure consistency of assumptions in regional and local studies with global socio-economic trends that underlie past (SRES) or next generation (RCP/SSP) global greenhouse gas emissions and climate change scenarios.

The currently limited, simplistic or non-use of quantitative or qualitative information on future social, cultural and economic changes across Australia and New Zealand in impacts and vulnerability studies severely limits the confidence that can be assigned to conclusions about long-term vulnerability and adaptive capacity to climate change in human and mixed natural-human systems at sectoral, national or regional-scale.

25.5. Sectoral Assessments of Impacts and Adaptation Options

25.5.1. Freshwater Resources

The impact of climate change on water resources is a significant cross-cutting issue. Climate effects on people, agriculture, ecosystems and industry are strongly influenced by the climate impact on water. The variability of river flows in Australia and New Zealand are strongly influenced by ENSO and IPO (Chiew and McMahon 2002;

McKerchar and Henderson 2003; Power et al. 2006), and floods and droughts tend to cluster over periods lasting several years or decades (Kiem et al. 2003; McKerchar et al. 2010; Verdon et al. 2004). Runoff and river flows is mainly influenced by precipitation, with a 1% change in mean annual precipitation in Australia generally amplified as a 2-3% change in mean annual runoff (Chiew 2006; Jones et al. 2006). Runoff will also be affected by changes in potential evaporation, dominant hydrological processes, vegetation response and surface-atmosphere feedbacks in a warmer and higher CO_2 environment (Betts et al. 2007; Donohue et al. 2009; McVicar et al. 2010; Petrone et al. 2010a).

Predictions of climate change impact on freshwater resources have improved since AR4 with better interpretation of GCM projections (Chiew et al. 2009a; Perkins et al. 2007b; Smith and Chandler 2010), downscaling of GCM outputs for hydrological simulations (Bennett et al. 2010; Bright et al. 2008; Charles et al. 2007b; Chiew et al. 2010; McMillan et al. 2010) and extensive hydrological modelling studies. Figure 25-8 shows projections of climate change impact on mean annual runoff across Australia for a 1°C global warming. The projections over the key regions come from hydrological modelling in the CSIRO Sustainable Yields studies using point and catchment-scale climate data downscaled from climate projections from the IPCC AR4 GCMs (Chiew et al. 2009b). There is considerable variation in the future runoff projections, mainly because of the uncertainty in the GCM rainfall projections. Future freshwater resources availability in south-eastern Australia (which supports more than 70% of the population and irrigated agriculture) and in the far south-west is likely to decline. The direction of rainfall and runoff change is less certain in northern Australia. The hydrological models also predict changes to other flow characteristics, like the variability in reservoir inflows, and floods and low flows. The low flows and loss of connectivity in the more frequent long dry periods in the future will affect aquatic ecosystems (Lake 2008) (see section on 'Natural ecosystems') and may exacerbate water quality problems (Viney et al. 2007; Whitehead et al. 2009).

[INSERT FIGURE 25-8 HERE

Figure 25-8: Projections of climate change impact on mean annual runoff for a 1°C global warming (median warming by 2030 relative to 1990). [*Need to check with section on 'Climate' (Penny) to ensure consistency (both the presentation/illustration and the numbers for rainfall), and/or say in text or here, that there is little difference between AR4 and AR5 (hopefully). Could possibly also do this for NZ – if Penny can do pattern scaling also for NZ, and we can apply Budyko – but being surrounded by oceans and the high dependence on catchment size and source region, I am not sure if the GCM rainfall change for NZ means much (ie need downscaling).*] The change in runoff per degree global warming scales relatively linearly up to 2-3oC warming (Post et al., 2011a) [*IUGG July 2011 paper – add reference*]. The top row shows percentage change and the bottom row shows change in runoff depth. The median and dry and wet (10th and 90th percentile) range are shown. Modelled values for south-eastern Australia (Chiew et al. 2009b), northern Australia (Petheram et al., 2011) [*Paper submitted to Journal of Hydrometeorology*], south-west Western Australia (CSIRO 2009) and Tasmania (Post et al., 2011b) [*In Press paper in Journal of Hydrology*] come from the hydrological modelling in the CSIRO Sustainable Yields projects (http://www.csiro.au/partnerships/SYP.html) and the South Eastern Australian Climate Initiative (http://www.seaci.org), informed by projections from the IPCC AR4 GCMs. Values for other areas are derived using the Budyko water and energy balance relationship (Teng et al., 2011) [*Paper submitted to Journal of Hydrometeorology*].

In New Zealand, projections of future river flows are highly dependent on the size and headwater region of the catchment. For example, the Rangitata River in Canterbury has its source in the Southern Alps where mean annual precipitation is projected to increase by as much as 400 mm compared with little change on the Canterbury Plains. The mean annual river flow for the Rangitata is projected to increase by about 8% by 2040 (Bright et al. 2008). Projected changes to the phase of precipitation (rain or snow) are also important for many New Zealand rivers. For example, winter flows in the Clutha River is projected to increase substantially (by xx-xx% by 2090) [*Andrew - See if we can estimate this from the paper*] in response not only to the projected increases in precipitation in the source alpine region but also to more of the precipitation falling as rain rather than as snow. This also has an impact in spring and summer flows, as the average annual total snowmelt is projected to decrease by 5-60% by 2090 (Poyck et al., 2011). [*Poyck et al. Combined snow and streamflow modelling to estimate impacts of climate change on water resources in the Clutha, New Zealand. Submitted to Journal of Hydrology (NZ)*] [*Andrew – See if we can add 1-2 sentences (i) perhaps stating that apart from these, there is no/few other studies on climate change impact on NZ* *water resources, and/or (ii) see if we can broadly generalise likely impact on flows from Penny's section on precipitation projections.*]

Extreme precipitation events are likely to become more intense in the future because warmer temperatures will provide stronger convection and an ability to hold more moisture in the air (Abbs 2009b; CSIRO and BoM 2007). Ensembles of future projections from GCMs show higher intensity extreme rainfall events with longer dry spells (Alexander and Arblaster 2009). (Rafter and Abbs 2009b), in a statistical study of CMIP3 GCM rainfall simulations across Australia, showed increases in future daily rainfall with return periods of 10 to 50 years. Fine-scale regional climate modelling in south-eastern Australia showed higher intensification of short duration (sub-daily) rainfall than longer duration rainfall (Abbs and Rafter 2009).

The flow response to projected changes in extreme precipitation depends greatly on the nature of the catchment. High resolution downscaling (Carey-Smith et al. 2009; Griffiths 2007a) and hydrologic analysis in New Zealand (MfE 2008c, 2010b) indicate that: the 100-year ARI flood peak for Stoney Creek in Central Otago will increase by 7% by 2040; the 100-year ARI flood for Hutt River near Wellington will become a 33-year ARI flood; the 50-year ARI peak flow for the Buller River on the west coast of the South Island will increase by 10% by 2030 (Gray et al. 2005); and the 100-year ARI flood peak for the Leith River in Dunedin will increase by 17% by 2080.

The higher intensity storms will cause greater stormwater runoff and sewer overflows in urban areas (Howe et al. 2005a; MfE 2008c), increase flood risks (which may be exacerbated in coastal areas due wind generated storm surge and wave set-up) (McInnes et al. 2005a; McMillan et al. 2010; MfE 2010b) and increase erosion and sediment and nutrient delivery to waterways particularly in high runoff events following long dry period. Adaptation in urban areas include retaining floodplains and floodways, adapting ands retrofitting existing systems to attenuate flows and water sensitive design in new developments (Howe et al. 2005a; Skinner 2010).

Climate change will impact on groundwater through changes in groundwater recharge rates and the relationship between surface waters and aquifers that are hydraulically connected. Dryland diffuse recharge in most of the west, centre and south of Australia is likely to decrease because of the reductions in rainfall, and increase in the north and some parts of the east because of the higher rainfall intensity (McCallum et al. 2010); Crosbie et al., 2011) [*Crosbie et al. Diffuse recharge across Australia under a 2050 climate: modelling results. CSIRO report or paper being prepared*]. In New Zealand's Canterbury Plains, groundwater recharge and the area of land able to be irrigated are projected to decrease by about 10% by 2040 (Bright et al. 2008). However, it is difficult to accurately quantify the climate change impact on recharge because of the poor knowledge of current recharge rates, uncertainties in future rainfall projections, and uncertainty in process changes (in particular vegetation) that affect recharge (Crosbie et al. 2010; Holman 2006).

In Australia, water managers and policy makers at national, state and catchment management levels are developing sustainable water strategies to cope with a variable and changing water future. Examples include the Australian Government's 'Water for the Future' programs (at AUD$12.9 billion this is the single largest investment in climate change adaption), Victoria's 'Our Water Our Future' programs, New South Wales' 'Water for Life' program and Queensland's 'ClimateSmart Adaptation Action Plan'. Many capital cities are moving away from traditional reliance on catchment runoff and groundwater as these sources are most sensitive to climate change and drought. Instead they are diversifying by investing in desalinisation plants and water reuse. They are also reducing water demand by implementing water conservation measures and water sensitive urban design (see also 25.6.3.2). Adaptation in regional areas include spending billions to upgrade irrigation infrastructure, improve on-farm irrigation efficiency, buy back water entitlements, develop more equitable water sharing plans to cope with current and future climates and assist rural communities adapt to a future scenario of reduced water availability (see 25.6.3.2).

In New Zealand, the Ministry for the Environment has established the 'Land and Water Forum' whose brief is to advise on how water should be managed in New Zealand. In June 2009, the Ministry announced the 'New Start for Fresh Water' strategy which outlines current and future issues water managers and water users face, and the potential implications of water management choices.

25.5.2. Terrestrial and Inland Freshwater Ecosystems

Many terrestrial and freshwater species in New Zealand and Australia are endemic (80 to 100% in many taxa), with narrow geographic and climatic ranges that in many cases are also highly fragmented (Lindenmayer 2007), (Steffen et al. 2009), (McGlone et al. 2010). Protected areas occupy approximately 12% of Australia (CAPAD 2008) and ~one third of New Zealand (MfE 2010a) but many reserves are small and isolated and there is under-representation of some key ecosystems (Sattler and Taylor 2008), (Walker et al. 2006). In Australia, fragmentation of habitat combined with flat topography (99% of the continent is less than 1000m above sea level), is likely to limit the potential for either latitudinal or altitudinal migration as climate zones shift and may increase the spatial impact of climate extremes, such as heavy rainfall, flooding and droughts (Steffen et al. 2009).

Episodic climate events are important drivers of ecological structure and function in both terrestrial and freshwater systems in Australia. Many Australian species are well- adapted to short-term climate variability especially in the arid and semi-arid regions, but are vulnerable to the impacts of longer-term shifts in mean climate and increased frequency or intensity of extreme events, especially fire, drought and floods (Steffen et al. 2009). Predicted increases in the frequency and intensity of fire regimes in many regions may be one of the most significant drivers of ecosystem change (Bradstock 2010).

By contrast, New Zealand species currently experience little moisture stress or prolonged periods of hot or cold, with climate extremes buffered by the oceans (McGlone et al. 2010). Temperature and rainfall vary greatly within seasons, and the New Zealand biota is generally considered to be pre-adapted to future change, relative to other continents (McGlone et al. 2010). [*see if this statement can be corroborated and give confidence rating*]

Multiple interacting non-climate stresses

A recent review of global environmental impacts ranked New Zealand 18th within the 20 worst ranked countries on the basis of an index of proportional composite environmental impact (179 countries ranked with respect to their available resources); Australia was ranked 9th in the 20 worst countries for absolute environmental impacts (out of 171 countries) (Bradshaw et al. 2010). Climate change is a new stressor that adds to, and interacts with, the range of existing stressors that have already significantly changed and diminished biodiversity in Australia and New Zealand. The most important proximate drivers of change in biodiversity that will interact with climate change include loss and fragmentation of habitat associated with land clearing, redistribution of water resources, and changes in nutrient distributions in soil and water, changes in fire regimes, mining, introduction of exotic species and salinity. Several other drivers that act mainly through socio-economic forces and institutional arrangements at a national and a global level and which have indirect impacts on organisms include human population growth, global markets and globalization, primary industries, and perverse incentives including subsidies for fisheries, forestry, land clearing, agriculture, and grazing.

Australia's natural environment has been profoundly affected by human settlement. Since European settlement 220 years ago, large areas of the continent have been cleared for agriculture and much of the remaining natural habitat is highly fragmented. Additional impacts stem from alterations to watercourses, erosion of topsoil, nutrient addition to soils and waterways, increased salinity, pollution, introduction of exotic species, altered fire regimes, increased total grazing pressure, and hunting (SoE 2006), (Steffen et al. 2009). There have been massive declines in diversity, range and abundance in plants and vertebrate taxa and mammal extinction rates in Australia are the worst of any continent (Lindenmayer 2007).

Over the 800 years of human habitation in New Zealand, the landscape has alo suffered extensive habitat destruction with only 23% of pre-human indigenous vegetation cover remaining (MfE 2000), (Kelly and Sullivan 2010). Coastal, lowland and montane environments have been substantially modified because of their accessibility and value to agriculture and urban land uses. By 2002, >70% loss of indigenous vegetation in 57% of land environments had occurred, with poor protection (<20% land area protected) in more than two thirds of the country (Walker et al. 2006). Of the 73 political districts, 30 have experienced greater than 90% deforestation (Ewers et al. 2006). The much-reduced areas of indigenous cover remaining in the most threatened environments support a disproportionately large percentage of New Zealand's threatened species, habitats and ecosystems (Walker et al. 2006), (McGlone et al. 2010). Native vegetation loss is continuing, with recent clearance occurring mainly on more marginal land, mostly for exotic plantation forestry (Ewers et al. 2006; McGlone et al. 2010). Protected areas occupy approximately one third of New Zealand, the highest percentage of any OED country (Walker et al. 2006), (MfE 2010a). However, most reserves are in mountainous and upland areas, are small and isolated, and there is under-representation of some key ecosystems (Walker et al. 2006); when New Zealand is classified into 20 environments, three have less than 1% legally protected, and only 3 environments have more than 90% (MfE 2010a). New Zealand also has one of the worst records of indigenous biodiversity loss and has nearly as many exotic, naturalized plant species as it has native plants (c. 2200) (McGlone et al. 2010). Exotic mammalian predators continue to exert considerable stress on the flora and fauna of lowland and montane environments (McGlone et al. 2010). Freshwater ecosystems in the lowlands and eastern regions remain under considerable pressure from abstraction, agricultural development and pollution (e.g. (Ling 2010). These pressures will very likely exacerbate future impacts of increased incidence and severity of drought (McGlone et al. 2010).

Climate change will also interact with existing and emerging pathogens. Soil warming is likely to increase the geographic range of the invasive root pathogen *Phytophthora cinnamomi* in Australia (Pritchard 2011) but impacts on newly emerging threats such as Myrtle rust (Carnegie et al. 2010) are uncertain. A significant association between amphibian declines in upland rainforests of North QLD and three consecutive years of warm weather (Laurance 2008) suggests future warming could increase the vulnerability of frogs to chytridiomycosis caused by the chytrid fungus *Batrachochytrium dendrobatadis*, implicated in both Australian (Murray et al. 2011) and global amphibian decline (Lotters et al. 2009).

Australia and New Zealand still lag behind the Northern Hemisphere in documentation of observed biological changes consistent with a climate change signal, but published evidence documenting change at the genetic, species and ecosystem levels is increasing. Many of the observed changes are likely to have significant non-climatic contributions and the precise role of different factors may continue to be impossible to quantify in most cases. Since the AR4, there is increasing documented evidence in Australian terrestrial and marine environments of changes in species distributions (generally, though not exclusively in a southerly direction or upwards in elevation, mostly seen in birds, flying insects and pelagic marine species); advances in species life cycles; and changes in the genetic constitution of some insect and bird species. Some previous conclusions about the potential role of climate change in observed southerly range shifts of some species (e.g. flying foxes along the east coast of Australia (Roberts et al. 2011) have been discounted after more thorough statistical analysis of shifts in relation to climate. There have been increasing numbers of studies reporting changes in vegetation over past few decades but there remains uncertainty and debate as to the causes of these changes, given the potential role of multiple drivers, including direct impacts of temperature and rainfall, increasing CO_2, changes in fire and grazing (both native and exotic species) regimes, and altered landuse and water resource management. Long term drought in south east Australia has been associated with declines in many taxa including amphibians (Mac Nally et al. 2009).

There is little documentation of observed change in freshwater systems that can be distinguished from contemporaneous impacts of changes to allocation and management, although some changes in the composition of freshwater assemblages consistent with climate change expectations have been published (Chessman 2009). The impacts of ongoing drought on freshwater systems in the eastern states and the Murray Darling Basin have been severe, especially near the mouth of the Murray where reduction in environmental flows together with over-allocation of water resources has increased salinity levels (Pittock and Finlayson 2011c).

There have been few observations of biodiversity change in New Zealand directly attributed to recent climate change, as distinct from climate variability (McGlone et al. 2010). Some changes in seabird numbers appear due to changes in marine productivity, rather than directly to climate (Shaffer et al. 2006) [*will shift to marine section, just a placeholder*]. Despite intensive investigation at multiple sites, alpine treelines appear to have remained in approximately the same position for several hundred years, despite 0.9°C average warming (equivalent to 150 m rise in altitude) (McGlone et al. 2010).

Assessment of potential future impacts of climate change at the species level have mainly been undertaken with species distribution modeling (SDM), using specific GCMs and emission scenarios. These modeling exercises for a variety of taxa and regions consistently indicate future contractions of geographic range in native species, even when optimistic rates of dispersal are assumed (e.g. WA banksias, (Fitzpatrick et al. 2008), koalas (Adams-Hosking et al. 2011), northern macropods (Ritchie and Bolitho 2008), native rats (Green et al. 2008b), the greater glider (Kearney et al. 2010) and quokkas (Gibson et al. 2010)). While the magnitude of range contraction projected depends on the climate scenario and time slice modeled, the overall conclusions of these studies are consistent. In many cases, loss of range appears driven primarily by rainfall, rather than temperature. Increasingly, projections of range changes using these SDMs are being incorporated into broader risk assessments that take species life history characteristics and potential adaptive capacity into account (e.g (Williams et al. 2008) (Cabrelli & Hughes in prep.).

Species distribution modelling and other assessments of how climate change will affect invasive species indicates that some species will be advantaged and others disadvantaged (e.g. (Gallagher et al. 2010; Sims-Chilton et al. 2010). Climate change is also very likely to interact with the efficacy of existing biological control programs, but the directions will be species-specific (eg. (Sims-Chilton et al. 2010).

Reports of drought-related mortality in savanna trees in north east Australia (Fensham et al. 2009), *Eucalypts gunnii* in sub-alpine regions in Tasmania (Calder & Kirkpatrick 2008), and mass die-offs during heatwaves (e.g. flying foxes in eastern Australia (Welbergen et al 2008), Carnaby's cockatoos (Saunders in review) suggest that extreme heat will likely be a significant driver of biodiversity loss (e.g. (McKechnie and Wolf 2010).

The potential response to elevated CO_2 has been investigated for relatively few species in Australia (68 vascular plant species, 0.37% of the flora) (Hovenden and Williams 2010), and even fewer in New Zealand (Ross et al. 2006). Elevated CO_2 has been found to have little impact on growth and physiology of most grass species studied, but more impact on trees; reduction in N and increase in secondary metabolites are common responses, with implications for herbivores. The low nutrient status of most Australian soils and importance of fire is likely to mean that responses to elevated CO_2 by Australian plants may be different to those reported elsewhere (Hovenden and Williams 2010). If rising CO_2 stimulates productivity, especially in fire-promoting species such as eucalypts, then this may contribute to fires becoming more frequent and severe (Hovenden and Williams 2010) (Bradstock 2010). If elevated CO_2 also increases the concentration of secondary compounds such as leaf oils plants may are likely to become more flammable.

In Australia, the most vulnerable ecosystems are considered to be the alpine zones, especially from loss of snow cover and subsequent invasion by exotic species (Pickering et al. 2008); low-lying coastal wetlands such as Kakadu National Park subject to saline intrusion from rising sea level (Steffen et al. 2009); biodiversity-rich regions such as the southwest of WA (Yates et al. 2010b), (Yates et al. 2010a) and the wet tropics in North QLD (Shoo et al. 2011), (Stork et al. 2007); inland freshwater and groundwater systems subject to drought impacts combined with over-allocation for agriculture (Lake and Bond 2007) (Pittock 2008), (Nielsen and Brock 2009); and mire (peat-forming) wetlands along the east coast that are highly sensitive to changes in the hydrological cycle (Keith et al. 2010).

In New Zealand, direct impacts of future climate change are likely to be less important than the interactions of changing climatic variability and extremes on existing stresses such as invasive species (McGlone et al. 2010). Warmer and drier winters may extend the breeding season of many exotic mammalian predators, allowing populations to recover more quickly from control operations (McGlone et al. 2010). The species-rich biota of the alpine zone may be at risk through increasing shrubby growth and loss of herbaceous taxa and if it allows easier establishment of invasive species (McGlone et al. 2010). Freshwater ecosystems in New Zealand are relatively simple and species poor, compared to other continents. Many species of indigenous fish are likely to be little affected by temperature change (McGlone et al. 2010) but a subset of fish and invertebrates are cold-water adapted and these may be more vulnerable (e.g. alpine mayflies (Winterbourn et al. 2008), (Hitchings 2009). Warming is likely to inhibit eel migration upstream (August and Hicks 2008). Establishment of tropical and sub-tropical aquarium escapees may increase with warming (McGlone et al. 2010) and at least six species of exotic ant species are likely to find increasingly favourable conditions if they invade (Harris and Barker 2007; Ward 2007). Warming and drying may encourage the spread of existing invasives such as *Pheidole megacephala* that is already present but currently has little impact (Harris and Barker 2007). Suitable habitat for some restricted native species is projected to increase with warming (e.g. native frogs (Fouquet et al. 2010) although limited dispersal ability is likely to limit range expansion to these areas. Tuatara populations are likely to be threatened as warming increases the ratio of males to females (Mitchell et al. 2010b).

The vulnerability of freshwater and terrestrial biodiversity to negative impacts of climate change is generally considered to derive, at least in part, from the limited adaptive capacity of species to adapt at a rate commensurate with projected change. Little is known about the capacity for most species to adapt either genetically (Hoffmann and Sgro 2011), or via phenotypic plasticity. In Australia, lack of topographic relief will limit the ability of most species to adapt to shifting climate zones by moving to higher elevations (Steffen et al. 2009), although in New Zealand there may be scope in some regions for such shifts. Many freshwater systems in Australia and NZ run east-west, limiting adaptive movement of aquatic species between catchments as warming proceeds. Example of dispersal barriers for freshwater fish movement (Morrongiello et al. 2011). In both countries, however, fragmentation of remaining habitat will limit establishment of new populations in more climatically suitable areas, even for the more mobile species (Steffen et al. 2009).

While existing environmental issues in New Zealand, particularly invasive species and ongoing decline in the extent of native vegetation remain the primary focus of research (Kelly and Sullivan 2010; McGlone et al. 2010), the potential for planned adaptation strategies to ameliorate some of the most negative impacts of climate change on terrestrial and freshwater ecosystems is receiving significant research attention in Australia. The National Adaptation Research Plans for terrestrial (Hughes et al. 2010) and freshwater (Bates et al. 2011), developed under the auspices of the National Climate Change Adaptation Research Facility (NCCARF) have identified research priorities which include the identification and protection of current and future refugia (Shoo et al. 2011), reduction of non-climatic threats to increase resilience of ecosystems to the impacts of climate change, and building and restoring habitat connectivity to promote adaptive capacity. Development of more strategic monitoring strategies to detect climate change impacts is underway in many regions (e.g. WA biodiversity hotspot (Abbott and Le Maitre 2010). More controversially, active interventionist strategies such as assisted migration are receiving greater attention, both as a general principle (Hoegh-Guldberg et al. 2008) and with respect to particular vulnerable species, such as the tuatara (Mitchell et al. 2010b; Mitchell et al. 2008).

_____ START BOX 25-1 HERE _____

Box 25-1. Climate Change and Fire

Fire is a common feature of Australian forests – many plants, animals and ecosystems have evolved to survive it, and some even require it to reproduce (Cary et al. 2003; Mackey et al. 2002). However, bushfire (wildfire) is also a significant natural disaster that has caused over 800 deaths and more than US$2 billion in Australia since the mid 1800s (Collins 2009; Romsey-Australia 2010). The hot, dry and windy summers in south-east and south-west Australia provide conditions for bushfires that are often intense and difficult to control (Adams and Attiwill 2010). In contrast, in humid northern Australia, low-intensity fires often burn across large areas (Russell-Smith et al. 2009). Bushfires in south-east Australia tend to be most common in drought and El Nino years. For example, the 'Black Saturday' bushfires in Victoria in February 2009, which burnt over 4,500 km^2 and caused 173 deaths and destroyed over 5,000 buildings (Cameron et al. 2009; Romsey-Australia 2010), occurred during a drought which has lasted for 13 years (CSIRO 2010) and over consecutive hottest days on record (Tolhurst 2009).

Bushfires are likely to become more intense and occur more frequently in the future (Cary et al. 2003; Lucas et al. 2007c; Williams et al. 2001). In south-east Australia, the number of days with very high and extreme fire danger (calculated based on daily temperature, precipitation, relative humidity and wind speed) is projected to increase by 4-25% by 2020 and by 15-70% by 2050 (Hennessy et al. 2006). Fuel load is also likely to increase with higher CO_2 enhancing vegetation production (Donohue et al. 2009). The fire season length is likely to be extended, with the window of opportunity for controlled burning shifting toward winter. Increased forest fires will affect various sectors: bushfires can cause deaths and damage properties (Adams and Attiwill 2010); fires reduce agriculture and forestry production [*references?*]; forest regeneration following wildfires can reduce catchment water yields (Cornish and Vertessy 2001; Kuczera 1987; Murray-Darling-Basin-Commission 2007); reduced vegetation cover increases erosion risks and material washoff to waterways (Shakesby et al. 2007; Wilkinson et al. 2009); bushfire smoke can cause asthma (Johnston et al. 2002); and wildfires change vegetation communities and ecosystems (Gill and Bradstock 2003). In Australia, managing fire regimes (which focus on building/zone regulations, fire detection, fire suppression and fuel management) under climate change will become increasingly challenging. Many Australian authorities are taking into account climate change in rethinking approaches to managing fire to restore and rebalance ecosystems while protecting human life and properties (Adams and Attiwill 2010). [*Need more references and examples – of climate change considerations in developing fire management plans – or of adaptation? Add NZ issues or revise Box title to make clear this is about Australia only.*] Various sectors, for example water (Van Dijk et al. 2006), actively take into account the impact of increased bushfire risk in planning for the future.

_____ END BOX 25-1 HERE _____

25.5.3. Coastal Systems and Low-Lying Areas

25.5.3.1. Key Climate Drivers

Australia's coastline is almost 60,000 km [d*epending on source: ranges from 35000 DCC (2009) to ~80,000*] in length spanning tropical waters in northern Australia to cool temperate waters of Tasmania (Richardson and Poloczanska 2009). About 85% of the Australian population lives within 50 km of the coast and this coastal zone is densely populated, particularly on the eastern seaboard (DCC 2009). In New Zealand… [*text to come*]. As a result, there are a range of non-climate stressors, such as pollution, sediment loads, population growth, and landscape modification that also must be factored when considering climate impacts at the coast. The main climate-related vulnerabilities of the coastal zone are to sea level rise, extreme events, and changes in ocean temperature. These physical drivers will impact on both the natural ecosystems and human-dominated elements of the coastal zone.

Sea level, and hence coastal geomorphology, has been relatively constant for the past 6,000 years, within 1-2 meters of present levels (Church et al 2008). Globally, average sea level has risen about 20 cm since the late 19th century, largely due to thermal expansion with a relatively minor contribution from melting land ice. This rate of rise has accelerated in recent decades (Rahmstorf et al 2007). [*cross-check with WGI and Section 25.3*] Trends around Australia's coastline are less certain based on monitoring systems that only started in the early 1990s, however observed recent sea-level rise has been lower along the central east coast and greater along the western and north coasts (Church et al. 2009; DCC 2009). Regional variability in the magnitude of sea-level rise is linked with changes in ocean circulation (Church et al. 2009). Future projections of sea level have been used to set coastal planning regulations (e.g. 1 m rise), although the legal architecture is still being debated (McDonald 2010). Variation in the land forms and substrate around Australia (DCC 2009) will also result in variable impacts from sea level rise, such as coastal erosion. [*cross-check with WGI and consistency across this chapter*]

Extreme events include tropical cyclones, which are accompanied by significant rainfall which subsequently floods the landscape and flows into coastal catchments. There is ongoing debate as to long-term global trends in the occurrence and frequency of tropical cyclone activity (e.g. Emanuel 2005; Elsner et al. 2008). In the Australian region, Nicholls et al. (1998) reported an apparent decline in numbers of weak tropical cyclones in the Australian region over the period 1969/70 to 1996/96 based on satellite observations. Hassim and Walsh (2008) suggest that the number, duration and maximum intensity of severe tropical cyclones off WA have been increasing since the 1980s, but in the eastern region the number has decreased with no obvious trend in either intensity or duration. There has been no observed change in the latitudinal distribution of tropical cyclone activity, but southward movement in future has been postulated (ref). Global wind speeds (5-10% total increase) and extreme average wave heights have risen over the past 23 years, with extreme heights rising by up to 1% per year in temperate latitudes (Young et al 2011). Southern Australia has the strongest trends in this global pattern of increasing wave heights.

25.5.3.2. Importance of Coastal Ecosystems

Australia's natural coastal features at the interface between the ocean and the land include coastal deltas, floodplains, beaches, mangrove forests, seagrass beds, and saltmarshes. Just offshore in fully marine waters are kelp forests and coral reefs. World Heritage status has been conferred on some coastal icons, such as the Great Barrier Reef, Kakadu, Shark Bay and Fraser Island. Diversity is high for many groups: Australia's coral reefs provide habitat for some 400 species of coral and more than 1500 species of fish (Hoegh-Gulberg et al 2007). Macro-algal species grow close to shore around Australia; there are an estimated 3,000-7,000 species, with the greatest diversity in southern waters. Mangroves are most diverse in the north, with over half the world's species occur in Australia. They are an important buffer between land and sea, filtering terrestrial discharge, and preventing erosion. Mangroves are also highly productive, and act as a breeding habitat for many commercially valuable species (e.g. Gillanders et al 2011). Many coastal habitats are important for protected species: saltmarshes in Victoria are critical for the endangered orange-bellied parrot, while wading birds such as the northern hemisphere migrant Eastern Cerlew, also rely on south-east Australia saltmarshes. In the north, dugong rely on healthy sea grass beds.

New Zealand… [*text to come*].

25.5.3.3. Observed Impacts

Coastal protection to sea level rise and storms is provided by a range of natural habitats, including reefs, mangroves, sand dunes and offshore sea grass beds and macro-algal forests (Costanza 1999; Beck et al. 2011). These habitats absorb pollutants, regulate water flow, and buffer the action of waves, particularly in extreme events. There is little evidence to date of climate impacts on these coastal habitats, although several studies suggest impacts are likely (Lovelock et al 2009). Rising sea level can interfere with these natural protection systems, particularly when coastal hardening prevents landward retreat. Loss of these coastal habitats will impact biodiversity, such as loss of habitat for nesting birds (Chambers et al 2009). Interactions with declining rainfall will lead to changes in sediment supply to the coasts and the salinity balance in coastal estuaries (Gillanders et al 2011). Other climate drivers, such as a change in pH will also impact coastal habitats; corals (e.g. Hoegh-Guldberg et al 2007), coralline algae (Anthony et al. 2008), bryozoans, and other benthic calcifiers will show reduced calcification and/or increased dissolution (e.g. Fabricius et al 2011), resulting in loss of coastal protection services (Wernberg et al. 2011). Coastal habitats also have value for carbon capture and storage, particularly sea grass, saltmarsh and mangroves, and may become increasingly important in mitigation efforts (e.g. Irving et al 2011).

New Zealand… [*text to come*].

25.5.3.4. Projected Potential Impacts

Changes in the coastal zone are expected in future as a result of climate change, and future population growth will exacerbate the challenge presented by climate change. With regard to natural systems, mangrove areas are likely to expand further landward, driven by sea-level rise and soil subsidence due to reduced rainfall (Lovelock et al 2009). Estuaries as habitats will be impacted by changing rainfall or sediment discharges, as well as connectivity to the ocean as a result of changes in wave direction (Hemer et al). Saltmarsh areas may be overtaken if they cannot keep up with the landward movement (DCC 2009). In cases where landward retreat is not possible due to the built environment, coastal habitats, such as saltmarshes and mangroves, may be lost (DCC 2009). The change in the main climate drivers (e.g. temperature, sea level rise and rainfall) are likely to lead to a number of secondary effects, including erosion, landslips, and flooding, all of which can impact coastal habitats and their dependent species.

New Zealand… [*text to come*].

25.5.3.5. Valuation of Potential Impacts

With regard to the human coastal settlements, the loss of residential buildings for a 1.1 m rise in sea level has been estimated at $63 billion (DCC 2009). Protection of the coastal zone will be possible in some regions, although this may also result in loss of beaches (McDonald 2010) or other habitats with recreational or ecosystem service value. Damage to port infrastructure could be very large – exports worth 43 billion were bulk-shipped from ports in 2007-08 (DCC 2009). Tourism in the coastal zone is dominant –GBR tourism is worth $6 billion, Gold Coast $4 billion per annum, all of which are disrupted by climate events – particularly extremes. The social value of beaches estimated at many hundred of millions of dollars per year (DCC 2009). Loss of species that use these beaches, such as shorebirds, turtles and sea lions will impact on tourist experiences, and eventually impact businesses. Valuation of ecosystem services are controversial (e.g. Costanza 1999), however, loss of coastal habitats will result in significant costs to society from direct impacts such as storm surge, and from more diffuse services such as provision of fish for food, and clean ocean water.

New Zealand… [*text to come*].

25.5.3.6. Adaptation Options, Needs, and Information Base

[*to come post-ZOD. Drafting notes:*]

- *Adaptation needs and gaps – information on historical change of coastal habitats is needed to understand the response to climate drivers.*
- *Observed and expected limits to adaptation – interaction with human land use will be key.*
- *Planned and autonomous adaptation – rates of sea level rise can be managed by most natural habitats – growth rates exceed the rate of sea level rise. However, differential migration of mangroves (fast) vs saltmarshes (slow) may reduce the area of the slower migrating ecosystem, with impacts on the dependent flora and fauna. Planned adaptation may include the removal of human barriers to landward migration, translocation of seagrass beds to southerly locations, or environmental flows to keep estuaries open and functioning. For beaches, coastal nourishment may be required if sediment input declines.*
- *Valuation of adaptation – will be in the ecosystem services that persist, protection of species*
- *Practical experiences of adaptation, including lessons learned – examples from the Pacific*
- *Adaptation end to be completed pending feedback on earlier content. Plenty to say, but need to check where else these issues are covered in the chapter*
- *New Zealand parts needs input – at minimum where indicated.*
- *Could highlight some case studies – good for boxes? Examples: Tourism, iconic species, ecosystem services.*

25.5.4. Ocean Systems, including Fisheries

25.5.4.1. Key Climate Drivers

Australia has sovereign rights over around 8.1 million km^2 of ocean (excluding Australian Antarctic Territory) compared to 7.7 km^2 for the land area (Richardson and Poloczanska 2009). The southward flowing East Australian Current (east coast) and the Leeuwin Current (west coast) carry warm-water into southern regions and have considerable influence on the distribution of marine species. To the south, the southern ocean flows from west to east, and connects the Indian, Pacific and Atlantic Oceans.

Climate change is already impacting the oceans around Australia (Poloczanksa et al. 2007; Lough and Hobday 2011). Instrumental and satellite analyses have shown tropical waters have warmed from 1950 to 2007 by 0.11°C decade^{-1} along the NW coast and 0.12 °C decade^{-1} along the NE coast (Lough 2008) – a rate of ~1.1 – 1.2 °C century^{-1}. This observed warming means average climate zones have shifted more than 200 km south along the NE coast and about half that distance along the NW coast. If current trends continue, annual average sea surface temperatures in northern regions could be ~0.5°C warmer and those of more southern parts ~2.0°C warmer within the next 100 years. The rate of warming is even faster in southern Australia, with documented warming along the south-east coast of 2.28°C century^{-1} and a salinity increase of 0.34 psu century^{-1} which corresponds to a poleward advance of the East Australia Current (EAC) of ~350 km (Ridgway 2007). These changes are due to both background warming (surface flux) and strengthening of the EAC (Ridgway 2007; Hill et al. 2008; Hill et al 2011). On the west coast, there has been a mean temperature rise of 0.013°C year^{-1} since 1951, corresponding to ~0.6◦C over the past 50 years (Pearce and Feng 2007). As a result of these temperature changes, SW and SE Australia are recognized as global warming hotspots (Hobday and Pecl in review).

Changes in water chemistry, as a result of the oceans absorbing CO_2, are less well documented around Australia (Lough and Hobday 2011) and New Zealand. The pH of the global oceans has already decreased by 0.1 (Feely et al. 2004; Sabine et al. 2004) and a similar decline is also likely for Australia's and New Zealand's oceans. This decline will have significant consequences throughout the regions marine ecosystems, especially those involving organisms that form calcium-based skeletons and shells (e.g. Hoegh-Guldberg et al. 2007; Moy et al. 2009). Acidification impacts will affect calcification rates of calcareous phytoplankton (Hallegraeff et al 2010) and thus the relative dominance of different forms (Cubillos et al 2007; Thompson et al 2009). Calcareous zooplankton (e.g. foraminifera) will also be impacted (Richardson et al. 2009). Reduced fertilisation success in some Australian marine invertebrates (Parker et al. 2009) and impaired olfactory-based navigation among reef fishes has been documented (Munday et al. 2008). The interaction between pH and temperature changes are less clear, with some studies showing amplified responses (e.g. Anthony et al 2008) and others showing that temperature dominates (e.g. Byrne et al 2009). Coral growth experiments have shown positive responses to slight declines in pH, followed by negative responses when pH falls below critical thresholds (Anthony et al 2008). Computer modeling based on physiological principles is also possible; Anthony et al (2011) show that major changes to reef structure are likely if acidification and warming continues.

In New Zealand, general warming has also been reported, but there are no specific changes in pH that have been documented. [*more text on New Zealand to come*]

25.5.4.2. Observed Impacts on Species Abundance, Distribution, and Phenology

Observed impacts on marine species around Australia have been reported from a range of trophic levels. Most marine impact studies show patterns "consistent with climate change", rather than specific attribution. Attribution studies are hard, but urgently needed in order to develop effective adaptation strategies (Brander et al 2011). Observed biological changes around Australia are predominately reported as changes in local patterns, such as abundance and growth, or as changes to range and distribution. Many studies are from the south-east, where observed warming has been greatest.

With regard to local changes, a 50% decline in the spring bloom biomass and growth rate (via chlorophyll a) has been found for 1997-2007 off eastern Tasmania (Thompson et al. 2009), where cold water zooplankton have also become less common (Johnson et al 2011). Growth of southern rock lobster, positively related to water temperature, has increased in southern Tasmania, however, recruitment of juvenile lobsters is negatively related to temperature and has concomitantly declined (Pecl et al 2010; Johnson et al 2011). Similar declines in growth have been postulated for abalone (Johnson et al 2011). Macroalgal cover, dominated by canopy-forming *Macrocystis*, is also in decline in this region (Johnson et al 2011). Cold water subtidal seaweed species show general southern retreat on both east and west coasts of Australia (Johnson et al 2011; Wernberg et al, 2011). Declining growth rates in one coastal fish, particularly at the warm end of its range suggest that the direct metabolic effects of increasing temperatures on this species may lead to declining productivity and range contraction (Neuheimer et al 2011). In tropical waters, corals are already exhibiting reduced calcification rates over the past decade (De'ath et al. 2009).

Changes in New Zealand… [*NZ material to come*]

Distribution changes have been widely reported for Australia, with Madin et al (2011) reporting some 47 marine examples. These changes are primarily driven by increases in water temperature and changes in ocean currents (Booth et al 2011). For example, aided by a strengthening EAC, a sub-tidal sea urchin has moved ~160 km decade^{-1}

over the past 40 years into Tasmanian waters (Ling et al 2009), and is considered to negatively modify habitat for a wide range of invertebrate species (Ling 2008; Johnson et al 2011). At the same time, some forty-five fish species, representing 27 families (~30% of the inshore fish families occurring in the region), exhibited major distributional shifts thought to be climate related (Last et al 2011). Tropical fish species have also moved south along the east coast of Australia, and are more regularly surviving the increasingly mild winters (Figueira et al 2009; Figueira and Booth 2010). Current warming trajectories predict all Sydney winters will be survivable by five of these tropical fish species by 2080 (Figueira and Booth 2010). Intertidal snails, limpets and barnacles have also extended their range in Tasmania, with some 50% of species found further south in 2008 compared to the 1950's (Pitt et al 2010). Further north, in Queensland and NSW, biogeographic boundaries have not yet been crossed, and almost no change in species distribution has been reported (Poloczanska et al 2011). Together, these marine distribution and abundance changes are modifying community structure in many regions (e.g. Johnson et al 2011; Wernberg et al 2011).

Changes in New Zealand… [*NZ material to come*]

There are few Australian examples of changes in phenology for marine species, in contrast to terrestrial systems. The timing of recruitment in southern rock lobster has shifted in response to warming in Tasmania (Frusher et al in review), while for southern bluefin tuna changes in the timing of arrival and departure from summer feeding grounds in the Great Australia Bight are associated with warmer temperatures (Randall et al in prep).

25.5.4.3. Impacts on Fisheries and Aquaculture

A range of marine species impacted by climate change are also valuable fishery species. The value of Australia's fisheries output has declined over the decade to $2.2 billion in 2007-08 (GVP, ABARE 2010). Wild catch production fell by 6% in this period; thus the main cause for overall decline is a reduction in unit prices of key wild caught species such as rock lobster, prawns, abalone and wild caught tuna (ABARE 2010). The majority of Australia's species are considered sustainably managed, however, future climate change may impact the profitability of the sector (Hobday et al 2008; Pecl et al 2011; Norman-Lopez et al in review). Some aquaculture species, such as salmon, are considered vulnerable to warming waters around Tasmania (Hobday et al 2008), but a range of adaptation options exist for this industry (Battaglene et al 2008). Experiments have shown that metabolic efficiency, calcification rates and growth rates of molluscs, including the blue mussel *Mytilus edulis* and the Pacific oyster *Crassostrea gigas*, will be impaired by a warming ocean, with economic consequences (see Hobday et al. 2008).

Changes in New Zealand… [*NZ material to come*]

25.5.4.4. Projected Potential Impacts and Adaptation Options

Warming oceans are projected around Australia, in particular for the east coast of Australia (Hobday and Lough 2011). The EAC is projected to strengthen by 20% over the coming decades (Ridgway 2007), while changes in the Leeuwin Current flow are less certain and it may in fact weaken (Feng et al 2009). Marine protected area planning will be impacted by the projected environment shifts – the assumed environment will no longer be present in the same location (Hobday 2011). Future changes in species distribution as a result of physical projections have focused on fish. Under all SRES scenarios and models, pelagic fishes such as sharks, tuna and billfish are projected to move further south on the east and west coasts of Australia (Hobday 2010). These movements differ depending on species sensitivity to water temperature, and can also lead to shifts in overlap between species, which has implications for fisheries management (Hartog et al 2011). A southward shifts in fishery activity have already been reported for southern rock lobster (Pecl et al 2009), but given the flexibility in more northern fleets, adaptation to climate change is considered possible by most participants.

The projected changes for a range of marine taxa are summarized in the Marine Report Card for Australia (Poloczanska et al 2009), and include positive and negative changes in abundance, distribution, physiology and phenology. Changes in abundance of some species will in turn lead to impacts on fisheries production and profit (e.g. Norman-Lopez et al in review), while local conditions mean some aquaculture operations will face challenges in continuing to grow the same species (Hobday and Poloczanska 2008). Translocation may be possible for some high value species, and maintain production in the face of declining recruitment and has been trialled for southern rock lobster (Green et al 2010). In fact, adaptation options exist for a range of marine species, from the landscape scale, such as habitat provision (Hobday and Poloczanska 2010) to the individual species, such as translocation of turtle nesting colonies (e.g. Fuentes et al 2009) or burrow modification for nesting seabirds (e.g. Chambers et al 2009). For southern species found on the continental shelf, however, options may be more limited, as suitable habitat will not be present in future – the next shallow water is Macquarie Island.

Clearly, more experimental and field work is needed in concert with modeling studies to explore climate impacts and future impacts for most marine taxa. This challenge is complicated by interacting non-climate stresses, including habitat degradation, coastal pollution and fisheries that are hard to separate from climate effects (Poloczanska et al 2007). This attribution is an important step in developing appropriate adaptation options for marine species (Brander et al 2011).

[Notes]

- *New Zealand parts needs input – need to review literature*
- *Fisheries and aquaculture sections very short – word limit already exceeded…*
- *Adaptation section could be extended significantly on "prospects", but little demonstrated evidence to date.*

25.5.5. Forestry and Biofuel Production

25.5.5.1. Forestry

Of Australia's 149 million hectares of native and plantation forest (Montreal Process Implementation Group for Australia 2008), 112.6 million hectares are under tenures that allow harvesting. In addition there are 9.4 million hectares of multiple-use public native forests one of the allowable uses of which is wood harvesting. The remaining 2.02 million hectares are soft- and hardwood plantations (Gavran and Parsons 2010).

Manipulative experiments in the field and in pots together with modeling studies provide limited evidence of Australian forest tree species responding to elevated CO2, increased temperatures and changed water availability (Medlyn et al. 2011). Growth trials conducted in Australia, have shown strong positive responses to elevated CO_2 (Atwell et al. 2007; Ghannoum et al. 2010; Roden et al. 1999) with variations based on species and/or local environmental conditions (e.g. nutrient availability, water availability). *Eucalyptus grandis* grown in the South Africa showed no growth response in unfertilised trees but a strong response in fertilised trees (Diogo 2002) [*need to confirm – reference has not yet been sighted by authors*]. Above-ground growth productivity increases are likely only in the most fertile sites. As fertility declines, production may still increase, but is likely to be diverted belowground. Increased photosynthesis under elevated CO2 did not persist in some experiments (e.g. McMurtrie et al. 2009) [*need to confirm – reference has not yet been sighted by authors*].

Changes in individual plant growth reflect extant optimal temperature tolerance and a capacity to acclimatize: but optimum temperatures may change with overall temperature regime (Slatyer and Morrow 1977). This response has been demonstrated in a range of eucalypts(e.g. Ferrar et al. 1989) and rainforest species (Cunningham and Read 2002). Increased growth under elevated temperatures may be expected in ecosystems where growth is currently cold-limited, whereas ecosystems that are currently at or above optimum temperature will be negatively affected [*reference?*]. Heat stress and frost tolerance are likely to be very important determinants of future forest distributions. For example, a reduction in the number of frost events is likely to allow upwards expansion in the range of *E. pauciflora* (Wearne and Morgan, 2001), *E. delegatensis* and *E. dives* (Bell and Williams 1997). The reduction of frost hardiness through increased leaf temperatures could cause damage to such plants when frosts do occur (Barker et al. 2005).

The tolerance of species to water availability differs (Drew et al. 2009, Battaglia and Williams 1996, White et al. 1996). Associations between increased tree cover and increasing (Fensham et al 2009, Pekin et al. 2009) and decreasing water availability and reduced forest growth (Keith et al. 2009; Myers et al. 1996; Stoneman et al. 1997) have been identified in Australia. Under drought conditions the length of time (Mendham et al. 2005), severity of water restriction (Blackman et al 2009) and timing of rainfall (Pook 1985, Pook 1986) are important in determining the response and survival of plants. Increased vulnerability to damage from pests and fire occurs following drought periods (Kliejunas et al. 2008; Pinkard et al. 2009).

There remains uncertainty about how individual plant species will respond. Theoretically, increased CO_2 could lead to reduced drought stress but the experimental evidence is mixed (see review in Medlyn et al. 2011). An outstanding question is whether forest water use will decrease at high CO_2 levels, or whether leaf area increase as a result of higher productivity with no concomitant change in water use. Lack of available water at high or extreme temperatures is expected to exacerbate heat stress. Warmer temperatures may increase a plant's response to CO_2. Elevated CO_2, along with rising temperatures, can result in delayed acclimation and advanced de-acclimation, potentially reducing the length of time plants are frost tolerant and, hence, increasing the length of the growing season of these plants (Woldendorp et al. 2008).

25.5.5.1.1. Distribution (for production species)

Predictions of future distribution or suitability for growth under particular climate regimes rely on quantitative models: either ecophysiological models (Battaglia et al. 2009) or bioclimatic models (Hughes et al. 1996). Plantations in the south-west of Australia are likely to be the most effected by predicted changes in climate due to reduced precipitation rates: this is indicated by both ecophysiological and bioclimatic models (Battaglia et al. 2009; Hughes et al. 1996). The potential for an increase or decrease in plantation productivity will depend on whether elevated CO_2 increases production, whether hot-dry days directly damage or kill plants, and the response of pest species (Battaglia et al. 2009). If photosynthetic rates are increased and the increase is maintained, then there is potential for marked increases in productivity in cool wet locations (Battaglia et al. 2009).

25.5.5.1.2. Phenology

There is very limited evidence of phenological responses to climate cues in Australia. Limited evidence exists of eucalypt flowering periods changes correlated with rainfall (Williams et al. 1999, Keatley et al. 2002) and temperature (Keatley et al. 2002). Rising temperatures in subalpine regions of southeast Australia has been related to advanced flowering in some species: yet others did not demonstrate a response or flowered later (Gallagher et al. 2009; Jarrad et al. 2008). A single study of elevated CO2 showed no effect on the flowering times of plants, whereas increased temperature did produce a general effect of earlier flowering (Hovenden et al. 2008).

25.5.5.1.3. Pathogens, pest insects and weeds

These all pose significant threats to Australia's forests and are costly to manage. Pathogen outbreaks are mostly recorded from monoculture plantations rather than undisturbed native forests (Carnegie et al. 1997; Park et al. 2000). The increase or decrease of individual pathogens will depend on individual species of pathogen in a similar way to trees – dependant on their physiology, climate tolerance, interactions between pest and host (Old and Stone 2005). Increase or decrease (reviewed in Table 4.1 Boulter et al. in review). These changes in distribution also have implications for beneficial insects that play a role in ecosystem function. For example, insect parasitoids that help control herbivorous pests have become less common and effective as drier conditions have developed in South Australia (Kriticos et al. 2009). Changes in the feeding habits of insects have potential implications for the effectiveness of weed biocontrol agents (Scott et al. 2008). As temperatures increase, we would expect tropical and sub-tropical weed species (e.g. *Acacia nilotica* – prickly acacia) to expand their range further south to areas previously too cold for their success (Kriticos and Filmer 2007). Likewise, those species in cool locations (montane and alpine species) will retract in both latitude and altitude as temperatures increase (e.g. *Cytisus scoparis* – scotch broom) making control methods more effective as these species reduce in range and vigour (Murphy et al. 2008). Weed species may exist as 'sleeper cells' in soil seed banks and respond as the condition of native vegetation deteriorates as a result of increased fire frequency or intensity, or intense drought (Kriticos 2008). Southern regions of Australia are forecast to expect a 20% increase in weed species threat (Ziska et al. 2004; Ziska and Teasdale 2000).

Resource availability will also be important in determining weed growth under climate change (Kriticos et al. 2009) with increased competition for nitrogen to maintain C:N ratios as atmospheric CO_2 increases will favour leguminous species (e.g. *Genista monspessulana* – cape broom and *Ulex europaeus* – gorse). Improved water use efficiency under elevated CO_2 may allow some species to invade drier sites (e.g. *Cryptostegia grandiflora* – rubber vine). In drought-prone areas, the length of growing season is unlikely to be affected by increased water-use efficiency of plants and is unlikely to have a significant effect on distribution (Potter et al. 2009; Scott et al. 2008). Any increased growth will include increased root biomass that might in turn lead to the dilution of herbicides and reduce the effectiveness of current weed management techniques (Steel et al. 2008).

25.5.5.1.4. Fire

Williams et al. (2009) undertook a sensitivity analysis at the national scale as well as with specific regional case studies. In their analysis they determined that increased fire danger indices may result in shorter intervals between fires, particularly in southern Australia. Williams and Bradstock (in Steffen et al. 2009) identify as a result, that the risk to biodiversity differs across the country. In particular, they state that the biodiversity values of sclerophyllous vegetation of south-eastern and south-western Australia appear to be at higher risk than those of the savanna woodlands of northern Australia.

[*note: section currently missing material from New Zealand*]

25.5.5.2. Biofuels

Increasing interest in biofuel production and use in Australia is driven more by government policy on sustainability and the approach of peak-oil rather than adaptation to climate change. Crops planted specifically for biofuel production will potentially suffer the same constraints and threats that may be imposed by a changing climate on those grown for food, fibre or fodder. These issues are dealt with above and in section 25.5.1.6 below.

In 2001 the Australia set a non-binding 2010 target of 350 million litres p.a. (Sorda et al. 2010). On 1st July 2011, arrangements that neutralise taxation of renewable fuels where extended for a further 10 years. To 2008, annual production of biofuels in Australia was estimated at 168 ML (Hayward et al. 2011b) with a reported capacity in 2010 to produce 885 ML (ABARES 2011a).

Biofuels in Australia derive from existing oilseed feedstocks, waste oils and grease, tallow, sugar cane, molasses and grains (O'Connell et al. 2007; Stucley 2010). Potential second generation fuels in Australia include crop residues, grasses, farm forestry crops, forestry products and urban waste streams. These require research and development to become cost-effective (O'Connell et al. 2007).

Environmental gains in substituting biofuels for petroleum products have been postulated including salinity mitigation (O'Connell et al. 2007), carbon sequestration (Turner and Lambert 2000), biodiversity gains and reduced greenhouse gas emission. Potential energy-production from forests including biofuels has had limited realisation due to cost, uncertainty surrounding sustainability, and lack of efficient processes for producing fuels (Raison 2006). The development of feedstocks and other plantings as biofuels must address issues relating to competing land-uses, environmental roles of the plants, distance to processing plants and shifting zones of agriculture (Herr and Dunlop 2011) as well as a full life-cycle carbon analysis (Turner and Lambert 2000).

[*note: section currently missing material from New Zealand*]

25.5.6. Food and Fibre Production Systems

25.5.6.1. General

Changes in agricultural production would have marked effects on the economies of both Australia and New Zealand. Australia produces 93% of its domestic food requirements while still exporting 76% of agricultural production amounting to 11.9% of total export value (Department of Agriculture 2010). In New Zealand, exports are dominated by agricultural products with dairy products contributing 15% of GDP and 26% of total exports (Schilling et al. 2010); 95% of all dairy products are exported and New Zealand contributes 35% of the world trade in dairy products [*check consistency with 25.4, consider consolidation*].

Projected changes in agricultural productivity differ markedly between Australia and New Zealand. Scaling the results of Cline (2007) to 2050, Gunasekara et al (2007a) found a 17% reduction in agricultural productivity in Australia compared to no climate change but a +1% change for New Zealand. In this analysis, Australia is the third most negatively affected region (behind India and developing countries) while New Zealand is the only country/area to have a positive response. These are 'indicative' changes rather than precise forecasts (Gunasekera et al. 2007a), they are also national figures and thus ignore potentially important regional and sector differences, and they do not include the impacts of adaptation. Since the AR4 (Hennessy et al. 2007) there has been greater scrutiny of regional impacts, improved understanding of impacts based on experimental studies (in particular wheat in Australia and pasture in New Zealand) and considerable investment in adaptation research.

25.5.6.2. Adaptation

In a survey of nearly 4,000 Australian farmers, almost 50% were prepared to adapt, believed in building resilience to climate change but lacked resources to effectively implement these strategies; about 25% were comfortable with their current situation, did not believe in climate change and felt no pressure to make changes; a further 25% were farmers under considerable pressure lacking the financial resources to adapt and often "isolated from support and social systems that could help them make the changes required" (Hogan et al. 2011). However, almost 80% of farmers were interested in adopting sustainable practices although not explicitly as a response to potential climate changes (Hogan et al. 2011). Working in a number of projects in the eastern region of New Zealand, Kenny (Kenny 2011b) also found a willingness to engage in ways which might improve resilience.

The capacity to adapt, together with the extent of the impacts, together define the vulnerability of rural communities (Nelson et al. 2010). Nelson et al (2010) combined adaptive capacity (estimated using rural livelihood analysis) with exposure to climate change to produce a vulnerability assessment based on pastoral agriculture. The areas likely to experience the greatest impacts were not necessarily those that were most vulnerable because they also had high adaptive capacity. For example, Western Australia had high or moderate exposure in pasture production and farm incomes to climate change but had low to moderate vulnerability because of the high to moderate adaptive capacity. South-east New South Wales was a region that combined both high impacts and low adaptive capacity resulting in high vulnerability. Coastal and peri-urban regions in south-eastern and south-western Australia that engage in small-scale beef production were high to moderately vulnerable due to low adaptive capacity and anticipated reductions in farm incomes; this result is particularly interesting as it is for an area where pasture production is predicted to increase under climate change – and would have resulted in an entirely different conclusion if this had been the only metric used. A multidisciplinary (including social and biophysical scientists and economists), context specific (i.e. for specific places and times) approach that includes collective decision making and policy processes that will result in adaption and mitigation are seen as priorities for addressing the vulnerability of Australian agriculture to climate change (Pearson et al. 2011).

As an immediate strategy it is proposed that adaptations that are suitable to counteract climate variability are encouraged until such time as the climate forecasts or changes become more evident (Howden and Stokes 2010). Where variability is already high vulnerability can be substantially reduced by the adoption of appropriate strategies (Nelson et al. 2005) e.g.in a 12 year study in northern Queensland, O'Reagain et al (2011) tested different grazing strategies to counter variable rainfall; the best strategy (in financial terms) was a conservative strategy with moderate stocking rate; this proved as profitable as variable stocking polices with less risk. In situations where variability is currently low but expected to increase under climate change, the timing of introduction of adaptation, particularly if they imply some more conservative strategy, will be critical. A further case would involve enterprises where variability is currently managed by large external inputs (e.g. of water, feed or fertiliser); here the important question is how climate change might modify both the cost and effectiveness of these interventions (positively or negatively).

Climate forecasts (3-9 month projections) have not proven effective tools for land managers. Included in the O'Reagain et al (2011) study was a variable stocking policy partly driven by a climate forecast; this had no advantage in financial outcome over the conservative strategy and introduced greater risk. Ash et al (2007) explore many reasons for the lack of benefit in climate forecast information but highlight the serious constraint introduced by the uncertainty in the forecasts themselves. Distinguishing this kind of climate forecast from the long-term trend (30-100 years) projections is an important step in convincing land managers of the benefits of adaptation to long term climate change.

Adaptation can also involve 'future-proofing' currently important technologies For example, in New Zealand nitrification inhibitors are promoted for their value in reducing nitrogen emissions (NO_3 and N_2O) and increasing fertiliser use efficiency; however, in the case of the widely used DCD (dicyandiamide) its efficacy is strongly temperature dependent (Kelliher et al. 2008) and higher soil temperatures would be expected to increase degradation and reduce the period of effective inhibition. Other important examples are biocontrol systems and plant germplasm where maintaining plant and disease resistance will be important (Chakraborty et al. 2011; Howden et al. 2010). This adaptation is the province of scientists and technologists; to date little work has been done in this space.

25.5.6.3.Arable Production

Since the AR4 (Hennessy et al. 2007) major experiments have been instigated in Australia to study the impacts of global change on wheat (Fitzgerald et al. 2010) and additional modelling has been completed (Crimp et al. 2008; O'Leary et al. 2010). These studies suggest it is likely that positive yield responses can be achieved through adaptation, primarily selection of appropriate germplasm (O'Leary et al. 2010), by the 2030s (Garnaut 2008a). The timing of introduction of new germplasm will be important in order to gain these benefits.

It is very likely that grain quality will decline (mainly protein content but also minerals such as zinc and iron) (Crimp et al. 2008; Fitzgerald et al. 2010; Norton et al. 2010). Field experiments show decreases in protein content (at 550 ppm CO_2) of 4-11%; additional N fertiliser of 40 to 220 kg/ha are projected to be required to maintain protein at current levels (Crimp et al. 2008) although further research will be necessary to ensure that this input is effective given the potential for lower nitrate assimilation under elevated CO_2 (Bloom et al. 2010).

Likely changes in pathogens and host-pathogen interactions remains an area of high uncertainty for wheat and other arable crops (Chakraborty et al. 2011). The performance of currently effective resistance genes and resistant varieties under elevated CO_2 and temperature change has been identified as a particularly important issue (Chakraborty et al. 2011; Melloy et al. 2010).

25.5.6.4.The Pastoral Industry

Modelling carried out for the Garnaut Review (Garnaut 2008a) by McKeon et al (2008) suggests it is likely that an increase in temperature of 3°C would result in a 4% reduction in the gross value of the Australian beef, sheep and wool sector – the most important agricultural sector by value. An increase in CO_2 (to 750 ppm) would result in +2% increase; 10% more rainfall in +12% and 10% less rainfall in -13% changes in value. In summary, for Tasmania and Victoria changes in livestock production are predicted to be of the same order as changes in rainfall (because low temperatures may still limit growth); for other areas production is projected to be greater – though of the same sign – as changes in rainfall.

The most recent impact assessment for the New Zealand pastoral sector uses two temperature scenarios based on 25% and 75% of the upper and lower bounds projected by the TAR and statistical downscaling to give national coverage with some preliminary analysis based on AR4 models (Wratt et al. 2008). The pasture growth is calculated using a simple model based on growing degree days and soil moisture. Compared to the 1972-2002 period the predictions for national production for the 2030s are a -2.8% to -4.3% change in dairy and -6.1% to -8.8% in sheep and beef. At a regional level, using predicted effects on national export revenue and comparing to 1972-2002 there is a range of response across all scenarios from -32% to -56% (Hawkes Bay) to +3 to +26% (Nelson) for dairy and for sheep and beef -33% to -59% (Hawkes Bay) and +4 to +19% (Southland). These predictions are not generated by biophysical models that include elevated CO_2 responses so cannot be assessed as more than likely; nevertheless they provide an interesting picture of little average change but potentially important regional impacts. Confidence in the ability of biophysical models to simulate CO_2 impacts has increased as more experimental data have become available on nutrient interactions, particularly nitrogen dynamics, which appear to play a major role in determining the response to CO_2 (e.g. (Hovenden et al. 2008; Newton et al. 2010; Rutting et al. 2010) in interaction with phosphate dynamics . Experiments on elevated CO_2 and temperature have now been in progress long enough to provide datasets to validate biophysical models (Li et al. 2012). When these models are linked to farm management models (Dynes et al. 2010) the potential exists to quantify impacts at the farm-scale i.e. at the point where on-farm decisions are made. The lack of farm scale impact studies and of consequences for regional economies e.g. (Heyhoe et al. 2007) (rather than just for specific sectors within regions) are notable gaps in our current understanding for both Australia and New Zealand.

25.5.6.5. Viticulture and Horticulture

Observed trends to earlier maturity, primarily driven by early onset of ripening (Sadras and Petrie in press), have been reported for winegrapes growing in south-eastern Australia over recent decades (Petrie and Sadras 2008; Webb et al. 2011b), though in the west of the continent this trend has not been observed (Webb et al. 2011b) ([INSERT FIGURE 25-9 HERE
Figure). Earlier ripening, because it occurs in a warmer period of the year, can have implications for winegrape quality (Coombe and Iland 2004). In general, grapes produced in warmer climates have lower total anthocyanins (red colour compounds) compared with grapes grown in cooler climates, though in some growing regions and seasons, with sub-optimal temperatures currently, anthocyanin production may increase with warming (Cozzolino et al. 2010). Other observations indicate that in recent warmer vintages, with possible de-coupling of sugar development from harvest timing (Petrie and Sadras 2008), there has been a trend to increased alcohol in wine (Godden and Gishen 2005; Varela et al. 2010), while an irrigated field-trial found no effect on yields after vines were artificially warmed through parts of the growing season (Sadras and Soar 2009).

[INSERT FIGURE 25-9 HERE
Figure 25-9: The observed day of year (DOY) at maturity recorded for six blocks from four regions in Australia (a) Central Victoria: Marsanne (1939-2009) (solid circles), Shiraz (Mc) (1940–2009) (open circles) and (b) Rutherglen (Vic.): Muscat a Petit Grains (1945–2009) (c) Mornington Peninsula (Vic.): Chardonnay (1985–2009) (solid circles) and Pinot Noir (1984–2009) (open circles) and (d) Margaret River (WA): Cabernet Sauvignon (1973–2009). The best fit linear regression indicates the average trend in the maturity day.]

Shifts in climate extremes may be more relevant to perennial horticulture than shifts in the mean temperature (Grace et al. 2009). Heatwaves have been impacting farmers in southeast Australia with increasing frequency, highlighting the importance of access to, and provision of, water in ameliorating potential devastating impacts (Webb et al. 2010b). With projections for warmer and drier conditions in the southern region of Australia access to water may become problematic in future for farmers in this region (Cai et al. 2009b).

Future shifts to winegrape phenology have been modelled for Australia indicating earlier budburst, veraison and harvest for most regions and future scenarios (Webb et al. 2007a). With future warming, reductions to winegrape quality have been projected if no adaptive measures are implemented (Webb et al. 2008), and the number of current regions suitable for growing quality grapes expected to decline (Hall and Jones 2009).

The options for adaptation in winegrape and perennial horticulture sectors include: geographical shifting; changing varieties or cultivars grown; adopting various management practices that increase the resilience of the crop to the future conditions (Webb et al. 2010a; Webb and Whetton 2010); and/or exploiting genetic and breeding potential in the various sectors e.g. winegrapes (Webb et al. 2011a); peaches (Topp et al. 2008); or strains of yeast for winemaking (Varela et al. 2010). Communicating to farmers regarding their exposure to climate shifts (Hayman and Alexander 2010) and the way farmers choose to respond (Marshall et al. 2010b) affects the potential to moderate impacts from climate change. Furthermore, consideration of consumers' perception of how industries are responding to the climate change issue is becoming more important (Anderson et al. 2008).

If adaptive measures are implemented suitability may improve for grape-growing in current cooler regions (Webb et al. 2010a), as options to introduce different varieties of winegrapes broaden (Smart 2010; Webb et al. 2011a). Potential also exists for development of cooler or more elevated sites within some regions (Hall and Jones 2010), and/or expansion to new regions, with some growers already making moves to avoid threats from the changing climate (Smart 2010). For horticulture, pome- and stone-fruit growing may become more marginal in some regions (Darbyshire et al. 2011; Putland et al. 2011), while frost-free areas for growing subtropical crops (e.g. avocado) may expand (Liu et al. 2011).

25.5.6.6. Water and Agriculture

[*note: need to reconsider how we handle water across different sections: 25.5.1, 25.5.2, and 25.6*]

Changes in climate and atmospheric CO_2 concentration can potentially alter both water demand and supply. The sensitivity of many crops to changes in rainfall (see sections above) highlights the importance of irrigation both for current production and as an adaptation to global change. While dryland agriculture still dominates the land area in Australia (Department of Agriculture 2010), nationally 50% of water consumption is used by agriculture; with 70% of this water used in the Murray-Darling basin (Quiggin et al. 2008) which contributes about one-third of the gross value generated by Australian agriculture (Robertson 2010). The Murray-Darling (see Box 25-2) includes over 90% of all the irrigated land used for cereals, cotton and rice and more than 50% of the irrigated area used for fruit, grape vines and pasture (Quiggin et al. 2008). Various scenarios are explored for the region by Quiggin et al (2008); in the most likely climatic outcome for "business as usual" emissions (A1F1 emissions path without mitigation), reductions in inflow are expected leading to estimated losses of A$540 million by 2030 and A$2.15 billion by 2050; by 2100, both this median and the 'dry' "business as usual" scenarios (Garnaut 2008a) would reduce inflows to the point that irrigation would not be possible. Water availability also places constraints on the expansion of agriculture: 17 M ha in northern Australia are considered suitable for arable cropping expansion but there is sufficient water to use less than 1% of this land (Webster et al. 2009).

_____ START BOX 25-2 HERE _____

Box 25-2. Climate Change and Biosecurity

Australia and New Zealand have a diverse native flora and fauna and a large agricultural sector relatively free from serious pests and diseases, present in other countries. Biosecurity relates to the continued freedom from these pests and diseases not only to protect the native environment and agricultural sector but also to enhance the capacity to trade with other countries.

Projected future climates will influence the entry, establishment and spread of pests, weeds and diseases which will require a revision of current biosecurity practices such as preparedness, prevention, containment policies, and trade and market access protocols (Figure 25-10). Understanding these threats will enable industry and quarantine agencies to better prepare and adapt to any increased risks.

[INSERT FIGURE 25-10 HERE
Figure 25-10: Biosecurity and climate change and the implications for policy (Luck et al.).]

Increasing temperatures will directly influence insect development, survival, fecundity, feeding behaviour, range and abundance (Bale 2002). Insects may respond with faster development times and shorter life cycles (Bale 2002; Harrington et al. 2001a; Harrington et al. 2001b). Increasing temperatures are also predicted to cause changes in pest and disease distribution which may cause some species to expand their normal range into a new environment, potentially extending agricultural losses (Luck et al. 2011). The Queensland fruit fly (*Bactrocera tryoni*) was predicted to expand its range southward as temperature increases (Sutherst et al. 2000). Projections for the exotic Asiatic citrus psyllid, *Diaphorina citri* showed that regions located on the southern inland and coastal regions, encompassing the major southern citrus growing regions of Australia, could become more suitable for *D. citri (Aurambout et al. 2009)* however this study also showed that the insect feeding periods would be reduced due to changes in the citrus crop which may result in reduced populations.

Increasing atmospheric CO_2 concentrations can also affect agricultural pests and diseases. Aphid fecundity significantly decreased when grown under high atmospheric CO_2 in a study of *Rhopalosiphum padi*, the vector of Yellow Dwarf Virus in wheat (Trebicki et al.). This suggests that shorter generation times and higher aphid populations as a result of increasing temperatures may be compensated by the effects of increasing CO_2. The wheat crown rot pathogen, *Fusarium pseudograminearum*, significantly increased in wheat stubble when grown under eCO_2 although disease symptoms did not increase (Melloy et al. 2010). In the absence of high crown resistance in wheat varieties, a reduction in yield and quality in future climates may be predicted, particularly when coupled with drier years. In a study of the Wheat Stripe Rust pathogen, *Puccinia striiformis*, symptom progress, disease resistance and fecundity of the pathogen was unaltered under high CO_2 (Chakraborty et al. 2011). Wheat Stripe Rust is limited by temperatures above 23°C therefore, under future climates, the pathogen is predicted to become a less of a problem for the wheat industry.

Drought and the resultant plant stress may cause some crops to be more susceptible to pest attack especially when combined with higher temperatures (Fuhrer 2003; Rosenzweig et al. 2001). Conversely, drought may reduce the incidence of some pathogens that require water or humidity for development (Chakraborty 2005). Increased winds and driving rains associated with severe weather events will enable the widespread dispersal of insect and pathogens, possibly resulting in new incursions in previously uninfected sites (Anderson et al. 2004; Rosenzweig et al. 2001). This was demonstrated using aerobiological simulations which showed that the Asiatic soybean rust (*Phakopsora pachyrhizi*) spores were blown from north-western South America to the south-eastern U.S. in September 2004 on winds associated with Hurricane Ivan (Isard et al. 2005).

Predictions of future climate trends indicate that the nature, extent and intensity of climatic changes will vary both spatially and temporally. The responses of pest and disease species to these changes are expected to be species-specific and region-specific and made more complex by their interactions and interdependencies. No generic predictions are possible to define the impact of climate change on plant biosecurity, but the development of more integrated computer models and the collection of biological data will help improve our understanding of these processes and potentially estimate outcomes of specific cases or extract general trends for commodities and/or agricultural production zones.

_____ END BOX 25-2 HERE _____

In New Zealand the area under consented irrigation has risen by 82% since 1999 and is now over 1 million hectares; the biggest increases occurring in Canterbury (63 per cent) and Otago (15 per cent); 76% of the irrigated area is pasture (Rajanayaka et al. 2010). The New Zealand dairy herd has doubled in size between 1980-2009 and has moved from the traditional high rainfall zones (>2000 mm $year^{-1}$) to lower rainfall areas (600-1000 mm $year^{-1}$) where irrigation is essential; further expansion will necessarily be into these dryland areas with increasing dependence on irrigation (Robertson 2010). Predictions for reduced rainfall in eastern areas of New Zealand (Wratt 2009) may increase the benefit to be gained from irrigation (Lieffering and Newton 2009) but reduced inflow may increase competition for an increasingly scarce resource.

_____ START BOX 25-3 HERE _____

Box 25-3. Synthesis: Multiple Lines of Evidence for a Changing Climate

[*Note: the intent is to provide a synthesis box or table that demonstrates already occurring impacts of a changing climate. At present, this table is populated almost exclusively with material from terrestrial and some freshwater and coastal ecological systems*.]

[INSERT TABLE 25-1 HERE
Table 25-1: Examples of observed changes in species, natural ecosystems, agriculture and….. *consistent* with a climate change signal, published since the AR4.]

_____ END BOX 25-3 HERE _____

25.5.7. Urban Areas and Infrastructure

Urban areas in Australia and New Zealand are affected by multiple stressors, bringing with them challenges but also opportunities. Key impacts of climate change to be considered are temperature rise, sea level rise, more intense rainfall, flooding, bushfires, tropical cyclones, severe storms and drought and heat waves. These impacts on the urban environment affect human health, the built environment and the disruption of key infrastructure services such as energy, water, transport and communication. Impacts are compounded by the effects from urbanisation and population growth particularly within the coastal zones. Cities play a key role for large political, economic and social processes. These impacts and adaptive responses are discussed below within the urban environment.

25.5.7.1 Health

Health impacts from climate change in the urban environment are dominated by temperature related issues. During January and February 2009, south-eastern Australia experienced an exceptional heatwave with record maximum temperatures and consecutive days above 40°C observed for many locations (Bureau of Meteorology 2009). Over this period, there was a 25% increase in total emergency cases and a 46% increase over the three hottest days. A 34-fold increase in cases with direct heat-related health problems was observed with 61% of these being people aged 75 years or older. There were 374 excess deaths, representing a 62% increase in total all-cause mortality (Victorian Government 2009a). An increased risk of acute myocardial infarction admissions to hospital during hot weather influenced by age and socioeconomic inequality was observed in Melbourne, Australia (Loughnan et al. 2010). When the mean daily temperature is more than 30°C in Melbourne, the average daily mortality of people aged 65 years or older is about 15-17% greater than usual. When the mean daily minimum temperature is more than 24°C, the mortality is about 19-21% above normal (Nicholls et al. 2008). In Brisbane during the 2004 heatwave, the mean number of deaths from non-external cause mortality increased from 13.88 to 16.76, and cardiovascular mortality increased from 5.64 to 6.76, compared to the same period in 2001-03 (Tong et al. 2010). In New Zealand, warmer winter-time temperatures are likely to have positive health benefits, particularly for Pacific Islanders living in New Zealand, with fewer cold-weather related illnesses and related hospital admissions (Gosai et al. 2009).

By 2100, the number of annual temperature-related (heat and cold) deaths is expected to increase sevenfold in the Northern Territory and three times in Queensland, while temperature-related deaths are projected to drop by 30% in New South Wales and by 25% in the Australia Capital Territory compared to a 2100 baseline world with no human-induced climate change (Garnaut 2008b). In Sydney, assuming no adaptation, the average heat-related mortality rate (per 100,000) is projected to increase by 6.2 from 1961-1990 to 2070-2099 for SRES A2 scenario, and by 5.5 for SRES B2 scenario, using the HadCM3 climate model (Gosling et al. 2010).

Australia's population is highly urbanized with over 75% living in 17 major cities and 60.8 % living in the five largest coastal capital cities, contributing substantially to the economy (Australian Government 2010). Adaptation for heat-related health problems involves reshaping government policy, improving healthcare services, developing early warning systems to reach all citizens with a social network back-up for those most at risk, preparing health system/emergency departments, improving maintenance programs for key services, seeking behavioural changes and community awareness to reduce exposure to heat stress, retrofitting old houses with better insulation, and developing emergency response plans (Wang and McAllister 2011). (Kiem et al. 2010) identified a failure in communication with no clear public information or warning strategy, no clear thresholds for initiating public information campaigns or incident response resulting in mixed messages to the media and public during the southern Australian heatwave of 2009. Additionally, emergency management response services were found to be underprepared and relied on reactive solutions with an overall lack of surge planning (Queensland University of Technology 2010). The Victorian government has developed a heatwave plan to coordinate state-wide response and maintain consistent community-wide understanding of health impacts by a Heat Health alert system, building capacity of councils to support communities most at heat-related risks, supporting and funding of health services, distribution of public health information, and a Heat Health Intelligence surveillance system (Victorian Government 2009b). Plans to introduce pricing to charge more during peak times leaves low-income residents more vulnerable to heat waves (Strengers and Maller 2011).

Greening cities is an adaptation option to reduce the heat related health impact of climate change (Bambrick et al. 2011), and is often represented by ground vegetation, trees, forests, parks and also green roofs (Bowler et al. 2010). Green roofs increase insulation and evapotranspiration which reduces the cooling demand of the building. Although there are a few examples in Australia, there remain many barriers in Australia to widely adopt green roofs, due to lack of standards, high cost, and understanding of their benefits, in addition to a very different climate in Australia in comparison with Western Europe and North America where green roofs are becoming common (Williams et al. 2010). A building design with proper shading, insulation, ventilation and air-conditioning may considerably improve interior temperature during heat waves (BRANZ 2007). Greening options and climate-sensitive building design can be used to reduce urban heat island effects, which have been estimated to be 3-4°C at 2am in January in Melbourne (Coutts et al. 2010).

25.5.7.2. Built Environment

Impacts on the built environment (residential houses, institutional, industrial and commercial buildings) from hazards such as coastal and river flooding and storms (including cyclones) include increased damage to energy/telecommunications infrastructure, goods and chattels, internal features (e.g. underfloor/wall insulation), internal plasterwork and refurbishments, roof damage and weathering damage. Intrusion of sewage and/or sea water can corrode masonry (O'Connell and Hargreaves 2004).

By 2100, assuming a building growth rate that follows the population growth at current trends and a 4% discount rate, the cumulative net present value of average damage cost due to cyclones is estimated at 433 million in Cairns, 519 million in Townsville, 314 million in Rockhampton and 6.76 billion in Brisbane (Stewart and Wang 2011). Considering a moderate climate change scenario (25% reduction in cyclone occurrence frequency and 10% increase in mean wind speed) the net present value of average damage costs is projected to increase by 31% in Cairns and Townsville, 35% in Rockhampton, and 47% in Brisbane. For a high climate change scenario (20% increase in mean wind speed, and no change in cyclone occurrence frequency), the increases are projected to be 116%, 117%, 120% and 134%, respectively. In another study for Queensland, the annualised residential damage by cyclones and storm tides is projected to increase from AU$482 million in 1990 to AU$1333 million in 2090 for the A1FI emission scenario (Waters et al. 2010).

The economic assessment of adaptation strategies for residential buildings exposed to cyclones suggests as most cost-effective the design of new buildings to withstand 50% higher wind pressures (increase of one level in the wind classification). The net present value of the average net benefit to implement this approach in Brisbane is AU$38 million by 2030, AU$142 million by 2050, AU$240 million by 2070 and AU$340 million by 2100 assuming a moderate climate change scenario (25% reduction in cyclone frequency, 10% increase in wind speeds) (Stewart and Wang 2011). A lifetime inspection and maintenance program for buildings in cyclone regions is suggested (Mason and Haynes 2010).

Increased carbon dioxide concentrations in the atmosphere will also expose buildings to increased damage risks due to accelerated deterioration of concrete structures (Stewart et al. 2011b; Wang et al. 2010e). For concrete buildings, the carbonation depth will increase up to 18% by 2040, 30% by 2070 and 46% by 2100 (A1FI emission scenario), which will lead to an increase in carbonation-induced corrosion initiation and damage (Wang et al. 2010c).

There is an increasing likelihood of the occurrence of bushfires associated with climate change. Using the annual accumulative Forest Fire Danger Index, the number of very high fire danger days in southeast Australia is projected to increase by 2-13% (low emission scenario) and 10-30% (high scenario) by 2020, and by 2050, it rises to 10-50% and 20-100%, respectively. Extreme fire danger days also increase significantly (Lucas et al. 2007b). However, if adaptation measures to reduce the damage risks to houses by bushfire are well implemented, then building losses are likely to not increase in response to the projected increase in fire danger days (McAneney et al. 2009). More adaptation initiatives are likely to result from recommendations resulting from the 'Black Saturday' bushfires, for example, by applying more stringent planning and regulations and avoidance of developments in high bushfire risk areas, enhanced constructions standards, designs of building specifically addressing the risks on the site amongst many others (Victorian Bushfire Royal Commission 2010). Wildfire risk is also expected to increase in New Zealand in areas where rainfall is projected to decrease (Pearce et al. 2005) however it is not expected to pose significant risk to urban areas.

Climate change will increase the number of very hot days resulting in excessive indoor temperatures. Options for new and existing buildings for reducing the impact of overheating include controlling solar gain (e.g. using eaves or window shades), providing ventilation (e.g. fans, passive vents), using reflective bright roof paint, and reducing lighting and equipment loads (e.g. using energy efficient light bulbs) (O'Connell and Hargreaves 2004).

25.5.7.3. Energy Demand

Demand for electricity in New Zealand and Australia will be driven by population and economic growth as well as changing technologies and comfort expectations (Strengers 2008b; Strengers and Maller 2011). 67% of householders in Australia use either air-conditioners or evaporative coolers (Carmichael 2009). Energy modelling projections show the cooling load for Australian houses to triple by 2070 compared to current levels, while there is a noticeable decrease in heating load in cooler climate zones. The home air conditioning requirement is projected to increase by an average of 76% across the country by 2070 (BRANZ 2007).

Buildings in different locations and with different energy efficiency ratings will be impacted by climate change at different scales. The cooling and heating energy requirement of an Australian house compared to 1990 in Darwin, Alice Springs and Sydney increases 227 MJ/m2, 80 MJ/m2 and 49 MJ/m2 by 2050 and 540 MJ/m2, 305 MJ/m2 and 170 MJ/m2 by 2100, respectively, for the A1FI scenario (Wang et al. 2010f).

Adaptive response to overheating are greening spaces and installation of better insulation, which also reduces peak energy demand and thus represents an additional adaptation option to reduce the risk of black- or brown-outs. Insulation has increased in Australian housing from 52% to 61% from 1994 to 2008 with most of Australian new house designs requiring a minimum of 4 to 5 stars with this requirement scheduled to rise to 6 stars in 2011 (Carmichael 2009). Improvements in building envelope energy efficiency should be considered in building design and operation stages. It was found that for existing houses in temperate regions, improvements from 2 to 5 stars may be required to counteract the effects of a 6°C warming whereas for new houses, from 5 to 7 stars is required. In warmer regions additional measures such as alternative technologies (high efficiency appliances, on-site renewable energy etc) may be required (Ren et al. 2011 (in press)).

To promote building energy efficiency, the Australian Building Codes Board (ABCB) has increased the stringency of the Building Code of Australia (BCA) to ensure the industry adopts energy efficient measures for all commercial buildings and new residential buildings (Council of Australian Governments (COAG) 2009). The climate adaptive capacity of buildings can also be enhanced by the improvement of energy management (Karjalainen 2009; Moon and Han 2011; Orosa and Oliveira 2010; Strengers 2008a) and reduction of lighting and equipment loads (BRANZ 2007), passive design (Peterkin 2009; Su 2009), use of energy efficient appliances (Thatcher 2007a), reflective paint

(Gurzu et al. 2010), development of green infrastructure and urban planning (Bowler et al. 2010; Coutts et al. 2010; Zhao et al. 2011). Occupant behaviour can have a significant impact on energy consumption (Stephenson et al. 2010) however, occupants can consume more energy by taking advantage of improved energy efficiency (Howden-Chapman et al. 2009).

25.5.7.4. Water

25.5.7.4.1. Water supply and demand within cities

Many cities in Australia and New Zealand are facing challenges of increasing temperature and reduced rainfall in addition to an increasing water demand. This will increasingly expose Australia and New Zealand to the risks of severe water shortage.

Due to a reduction in rainfall, a decrease in storage of water-supply reservoirs was seen in many cities. Sydney, South Western Western Australia and Melbourne experienced water-supply reservoirs at low levels (Shrestha et al. 2009; Warner 2009), (Bates et al. 2010; Wallace et al. 2009) (Petrone et al. 2010b). (Gato et al. 2007). However, the WSAA report card (9/10) shows residential water consumption (kL per capita) projected to decrease by 2056 based on 2009 levels for Sydney, Adelaide, perth and Canberra with an increase for Brisbane.

The key factors influencing urban water demand to 2056 are identified as population growth, climate change, the design of our cities, housing types and density, uptake of water efficiency appliances, water restrictions and permanent water saving rules (for example, not using sprinklers in the middle of a hot day), increased water prices, economic growth, and changing demographics (Water Services Association of Australia 2010). Strategies to change effective water-saving behaviour are also an effective way to reduce water demand (Chanan et al. 2009). Initiatives for retrofitting of water efficient devices and technical improvement to household water infrastructures were also considered to be important measures (Lawrence and McManus 2008) as well as education (Mead and Aravinthan 2009).

The effect of projected population growth and climate change on sustainable water supply in the Wellington area was analysed by (Ibbitt and Williams 2009). By 2050, present-day water supply (including planned storage upgrades) should sustain the projected increase in population of 100,000 people (with a corresponding 25% increase in average daily demand). However, under three climate change scenarios to 2050 (low, mid, and high emissions), mean rainfall is projected to decrease, particularly in summer, and projected increases in temperature are likely to cause the per capita water demand to rise by 1–2%. The combined effect of these projected changes in climate is a reduction in the sustainable 2050 population of between 4 and 7.5% (20,000 – 36,000 people), representing approximately half of the incremental benefit of the planned storage upgrades. Similar results of relatively small changes in water demand associated with climate change were found by (Ruth et al. 2007) for Hamilton.

Recycling is potentially effective in distant and drier areas (Attwater et al. 2006; Naji and Lustig 2006; Radcliffe 2010) with greywater usage more significantly reducing main water supply than rainwater harvesting at 32.5% and 25.1 % respectively at Cranbrook, Western Australia. In Adelaide, both rainwater and recycling water has been adopted with the level of water-self-sufficiency estimated at around 60% (Barton and Argue 2009).

Rainwater use can address growing water shortages with rainwater tanks intercepting roof runoff, with the maximum stormwater reduction 48.1% or 68.3 m(3)/lot/year (Zhang et al. 2010). The water quality is a key factor in the use of rainwater tank to collect rainwater (Kus et al. 2010) (Rodrigo et al. 2010) and there are social, institutional, and economic factors influencing sustainable rainwater management in Australia (Brown et al. 2009a; Brown and Farrelly 2009; Fletcher et al. 2008a; Gardner and Vieritz 2010; Mankad and Tapsuwan 2011; Rozos et al. 2010). Investment in new water infrastructure, such as new dams, is another means to increase water supply or water storage (Ruth, Bernier et al. 2007).

The use of wastewater is being promoted through policy. However a barrier can be a lack of community support (Hurlimann et al. 2008) as seen in Toowoomba, Queensland where residents voted against the construction of an indirect potable wastewater reuse scheme (Hurlimann and Dolnicar 2010). This lack of community support is due to competing environmental, scientific, and cultural discourses about the use of wastewater emerging from community, government, and industry responses (Mankad and Tapsuwan 2011).

The current planned desalination capacity is 35% of capital city water consumption in 2008/9 which has the ability to increase capacity to 49% (WSAA 910). All capital cities except Darwin considered to build at least one desalination plant as a means to provide water security after the prolonged drought that significantly reduced dam storage in the past (El Saliby et al. 2009). Desalination can be considered a costly option for Sydney and Melbourne (Warner 2009).

Cities can be designed better and re-plumbed to ensure that they are more resilient to water supply shortages. Key features would be a diverse portfolio of water resources with water captured and retained for use with an integrated approach in planning for the urban water cycle (WSAA 9/10).

25.5.7.4.2. Stormwater and wastewater management within cities

Existing aging stormwater and wastewater infrastructure problems in many New Zealand cities such as cross contamination, low outfall head, inadequate pipe volume capacity and saltwater intrusion are likely to be exacerbated in the future due to projected increases in heavy rainfall events and sea level rise (Baldi et al. 2008; Christchurch City Council 2010; Fitzharris 2010; Jollands et al. 2007; Wellington City Council 2010). Incidences of sewer overflows will increase because of higher peak flows. Risk of pipe failure and collapse will increase in regions where drier soil conditions are projected. There is increased potential for corrosion and odours in sewerage network as a result of increased sewage concentrations associated with water conservation, higher ambient temperatures and longer travel times in the sewer network (Howe et al. 2005b). (Davis et al. 2010) describe a model simulation of the effect of climate change on stormwater flooding for a stream catchment in North Shore. A mid-to-high range projection of 3ºC increase in annual mean temperature resulted in an adjustment of the 100-year design rainfall from 220 mm/day to 257 mm/day. While the difference in flood depth and extent for the current and future climate were fairly minor along the steep-sided main channels, the inundation for the future scenario increased on the flat flood plains. It was also found that some drainage infrastructure may not have sufficient capacity for future floods of this magnitude.

Stormwater harvesting is considered an effective option to reduce stormwater runoff and as a viable alternative water supply (Fletcher et al. 2008b). The performance of stormwater harvesting shows variable levels of potable water savings, with collection recording from 20% to up to 100% of the mean annual rainfall (Fletcher et al. 2008a). Stormwater collection schemes have been implemented in many cities in Australia (Rinck-Pfeiffer, David et al. 2008) however significant barriers exist, including institutional arrangements, costs, responsibilities, and regulations and approvals processes for more sustainable practices (Brown and Farrelly 2009).

Drainage management adaptation strategies include ongoing review, monitoring and planning that considers the likely impact of climate change, retaining flood plains and floodways and adapting existing systems to attenuate flows, and water sensitive design in new developments to reduce runoff rates. Adaptation for sewerage systems includes measures to reduce peak flows in wet weather and measures to manage sewage quality (Howe et al. 2005b).

25.5.7.5. Coastal and River

25.5.7.5.1. Coastal

In the Hunter, Central and Lower North Coast region of New South Wales, there are significant residential and industrial areas located in low-lying areas (<2.5m Australian Height Datum) including 31,000 householders with 8.5% of the total population in the region. Moreover, 16% of the total population is directly exposed to 1-in-100 year flood events, with 25% of all householders in low-income, and the elderly 17% of the total exposed population. There are more intangible costs related to health effects, stress and disruption of services perceived by affected householders than tangible costs (HCCREMS 2010). At present, it is estimated that about 227,000 people in Southeast Queensland are at risk of inundation from a 1-in-100-year storm tide. If the population does not change, 0.2m sea level rise could see this number increase to 245,100 by 2030 and 0.5 m sea level rise would affect 273 000 people by 2070. In Southeast Queensland, storm tides due to extreme weather events will be more intense and frequent. The current 1-in-100-year event will have a probability of occurring every 61 years by 2030 (A1B emission scenario) (Wang et al. 2010d). In Australia, between 187,000 and 274,000 residential buildings (valued between AUD51 and AUD72 billion, based on 2008 figures) and between 5,8000 and 8,600 commercial buildings (valued between AUD58 and AUD81 billion) are exposed to inundation and erosion at a sea level rise of 1.1m assuming a high end scenario for 2100, with Queensland and New South Wales most impacted (Australian Government Department of Climate Change and Energy Efficiency 2011).

The impacts of sea level rise of +0.4m by 2040 and +0.8m by 2090 on the 100-year average recurrence interval storm tide inundation in the Christchurch estuary area (2010 base case, +1.88m above mean sea level) showed that the increase in total buildings flooded was 16% (2040 case) and 31% (2090 case). The corresponding estimated increase in replacement costs (2010 dollars) to flooded building contents is NZ$630M (2040 case) and NZ$1.2B (2090 case) (Reese, 2011). Several options exist to reduce the impact of flooding on buildings, including raising floor levels (or building additional storeys), using strong piled foundations, using water-resistant insulation materials, raising the height of wiring, outlets, hot water cylinders, and meter boards, and ensuring weathertightness (O'Connell and Hargreaves 2004).

There has been no comprehensive study on how climate change will affect coastal inundation risk in New Zealand cities (Ministry for the Environment 2008). However, for many urban areas at or near sea level there are likely to be increased costs associated with increased damages to and/or enhanced protection of dwellings and infrastructure from future high tide / storm surge events on top of a higher mean level of the sea (Stephens and Bell 2009).

Adaptation through planning regulations can be used to reduce the impact of sea level rise. For example, if planning regulations allow no further development in high risk areas (but with no action to protect existing housing stock), the impact of 2.5m storm tides with an additional 0.2m sea level rise in 2030 could be limited to approximately 40,300 residential buildings instead of 61,500 with a cost of about AU$1.3 billion instead of AU$2.0 billion (Wang et al. 2010d). In most cases, avoidance of future risk through new developments in high risk areas is the most cost-effective adaptation response (Australian Government Department of Climate Change and Energy Efficiency 2011).

25.5.7.3.2. River

Climate change is expected to increase the frequency and intensity of extreme rainfalls resulting in an increase in river flooding (Ministry for the Environment 2010; Rafter and Abbs 2009c). Impacts on urban river flooding have been assessed for a few New Zealand case studies, e.g. (Davis et al. 2010; Ministry for the Environment 2010; Reese 2011; Sturman et al. 2011b; Sturman et al. 2011a). In most cases, projected changes to extreme rainfall are translated to likely changes in flood peaks and resultant inundation using dynamic catchment hydrological and river hydraulic models (Ministry for the Environment 2010). Damages and costs have been assessed using tools such as Riskscape (www.riskscape.org.nz). For example, (Sturman et al. 2011b; Sturman et al. 2011a) show that the 100-year ARI flood peak for the Heathcote river in Christchurch changes from approximately 60 cumecs (current climate) to approximately 90 cumecs (2090, temperature increase of 2°C, A1B emission scenario, average of 12 climate models) to greater than 120 cumecs (2090, temperature increase of 5°C, A1FI emission scenario, most sensitive climate model). Using these projected changes to the flood peak and the resultant likely increases to inundated area (taking into account sea level rise), the estimated increase in replacement costs (2010 dollars) to flooded building contents is between NZ$114M (2090 mid-range scenario) and NZ$315M (2090 high range scenario).

Flooding is the most costly natural disaster in Australia (AUD$314m on average each year, (Bureau of Transport Economics 2001)Bureau of Transport Economics, 2001). In coastal cities and townships, flood risks and storm surges will significantly increase from the combined effect of higher intensity rainfall events, higher peak flows and higher sea water levels and potential changes in wind speed (McInnes et al. 2005b; McInnes et al. 2005c).

Adaptation to increased flood risks from climate change is happening – through updated flood design levels, the need for flood mitigation plans to account for climate change and through building regulations (e.g., higher floor levels in coastal areas) – Ron Cox or Engineers Australia should be able to give some examples, I'd also look up the papers in the September 2010 Engineers Australia conference on Practical Response to Climate Change.

25.5.7.6.Transport

The main issues for land based transport in Australia due to climate change are sea level rise and the increased frequency and intensity of extreme weather events. The potential impacts include high temperature impacts on steel bridges and rail tracks, temperature and solar radiation on asphalt road surfaces, decreased precipitation resulting in impacts on structures and foundations and transport infrastructure, flood damage to road, rail , bridge and tunnel infrastructure, sea level rise and storm surge on transport infrastructure in coastal areas including corrosion and the susceptibility of bridges to increase in coastal winds. Additionally projected climate change may push environmental conditions for which transport infrastructure was not designed for across the long design life of the infrastructure. (Taylor, 2010).

Nationally, between 26,000 and 33,000 km of roads are potentially at risk from the combined impacts of inundation and shoreline recession for a sea level rise of 1.1 m (high end scenario for 2100) with a replacement value of $46-60 billion(2008) and 1200 –1500 km rail at a replacement value of $4.9-6.4 billion. Most of the risk is to main roads, unsealed roads and tracks rather than highways. However, the disruption to freeways on transporting good and people are higher. Western Australia has the greatest length of roadway impact at a replacement value of $8.7-$11.3 billion due to unsealed roadway while QLD has the greatest value at risk at a replacement value of $9.-$12.9 billion due to a greater percentage of freeway and main roads. Replacement value of rail is $1.7-$2.3 billion for QLD, $0.6 - $1.3 billion for each of NSW and SA, and $0.1 - $0.5 billion for NT and WA. (DECCEE,2011). Substantial indirect costs are likely to be experienced due to network effects including costs due to delays, losses from toll roads, freight supply interruption, detours and trip cancellations (Middlemann 2007; Maunsell 2008; Koetse & Rietveld 2009). The greatest public costs have been found to be related to disaster assistance, and road maintenance, relocation and repair (Middlemann 2007).

A robust transport network is essential in order to accommodate emergency services and planning particularly with respect to emergency evacuations (NCCARF position paper, 2011; see Box 25-4).

Climate change will pose significant risks to New Zealand's land transport network (highways, rail, ports, coastal shipping) through increases to coastal inundation (particularly for land below 5m above sea level), inland flooding (particularly in present-day flood-prone areas), erosion resulting from heavy rainfall (particularly in areas with cuttings for road and/or rail), and prolonged high temperatures leading to rail buckling (Gardiner et al. 2009b; Gardiner et al. 2008). In locations where rail track conditions are poor, the mean number of speed restriction days is predicted to double from a base year of 6 per year in 1990 to 13 days per year in 2040 and to 23 days per year by 2090 (based on the average of 12 climate models and the A1B emission scenario (Gardiner et al. 2009b). However, by optimising the design temperature and achieving a high standard of maintenance, climate change will play a minimal role in influencing the risk of heat buckling, even in areas subject to the highest temperatures.

Increasing carbon dioxide concentrations will also lead to accelerated deterioration of bridges and port structures (Wang et al. 2010b).

25.5.8. Rural Areas

Rural communities in Australia and New Zealand are distinctive from urban populations; they have a high proportion of older people (Mulet - Marquis and Fairweather 2008), experience lower incomes, lower standards of living and higher levels of unemployment (Stehlik et al. 1999). Central to a rural community is its identity, including its heritage, social and cultural values, and its people; its uniqueness traceable to their distinctive location factors and environmental conditions (Joseph et al. 2001). Rural communities that are vulnerable to climate variability and change are susceptible for a complex set of environmental, economic and social reasons (Nelson et al. 2010). Further, there is robust evidence that exposure to climate variability and change alone is not a good measure of vulnerability as rural communities that are most exposed to climate risk are often highly adapted to it (Nelson et al. 2005, 2010, Meinke et al. 2006, Reidsma 2007). Yet there remains a question as to the transferability of those adaptive capacities because many of them are site and enterprise specific, and also because of a dearth of current analogues for likely future climates (Burke et al. 2009).

The vulnerability of rural communities to climate change differs within and between countries with increased vulnerability in some regions but enhanced potential in others. Under climate change rural communities are likely to have increased exposure to fire (Pearce et al. 2011), floods (Kouvelis et al. 2011), drought (Clark and Tait 2008), heatwaves (Wang and McAllister 2011, and coastal erosion and inundation (Blackett et al. 2010b). Exposure to frost is also likely to change (Clark and Sturman 2009b). Climate change though is not the sole pressure on rural communities as it operates in conjunction with other social and economic pressures, such as declining terms of trade and introduced legislation such as the Emissions Trading Scheme (NZ ref; Nelson et al. 2010). Furthermore, the effects of climate change impacts on a range of aspects, such as natural resource availability, agricultural productivity, mining activities (Gerard et al. 2011), modes and forms of production (Blackett et al. 2010b), operation of energy, water and transport infrastructures (Gardiner et al. 2009a), recreational facilities (Blackett et al. 2010b), sites with archaeological and cultural value (Kouvelis et al. 2011), population health, and social and economic development.

Altered growing conditions and/or land use change will directly impact farm production and profitability and this will translate into effects on rural communities, particularly on employment levels (Bevin 2007; Kerr and Zhang 2009), service provision (Bevin 2007; Stehlik et al. 2000; Unknown 1997), and reduced voluntarism (Kerr and Zhang 2009). Moreover, social cohesion, a key component of rural communities, lessens with the impacts of climate change (Kenny 2001). At the community level this can result in the loss of community networks, services and resources. At the family level, family cohesion is threatened particularly if family members, such as adult women, leave to gain employment elsewhere (Alston 2007; Alston 2010; Stehlik et al. 2000), underlining that some impacts of climate change are gendered (Alston 2007; Alston 2010; Joseph et al. 2001; Stehlik et al. 2000). There is robust evidence that the effects of prolonged drought has a multitude of interrelated negative social impacts in rural communities, including: farm closures, increased poverty, increased off-farm work, increased social isolation and associated health impacts, accelerated rural depopulation, and the closure of key services (Edwards et al. 2008, Alston et al. 2011a,b). However, positive social change can occur too such as an increased membership of community organisations and thus potentially increasing levels of social capital (Edwards et al 2008).

Farmers making strategic and tactical decisions have the most significant social, economic and environmental implications for rural communities (Clark and Tait 2008) as their actions impact on a range of stakeholders in the community and beyond (Pomeroy 1996). Farmers are already undertaking adaptation in response to existing climate variability and trends in order to maintain production and infrastructure, such as Australia's rice industry (Gaydon et al. 2010; SunRice 2005). Climate changes can also impact on rural communities through land-use change, as evidenced by past experience of decadal climate variations (Nidumolu et al. 2011). Recent examples of transformational changes[1] include the wine, peanut and rice industries, which have, or are, looking to relocate part of their operations in response to recent climate change or perceptions of future change and its effects (Gaydon et al. 2010, Park et al. submitted, Thorburn et al. 2011). Climate change could also result in changes or relocations in the fishing industry as the abundance and distribution of species change (Hobday 2010, Last et al. 2011) with the responses mediated by fishery management and policies thus impacting on the coastal rural communities. Furthermore, there is high agreement that the reductions in precipitation and increases in evaporation projected for Southern Australia could cause changes in land use as marginal cropping lands increasingly become more suited to lower productivity grazing activities. (Nidumolu et al. 2011). In New Zealand there is medium confidence that some rural land uses will have to move southward as some systems are more vulnerable to climate change than others, such as winter frost-dependent kiwifruit crops being moved south, thus making communities with commodity-specific infrastructures such as processing plants, more susceptible than others (Grimes and Young 2009).

[INSERT FOOTNOTE 1 HERE: Associated with the relocation of people, enterprises and industries.]

Water is a critical resource throughout Australia and New Zealand, and where projections are for lower water availability under hotter, drier conditions, potential conflict is predicted between its multitude of users, including; rural townships, indigenous communities, agricultural producers, extractive industries, processing and manufacturing sectors, the environment, and large urban centres (Moffat 2009; Hodgkinson et al. 2010). There is medium confidence that projections of reduced flow in southern Australian rivers and resultant policy responses would increase tensions between water uses and require industry change or relocation (Hennessy et al. 2007; Dovers and Hezri 2010). For example, in 2010, proposed limits to agricultural water diversions in the Murray Darling Basin caused emotional public protests with rural communities expressing anxieties about unemployment, social decline, and loss in life style resulting from the proposed policy changes (Schrobback et al. 2011). In New Zealand, farmers have turned to increased irrigation to manage seasonal deficiencies but the future ability of farmers to rely on water solutions is probably going to be limited as water schemes reach maximum capacity, and public angst regarding the utilisation of water on farms increases, particularly in Canterbury (Clark and Tait 2008). (NZ ref)

The possible effects and implications of climate change on Maori culture, health, knowledge and economic enterprises will be significant. Of greatest concern for Maori society is the potential adverse effects on rural water resources and infrastructure as water quality is fundamental to maintain and support the health and wellbeing of whanau, kura kaupapa and marae (Kouvelis et al. 2011). However, the administration of Maori land in collective ownership under the Ture Whenua Act (1993) as well as cultural values attendant to Maori as tangata whenua and kaitiaki ensures that Maori enterprises are tied to a location in ways other rural/agricultural enterprises are not, so adaptation decisions need to be location specific (Joseph et al. 2001).

Overall, social structures, norms and values dictate how different groups within rural communities will be effected by, and will adapt to, the physical effects of climate change. Although there are differences in vulnerabilities, needs and capacities, the various stakeholders within rural communities are bound by similar parameters, such as the dependence upon critical infrastructure and resources, economic conditions, government policy direction, and societal expectations (Loechel et al. 2010). Consequently, rural community adaptation to climate change will require an approach that devolves decision-making to the appropriate level where the knowledge for effective adaptation resides, using open communication, interaction and joint-planning (Loechel et al. 2010; Nelson et al. 2008). Currently, the narratives of rural communities are dominated by notions of decoupling and social fragmentation, and unless solutions are found to solve this problem, the effects of climate change will prevail on communities who are ill-prepared socially, and therefore economically and environmentally.

25.5.9. Energy Supply (including Mining) and Transmission

25.5.9.1. Mining

Mining constitutes a significant economic activity in Australasia, with about 8% of GDP being generated in Australia and just over 1% of GDP in New Zealand (ABS 2011a; Stats NZ 2010e). Australia is the world’s largest exporter of black coal, iron ore and gold, and thus any climatic impacts on the industry could be expected to have global implications (Hodgkinson et al. 2010a). Mining in Australia is exposed and sensitive to climate variability and change, particularly in the production phase, through climate-driven limits on energy and water availability, and the impact of temperature extremes, storms and flooding on equipment and human resources. However, post-mining site rehabilitation is also of concern given the long lifetime of mines (with some mines currently planned potentially operating beyond 2050) and the potential for altered climatic conditions as well as societal expectations over such timescales (Hodgkinson et al. 2010a; Hodgkinson et al. 2010b; Pearce et al. 2009).

Recent extreme climatic events in Australia have shown the mining sector to be vulnerable to climate variability and extremes: the January/February 2011 floods are estimated to have reduced coal exports alone by between 25 and 54 million tons, equating to some A$5-9bn in lost revenue (ABARES 2011b; QRC 2011; RBA 2011). Direct flood impacts were exacerbated by disruptions to rail transport as well as constraints from environmental discharge regulations, highlighting interconnected vulnerabilities between the mining industry and other parts of society (QRC 2011). A limited number of companies have performed in-house impact assessments for on- and off-shore changes in climate conditions (Mills 2009; Stroud 2009). The expected increase in extreme climatic events (floods, droughts, storms, heat waves) in many mining areas (see 25.3) suggests that in the absence of adaptation, this vulnerability would increase (Hodgkinson et al. 2010a; Hodgkinson et al. 2010b), but no quantitative projections of potential impacts from or vulnerability to climate change are available as yet.

Stakeholder workshops suggest that the adaptive capacity of the mining industry is high, but may be constrained by competition for locally shared resources such as energy and water at the community level, as well as views about acceptable levels of pollution and discharge regulations including those associated with extreme events (Hodgkinson et al. 2010a; Loechel et al. 2010; QRC 2011). Studies that assess adaptation options using cost-effectiveness or cost-benefit frameworks are not yet available. Due to the currently limited integrated and quantitative studies, our confidence in conclusions regarding the adaptive capacity and hence long-term vulnerability of the mining sector to climate change is low.

No studies could be identified for vulnerability or adaptation options for mining operations in New Zealand.

25.5.9.2. Energy Generation and Supply

Energy generation in Australasia is exposed and sensitive to climate variability and change mainly through drought conditions affecting hydrolake inflows, but potentially also through impacts of changing wind patterns on wind power generation. New Zealand currently generates 65% of its electricity from renewable resources (mostly hydropower), most of which are exposed and sensitive to climate variability and change (about 8% comes from geothermal power). The share of renewable energy in electricity production is projected to grow to 83% by 2030 under a central reference scenario including a carbon price, mainly due to the expansion of wind energy. Total energy consumption is projected to grow by 0.9% during this period, but this projection does not consider the impacts of climate change on electricity demand (MED 2010). Projected climate changes for New Zealand indicate on average reduced winter electricity demand by 1-2% per degree warming and reduction in annual average demand, but a possible increase in summer daytime demand in the northern parts of the country once average temperatures exceed 19-20°C (Jollands et al. 2007; Stroombergen et al. 2006). No quantitative projections of climate-driven electricity demand changes in New Zealand are available beyond 2030.

The vulnerability of New Zealand's electricity generation to climate variability has been demonstrated by dry years resulting in low hydro storage lake replenishment, prompting energy savings campaigns to avoid brown-outs *[give years; MED ref]*. Climate change is projected to reduce this vulnerability over the next few decades as catchments of main hydro lakes are projected to receive increased average precipitation, and a greater percentage of precipitation is expected to fall as rain rather than snow. These changes are projected to increase inflow during the winter half-year by between 5 and 10% before 2020 (McKerchar and Mullan 2004). This initial benefit could eventually reverse as glaciers disappear and thus seasonal melt water reduces hydrolake inflows, but no quantitative modelling studies of this longer-term risk exist as yet (Renwick et al. 2009).

The share of renewable energy sources in Australian electricity generation is lower than in New Zealand, at 7% in 2007/08 but projected to grow to between 19 and 50% by 2030 under a variety of carbon price and technology assumptions (Hayward et al. 2011a; Syed et al. 2010). Total energy consumption in Australia is projected to grow by 1.4% and electricity generation by 1.8% per annum during this period (Syed et al. 2010), but this projection does not consider the potential impacts of climate change on electricity demand. Annual average regional peak demands would reduce by -2(±1)% per degree Celsius warming in New South Wales but increase by 1.1(±1.4) and 4.6(±2.7)% in Queensland and South Australia, respectively (assuming constant energy efficiency) (Thatcher 2007b). Changes in yearly average demand follow similar patterns, with demand increases in Queensland and South Australia but reduced demand in New South Wales and Victoria for warming of less than 5°C (Howden and Crimp 2001). Summer peak demand is expected to increase with rising temperatures (Wang et al. 2010a) and to rise more than baseload or average annual peak demand (Australian Government 2008; Thatcher 2007b), but the implications for regional or national security of supply have not been quantified.

Persistent dry periods in Australia increase risks to meeting prescribed standards of security of supply due to reduced hydropower generation and the reduced availability of cooling water for thermal generation (AEMO 2011;

ATSE 2008; Parsons Brinkerhoff 2009). With on-going climate change, the latter impact may require a switch to dry-cooling of generation plants which would reduce their efficiency and thus exacerbate any supply shortages and increase energy costs (Graham et al. 2008). However, no quantitative modelling studies of the impacts of future climate change on energy generation or the implications of an increased use of renewable energy sources on security of supply could be identified.

25.5.9.3. *Energy Transmission and Distribution*

Electricity transmission and distribution systems across Australasia are at increasing risk from changes in climate extremes (*very high confidence*), particularly high temperatures (leading to increased power line sagging and reduced ratings for lines and transformers), tropical cyclones and high winds (potential damages to pylons and short-circuits from overhead lines), and bush fire (ATSE 2008; Dubus 2011; Maunsell and CSIRO 2008; Michaelowa et al. 2011; Parsons Brinkerhoff 2009; Yates and Mendis 2009). Qualitative assessments for Australia assign high risk to distribution networks in all Australian states except Tasmania and ACT by 2031-2070 (Maunsell and CSIRO 2008), with increased bushfire risk in all regions, cyclone activity in tropical regions, and changes in the generation mix requiring significant upgrades to network infrastructure (Parsons Brinkerhoff 2009). Increases in peak power demand also results in increases in energy transmission losses, e.g. during the 3-day hot spell in January 2009, peak power demand increased to 2000 MW (24%) resulting in electrical losses increasing by 53% (Nguyen et al. 2010). However, future risks to transmission and distribution networks under climate change have not been quantified.

Adaptation options for the transmission and distribution system include increases in asset replacement programmes, vegetation management, insurance, and storm-strengthening new assets (Ebinger and Vergara 2011; Parsons Brinkerhoff 2009). The additional costs to Australia networks from climate related pressures have been estimated at A$2.5 billion over the next 5 years, with more than half of the cost to meet increasing demand for electricity for air conditioning and the remainder to maintain target performance levels against increasing risks (Parsons Brinkerhoff 2009). Towards the end of the 21st century, operating and capital costs have been estimated to increase by 10 to 20% under unmitigated climate change, but by less than 10% under stringent mitigation scenarios (Maunsell and CSIRO 2008). Underground cabling would reduce risk from and to bushfires but is hampered by large investment costs (not include in the above) and barriers arising from decentralised ownership of assets, lack of industry coordination but centrally set performance targets (ATSE 2008; Parsons Brinkerhoff 2009). For New Zealand, increasing temperatures and high winds are potentially the most relevant risk factors (Jollands et al. 2007; Renwick et al. 2009), but no quantified national or regional assessment of changes in risk or maintenance costs is available.

25.5.10. Tourism

Most tourism in Australian and New Zealand depends on the natural environment and is therefore exposed to climate change, e.g. higher temperatures and environmental change (Becken and Hay 2007) and climate variability (Becken et al. 2010), as those changes can affect both natural resources and create hazards for access and tourism participation (*high agreement, robust evidence*). Recent examples include: the warm 2006 winter ski season (0.86˚C warmer than average) saw a decline in skier days of 17.7% for Victorian skifields, and 10.6% for New South Wales fields (Pickering et al. 2010); the 2011 Queensland floods have been estimated to have cost the tourism industry about A$400 million (RBA 2011); flooding in the north of Australia in January 2009 resulted in the collapse of a large section of the Barkly Highway cutting off northern access between QLD and the NT for several weeks; and cyclone Monica (April 2006) and Tropical Low George (March 2007) both resulted in substantial flooding in the Kakadu region, including inundation of tourist accommodation (TNT 2009). In the Cairns region, severe bleaching (>60% of coral cover bleached) of some inshore reefs was observed in both 1998 and 2002 (Berkelmans et al. 2004) (see 25.5.1.4), however, given the patchiness of bleaching to date and recovery between events, reefs have remained attractive enough to tourism (Turton et al. 2009). Research on the impacts of drought on tourism in the Murray-Darling river system indicates that 20% of past visitors to the region reported that their travel was affected by drought, with 9% saying that they visited less often, shortened their stay (5%), spent less (5%), or would not visit in the future (2%). Economic modelling estimated that these changes resulted in a loss of A$70 million for 2008 alone

(Tourism Research Australia 2010). Tourism is also impacted upon by bushfires, such as the 2006/07 fires in Victoria that lead to decreased visitation and the perceived risk of a negative destination image (Sanders et al. 2008).

Future climatic changes and their relevance for tourism have been modelled for a number of sub-sectors. For the Australian Alps, the area with at least 30 days snow cover is projected to decrease by 14-54% by 2020 and by 30-93% by 2050 in the absence of additional snowmaking facilities, for a range of climate models and emission scenarios (Hennessy et al. 2008c). In New Zealand, maximum average snow depths (on 31 August) at a range of ski fields are projected to be reduced to 79-93% of the current maximum average by 2040, and to 54-80% by 2090, depending on elevation and location and for the A1B emissions scenario (Hendrikx and Hreinsson 2010). Under the warmer A1FI scenario, maximum average snow depths would be reduced further to 45-83% by 2040, and to 9-48% of the current maximum average by 2090 (Hendrikx and Hreinsson 2010).

In the Blue Mountains, Australia, (Lucas et al. 2007a) found that at Richmond the current annual-average number of very high and extreme fire weather days increased from 13.8 at present (1973-2005) to 13.8-16.3 by 2020 and 14.5-23.6 by 2050 for 2 different GCMs for the SRES range of emissions scenarios *[cross-check 25.3]*. Increased fire risk and frequency will restrict access for tourism and reduce visitation. Increasing temperatures in the Northern Territory are projected to increase heat stress of tourists and increase operational costs of accommodation providers due to higher air conditioning demands. The frequency of very hot days (above 35°C) in Darwin, for example, currently averages 11 per year, but this is projected to rise to 28 to 69 days per year by 2030 (mid emissions scenario) and 49 to 153 by 2070 (low emissions scenario) (CSIRO, 2007) *[cross-check 25.3]*. Long-term changes, such as sea level rise, have been discussed as additional pressures on coastal shorelines and tourist resorts (Buckley 2008).

There is *limited evidence* and *medium agreement* that climate change could impact on participation in tourism. For example, in years of poor snow condition, 69% of Australian skiers would ski less often, 5% would give up and 16% would ski overseas (Pickering et al. 2010). Further, limited evidence from the international literature suggests that tourist flows generally shift in preferred destinations to higher latitudes (Hein et al. 2009; Yu et al. 2009) and altitudes (Bigano et al. 2005). An attempt to model the impacts of climate change in Australian regions (including international changes in tourism demand) shows that, overall, the Alpine region is most affected; however, the study also highlight the difficulties in predicting tourist behaviour for many decades into the future (Pham et al. 2010). This research indicates that wider tourism flows effects need to be considered to assess regional vulnerabilities. Some destinations are believed to benefit from climate change; e.g. Margaret River in Western Australia is predicted to experience warmer temperatures and lower rainfall which would augment the attraction of the area's beaches and outdoor activities and the fact that hotter, drier conditions may make other parts of the state less attractive places (Jones et al. 2010). No comparable research on regional shifts within New Zealand is available, but historical analogues indicate that warmer and drier conditions generally benefit tourism, whereas more precipitation and increased extreme events tend to be detrimental. However, the high short-term variability of weather and climate in New Zealand means that tourists and tourism operators generally show less dependence on specific weather patterns for their activities (Becken et al. 2010).

Ski fields have been at the forefront of climate change adaptation (Bicknell and McManus 2006), most notably through their investment in snowmaking to compensate reduced snow availability. Using the NIWA snow model, (Hendrikx and Hreinsson 2010) predict that at the higher locations on each ski field by the 2090s in a worst case scenario (A1FI emissions scenario and worst year in 20), the average percentage of time suitable for snowmaking (between 1 May and 31 July) will range from 59% to 32% for different ski fields, relative to the average conditions at each field during the 1990s. Despite these reductions in natural snow and snowmaking opportunities, at all upper elevation sites, target levels of snow depth could still be realised, albeit only with additional snowmaking equipment. Snowmaking may be limited in some places in New Zealand and many places in Australia by water availability and snow-making costs. (Pickering and Buckley 2010) estimated that the investment costs for 700 snow guns required to maintain skiing conditions in Australia's six main resorts until at least 2020 would require A$100 million in capital investment, and 2500-3300 million litres of water per month (equivalent to about 50-70% of the total average monthly water consumption by Canberra; ABS 2006) .

Some tourist destinations are starting to prepare for increasing extreme events. Examples include crisis management templates (Tourism Queensland 2007), business toolkits (e.g. to cope with bushfires, Tourism Victoria 2010), and the demand for destination disaster response plans (Becken et al. 2011). While no dedicated scientific research on water efficiency in tourism exists, the Australian Government encourages water conservation in hotels (e.g. water fact sheet by Tourism Australia). Apart from those examples, for tourism in Australia, (Turton et al. 2010) report that the sector is not ready for investing into climate change adaptation due to perceived uncertainties of climatic changes, and a perceived lack of clarity about who is responsible to take leadership. This finding is confirmed by (Sanders et al. 2008) who noted the lack of forward planning by tourism operators despite obvious risks, such as bush fires, and by (Bicknell and McManus 2006) who found little concern amongst ski field operators about long term climate change. It is noteworthy, however, that the tourism sectors (at all levels) in Australia and New Zealand have become proactive in climate change mitigation to reduce energy costs and to manage consumer perceptions of low carbon footprints (Becken and Clapcott 2011; Zeppel and Beaumont 2011). This involvement could be a useful antecedent of future interest in climate change adaptation.

Impacts on tourism will also be affected by changing tourism flows between Australia and New Zealand. Comparative climate impact modelling and consumer research in relation to ski tourism are underway [*more results in next 6 months*]. Moreover, tourism activity in Australia and New Zealand can be influenced strongly by climatic events elsewhere in the world (e.g. the Northern hemisphere snowstorms in 2010 and 2011), and by other drivers of change such as increasing global oil prices (Becken 2011). Flow-on effects of climate change and responses outside the Australasian region are considered in 25.7.

Overall, the adaptive capacity of tourism (as a whole, rather than individual products or locations) appears and is believed by the tourism sector to be high, largely due to short investment horizons, substitutability of products (and to some extent destinations) and a high proportion of human capital compared with built assets (Wilson and Turton 2011). However, it is possible that tourists and individual tourism operators are more adaptive than the communities that collectively depend on tourism (Becken et al. 2010; UNWTO et al. 2008). At this stage, the predominant focus of imapcts and adaptation research has been on managing individual extreme events and associated health and safety, and access issues rather than long-term changes looking ahead for more than one decade. Further engagement with, and investment in adaptation measures has the potential to reduce tourism's vulnerability substantially *[need ref, this is not self-evident]*. However, due to the limited information on future behavioural drivers of tourism demand at many scales and its interaction with other climate-related stresses (such as potential increases in oil prices and attitudes of tourists to long-distance travel), we have only *medium confidence* in this overall assessments of vulnerability and adaptive capacity of the tourism sector as a whole in the Australasia region.

25.5.11. Human Health

25.5.11.1. Heat-Related Mortality: Susceptibility

Climate change is expected to result in substantial increases in extreme hot weather. Without climate change mitigation, the number of days over 35°C each year is projected to rise from 9 to 27 in Melbourne, 1 to 21 in Brisbane and most dramatically from 9 to 312 in Darwin by 2100 (Queensland Health 2004b). Thus heatwaves are projected to occur more frequently in the future, and to be more intense and longer lasting (Queensland University of Technology 2010). Weather projections for Adelaide, for example, suggest average summer temperatures will rise 0.4–1.3° C by 2030, and 0.8–4.0°C by 2070 (Suppiah et al. 2006) (Nitschke et al. 2007), while the average number of days per year above 35°C, currently 17, is projected to increase to 36 by 2070 under a median A1F1 scenario.

Bi et al. (2008) assessed the relationship between weather and mortality in the population in subtropical Brisbane. They found that in summer, a higher minimum temperature was associated with higher mortality in the elderly and those with cardiovascular disease. In winter, negative correlations were found between temperature and mortality for people with cardiovascular and respiratory diseases. Vaneckova et al. (2008) found that maximum temperature had a significant effect on mortality in temperate Sydney, with air pollutants (ozone and particulate matter) confounding the association. The observed change in mortality was estimated to be between 4.5% and 12.1% for a 10ºC increase in maximum daily temperature with air pollutants included in the model. When air pollutants were removed from the model, these mortality percentages changed by -1.1% to 0.9%. Tong et al. (2010) found a substantially increased number of deaths in the Brisbane heatwave of 2004, when the temperature ranged from 26°C to 42°C. There was a 23% increase in all deaths except injury and suicide, compared with those in the same (non-heatwave) periods of 2001-2003, when the temperature ranged from 22°C to 34°C.

25.5.11.2. Heat-Related Mortality: Projected Impacts

By 2100 the annual heat-related death rate in Australia for people aged over 65 is projected to increase from the 1999 baseline of 82 per 100,000 to 131 per 100,000 for a scenario of stabilising the CO2 concentration at 450 ppm, and 246 per 100,000 for a larger emissions scenario (resulting in a 3.8ºC warming by 2100 relative to 1990) (Woodruff et al. 2005).

Bambrick et al. (2008) found that temperature-related mortality and morbidity are highly variable, with different daily maximum temperature thresholds being estimated for different locations. Projected mortality varied widely over place, with climate change reducing temperature-related deaths and hospitalisations (due to fewer cold weather-related deaths) in some parts of Australia, but increasing them in others. Overall, total temperature-related deaths in Australia would change little until about 2070. The annual net increase for unmitigated climate change, relative to no climate change, would be an additional 1250 deaths in 2070 (+14%), rising to 8628 in 2100 (+100%). These increases are due almost entirely to the states of Queensland and Western Australia and the Northern Territory, with little change in the south-east of the country. Bambrick et al. 2008 considered change only in daily maximum temperature. In contrast, Gosling 2009 considered also increase in temperature variability, and estimated a 344% increase in heat-related deaths in Sydney in 2050.

25.5.11.3. Heat-Related Morbidity

Sub-lethal health impacts, measured by ambulance calls and hospitalisations, are also susceptible to extremes of heat. In Adelaide during a period of 13 years (1993-2006), the number of people requiring ambulance transport during heatwaves increased by 4% when compared with non-heatwave periods. A corresponding increase in total hospital admissions of 7% was observed during heatwaves (Nitschke et al. 2007). In one New South Wales study, the association between emergency hospital admissions due to heat-related injuries, dehydration and other disorders of fluid, electrolyte and acid–base balance, increased significantly during periods of extreme heat (Khalaj et al. 2010).

Accordingly, the annual number of temperature-related hospitalisations in South Australia under the A1FI scenario at 10th percentile rainfall and humidity, 90th percentile surface temperature is expected to increase by 110% by the year 2100 (Bambrick et al. 2008). Patients with renal disease, especially renal failure, are more susceptible to an extreme heat event (Nitschke et al. 2007); (Khalaj et al. 2010); (Hansen et al. 2008b). Nitschke et al. 2007 demonstrated that admissions for renal disease and acute renal failure were increased during heat waves compared with non-heat wave periods.

Nitschke et al. (2007) also observed an increase of 8% in admissions for ischaemic heart disease among people aged 65–74 years in heatwave conditions in their Adelaide study. In contrast, a decrease in admissions for cardiovascular conditions was seen among people aged 75 years and older in heatwaves. Total and age-group specific cardiovascular admissions did not increase. The authors postulated that the positive outcome could be due to the high prevalence of air-conditioning (82%) in Adelaide, and suggested factors such as good care of the elderly and social cohesion could also have contributed. Tong et al. (2010) found that the 2004 Brisbane heatwave increased cardiovascular deaths by 20% when compared with the same (non-heatwave) periods of 2001-2003. Loughnan et al. 2010 included socio-demographic and spatial information into analyses of admissions for acute myocardial infarction (AMI) and ambient temperature to present a more holistic picture of public health vulnerability to hot weather. They demonstrated a 10.8% increase in admissions for AMI on days exceeding a 30°C threshold in

Melbourne, and a 37.3% increase in admissions for AMI during short episodes of heat (defined as when the 3-day average temperature was ≥ 27°C).

The number of dangerously hot days, when outdoor work becomes impossible, is projected to increase substantially in Australia by 2070(Maloney and Forbes 2010). Most workers will self-pace to avoid physical exhaustion, but heat-related health risks will increase when work is "externally paced" (Hanna, Kjellstrom et al 2011).

25.5.11.4. Mental Health

Nicholls, Butler and Hanigan 2006 related the suicide rate in New SouthWales to annual precipitation,and found that a decrease in precipitation of about 300 mm would lead to an increase in the suicide rate of approximately 8%.

Total mental health admissions were shown to increase by 7.3% in metropolitan South Australia during heatwaves - the increased admission rate was observed across all age groups (Hansen et al. 2008a). A positive association between ambient temperature and hospital admissions for mental and behavioral disorders was observed above a threshold of 26.7°C. Mortalities attributed to mental and behavioral disorders increased during heat waves in the 65 to 74-year age group and in persons with schizophrenia, schizotypal, and delusional disorders. Dementia deaths increased in those up to 65 years of age in this study (Nitschke et al. 2007).
A survey of 4000 Australian farmers was completed in 2008 (Hogan *et al*. 2011). A substantial proportion (19%, called “Transitioners”) were under considerable pressure and reported low adaptive capacity. They reported the greatest levels of farm-related pressures, the lowest incomes and the fewest resources with which to adapt to the demands of climate change. They also reported the worst health.

25.5.11.5. Mosquito-Borne Diseases

25.5.11.5.1. Dengue

In Australia, the current and historical distribution of the principal vector of dengue, *Ae aegypti*, has been described by biophysical modelling of water availability and temperature in water containers. These authors concluded that: “...the inland and northern limits are set by water availability and egg desiccation resistance, and southern limits by adult and larval cold tolerance.” (Kearney, 2009). It has been suggested that while climate change will favour the spread of the vector in Australia, installation of large water tanks could potentially have a greater effect on the future geographic distribution (Kearney, 2009) (Beebe, 2009). In Australia, several dengue epidemics occurred as far south as Northern New South Wales in the past century. The contraction of dengue to Queensland since the 1950s may be related to removal of water storage tanks. There is evidence that, within Queensland, the geographic range of dengue has expanded in recent years (Hu, 2011).

For Australia, under unmitigated emission scenarios, the geographic region suitable for the transmission of dengue was projected to spread southwards, increasing the population at risk to approximately 5-8 million people by the year 2100. Mitigation scenarios led to a marked reduction in population at risk of less than 1 million people (Bambrick, 2008). These estimates were derived from a global empirical model (Hales, 2002) which did not account for the maximum historical extent of dengue in Australia and elsewhere (Russell, 2009). Subsequent work should incorporate historical spatial patterns of dengue over the past century (van Kleef, 2011).

25.5.11.5.2. Ross River virus, Barmah Forest virus

Ross River virus is the most widely reported arboviral disease in Australia (Tong, 2008). It is a also definite threat to New Zealand, given frequent travel between the two countries, and recent incursions of exotic mosquito species (Derraik, 2006). The effects of global climate change on Ross River virus and related arboviruses such as Barmah Forest virus are not yet clear.

25.5.11.5.3. Malaria

Malaria is a potential threat to Australia, but is currently limited by low vector populations and effective clinical treatment rather than climate factors (Harley, 2011). Empirical models of the global geographic distribution of malaria can nevertheless be useful in estimating the potential impact of climate change on malaria. A recent model accounts for the historical limits of the disease, the effect of climatic and of social factors on the contraction of malaria in the past century (Beguin, 2011). Australia and New Zealand were projected to remain malaria free under a range of climate models using the SRES A1B climate change scenario for the years 2030 and 2050.

[*considering whether to cover seasonality of mosquito-borne diseases*]

25.5.11.6. Food-Borne Disease: Salmonella, Campylobacter

Bacterial causes of gastroenteritis, especially salmonella, are sensitive to temperature (Kovats et al, 2004) (Hall, Hanigan et al 2011) (Britton, 2010a) and are projected to increase as a result of climate change (Harley et al., 2011). Certain viral causes of diarrhoea, especially rotavirus, are more commonly reported in winter and may become less frequent as a result of higher temperatures (D'Souza, 2008) (Harley et al 2011). Water borne causes of gastroenteritis such as cryptosporidiosis have more complex relationships with climate, and may be affected in particular by heavy rainfall or flooding (Britton, 2010b).

For Australia, the Garnaut Review of climate change projected 205,000 - 335,000 new cases of bacterial gastroenteritis by 2050, and 239,000 and 870,000 cases by 2100, under a range of emission scenarios (Bambrick et al. 2008).

[*note: significant gaps in current draft regarding NZ material*]

25.5.12. Livelihoods, Immigration, and Security

25.5.12.1. Livelihoods

[*consider deleting entire livelihoods discussion as this is likely to be captured more effectively within sectoral sections, and in particular the rural section*]

In Australia and New Zealand, as elsewhere, those households whose livelihoods depend heavily on climate sensitive natural resources are most at risk from climate change (see Chapter 13).

The viability of livelihoods based on freshwater fisheries are at risk from both the effects of climate on flows, and from changing land uses on water quality (Ling 2010). Livelihoods dependent on oceanic and inshore fisheries are also at risk from changes in the abundance and distribution of species due to changes in oceanic currents and reef habitats in conjunction with fishing pressures (Last et al. 2011).

In forestry, further declines in clearing from native forests is likely due to policy decisions and not climate change, but the water-intensive nature of plantation forestry coupled with competition over land use mean that climate change may impinge on incomes based on plantation forestry in some areas (Stewart et al. 2011a). Offsetting these potential climate impacts on forestry are the opportunities afforded to the sector from climate change mitigation policies (Garnaut 2011) [*NZ ref*].

Research on the vulnerability of farming and grazing enterprises shows that vulnerability is unevenly distributed across rural areas. In the Murray-Darling basin, vulnerability is most acute in rural enterprises located in areas with limited population, and which rely on irrigation (Alston 2011). For many of these households, the prolonged drought in south-eastern Australia lead to: increasing poverty among farming families and farm workers, farm closures, increasing off-farm income and hence involuntary separation of families, increasing social isolation among men and rising stress levels and associated health impacts, accelerated decline of rural populations, delayed retirement plans, and in some cases suicide (especially of male farmers) (Alston 2010; Alston 2011).

Differences in the vulnerability of rural livelihoods are influenced strongly by differences in adaptive capacity (Nelson et al. 2009). Many farmers in eastern regions in New Zealand display a high degree of resilience to climate variability and are adapting proactively (Kenny 2011a). For these farmers, as with graziers in the upper Burdekin region in Queensland, knowledge is central to resilience, including the use of climate forecasts and information about longer terms changes in climate (Marshall 2009). Livelihood resilience is also a function of farmers' beliefs in their capacity to adapt, and their financial security, local knowledge, environmental awareness and strategic skills (Kenny 2011a; Marshall 2009; Marshall et al. 2010a). The implications of these differential levels of risk to rural livelihoods for the future of rural communities remains poorly understood. Based on evidence to date, for some industries in some locations climate change poses few risks and indeed may increase competitiveness, whereas for others climate change threatens the viability of rural enterprises and the communities they support (Bi and Parton 2008; Howden et al. 2009; Howden et al. 2008).

People whose livelihoods depend on tourism may also be vulnerable to climate change (Becken et al. 2010). Climate change will mean snow and snow making are no longer possible in low-lying alpine resorts in Australia (Pickering and Buckley 2010). Adaptation options for these resorts include diversifying into property development and summer tourism, but the implications of these changes for employment, and nearby towns that currently depend on ski tourism for income, are not yet clear (Pickering and Buckley 2010). Similarly tourism operations dependent on reef-based tourism may also be at risk, although resilience can be enhanced by investments in human capital, and some losses to livelihoods may be tolerated by those entrepreneurs who value their lifestyle as well as profitability (Biggs 2011) [*ref to come Becken on Queenstown resilience*].

25.5.12.2. Migration and Security

There is no evidence to date that climate induced changes to date are driving internal migration in Australia or New Zealand, although drought-induced farm closures imply some movement away from farms to larger settlements. However, such movements are likely to be a very small part of the larger migration process from inland to coastal areas in Australia, which has seen the population of non-metropolitan coastal areas rise while the population of inland and rural Australia falls (Gurran 2008). All of Australia's and most of New Zealand's major cities are all located on the coast, and this trend of population concentration in the coastal margin is expected to increase for some decades yet (DCC 2009; Freeman and Cheyne 2008; Mendham and Curtis 2010).

There is no evidence that climate change to date is increasing international migration to Australia or New Zealand, although there is much that has been written about this possibility in the future (Hugo 2010; McAdam 2010; Mortreux and Barnett 2009). Similarly, there is no evidence that climate change is a factor in migration between Australia and New Zealand, which is largely driven by New Zealanders seeking access to what they perceive to be Australia's better labour markets, even though the perception of a more attractive climate also plays a significant role (Green et al. 2008a).

It has been postulated that increased migration caused by climate change is a key mechanism by which climate change may increase the risk of violent conflict, especially civil conflicts within developing countries (Barnett 2003; Pearman 2009; Reuveny 2007). However this is a hypothetical connection that has minimal empirical evidence to support it. There is inadequate evidence to say with confidence that climate change is now causing migration or violent conflict within Australia or New Zealand, or within any countries within East Asia and the Pacific. The regional security outlook for the region is not expected to change in the immediate future due to climate change (Dupont 2008). However, there is *high agreement and medium evidence* increasing problems associated with disasters, disease, and border control may entail an increase in operations other than war for the region's armed forces (Bergin and Townsend 2007; Dupont 2008; Rolfe 2009; Sinclair 2008), and that integration of security considerations into adaptation and development assistance can play a key role in moderating the influence of climate change on forced migration and conflict in south-west Pacific (Barnett 2009; Rolfe 2009; Sinclair 2008).

25.5.13. Indigenous Matters

[*Note: material from Australia and New Zealand will be combined; NZ material consists only of bullet point thoughts at this stage.*]

25.5.13.1. Australia

Regional climate impact assessments and climate projection work have been recently published in peer-reviewed literature. Such work includes projections for the Torres Strait (Suppiah 2010, Green 2010) and the Kakadu region (Winderlich 2010). These regional studies are very valuable to the Indigenous communities in them because they enable locally specific adaptation responses to be tailored to the projected impacts. Suppiah (2010) and Green (2010) both highlight the urgent need to address the already known impacts from inevitable increases in storm surges on coastal villages, whilst simultaneously carrying out further research to increase the accuracy of climate projections. The co-authored assessment (Winderlich 2010) identifies the concerns surrounding saltwater intrusion on freshwater floodplains, the impacts on bush food, and the change in hunting strategies caused by different patterns of animal behaviour, as amongst some of the top priorities of Kakadu's Traditional Owners in relation to a changing climate.

In 2009, the federal government commissioned research on the risks from climate impacts to Indigenous communities in northern Australia (DCCEE 2010). This report highlighted how much remained unknown about the likely impacts on these communities, and therefore included recommendations to immediately and directly engage with affected communities to find out their priorities and concerns; and to set up a clearinghouse of regional-level information about climate change, and what adaptation strategies might be appropriate for Indigenous communities to undertake. This report also highlighted the need to avoid top-down policy that does not directly respond to a specific community's needs, as has often occurred previously in remote communities in other areas of policy, and which has frequently resulted in unfavourable outcomes for them (Petheram 2011). The sectoral breakdown of impacts in the DCCEE (2009) report identifies the elevated health risks for already vulnerable individuals (specifically the elderly and young and those with existing chronic conditions), and additional strains on already stressed transport and communications infrastructure in remote areas of the country. Another significant impact detailed in this report, and further illustrated through the use of case study material, is that on psycho-social health – that is how climate impacts on environmental systems are likely to have negative repercussions on the mental and physical well-being of Indigenous people due to the strong links between natural and human systems in their culture. This concept is discussed further in Green (2009) who comment on the 'conceptual divide' between different perceptions of individual and community health in Indigenous and non-Indigenous communities, and consequently the need to respond appropriately to them.

Other authors have explored the impacts of climate change on the psycho-social health of Indigenous Australians (Hunter 2009, Bambrick 2008, Fritze 2008). Hunter (2009) finds that anthropogenic climate change presents a different set of factors to those Indigenous people have previously contended with, and that in the short term, social and economic factors are likely to significantly mediate its impacts. Although Fritze (2008) does not focus explicitly on Indigenous communities, these authors share Hunter's findings in respect to extreme weather events having significant impacts on the mental health of already vulnerable groups. Petheram (2011) is one of the few published studies that directly engages with an Indigenous community to attempt to understand their priorities and concerns. Although their findings indicate that climate change is a concern, it is the associated indirect impacts on already pressing social and economic problems that are prioritised by these communities for adaptation planning. The issues raised by Hunter (2009), Green (2009) and Fritze (2008) are supported by the Petheram case study, and further backed-up by the wealth of work on how best to tackle Indigenous disadvantage using a broad-based 'hybrid economy' approach (Altman 2007).

There has been a significant amount of research on the direct health impacts from temperature extremes in Australia and their implications for public health (see, for example, Bi 2011). This study highlights the disproportionate impacts amongst already vulnerable groups (therefore echoing the concerns raised earlier by Bi (2008)). The impacts on some specific diseases have also been considered, with Russell (2009) identifying that with a changing climate, the secondary dengue vector currently responsible for several outbreaks in the Torres Strait might become established on the Queensland mainland.

In the wake of federal policy to develop an emissions trading scheme, one opportunity to provide jobs on country, strengthen culture and provide financial resources has arisen. The use of controlled burning regimes by Indigenous rangers was initiated in West Arnhem Land by a multinational in 2006 (Whitehead 2008). Traditional land management activities, such as re-engagement of low temperature, mosaic burning are slowing being recognised by non-Indigenous policy-makers as having multiple co-benefits. Other forms of Indigenous knowledge about weather and climate have been further documented by the Bureau of Meteorology (IWK 2011) as well as directly by communities themselves (Mirima 2011). The value of this local phenological knowledge is being documented and considered as a valuable addition to current environmental management techniques (Prober 2011, Green 2010).

The impacts caused by climate change on urban Indigenous communities have not been documented to date. Studies of vulnerable urban sectors would suggest that the issues of energy poverty and chronic health impacts are likely to feature significantly in this demographic, although at this point, specific case studies have not been made documented.

25.5.13.2. New Zealand

Maori society: climate exposure and sensitivity

- Primary industries
- Infrastructure and water resources
- Settlements and coastal communities

Direct and indirect climate change risks and impacts

- Climate extremes/hazards
- Primary industries
- Infrastructure and water resources
- Settlements and coastal communities
- Carbon markets and fuel poverty

Climate change opportunities

- Diversification of agriculture
- Carbon farming
- Renewable energy
- Sustainable development

Impediments to implementation of adaptation plans/policies

- Institutional structures
- Information and experience
- Sub-standard infrastructure
- Resources and technology
- Political representation/participation
- Remote and marginal lands
- Competing human-environment values

Social-cultural resilience to climate change risks and impacts

- Social-cultural values
- Customary process and environmental knowledge
- Ecological integrity and human well-being
- Long-term perspectives on place and people

Knowledge and information gaps

- Sensitivity and adaptive capacity in urban and city areas
- Solutions/options for highly vulnerable communities and land-based businesses
- Land-tenure in facilitating climate change opportunities
- Legal rights under the Treaty of Waitangi

25.6. Adaptation Decisionmaking Frameworks: Scale, Effectiveness, Opportunities, and Barriers

25.6.1. Cross-Sectoral Impacts and Vulnerability to Climate Change at National and Regional Scales

[*need to consider placement and framing of this information; keep here for the time being]*

Evidence of cross-sectoral economic impacts of climate change on Australasia is limited. One comprehensive study found that unmitigated climate change would result in substantial net negative impacts on Australia's economy and welfare. Based on modelled and assumed market costs of climate change impacts, real GNP is projected to be lowered in 2050 by between 1.8 and 2.3%, and in 2100 by between 1.3% and 7.6% under scenarios ranging from stringent mitigation to unmitigated emissions growth, relative to a world without climate change. This assessment includes the flow-on effects of a limited range of assumed climate change impacts in other world regions, but is restricted to selected economic sectors, and excludes non-market impacts as well as the risk of catastrophic impacts (Garnaut 2008c).

Model studies of the economic consequences of climate change remain highly uncertain and strongly depend on assumptions about valuation of non-market impacts and the treatment of the risk of catastrophic climate change, autonomous responses of key sectors to climate change and changing international linkages (Garnaut 2008c). Some geographic regions and economic activities are at particular risk of decline, for example it has been projected that the value of irrigated agriculture in the Murray-Darling basin, one of Australia's main agricultural areas, could decline by 92% or more under a no-mitigation case (Garnaut 2008, Table 6.4). An assessment of the impact of variation in agricultural sector response to climate change found that, in 2050, changes in wheat self sufficiency in Australia could range from a 30% increase to a 9% decline, and export availability could range from a 4% increase to a 2% decline [*check relative to what*] under alternative assumptions (Scealy et al. 2011). Alternative assumptions regarding climate-driven changes in crop productivity result in changes to the value of agricultural exports in 2030 from a 10.5% rise to 0.8% decline in Australia and from an 11.2% rise to 3.8% decline in New Zealand, relative to 2004 levels (Valenzuela and Anderson 2011). Another recent study found significantly greater changes, with reductions in Gross Cell Product (GCP) across Australia and New Zealand of -34% under a high emissions scenario and a single climate model by 2060 (Seo 2011); however, the reliance of this study on current spatial correlations between climate and economic productivity to predict impacts of future climate change strongly limits confidence in its conclusions.

[add post-ZOD relevant statements in other metrics where available (number or percentage of species at risk; number of people at risk; anything else in terms of big picture numbers across sectors.]

The potentially significant economy-wide impacts and threats to agricultural production and ecosystems in some sub-regions of Australia provide *limited evidence* and *medium agreement* that Australia is the developed country most vulnerable to climate change (Eriksen and Kelly 2007; Garnaut 2011; Palutikof 2010; Seo 2011). However, studies that quantify cross-sectoral impacts through other numerators proposed in the literature (Schneider et al. 2007) are virtually absent for the region, and no rigorous intercomparison of projected economic impacts or other key vulnerabilities has been undertaken with that of other regions. Hence confidence in comparative and absolute assessments of Australian economy-wide costs or vulnerability at national level remains *low*. No national-level economic impact or vulnerability assessments exist for New Zealand.

25.6.2. Cognitive and Socio-Cultural Factors Affecting Vulnerability and Adaptive Capacity

Psychological, social and cultural factors influence perceptions of climate change risks and response options, the valuation of non-monetary climate change effects, and can pose barriers to but also present opportunities for adaptation (Adger et al. 2009; Adger and Barnett 2009; APS 2010; Berrang-Ford et al. 2011; Breakwell 2010; Swim et al. 2009) [*AR5 refs*]. An emerging body of literature since the AR4 provides insights on these issues from Australasia.

26.6.2.1. Psychological and Social Determinants of Climate Change Risk Perceptions

Proactive adaptation to climate change is contingent on acceptance of a human influence on the global climate system and future projections of potential changes [*WGI AR5 refs*]. Recent surveys in Australia and New Zealand show that acceptance of the reality of climate change is uneven across society. There is *high agreement and robust evidence* that beliefs about the reality and causes of climate change are related to political preferences and gender (Leviston et al. 2011; Milfont submitted; ShapeNZ 2009), although actual voting behaviour in the context of climate change may be meditated further by parental status (Milfont et al. in press-b). Australians perceive themselves to be at significant risk from climate change compared to the 'spatial optimism' observed in New Zealand and many other countries, which may reflect recent climatic extremes with negative impacts on Australia and their perceived association with climate change (Agho et al. 2010; Ashworth et al. 2011; Gifford et al. 2009; Milfont et al. in press-a; Reser et al. 2011). Significant differences in risk perceptions with regard to cyclone risks in Darwin were also found to be related to residence times and expert knowledge (Li 2009). [*anything else in that category of social or psychological factors that influence risk perception – needs to be linked to factors relevant under climate change?*] Such differential concerns about climate change, associated risks and response efficacy are expected with *very high confidence* to influence the willingness of communities to implement proactive adaptation to climate change (Ashworth et al. 2011; Gifford 2011; Reser submitted; Reser and Swim 2011; Swim et al. 2009). However, place-based studies to quantify the influence of such factors on actual adaptation preferences and proactive adaptation responses at community level in Australasia are still lacking.

[*Are there studies from Australia or NZ that link community-level preferences for specific adaptation responses to community-level determinants such as social norms, social and cultural capital, etc?*]

26.6.2.2. Socio-Cultural Values Affecting Vulnerability and Adaptation Options

Psychological impacts of climate change (25.5.3.1) can affect risk perceptions, coping and adaptive capacity (Reser and Bentrupperbäumer 2001; Reser and Morrissey 2008, 2009). An emerging international literature also considers the importance of social and cultural values assigned to places and objects at risk to identify vulnerabilities and understand what adaptation outcomes would be considered as successful by affected communities (Adger and Barnett 2009; Adger et al. 2011; Doria et al. 2009). In Australia, research has focused on the value placed on rapidly disappearing winter snow cover (Gorman-Murray 2008, 2010), conflicts between environmental management and human uses of changing national park landscapes (Roman et al. 2010; Wyborn 2009), and non-economic values associated with water in rural communities (Alston 2010; Hurlimann and Dolnicar in press). These studies provide as yet *limited evidence* but *high agreement* that projected climate change impacts constitute significant losses to some parts of society, including gender differences, even if they are difficult to quantify in monetary terms and are not used in economic and quantitative risk analyses.

Individual and collective social and cultural values can also limit public support for and implementation of adaptation options compared to the range considered in theoretical analyses (*high agreement, robust evidence*). Key constraints have been identified mainly in the form of place attachment limiting the option of managed retreat from sea level rise (Agyeman et al. 2009; Hayward 2008a; King et al. 2010; Reisinger et al. in press 2012), and socio-economic factors and cultural values that limit acceptance of water recycling or pricing (Hurlimann and Dolnicar 2010; Hurlimann et al. 2008; Kouvelis et al. 2010; Kviberg 2008; Mankad and Tapsuwan 2011; Miller and Buys 2008; Pearce et al. 2007), including trade-offs between alternative adaptation responses (Hurlimann and Dolnicar in press). On the other hand, place attachment can also offer co-benefits between adaptation responses and general improvements to mental well-being (Berry et al. 2010).

25.6.3. Adaptation Frameworks, Institutions, and Policies: Effectiveness and Barriers

The AR4 found that Australia and New Zealand have high and growing levels of adaptive capacity, but that formidable environmental, economic, informational, social, attitudinal and political barriers to the implementation of adaptation remain (Hennessy et al. 2007). Developments since the AR4 allow us to provide more detail but also to qualify those conclusions.

A generic goal of adaptation policy is to mainstream climate change responses into broader sectoral management strategies (Adger et al. 2007; Dovers 2009) [*AR5 ref*]. If and where such mainstreaming is successful, this makes it problematic to identify and assess the effectiveness of specific climate change responses within decision-making frameworks that respond to multiple objectives and pressures. Adaptation to climate change has been incorporated explicitly in several recent policy reform processes in Australia, particularly in responses to persistent drought, water reform in rural and urban systems, and coastal management, which represent a combination of slow and rapid-onset challenges all of which are expected to worsen under future climate change projections. Compared to Australia, there has been notably less explicit attention by central government in New Zealand to the proactive integration of climate change into water management issues. Peer reviewed material on adaptation in these sectors – at least that which deals with policy action rather than general prescriptions for policy reform – is largely to be found in *outside* of the climate change literature. This suggests that the proposed mainstreaming or ‘normalization’ of adaptation is indeed occurring, at least to some extent, more than the climate change literature might suggest (Dovers 2009).

We first review evidence from literature that investigates adaptation from a dedicated climate change perspective, and then consider evidence of the effectiveness of and barriers to mainstreamed adaptation policies and institutional arrangements in the areas of water resource management and coastal development.

25.6.3.1.Institutions, Governance, and Policy Frameworks Directed at Adaptation

Australia has a three-tiered system of government comprising federal, state and local levels. Australian governments at all levels have made significant new investments since the AR4 into policy frameworks, provision of information, and enhancement of research capacity for adaptation. In 2007, the Council of Australian Governments agreed a joint adaptation framework (COAG 2007), which established the National Climate Change Adaptation Research Facility (NCCARF) and its eight sectoral Adaptation Research Networks, designed to address problems relating to adaptation and bridge the gap between science and policy complemented by the Climate Adaptation Flagship research program (CSIRO). A federal position paper on adaptation policy was released in 2009 (DCC 2010a), which set out the role of various levels of government, business and communities with regard to adaptation in Australia. Policies for adaptation are largely set at the state level, with implementation at local government level. Adaptation measures at state and local government level include regionally and locally relevant research into impacts and adaptation options, as well as new modeling and mapping, via government and academic collaborations. Federal government seeks to provide high-level direction and regional integration, including e.g. through funding a national-scale coastal risk assessment (DCC 2009) and supporting local government adaptation projects that apply a consistent risk management framework (AGO 2006).

New Zealand has largely continued with the approach and institutional responsibilities for adaptation in place during the AR4. Responsibility for managing natural hazards and resources is devolved almost entirely to local government, with central government providing guidance on decision-making within existing regulatory functions and responsibilities and supporting underpinning research (MAF 2007; Reisinger et al. 2011; Rive and Weeks in press). Consideration of climate change effects has been mandatory under the Resource Management Act since 2004 (NZ 2008). A sequential risk-management is recommended to assess impacts and response options, with quantitative information updated in 2008 based on AR4 results (MfE 2008f, e), together with guidance on tools for flood risk assessment (MfE 2010c) and integration of climate change into existing wider local government roles and planning frameworks (MfE 2008d). This guidance is non-binding.

Until recently, much of the available analysis of climate change decision-making, institutional arrangements and governance frameworks in Australia and New Zealand focused on mitigation (e.g. Greenaway and Carswell 2009; Griffiths et al. 2007). In Australia, comprehensive reviews of adaptation responses found a significant increase in the number of state and local-level adaptation plans and strategies with a strong effort in institutional capacity building, but weaknesses in how strategic goals are linked to practice and implementation (Measham et al. 2011; Preston et al. 2011). An emerging literature in Australia also critiques vulnerability assessments and adaptation planning for giving insufficient consideration to uncertainties and the complexity of evolving socio-ecological systems (Kennedy et al. 2010), and advocate greater use of adaptive management and real options to manage dynamic change (Dobes 2010; Hertzler 2007; Nelson et al. 2008).

Peer-reviewed evidence of the effectiveness of and barriers to adaptation in New Zealand remains limited, but reports and submissions from local government offer additional consistent insights. Together, these studies give *high agreement and much evidence* that the lack of binding guidance on climate change impacts and adaptation assessments together with resource limitations presents significant challenges to local government in New Zealand, as small councils with limited resources struggle to balance long-term community interests against vocal and short-term special interests (Glavovic et al. 2010; LGNZ 2007, 2008; Reisinger et al. in press 2012; Reisinger et al. 2011; Rive and Weeks in press).

Barriers to community-level adaptation identified across Australasia include (Abel et al. 2011; Blackett et al. 2010a; DCC 2010b; Dobes 2010; Dovers and Hezri 2010; Glavovic et al. 2010; Measham et al. 2011; Memon et al. 2010; Memon and Skelton 2007; Parliament of Australia 2009; Preston and Kay 2010; Preston and Stafford-Smith 2009; Preston et al. 2011; Preston and Jones 2008; Reisinger et al. 2011; Ross and Dovers 2008; Rouse and Norton 2010; Smith et al. 2008b; Tryhorn and Lynch 2010; Weber et al. 2011):

- Vocal scepticism with regard to climate change in some communities and domination of some local governments by special interest groups
- Lack of attention by planners to individuals' preferences and priorities
- Lack of or uncertainty in quantitative projections of future climate change, coupled with lack of institutional capacity to deal with complex and uncertain information in an often adversarial context
- Insufficient local level leadership and embedding of environmental policy integration
- Legal challenges about quantitative information, planning time horizons and entitlements
- Financial resource constraints for smaller councils
- Insufficient understanding and consideration of socio-economic drivers and trends, particularly within rapidly expanding coastal communities
- Inconsistency between national, regional and district levels of government, coupled with limited articulation of criteria and rankings for cost-benefit analyses and interpretation and weighting of underpinning principles and concepts such as sustainability

Collectively, these studies from Australia and New Zealand provide *high agreement* and *much evidence* that even though adaptive capacity to climate change in Australasia is high in general, its effective application at the community level remains more limited chiefly due to constraints in financial resources, social and institutional capital, limited vertical and horizontal integration of governance, and non-transparent and poorly articulated principles for reconciling long-term sustainability objectives and differing community values with near-term development pressures.

Recent studies provide suggestions and experience for how those barriers could be overcome with time. Key mechanisms include, with *very high confidence*, the building of more durable institutional processes across multiple scales and incorporating network, hierarchical and market governance approaches, and enhanced emphasis on community engagement through structured and deliberative participatory processes to reveal and reflect social preferences and avoid a purely science-driven decision-making paradigm (Hobson and Niemeyer in press; Larson 2010; Lennox et al. 2011; Mitchell et al. 2010a; Nelson et al. 2008; Ostrom 2010; Reisinger and Larsen 2010; Reisinger et al. in press 2012; van de Meene et al. in press; Weber et al. 2011). National-level support through a consistent information base for risk assessments, strong guidelines that reduce uncertainty and adversarial processes about scientific evidence and governing principles at the community level, and through support for adaptation research, would further contribute to a gradual reduction of these barriers and reduce the risk of local decisions being overly influenced by special interests (*very high confidence*) (Brown et al. 2009b; Frame 2008; Leitch and Robinson in press; Norman 2009; Preston and Kay 2010; Rive and Weeks in press; Rouse and Norton 2010; Smith et al. 2008b; Smith et al. 2010).

25.6.3.2.Mainstreamed Climate Risk Management in the [Australian] Water Sector

[N*ote: current draft is on Australia only. This is justified for rural water management, but there is a lot of useful literature on water management in NZ, from a governance/institutional/stakeholder engagement perspective for rural water use and allocation, and some work (in progress) on studies and policies to manage urban water supply and demand. Consider extending this section to cover water management in both Aus and NZ. Also considering to condense the generic discussion on water across Australia and NZ and provide a case-study box for the Murray-Darling Basin, or Melbourne, specifically*.]

25.6.3.2.1 Drought management and rural water reform

Drought has been a long-standing issue in Australia that is now considered explicitly in the light of climate change. Removal of drought responses from the area of ‘disaster’ policy in 1992 towards greater self-reliance signals the early ‘mainstreaming’ of climate change into risk management and allowing long-term adaptation responses (Botterill and Wilhite 2005) [*add ref Botterill and Dovers forthcoming*]. However, implementation of this concept has been retarded by alternating complacency and crises with the occasional resurrection of ‘exceptional circumstances’ that create difficulties in applying consistent levels and types of government support to affected businesses and communities (Nelson et al. 2008).

The Murray-Darling Basin (about 1 million km^2) accounts for more than 50% of Australia’s irrigated agriculture and is home to one world heritage site and 16 Ramsar wetlands. The drivers for change in the Basin are decades of over-allocation of water, the prolonged drought and climate change and other risks to water supply (examples include increased bushfire risk and interception activities like farm dams and forestry plantations).

South-eastern Australia was in a prolonged drought from 1997 to 2009 with unprecedented low river flows (Chiew et al. 2011; CSIRO 2010; Potter et al. 2010b). During the 13-year period, inflows into the reservoirs supplying the Murray-Darling Basin (Figure 25-11) and the city of Melbourne (Tan et al. 2010) were less than 50% and 40% respectively than the long-term average. Several studies have attributed the persistent dry conditions at least in part to climate change (CSIRO 2010; Murphy and Timbal 2008b) which may be linked to the rainfall and runoff declines in far south-west Australia which occurred since the mid-1970s (Bates et al. 2010; Bates et al. 2008; Hope et al. 2010). Projections from the majority of climate models also indicate a drier future on average in south-eastern Australia, particularly in winter when most of the runoff in southern Murray-Darling Basin and Victoria occurs (see 25.3).

[INSERT FIGURE 25-11 HERE
Figure 25-11: Annual series of total inflow into the Murray River showing the high inter-annual and inter-decadal variability and the low inflow over 1997-2009. (Source: Murray-Darling Basin Authority)]

The management of scarcity and variability in the Murray Darling Basin, Australia’s largest and most economically significant river basin, has been a subject of policy debate and reform for over a century (Connell 2007). Recent and major policy reform via and following the 2004 National Water Initiative (Hussey and Dovers 2007) has explicitly taken into account future climate change projections as a major influence, and address adaptation. The Murray-Darling Basin Authority was established in 2008 to develop and administer the first Basin Plan where the Commonwealth government sets the water sharing arrangement and the four state and territory governments develop water management plans to implement this. The Plan commenced in 2012 and will return an average of 3000 GL/yr to the environment, providing a more equitable sharing of water between irrigation and environment under current and future climates. More than AUD$10billion will be spent to obtain the 3000 GL/yr (25% of the current irrigation water use) through buybacks of water entitlements, upgrades of irrigation infrastructure and improved irrigation efficiency. In addition, the Basin Plan will also develop an efficient water-trading market including trading on behalf of the environment.

The policy reforms comprise an interdependent mix of strategies:

- Institutional and legislative change, including a National Water Commission (with an evaluation role), a reformed and independent Murray Darling Basin Authority, and new national water legislation.
- Limits to extractive use, defined by environmental sustainability.
- Improved water information and accounting systems.
- Statutorily based water plans for all regions.
- Nationally consistent water markets, making widespread trade of water entitlements possible.

The NWI constitutes a major institutional reform that, if fully implemented, would significantly enhance adaptive capacity to climate change and may equal best practice in adaptation to climate change in a relevant sector (Hussey and Dovers 2007; Schofield 2011). Progress has been critiqued in some detail and the overall efficacy of the approach remains untested (Byron 2011; Connell 2007; Grafton and Hussey 2007; NWC 2009; Pittock and Finlayson 2011a; Pittock and Finlayson 2011b; Wei et al. in press). Water markets offering flexibility in use and adaptation to changing circumstances have been established in many water systems and the volume and number of trades have increased [*refs*]. Statutory water plans have been slower to develop than planned, but are being developed [*refs*]. The total limit on diversions, however, has yet to be agreed following significant public and political contest and further integration of climate change projections (Crase 2011; Schofield 2011).

The principal factors influencing the more successful and less successful (thus far) elements of this policy reform vary. Intergovernmental and *political agreement* and leadership overall has been crucial, and especially to the creation of long term (2004-14) agenda of a *comprehensive framework policy*. Common to any policy reform agenda, *sufficient, reliable information* to inform policy decisions, and to support communication of such decisions, is also crucial. The well-studied status of the MDB has enabled much policy to be implemented, and plans to be well-informed, however the perceived lack of information in the draft Basin Plan documents regarding socio-economic impacts has proved politically difficult. [*need references to back up this para and establish the level of confidence in these statements, and/or ascertain level of agreement in the literature on these points*]

25.6.3.2.2 Urban water reform

There has been significant water resources adaptation and planning in response to the prolonged drought, likely drier conditions under climate change, and other drivers. Most jurisdictions in Australia, from catchment management authorities to states and territories, have developed water resources adaptation strategy in response to climate change. In Melbourne, the 2004 Victorian Government White Paper (DSE 2004) included an action that required all water authorities to prepare water supply and demand strategies based on an assessment of the various risks including climate change. The 2005 Melbourne Water Climate Change Study (Howe et al. 2005a) projected a 35% streamflow reduction by 2030 under the high climate change scenario. However, the need to adapt to changing climate patterns became an urgent reality in 2006 with very low reservoir storage levels following the protracted dry period since 1997, and accelerated the changes that were starting to occur.

Water resources planning and climate change adaptation in Melbourne (DSE 2007; MelbourneWater 2010) centred around securing new water supplies that are resilient to major climate shocks, implementing conservation programs to reduce demand and embarking on integrated water management and water sensitivity city planning with increased use of alternative water sources such as sewage recycling, stormwater reuse, groundwater use and rainwater harvesting (Skinner 2010). To secure water supply under a changing climate and to meet the growing demand with projected population increase from 4 million in 2010 to 7 million in 2050 (DSE 2008), Melbourne has since reconnected the Tarago Reservoir supplying about 15 GL/year and embarked on two major projects. The first was a desalinisation plant capable of supplying up to 150 GL/yr (about one third of current demand), completed in 2011 at a cost of $AUD3.5 billion. Melbourne is the fourth major city in Australia with a desalinisation plant – the first was completed in late 2006 in Perth in south-west Australia to cope with the decline in inflows since the mid 1970s, followed by the Kurnell Plant in Sydney and the Tugan Plant in south-east Queensland (WSAA 2010). The second project was a major AUD$1billion upgrade of irrigation infrastructure in northern Victoria returning one-third of the water savings (up to 75 GL/yr) to Melbourne via a 70 km Sugarloaf pipeline completed in 2010.

Several programs were also implemented to recycle 20 percent of Melbourne's wastewater to provide fit for purpose water. The extensive residential and industry water conservation programs (residential programs include water smart gardens, dual flush toilet, grey water system, rainwater tank rebate scheme and free water-efficient showerhead replacement) and permanent water savings rules and water restrictions which started in the early 2000s and a voluntary residential water use target program (Target 155) (Fitzgerald 2009) have also reduced total per capita water use by 40%. Melbourne's integrated planning considers supply and demand, as well as climate change impact on flooding risks and urban stormwater and wastewater infrastructures. Adaptations include retaining floodplains and floodways, adapting existing systems to attenuate flows and water sensitive design in new developments. Melbourne therefore serves as a real time case study for climate change adaptation.

The 'success' of various urban water reforms in the face of drought and prospects of climate change can be interpreted in different ways. In terms of proofing cities against future water shortages, whether enhanced or not by climate change, desalination and increased storage capacity is a positive outcome. Elements critical to achieving these outcomes have been: a moment of crisis driving policy change; political commitment to providing solutions to near and long term problems; sufficient financial resources (NWC 2009; Troy 2008). Uptake of household-scale adaptation options has been significant in some locations, but their long-term sustainability or reversibility in response to changing drivers remains an open question (Troy 2008). More critical assessments emphasise that enhancement of supply provides a disincentive for reducing demand or rethinking the mass supply and waste disposal system that defines current high levels of use and environmental impact (Barnett and O'Neill 2010). [*need additional refs to support these conclusions and provide confidence/uncertainty assessments for the conclusions*]

25.6.3.3. Progress and Barriers to Managing Coastal Hazards in a Context of Rising Sea Levels

Sea level rise is a significant risk to Australia and New Zealand due to the inevitability and potential for significantly accelerated sea level rise over the next several centuries, and the location of most major centres and the majority of population located near the coast, combined with a legacy of intensifying coastal development and infrastructure and rapidly rising property prices (DCC 2009; Freeman and Cheyne 2008; MfE 2008e; Stats NZ 2010b). Such movements mean there are more people and larger volumes of capital exposed to inundation from sea-level rise, and flooding and wind and wave damage from storms, while at the same time reducing adaptation options (Abel et al. 2011; Reisinger et al. in press 2012). Recent studies highlight institutional and governance challenges and opportunities for managing these risks and allow a preliminary assessment of the effectiveness of current governance and institutional arrangements for dealing with coastal hazards in a context of climate change.

A diversity of approaches to coastal risk assessment and management can be identified across the region. Five Australian states have adopted coastal planning measures aimed at reducing exposure to coastal hazards exacerbated by climate change and sea-level rise (Government of South Australia 1992; Government of Victoria 2008; NSW Government 2010; Queensland Government 2011; WA Planning Commission 2010). The Commonwealth has recommended a planning benchmark of 1.1m sea-level rise but this has yet to be adopted in any jurisdiction. The 1992 South Australian XXXXX requires consideration of up to 1.0m sea level rise in approving new coastal development. In NSW and WA, a sea level rise of 0.9 m by 2100 must be factored into the calculation of building set-backs in the coastal zone (NSW Government 2010; WA Planning Commission 2010). In Victoria and Queensland, this figure is 0.9m, although the Queensland Coastal Plan allows for the projected sea-level rise to be revised. Most states require additional allowance for storm surge. These instruments provide guidance to local authorities who must then incorporate the criteria into local planning instruments [*guidance on how to prioritise hard protection vs accommodation vs managed retreat?*]. In New Zealand, central government recommends planning for 0.5m sea level rise by 2100, with consideration of the consequences of greater increases of at least 0.8m particularly where large-scale and long-lived infrastructure could be affected, but this guidance is non-binding and a variety of time horizons, sea level provisions, rules and practices can be found at the local government level (MfE 2008e). The NZCPS 2010 provides guidance on principles to be considered in coastal management but this does not include quantitative information on future sea level rise.

[*Could condense this text into 2 sentences plus a table of current policies (including binding/non-binding, and whether they aid prioritization in the context of competing community values)*]

The incorporation of climate change impacts into local planning has been relatively piecemeal. Many local governments still lack the resources to undertake hazard mapping and policy design. Political commitment is variable and there is strong industry pressure on local authorities to compensate developers for any restriction on current or future land uses, even where there is no legal obligation to do so (Berry and Vella 2010; LGNZ 2008; McDonald 2007, 2010; McDonald 2011; Reisinger et al. 2011). In New Zealand, the 2010 revision of the NZCPS now requires a mandatory 100-year time horizon and consideration of managed retreat as a preferred response option over hard protection works, but there is as yet insufficient evidence about its ability to overcome barriers at the community level (Reisinger et al. in press 2012).

Retreat is discussed in numerous policy and planning documents but the predominant coastal planning tools remain traditional mechanisms such as setbacks, buffers, building design and built defences (Abel et al. 2011; Reisinger et al. in press 2012). Several councils have attempted to implement retreat policies, e.g. include Byron Shire Council in Australia and Environment Canterbury and Kapiti Coast District Council in New Zealand (ECAN 2005; KCDC 2010) [*ref to Byron Bay*]. Existing retreat policies have remained largely untested in New Zealand, but experience in Australia has already highlighted the potential for litigation and opposing priorities at different levels of government to undermine retreat policies (Abel et al. 2011; DCC 2010b; Parliament of Australia 2009). Academic studies that considered options for and constraints on retreat policies find that mandatory disclosure of information about future risks, community engagement and policy stability are critical, but that place attachment, special interests, community resources, concerns over liabilities and divergent priorities at different levels of government present powerful barriers (Abel et al. 2011; Agyeman et al. 2009; Hayward 2008b; Leitch and Robinson in press; McDonald 2007, 2010; Reisinger et al. in press 2012).

Courts in both countries have played an important role in upholding planning measures, but more litigation is expected as rising sea levels affect existing properties. In Victoria, the outcome of planning litigation has rested upon whether climate change would expose future property owners and the community to unreasonable risks and thus create a potential intergenerational liability [*refs*]. Other jurisdictions in Australia have been less willing to apply broader principles of ecologically sustainable development and have interpreted the relevant planning instruments more narrowly [*refs*]. In New Zealand, a landmark decision in 2011 allowed Tasman District Council to have its revised Structure Plan to take immediate effect, thus preventing coastal land owners from seeking building consents under the old provisions while litigation would delay the new rules from coming into effect [*Environment Court Decision No [2011] 47 ENV-2011-WG-000017*]. In general though, court decisions in New Zealand show more variable preferences for risk aversion or near-term development priorities (MfE 2008e; Rive and Weeks in press).

25.6.4. Limits to Adaptation, Critical Thresholds, and Irreversible Changes

[to come post-ZOD, based on review of material in sectoral assessments within this chapter]

- *Thresholds in natural or human systems where impacts and adaptation options take a step change*
- *Thresholds in human preferences for and feasibility of one or the other type of adaptation responses*
- *Biophysical limits to adaptation and risk of irreversible changes*

_____ START BOX 25-4 HERE _____

Box 25-4. Climate Change and Emergency Management

[*Note: This is an initial outline draft for comment only. As the SREX report is yet to be finalized and there is discussion over the wording which will continue until the final deadline. References have yet to be added.*]

Emergency management in Australia and New Zealand is conceptualized as similar to disaster risk reduction being concerned with prevention, preparedness, response and recovery. In practice however, relatively less attention is given to prevention.

To the extent that climate change is increasing uncertainty and the threat of extreme events, emergency management provides the main approach to adaptation in the absence of other action to reduce the risk. Emergency management also provides the institutions to deal with uncertainty, including experience with a risk based approach to the threat of disasters, and the capacity to manage recovery from climate related extremes. Australia and New Zealand have a long history of dealing with major events. Recent experience includes the Christchurch earthquakes, the 2009 Victorian wildfires, and 2011 flooding in Queensland and Victoria.

Emergency management organizations are concerned about the implications of climate change and have commissioned their own reports into the topic (eg AFAC 2009; Handmer and Brown 2009; others?).

Observed Trends

[from Executive Summary of Chapter 4 SREX -
these can/will be replaced with key references – and the wording may change]
Absolute losses from weather-related disasters have been increasing over the past few decades (high confidence). But anthropogenic climate change has so far generally not led to increasing losses (high agreement, medium evidence). This is particularly the case for large scale extreme events such as windstorms (including cyclones) and river floods. However, there are important exceptions to this general conclusion which are not captured by longitudinal loss studies, but where losses are nevertheless attributed to climate change. A proportion of losses from the European heatwaves of the past decade can be attributed to anthropogenic climate change (some evidence and medium confidence), and parts of the Arctic have been affected by warming with severe impacts on ecosystems and local communities (use Russian and Alaskan references). Also, studies of trends in long term loss records confront a range of issues. As a result their conclusions are contingent on data availability (most data are available for developed countries), type of hazards studied (many studies focus on cyclones, where there is low confidence in an anthropogenically induced change in the hazard), on the methods used to normalize loss data over time, and on record length (finding, or eliminating the possibility of, a trend or “signal” in a system characterised by large variability or “noise” is difficult and requires lengthy records). There are also a variety of confounding factors that can be identified but resist quantification and generally act to reduce vulnerability. These include improvements in warnings and emergency management and building regulations.

Observed Losses

[from Executive Summary of Chapter 4 SREX -
these can/will be replaced with key references – and the wording may change]
Most estimates of disaster impacts are based on direct losses only, recorded largely as monetized direct damages to infrastructure, productive capital stock and buildings, and as a result seriously underestimate total losses Such estimates exclude indirect losses which are primarily the economic flows that constitute livelihoods and economies, and intangible losses which include ecosystem services, human lives, quality of life and cultural impacts. In terms of observed and modelled indirect losses, there is robust evidence and medium agreement that extreme events can cause important adverse macroeconomic and developmental effects, such as reduced direct and indirect tax revenue, dampened investment and reduced long-term economic growth through their negative effect on a country’s credit rating and an increase in interest rates for external borrowing.

Projected Changes
[from Executive Summary of Chapter 4 SREX -
these can/will be replaced with key references – and the wording may change]
Exposure of people and economic assets to climatic extremes is increasing and is the major cause of the long-term changes in economic disaster losses (high confidence). Human exposure is increasing disproportionately rapidly because of rapid development in high hazard areas, such as coastal megacities.

Adaptation
Emergency management dominates as an adaptation approach largely by default in Australia (and NZ?) for a number of reasons: there is ongoing discussion about adaptation but little action; it can avoid changes to current activities; and as it is the standard, and reasonably successful, approach in Australia and New Zealand to uncertainty about extremes, it can be seen as a logical response. Recent post event inquiries in Australia and elsewhere highlight a number of "lessons" including the importance of managing or even reducing exposure to hazards, finding ways of reducing vulnerability, and highlighting the distinction between managing "routine" events which are generally well managed and less routine extremes where problems in the approach of emergency management often arise (Victorian Bushfire Royal Commission 2010; Queensland flood enquiry 2011; Pitt Review of the 2007 English floods 2008). However, significant change has not occurred. A key issue has been the use of emergency management to avoid other risk reduction strategies through trading the risk through developing an area exposed to flooding for example, against enhanced warnings and response (Handmer xxx).

_____ END BOX 25-4 HERE _____

_____ START BOX 25-5 HERE _____

Box 25-5. Insurance as Risk Management Tool for Climate Change

[*We are considering the value of such a box. Key constraint is paucity of published data from the region. We see little point in providing a general discussion that will or should be provided in WGII part 1, but feel that if we have a box it should provide information and insights specific to Australia and New Zealand.*]

_____ END BOX 25-5 HERE _____

25.7. Interactions between Impacts, Adaptation, and Mitigation Responses

The AR4 identified a range of interactions between adaptation and mitigation, including synergies and trade-offs, and policies that support both. It noted with *medium confidence* that creating synergies can increase the cost-effectiveness of actions and make them more attractive to stakeholders, but that the scale of interaction is often small compared to broader development trends and the opportunities for synergies are greater in some sectors than in others. In addition, decisions about adaptation and mitigation are often taken at different governance levels and by different parties, and benefits and costs accrue at different scales, making direct comparisons difficult (Klein et al. 2007). In addition to the dynamic relationship between adaptation and mitigation responses, individual adaptation options can also be synergistic and/or create barriers towards other adaptation options within and among sectors. An understanding of these interactions forms an important basis for developing a balanced portfolio of adaptation responses in the context of multiple climatic and non-climatic stresses (Klein et al. 2007; Yohe et al. 2007) [*AR5 refs*].

This section reviews the available evidence about such interactions from Australia and New Zealand. 25.7.1 covers synergies, co-benefits and trade-offs between impacts, adaptation and mitigation responses at local, national and regional scales. 25.7.2 evaluates the degree to which effects of climate change impacts, adaptation and mitigation responses globally could have flow-on effects on impacts and adaptation responses in the region of Australasia. 25.7.3 provides more specific details regarding the extent to which global mitigation action would avoid climate change damages in the region, and the extent to which regional or sub-regional cost-benefit analyses of alternative response strategies to climate change are currently available.

25.7.1. Local-Level Interactions between Impacts, Adaptation, and Mitigation Responses

Table 25-2 lists interactions between different adaptation responses that are either synergistic or entail trade-offs for adaptation within the same or other sectors. These interactions generally occur within geographic sub-regions defined by catchments or agro-ecological zones, but some interactions can extend to national level (e.g. impacts on local electricity supply and demand can have national effects). In many cases, adapting proactively to a future increase in climatic extremes (flooding, drought, storms) can render near-term co-benefits of greater resilience against particularly large but rare extremes, albeit at greater near-term costs [*refs*], but can also have trade-offs e.g. expanding irrigation to reduce risks to dryland agriculture could constrain urban development options that rely on increased water availability [*refs*].

[INSERT TABLE 25-2 HERE
Table 25-2: Examples of interactions between adaptation measures in different sectors. In each case, impacts or adaptation responses in one sector have potential to conflict (cause negative impacts) or be synergistic with adaption responses in another sector, or with another type of response in the same sector. [*We are still considering whether the table format is really the best use of space; also an open question is whether we have two tables, and if so, whether splitting between adaptation/mitigation linkages is the best option since some issues cover both, and some issues can have either (or both) synergies and trade-offs. Also considering whether to include co-benefits with other environmental management objectives*.]]

The relationship between mitigation and adaptation is often more complex than between adaptation responses because the costs and benefits are not equally experienced between different sectors and are experienced at multiple spatial and temporal scales (Berry and Paterson 2009). Globally coordinated efforts to reduce greenhouse gas emissions reduced magnitude and rate of climate change and hence reduce the need for adaptation [*AR5 refs*], but these are not necessarily the interactions that are of greatest interest at the local level.

At local scales, mitigation can influence adaptation needs and options through environmental or social co-benefits that strengthen the resilience of a system to climate variability and change (e.g. distributed energy generation from renewable energy systems can reduce transmission losses and reduces the risk of large-scale network failure during extreme climatic events [*confirm ref SREN*]). At the same time, some other mitigation strategies such as increasing urban densification can increase health risks during heat waves and compound stormwater management problems. Some adaptation measures have the potential to simultaneously reduce energy demand and/or net greenhouse gas emissions and thus lower national energy and/or mitigation costs (e.g. afforesting eroding grasslands will sequester carbon, reduce national greenhouse gas emissions and, depending on policy settings, may offer alternative sources of income for farmers [*ref*]). However, there is also significant potential for strategies designed to mitigate emissions to conflict with those designed to adapt to the climate impacts, e.g. through increased energy demand from air conditioning or desalination plants. A compilation of climate change-associated land-use plans and policies from Australia showed that of 25 specific plans, 12 exhibited potential for conflict between mitigation and adaptation strategies (Hamin and Gurran 2009). Models that simultaneously explore mitigation, impacts and adaptation (integrated assessment models, IAMs) are also developing (Bosello et al. 2009; Jotzo 2009) but their application at regional or sub-regional scales in Australasia is still limited.

Table 25-3 lists interactions between adaptation and mitigation responses and demonstrates a broad range of synergistic and counterproductive implications of individual responses. A key issue in Australasia is the mutual effects of climate change impacts, adaptation and mitigation responses on future land-use, which is explored in more detail in Box 25-6 for the Murray-Darling Basin in southeastern Australia. Note that table 25-3 does not include benefits from globally coordinated greenhouse gas mitigation in terms of reduced damages from climate change, which are considered in 25.7.2 and 25.7.3.

[INSERT TABLE 25-3 HERE
Table 25-3: Examples of interactions between adaptation and mitigation (green rows denote synergies where multiple benefits may be realized, orange rows denote potential tradeoffs and conflicts). [*Note: will need to add*

more material to this table and we are struggling with how to present a reasonably comprehensive overview with page constraints, and how to deal with the fact that most statements in this table are also (appropriately) contained in earlier sectoral discussions within this chapter. Suggestions and reflections would be very welcome. Also considering whether to present and discuss regional adaptation/mitigation strategies where they have been formulated and analysed in the literature, e.g. The relationship between adaptation and mitigation in managing climate change risks: a regional response from North Central Victoria (Jones et al. 2007).]]

_____ START BOX 25-6 HERE _____

Box 25-6. Land-Use Change in Scenarios of Combined Adaptation and Mitigation Responses

Afforestation as a greenhouse gas mitigation measure can have multiple co-benefits for adaptation such as controlling erosion on marginal farm land and enhancing biodiversity including through providing migration corridors, but can also result in trade-offs with adaptation of agriculture through enhanced water demand and the large-scale change of rural communities and employment [*refs to agriculture, forestry and rural subsections*].

(Baisden et al. 2010; PMSIEC 2010; Quiggin et al. 2010; Schrobback et al. 2011; Todd et al. 2009; Zhang and McDonald 2011)

[*Text to come; intent is to describe the rate, pattern and scale of land-use change under carbon pricing scenarios and compare and contrast them with land-use change and management issues from a climate change impacts/adaptation perspective, to identify any areas where land-use change driven by either mitigation or impacts/adaptation may have a significant bearing on the feasibility of pursuing the other strategy).*

We are also hoping for more material generated in response to Australian policy development.]

_____ END BOX 25-6 HERE _____

25.7.2. Intra- and Inter-Regional Flow-On Effects on Impacts and Adaptation Options

Flow-on effects from climate change impacts occurring in other world regions will exacerbate or counteract projected economic impacts within Australasia, albeit with varied effects on different sectors and sub-regions (*very high confidence*). Both Australia and New Zealand have export-oriented economies, including agriculture and tourism in both countries, and minerals and energy resources mainly in Australia (25.4). Climate-driven changes in economic activity and hence demand in key export destinations or competitors globally could therefore have a major influence on the net implications of climate change for those sectors in Australasia. The AR4 noted the possible significance of such effects but found an almost complete lack of research on this issue. Since the AR4, a gradually increasing but still limited amount of research has aimed to better understand and quantify risks and opportunities arising from flow-on effects and to consider them jointly with domestic impacts to climate change to inform integrated risk management approaches.

Climate change is projected to be associated with a decline in regional economic activity and hence the demand for Australia's commodity exports (mainly prices for coal and other minerals) particularly in rapidly growing Asian economies that are expected to be affected adversely by climate change [*AR5 refs*] (Garnaut 2008c). Modelling studies give *medium confidence* that Australia's terms of trade would deteriorate due to climate change by about 0.23% in 2050 and 2.95% in 2100 relative to a world without climate change (Harman et al. 2008), which would compound domestic impacts of climate change. Market impacts of unmitigated climate change in Australia by 2020, 2050 and 2100 are estimated to be a decline in: real GNP by 0.8%, 2.3% and 7.6%, and real GDP by 0.7%, 2.1% and 5.9%, respectively, relative to the case of no climate change (Garnaut 2008c) (Gunasekera et al. 2008; Harman et al. 2008). GNP – the more comprehensive aggregate economic measure – is projected to be affected more strongly than GDP because Australia's terms of trade are projected to fall under climate change scenarios (Garnaut 2008c).

These and other estimates of economic impacts of climate change need to be seen in light of inherent limitations of the economic modelling tools, in particular the lack of assessment of risk of highly adverse outcomes rather than most likely scenarios (see 25.8). In addition, assessment of flow-on effects on Australasia relies on assumptions about climate change impacts and economic responses in other countries, which is generally less certain and more reliant on simplified assumptions than for domestic impacts in the relevant analyses.

In comparison to Australia, New Zealand's economy relies more on agricultural than energy and minerals commodity prices. There is *limited evidence* but *high agreement* that higher global food prices driven by climate change impacts globally would offset adverse effects of climate change on New Zealand agricultural output, both in terms of producer returns and real gross national disposable income (RGNDI). Economic modelling studies suggest that producer returns in New Zealand sheep meat, dairy, and overall agriculture production could increase by around 18.2%, 21.5% and 14.6%, respectively, due to global impacts of climate change on agriculture [*need to check scenarios, time frames etc*] (Saunders et al. 2010). A range of scenarios for climate-driven increases in world commodity prices would increase RGNDI in New Zealand by between 0.6% and 2.3% [*need to check time frame*], even though real GDP in New Zealand could vary from a 0.4% increase (taking into account the effects of carbon fertilisation on agriculture) to a 0.4% decline (without carbon fertilisation effect) (Stroombergen 2010). Higher international agricultural commodity prices are not expected to outweigh the more severe adverse effects of climate change on the production of many agricultural products in Australia (Garnaut 2008c; Gunasekera et al. 2007b).

International tourism in Australasia is also subject to potential climate-related flow-on effects. Climate is an important factor for both the destination choice and timing of travel (*high confidence*) (Hamilton and Lau 2005; Lohmann and Kaim 1999). A range of climatic parameters have been found to be influential, including temperature, precipitation, humidity, sunshine hours and visibility (Amelung et al. 2007; Yu et al. 2009). Climatic conditions in both the country of origin and potential destinations are relevant (Agnew and Palutikof 2006; Maddison 2001). Recent studies from temperate countries indicate that currently, better (especially 'warmer') climatic conditions in the region of residence are related to a higher probability of domestic travel, whereas poor conditions increase the volume of international travel (Eugenio-Martin and Campos-Soria 2009; Rosselló-Nadal et al. 2011). Attempts have been made to predict tourist flows under the assumption of climate change scenarios and potential 'winners' and 'losers' in terms of tourist arrivals have been identified (Ehmer and Heymann 2008; Hamilton et al. 2005; Hein et al. 2009); but these approaches have also been heavily criticised, for example because of simplified approaches and the challenge of anticipating consumption trends (Gössling and Hall 2006) [*cross-check with AR5 ref; no need to repeat if covered there*].

A recent study on the influence of different climatic variables on seasonal arrivals to Australia indicates that the effects vary between seasons and countries. Visitors from the USA and the UK responded to maximum temperature and humidity (with more humid conditions related to greater arrivals), Japanese arrivals related to temperature and New Zealand tourists appeared relatively attracted by both sunshine hours and temperature (Kulendran and Dwyer 2010). Tourist flows are influenced by many factors besides the climate, in particular economic parameters (esp. disposable income), travel costs and distance (Schiff and Becken in press). Recent research on climate change policy and tourism attempted to assess the impacts of global climate policies on tourism demand (Gössling et al. 2008; Mayor and Tol 2007, 2008, 2010; Pentelow and Scott 2011). All studies found that only very high carbon prices [*check how high is that; give indicative number/range*] would result in significant impacts on tourist arrivals and flows. Increasing oil prices have potentially a greater potential in affecting a redistribution of global tourism, particularly for countries like Australia and New Zealand that are far from most countries of origin (Becken 2011).

Impacts on geopolitical stability in the Asia-Pacific region could present a significant flow-on effect for Australia and New Zealand. Climate change, through sea-level rise, reduced food production, water scarcity and other factors, could result in the displacement of large numbers of people in developing countries in the region and add to existing stresses, exceeding the resources of states to deal with it. It could contribute to destabilising, unregulated population movements in Asia and the Pacific, and destabilize governments and societies in the parts of Asia and the Pacific, resulting in additional external pressures and draws on domestic resources in Australia and New Zealand (Dupont and Pearman 2006; see also 25.5.12).

[*consider additional material re health impacts from migration and settlement patterns; Emma Britton*]

25.7.3. Regional Cost-Benefit Perspectives and Climate Change Impacts Avoided by Global Mitigation

The net economic effect of climate change consists of the costs of mitigation, adaptation and residual impacts. The likely costs of climate change adaptation are beginning to be estimated in detailed sector-by-sector studies and research aimed at evaluating the relative costs and benefits of alternate adaptation strategies, as well as tradeoffs between adaptation and mitigation, is emerging (Bosello et al. 2009; Jotzo 2009).

Garnaut (2008c) concludes that the costs of unmitigated climate change to Australia are greater than the costs of stringent global mitigation action with Australia taking its proportionate part. Benefits from reduced non-market impacts and the insurance value against the risk of highly adverse outcomes favour strong global mitigation action in that analysis. No estimates of economy-wide impacts of unmitigated or mitigated climate change or costs of adaptation are available for New Zealand, and estimates of mitigation costs in New Zealand have made highly simplified assumptions regarding climate change impacts, adaptation or climate policies in other world regions (Saunders et al. 2010; Stroombergen 2010; Stroombergen et al. 2009).

Some emerging evidence exists for the impacts that would be avoided at a sectoral level from global mitigation actions. Findings from the Garnaut Review (Garnaut 2008c) include:

- The Murray-Darling Basin produces around 40% of Australia's total gross value of farm output at present. A basin-wide sector analysis indicates a 12%, 49% and 92% fall in value of irrigated farm output by 2030, 2050 and 2100, respectively, under a high (A1FI) climate change scenario, but lesser reductions of 3%, 6% and 20% for global stabilisation of greenhouse gas concentrations at 550ppm CO_2-eq and 3%, 6% and 6% for stabilisation at 450ppm CO_2-eq.
- The difference in annual health care and surveillance costs relating to bacterial gastroenteritis differs between an unmitigated (A1FI) and 450ppm CO_2-eq stabilisation scenario by AUD$35.8 million by 2050 and AUD$174.2 million by 2100, while the difference in the annual number of workdays lost is 364,000 by 2050 and 1.8 million by 2100 (see also Bambrick et al. 2008).
- Up to 34% increase in the cost of water supply under an unmitigated (A1FI) scenario, compared to 4-5% cost increases under 450-550ppm CO_2-eq stabilisation scenarios.

There is insufficient evidence from New Zealand to determine the extent to which global mitigation action would reduce sector-wide or regional aggregated damages from climate change. *[Review this statement post-ZOD to see whether there are at least some examples; probably can use Mullan et al. drought study, Tegg/Jackson et al Hutt flood study; some health references. This is highly incomplete.]*

25.8. Multi-Sector Synthesis and Key Vulnerabilities

[Note: we do not have a proper draft for this section for the ZOD. We will develop this section post-ZOD based on ZOD chapter material. Below is an outline of our thinking to date for this section.]

Overall intent and approach for this section

The purpose of this section is to synthesise the chapter's key conclusions regarding impacts, vulnerability, adaptive capacity and potential adaptations. It will be assembled from summary statements amongst the chapter material and individual assessed studies as relevant, together with a judgement by the authors of the most significant risks (taking impacts and adaptive capacity into account), and including an outline of what responses may be most urgent (some risks may be very high in the more distant future but offer less near-term response options than others).

We are aiming to frame this discussion in a risk-management context, which would need to draw on relevant conceptual discussions in other AR5 chapters and the international literature since there is little that has been published on risk management with a specific regional focus (though many key experts that have contributed to the international literature on risk management are from Australasia).

Model-based estimates of economic impacts of climate change in Australasia (as in 25.6 and 25.7) and elsewhere are subject to important caveats, and are only one part of a comprehensive assessment of climate change impacts. Estimates for economy-wide costs are typically derived from aggregate economic models that take into account only impacts that are reflected in markets, are driven by assumptions about most likely impacts and economic responses without representing the risk of extreme outcomes, assume a high degree of substitution between economic activities and products, and do not identify impacts on specific regions or groups of people. Because of these and other limitations, such quantitative estimates are highly likely to be an underestimate of the full economic impacts from climate change (Ackerman et al. 2009) (Jotzo 2010).

In the Australasian region, the risk of highly adverse and irreversible impacts, along with non-market impacts such as the loss of iconic natural features and fundamental changes to the way of life of sections of the population, are a crucial aspect of possible climate change impacts. [*refer to examples eg Great Barrier Reef, Murray-Darling Basin, urban water supply etc, and/or refer to sections*] The most comprehensive study to date on economic impacts of climate change in Australia (Garnaut 2008) considered these effects qualitatively alongside quantitative modelling of market impacts, finding that non-market impacts and risks of high climate change damages are likely to be major factors for the utility of Australians in the future.

One theme of this section will be that significant progress in impacts research, development of risk assessment frameworks, and adaptation planning, has been made since the AR4 in Australia, but less so in New Zealand. Implementation of adaptation plans, however, is still at an immature stage. Several pending pieces of Australian legislation, including the Carbon Farming Initiative, and carbon pricing (to be followed up by some form of emissions trading within a few years), have the capacity to transform the energy sector, trade, infrastructure planning, primary industry and biodiversity protection, with as yet unknown consequences for adaptation planning over the next decade.

Graphical representation of risks

We plan to develop one or two synthesis graphical representations of risk and vulnerability. One possible approach being considered is to build on but modify the diagram used in the Australia-New Zealand Chapter of the AR4 (see below). That approach summarised sectoral coping range, adaptive capacity and vulnerability according to global temperature increase, and with an indication of the conditions under which these levels of warming may be reached.

The additional perspectives that we are considering including:

- Some regional breakdown, at least for those sectors where this is likely to be policy relevant and robust and regional differences could be significant
- Link to changes in precipitation as well as to temperature. In some sectors and regions precipitation change is likely to be a more important driver of change than temperature, at least in the short to medium-term, and since precipitation change can vary strongly regionally, it would be potentially advantageous to be transparent about how the conclusions are affected by precipitation change. This would result in a two-dimensional burning embers diagram, which would however make it difficult to show different sectors and would require different diagrams for different regions because precipitation changes (and confidence in those changes) varies significantly within the region.
- Lead time required for adaptive capacity to be realised, and thus the likelihood that it will be realised. This could include plotting the possible path of climate change scenarios along with timescales for adaptation.

Achieving any of the above options will likely require multiple panels, possibly located on a map of the region. Note that it may not be necessary to do both a regional and precipitation breakdown, if regions are defined so as to be coherent in their rainfall response. However, confidence in precipitation change in some regions is limited so we may want/need to capture alternative futures related to precipitation change in some way.

[SEE FIGURE 25-12 FOR AR4 SYNTHESIS FIGURE]

25.9. Concluding Remarks, Data Gaps, and Key Research Needs

[*Note: this section will be drafted following review and revision of the ZOD.*]

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Table 25-1: Examples of observed changes in species, natural ecosystems, agriculture and….. *consistent* with a climate change signal, published since the AR4.

Type of change	**Observation**
Genetic constitution	Shifts in an inversion polymorphism and an allozyme polymorphism in *Drosophila melanogaster* since the 1970s-1980s (Hoffmann & Weeks 2007). Declining body size in 4 out of 8 species of southeast Australian passerine birds and associated shift (~7°) in latitudinal size cline over past 100 years, nutritional cause considered unlikely (Gardner et al. 2009)
Geographic ranges	Range expansions of several bird species to higher latitudes or elevations (Chambers 2007; McAllan et al 2007) Shifts in southerly boundaries of approximately 100-150 km per decade with declines in some northerly parts of ranges, and southerly movement of the transition zone between tropical and temperate seabirds (Dunlop 2007; Olsen et al 2007) Southerly range extension of the barrens-forming sea urchin *Centrostephanus rodgersii* from the mainland to Tasmania, associated with the increased southerly penetration of the East Australian Current and subsequent expansion of suitable habitat (Ling et al 2008, 2009; Banks et al. 2010) 17 of 32 (53%) intertidal species shifted to more southerly distribution since the 1950s (average distance 145 km) off west coast of Tasmania (Pitt 2008)
Life cycles	Earlier arrival & later departure of some species of migratory birds in Australian breeding and feeding grounds (1973-2000) (Chambers 2008) Earlier laying date in helmeted honeyeater (1989-2007) Chambers *et al*. 2008; 8 out of 101 plant species from the Victorian coast show general trend toward earlier flowering over time, correlated with increasing temperature (Rumpff et al. 2010); [*check…*] (Gallagher et al. 2009) Significant advance in mean emergence date of 1.4 days per decade (1941-2005) in the Common Brown butterfly, correlated with increase in local air temperatures of 0.16ºC per decade (1945-2007) during developmentally sensitive part of annual life cycle (Kearney et al. 2010) 68% of changes in timing of Victorian waterbird arrival or departure significantly correlated with climate (Chambers 2010) [*Many of these individual examples will probably be replaced by meta-analyses between now an the FOD (done by either Lynda Chambers or LH)*]
Populations	Otolith analysis indicates significant changes in growth rates of long-lived Pacific fish species – increasing growth rates in species in top 250m associated with surface warming, declining growth rates in species >1000m associated with long –term cooling (Thresher et al. 2007) Decline in red-billed gull, *Larus novaehollandiae scopulinus* linked to changes in circulation indices (PDO and ENSO) in New Zealand (1983-2000) (Mills et al. 2008) Decline in recruitment of *Anguilla* spp. and several weeks advance in main migration over last 30+ years possibly associated with changing thermal fronts in spawning grounds (Jellyman et al. 2009)
Vegetation change	Expansion of monsoon rainforest over past 4 decades at expense of eucalypt savanna and grassland in Northern Territory associated with increases in rainfall and CO_2 coupled with changes in fire regimes (Banfai et al. 2007; Banfai & Bowman 2007) Increasing canopy cover in tropical savannas (Lehmann et al. 2008); increase of mire wetland extent (10.2% from 1961-1998) and corresponding contraction of adjacent eucalypt woodland, associated decline in evapo-transpiration in seven sub-catchments in south east Australia (Keith et al. 2010) Overall increase in mangrove extent (16.2%, 1974-2004) in Northern Territory, with slight loss in coastal areas, stability in the inter-tidal zone, and gain in upper-tidal zone at the expense of brackish swamps (i.e. overall landward expansion of mangroves), changes potentially associated with combination of sea level rise, local changes in hydrology, and elevated CO_2 (Williamson et al. 2011); Contraction of freshwater *Melaleuca* swamp forests on the floodplains of Kakadu National park in the Northern Territory (5% over 40 years) attributed to intrusion of saline water with rising sea levels, but amplified by past damage from feral water buffalo (Bowman et al. 2008) Vegetation thickening of 3.6% in second half of 20th century in semi-arid mulga woodlands in southwest QLD, but change highly variable amongst sites (Witt et al. 2009); Bowman et al (2010)

	conclude that expansion of monsoon rainforest into savanna vegetation in the Northern territory is most plausibly linked to increasing rainfall and/or elevated CO_2 Landward mangrove expansion in se Qld driven mainly by periods of increased rainfall (Eslami-Andargoli et al 2009) Approximately doubling of carbon stock in living vegetation since European settlement (1788-1988), estimated via a simple vegetation model based on canopy leaf properties, vegetation structure and cover with resource availability, attributed at least in part to increasing CO_2 (Berry and Roderick 2006) Remote sensing shows that vegetation cover increased ~8% over 26 years (1981-2006), consisting of larger increases in non-deciduous perennial vegetation (up 21%) and declines in deciduous, annual and ephemeral types (down 7%), over same time period rainfall increased 7% (Donohue et al 2009)
Disease	Emergence and increased incidence of coral diseases including white syndrome (Bruno et al. 2007, Dalton et al. 2010), and black band disease (Sato et al. 2009) associated with increasing sea surface temperatures
Sex ratios	Tuatara sex ratios becoming increasingly male with increasing temperature (Mitchell et al. 2008)
Community assemblages	Increasing water temperatures in freshwater streams in NSW associated with decline in families of cold water-favouring macroinvertebrates (1994-2007) (Chessman 2009)
Coral reefs	Eight mass bleaching events since 1979 triggered by unusually high sea surface temperatures [*need recent ref*] Calcification of *Porites* on Great Barrier Reef declined 21% (1971-2003) (n=4 reefs) (Cooper et al. 2008), 14.2% (1990-2005) (n=69 reefs) (De'ath *et al*. 2009)
Ecological condition	Decline in ecological condition, as measured by macroinvertebrate assemblages, in freshwater streams in Victoria consistent with impact of declining rainfall but also with increasing urbanization (1994-2004) (Webb & King 2009)

Table 25-2: Examples of interactions between adaptation measures in different sectors. In each case, impacts or adaptation responses in one sector have potential to conflict (cause negative impacts) or be synergistic with adaption responses in another sector, or with another type of response in the same sector. [*We are still considering whether the table format is really the best use of space; also an open question is whether we have two tables, and if so, whether splitting between adaptation/mitigation linkages is the best option since some issues cover both, and some issues can have either (or both) synergies and trade-offs. Also considering whether to include co-benefits with other environmental management objectives*.]

Primary driver	**Sector/s affected**	**Example**
Reduction of bushfire risk	Biodiversity, tourism	Potential for greater conflict between conservation managers and other park users in Kosciuszko National Park if increasing fire incidence causes park to be closed for greater lengths of time, either to reduce risk, or to rehabilitate native vegetation after fires (Wyborn 2009). Objectives of the Wildfire Management Overlay (WMO) in Victoria conflict with vegetation conservation (Hughes and Mercer 2009).
Reduction of bushfire risk and risk of energy transmission interruptions	Energy, biodiversity	Bush fire can disrupt electricity supply, but overhead power lines are also frequent causes of bush fires in Australia. Underground cabling would reduce risks in both directions but would come at a significant investment cost, which is made more difficult by multiple ownerships and lack of an overarching national strategy to achieve societal goals (ATSE 2008; Linnenluecke et al. 2011; Parsons Brinkerhoff 2009; Yates and Mendis 2009).
Reduction of risk to beaches & coastal infrastructure	Biodiversity	Provision of seawalls to reduce the impacts of rising sea levels provide habitat for intertidal organisms but these communities have different diversity and structure to those that develop on natural substrates (Jackson et al. 2008); groynes potentially alter diversity and community structure of beach fauna (Walker et al. 2008). Adaptation to rising sea levels through hard coastal defences would lead to negative impacts on biodiversity as habitats, such as salt marsh, are prevented from adapting to climate change by inland migration.
Reduction of risk from rising sea level	Indigenous communities	Potential cultural, land rights and economic issues are involved in prospective relocation of Torres Strait islander communities to alternative islands (Green et al. 2010).
Increased water security, water storage	Biodiversity	Australia has highest levels of per capita water storage anywhere in the world (Australian Bureau of Statistics, 2007), buffering urban settlements and agricultural systems against low levels of runoff and high interannual variability in river discharge. Altered flow regimes have significant negative impacts on freshwater ecosystems (Bond et al. 2008) (Kingsford 2011). Discharge from desalination plants (eg in Perth and Sydney) can lead to substantial increases in salinity and temperature, and the accumulation of metals, hydrocarbons and toxic anti-fouling compounds in receiving waters; potential for acute and chronic toxicity, and small scale alterations to community structure (Roberts et al. 2010)
Expansion of tourism industry from one to two seasons in response to decreasing snow	Biodiversity	Increased negative impacts on vegetation, soils and fauna during warmer months from increased visitation rate (Morrison and Pickering 2011)
More to come…		Co-benefits of afforestation and reduced deforestation for biodiversity and soil retention, but trade-offs with water use in water-stressed catchments Trade-offs between supply- and demand-side responses to water stress Co-benefits of over-designing flood and drought responses for reducing vulnerability to rare extreme events in the present climate

Table 25-3: Examples of interactions between adaptation and mitigation (green rows denote synergies where multiple benefits may be realized, orange rows denote potential tradeoffs and conflicts). [*Note: will need to add more material to this table and we are struggling with how to present a reasonably comprehensive overview with page constraints, and how to deal with the fact that most statements in this table are also (appropriately) contained in earlier sectoral discussions within this chapter. Suggestions and reflections would be very welcome. Also considering whether to present and discuss regional adaptation/mitigation strategies where they have been formulated and analysed in the literature, e.g.* The relationship between adaptation and mitigation in managing climate change risks: a regional response from North Central Victoria (Jones et al. 2007).]

Primary driver	**Sector affected**	**Interaction**
Adaptation to decreasing snowfall	Biodiversity, energy use, water use	Artificial snowmaking is an adaptation to decreasing snowfall in the Australian Alps and is estimated to potentially require large additional energy and water resources by 2020 of 2500-3300 million L of water per month, more than half the average monthly water consumption by the Australian Capital Territory in 2004-05. Increased use of snow manipulation techniques by ski resorts is likely to have negative effects on vegetation, soils and hydrology of subalpine-alpine areas within ski resorts (Pickering and Buckley 2010, Morrison and Pickering 2011).
Increased temperatures	Energy use	In temperate climates of New Zealand and parts of Australia, rising temperatures can reduce annual average demand and CO_2 emissions from thermal power generation (Stroombergen et al. 2006; Thatcher 2007b; Wang et al. 2010a). Rising temperatures increase summer peak electricity demand mainly for air conditioning, which in turns results in greater greenhouse gas emissions if the demand is met from fossil fuel powered generation. Reducing peak energy demand through passive housing design and other demand management measures could reduce vulnerability of the transmission and distribution network to climate extremes and associated adaptation costs, reduce transmission losses and reduce fossil fuel-based CO_2 emissions from thermal power stations (Nguyen et al. 2010; Parsons Brinkerhoff 2009; Yates and Mendis 2009)
Biosequestration, carbon farming	Water, biodiversity, agriculture, food security	If a carbon price makes forest establishment more attractive than grazing or cropping on large areas of productive agricultural land there are likely to be flow on effects to rural communities, food security and water security (Garnaut 2011). Water use by large-scale plantations can reduce streamflow and groundwater resources (FWPA 2009). But in inland areas where carbon plantings and woodland regeneration are more likely, impacts on water yield are likely to be lower (Polglase et al 2008, cited in Garnaut 2011 4th paper). Clearing of remnant vegetation for forest establishment and expansion of monoculture plantations is very likely to have adverse effects on biodiversity (Steffen et al 2009; Garnaut 2011 (Update paper 4)). Crossman et al (in press, cited in Garnaut paper 4) conducted simulations for agricultural regions of South Australia, estimated that a carbon price of $10 per tonne CO_2 would mean that single species plantings would return profits of $7 per hectare higher than biodiverse plantings.
Renewable wind energy production	Biodiversity	Wind-farms can have localised negative effects on bat and bird populations and if badly positioned can become a barrier to bird migration. However, risk assessment of the potential negative impacts of wind turbines on threatened bird species in Australia indicated low to negligible impacts on all species modelled (DEH 2006).
Urban densification	Biodiversity, water, health	Higher urban density can reduce energy consumption from transport and infrastructure but result in loss of permeable surfaces and tree cover, intensifying stormwater and flood risks, and in some climatic conditions exacerbating the discomfort and health impacts of hotter summers, "a density conundrum" (Hamin and Gurran 2009)
Biodiversity, green corridors for wildlife	Energy	Prioritising provision of connected habitat can reduce density of urban infrastructure and increase energy consumption from transport (e.g. Port Stephens Comprehensive Koala Plan of Management, New South Wales (NSW) (Hamin and Gurran 2009)
Renewable energy from second-generation biofuels	Biodiversity, rural livelihoods, agriculture	New crops such as oil mallees or other eucalypts may provide multiple benefits, especially in marginal areas, displacing fossil fuels or sequestering carbon, generating income for landholders and producing a range of products (essential oils, charcoal, bio-char, biofuels), and providing ecosystem services (AGO 2005, cited in Cocklin and Dibden 2009; (McHenry 2009).

Biosequestration, carbon farming	Biodiversity, agriculture, rural livelihoods	Large scale changes in land use through biosequestration may have co-benefits in addition to mitigation, including for biodiversity, water retention in soils, reducing salinity, indigenous and rural livelihoods Gunasekera et al. 2007, Lindenmayer 2007; Mackey et al. 2008). Planting of trees on farms (for carbon sequestration) has been shown to increase agricultural productivity via reduced stock losses in cold weather, protection from soil erosion (GHD Hassall 2010, in Garnaut paper 4) QLD govt has established the Carbon Accumulation Through Ecosystem Recovery information system to encourage landholders to manage regrowth for carbon sequestration and potentially participate in carbon markets (DERM 2009). Up to 14.8 million ha of previously cleared land with woody regrowth have been identified as suitable for ecosystem restoration and biosequestration in QLD (Fensham and Guymer 2009)
Reduction of emissions from fires	Biodiversity indigenous and rural livelihoods	CSIRO (2009) has estimated that improved management of savanna fires could reduce emissions by 13 million tonnes CO_2 equivalent per year (90% of current levels) between 2010 and 2050. Projects such as the Western Arnhem Land Fire Abatement project (collaboration between Darwin Liquefied natural gas, the NT government, Northern Land Council and indigenous landholders) applies fire management practices across 28,000 sq km and has demonstrated feasibility of reducing extent of late dry season fires (CSIRO 2009). Improved savanna management has biodiversity benefits (Woinarski et al 2009) as well as indigenous employment (Garnaut 2011 4th update paper)
Reduction in methane emissions	Biodiversity	Control of exotic vertebrate pests such as camels aimed at reducing methane emissions could have significant biodiversity benefits as these animals cause significant economic and biodiversity damage (need ref). Currently over 1 million feral camels in Australia, with the population projected to double over the next decade (NRMMCb 2010). Economic benefits of reduced grazing competition, infrastructure damage and GHGs could outweigh costs of camel reductions (Drucker et al. 2010)
Water security	No_x emissions	Improving efficiency of irrigation systems in response to reduced water availability may also help to reduce emissions of nitrous oxide from soils. (Garnaut 2011 4th update paper)

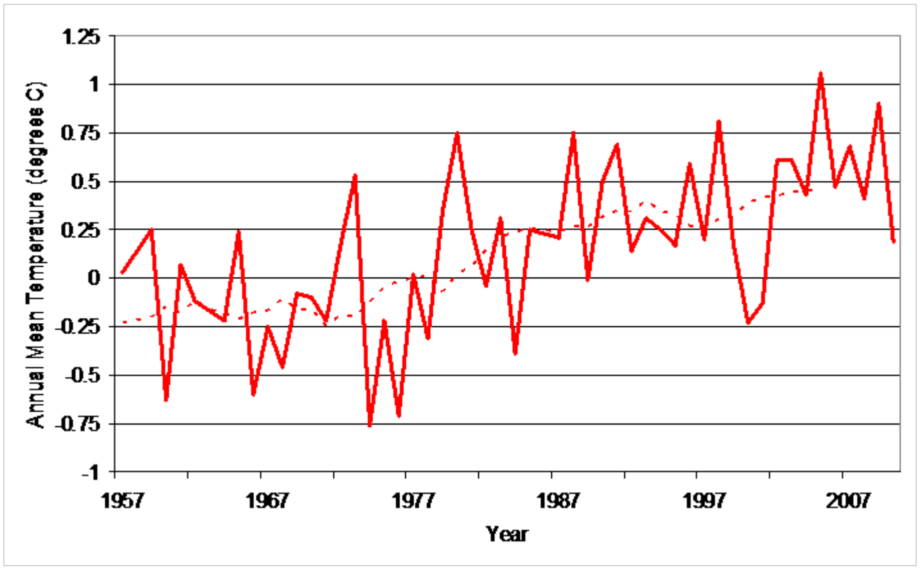


Figure 25-1

Figure 25-2

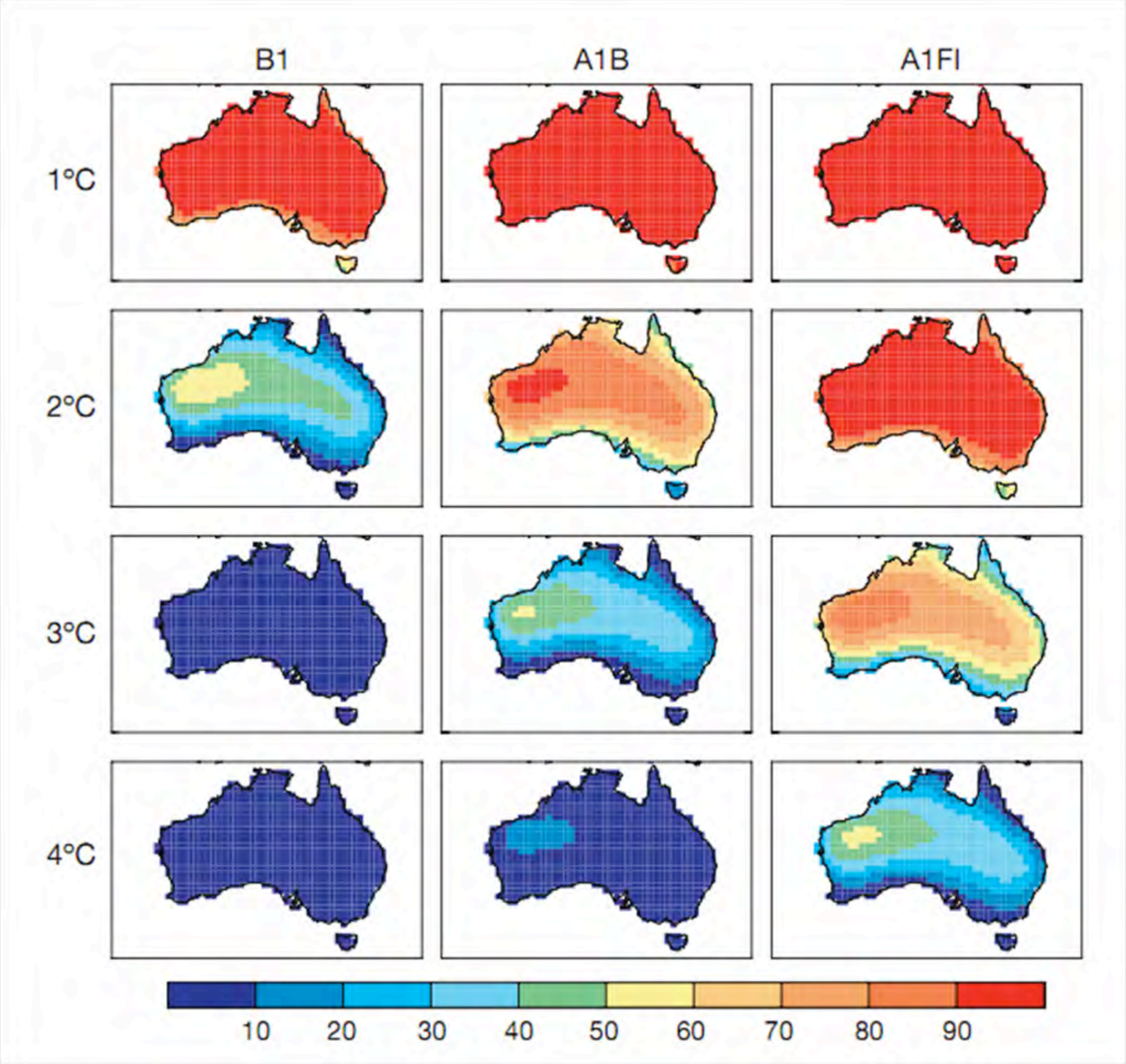


Figure 25-3

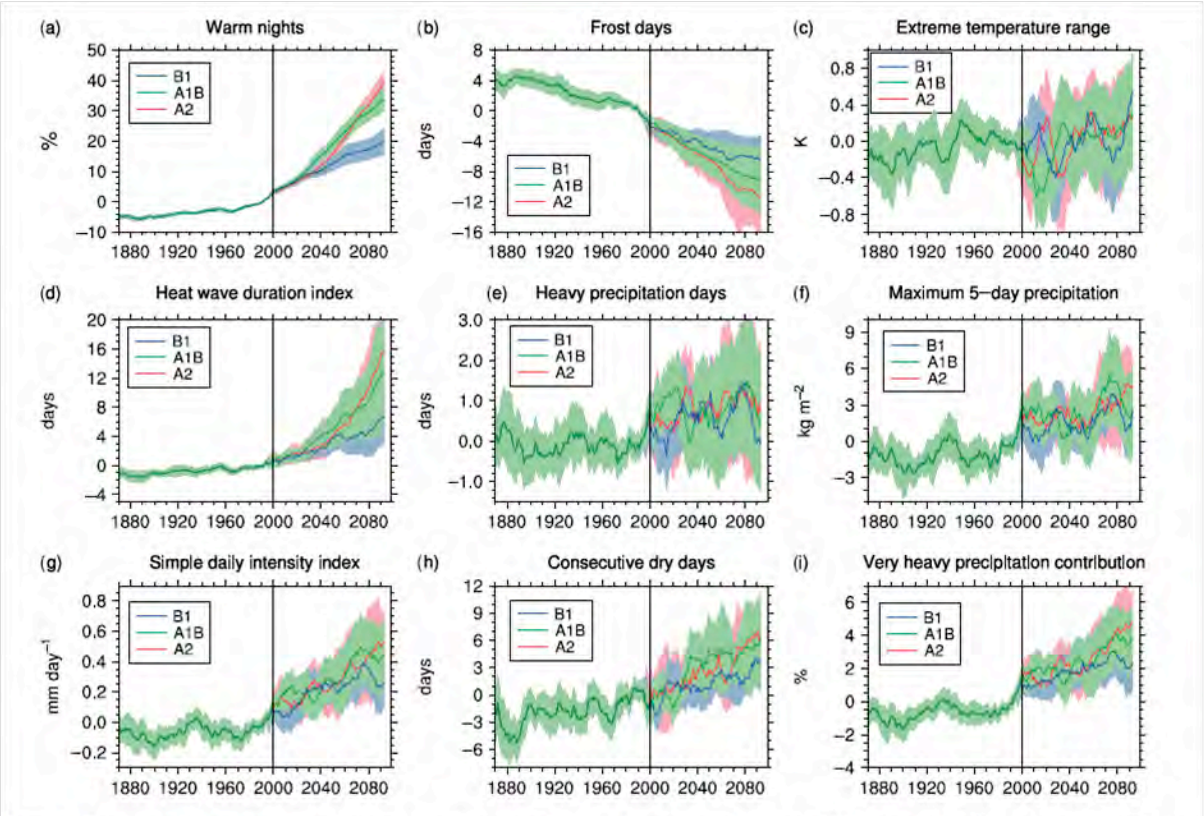


Figure 25-4: Time series of areally averaged extremes indices between 1870 and 2099.

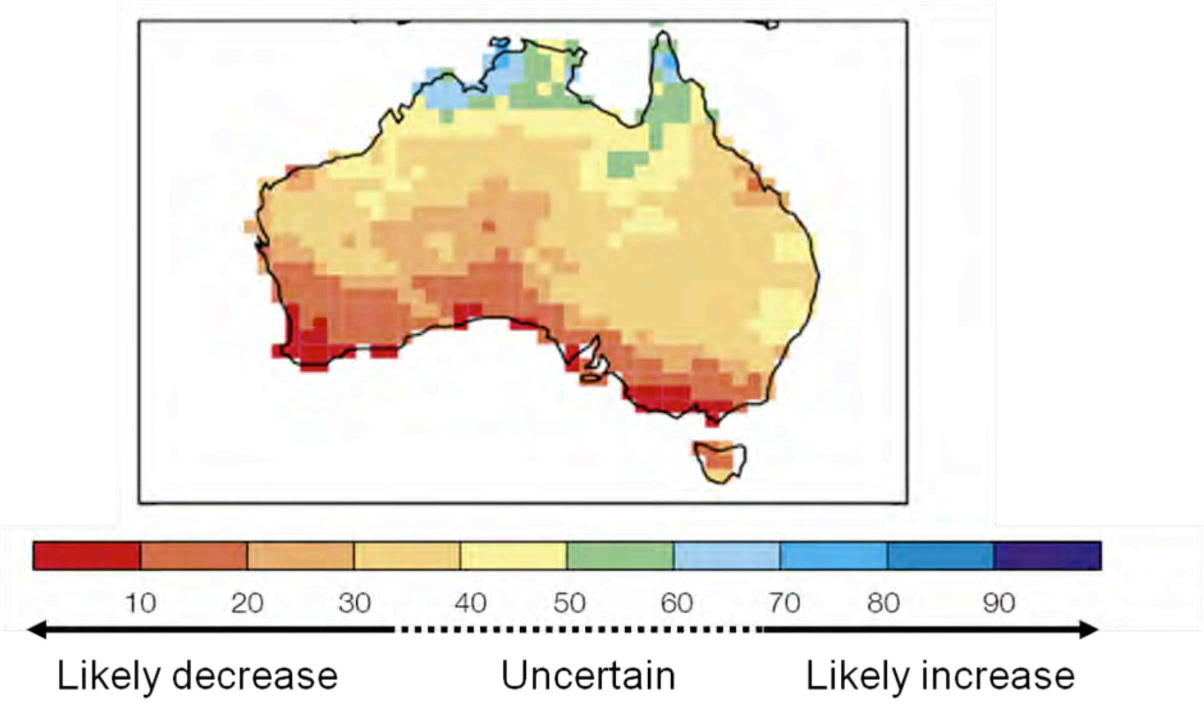
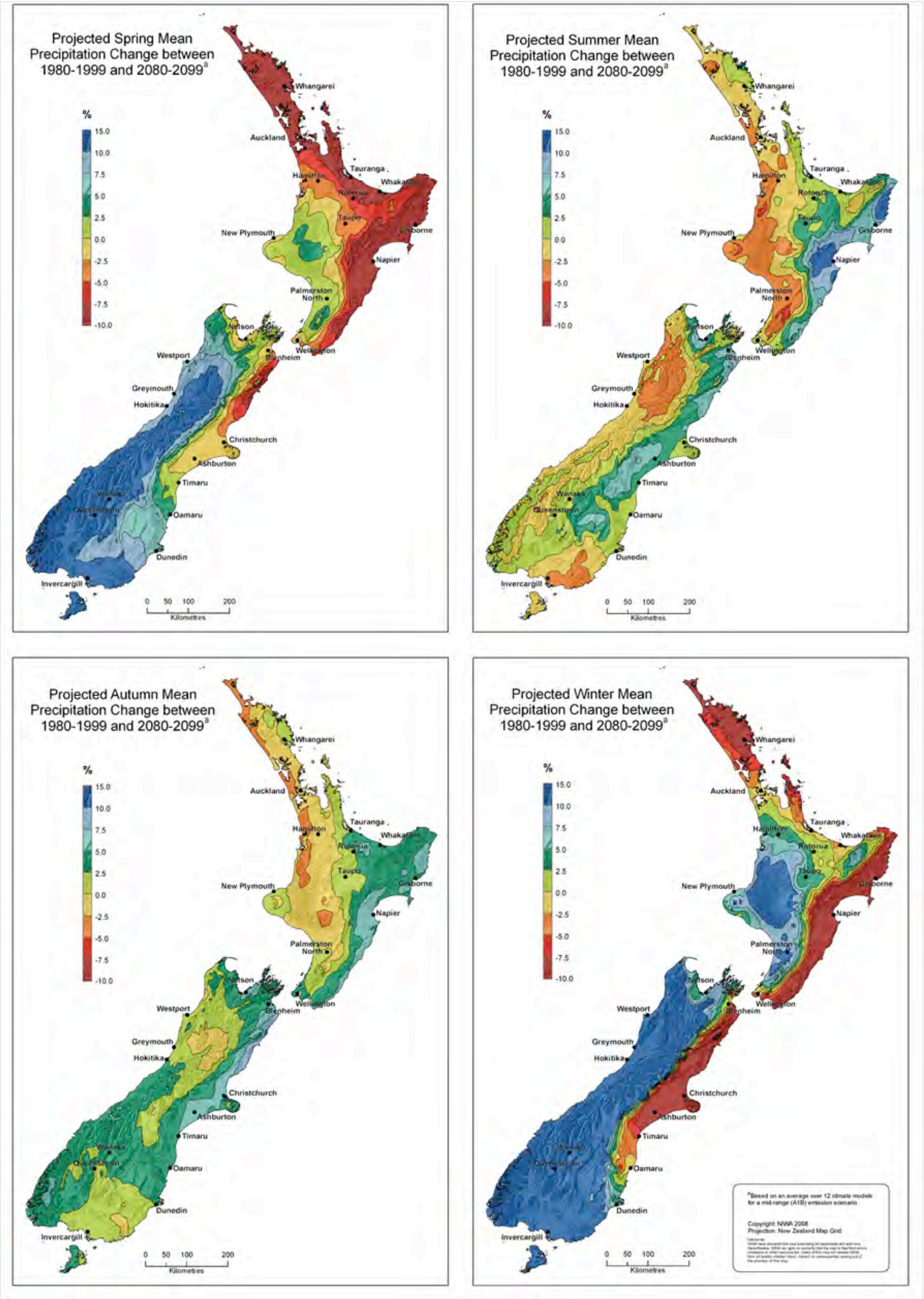


Figure 25-5



Projected Spring Mean Precipitation Change between 1980-1999 and 2080-2099[a]

Projected Summer Mean Precipitation Change between 1980-1999 and 2080-2099[a]

Projected Autumn Mean Precipitation Change between 1980-1999 and 2080-2099[a]

Projected Winter Mean Precipitation Change between 1980-1999 and 2080-2099[a]

[a]Based on an average over 12 climate models for a mid-range (A1B) emission scenario.

Copyright: NIWA 2008
Projection: New Zealand Map Grid

Figure 25-6

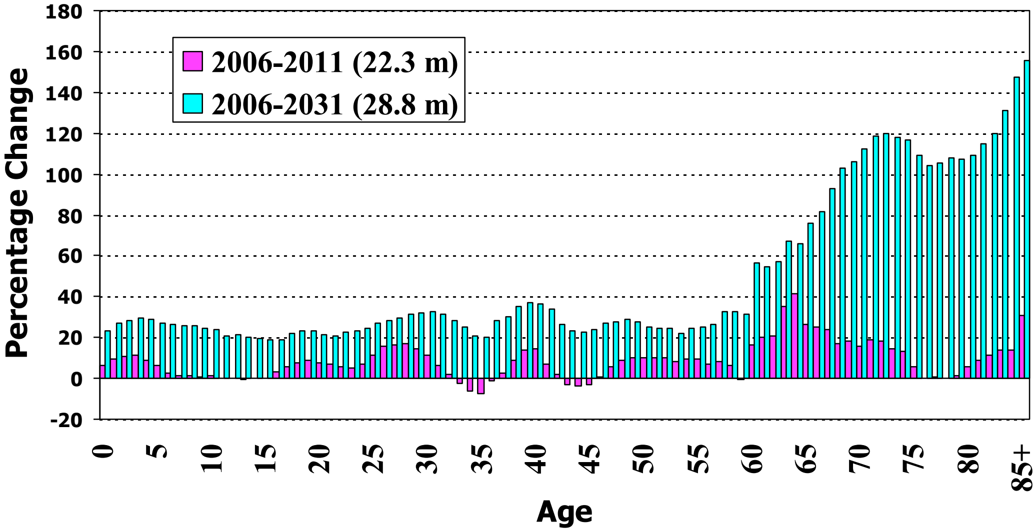


Figure 25-7: Structural aging – Australia: Change by Age: 2006-11; 2031 (Series B) (ABS, 2008).

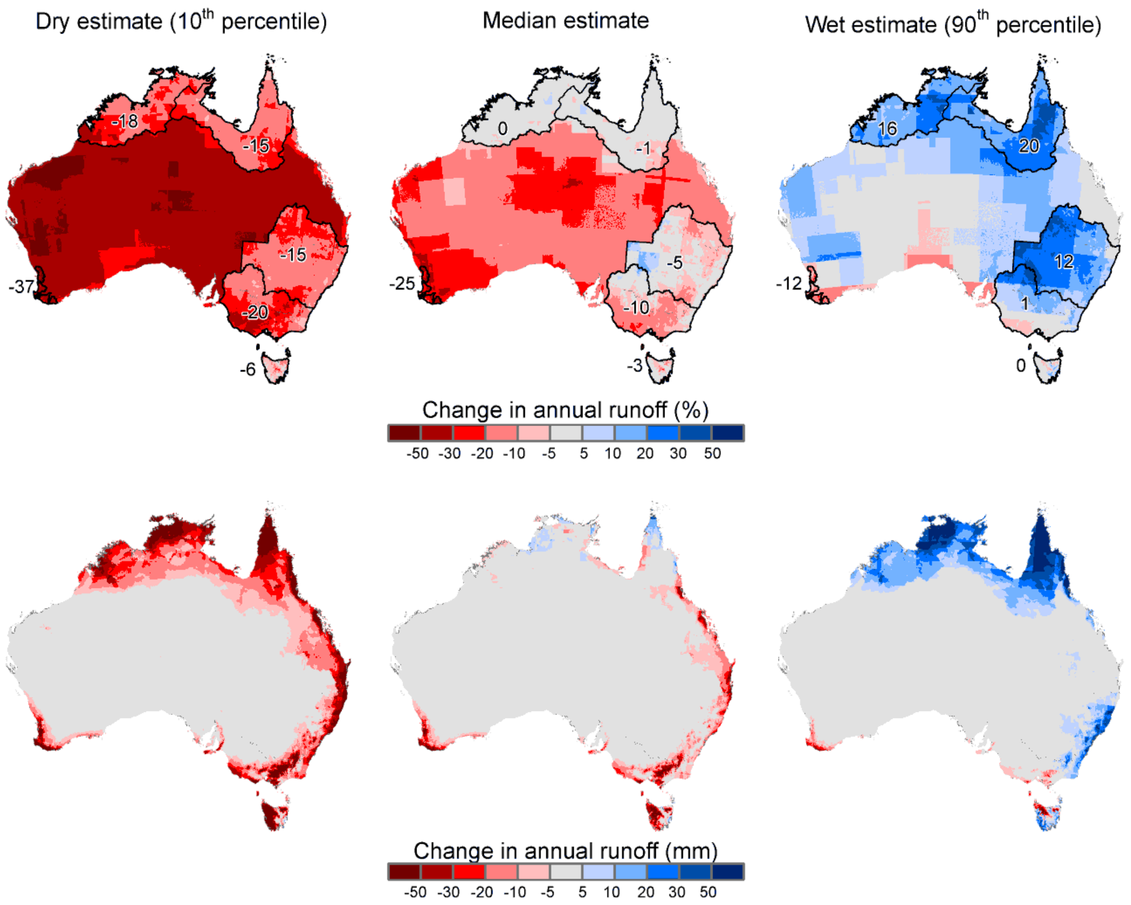


Figure 25-8: Projections of climate change impact on mean annual runoff for a 1°C global warming (median warming by 2030 relative to 1990). [*Need to check with section on 'Climate' (Penny) to ensure consistency (both the presentation/illustration and the numbers for rainfall), and/or say in text or here, that there is little difference between AR4 and AR5 (hopefully). Could possibly also do this for NZ – if Penny can do pattern scaling also for NZ, and we can apply Budyko – but being surrounded by oceans and the high dependence on catchment size and source region, I am not sure if the GCM rainfall change for NZ means much (ie need downscaling).*] The change in runoff per degree global warming scales relatively linearly up to 2-3oC warming (Post et al., 2011a) [*IUGG July 2011 paper – add reference*]. The top row shows percentage change and the bottom row shows change in runoff depth. The median and dry and wet (10th and 90th percentile) range are shown. Modelled values for south-eastern Australia (Chiew et al. 2009b), northern Australia (Petheram et al., 2011) [*Paper submitted to Journal of Hydrometeorology*], south-west Western Australia (CSIRO 2009) and Tasmania (Post et al., 2011b) [*In Press paper in Journal of Hydrology*] come from the hydrological modelling in the CSIRO Sustainable Yields projects (http://www.csiro.au/partnerships/SYP.html) and the South Eastern Australian Climate Initiative (http://www.seaci.org), informed by projections from the IPCC AR4 GCMs. Values for other areas are derived using the Budyko water and energy balance relationship (Teng et al., 2011) [*Paper submitted to Journal of Hydrometeorology*].

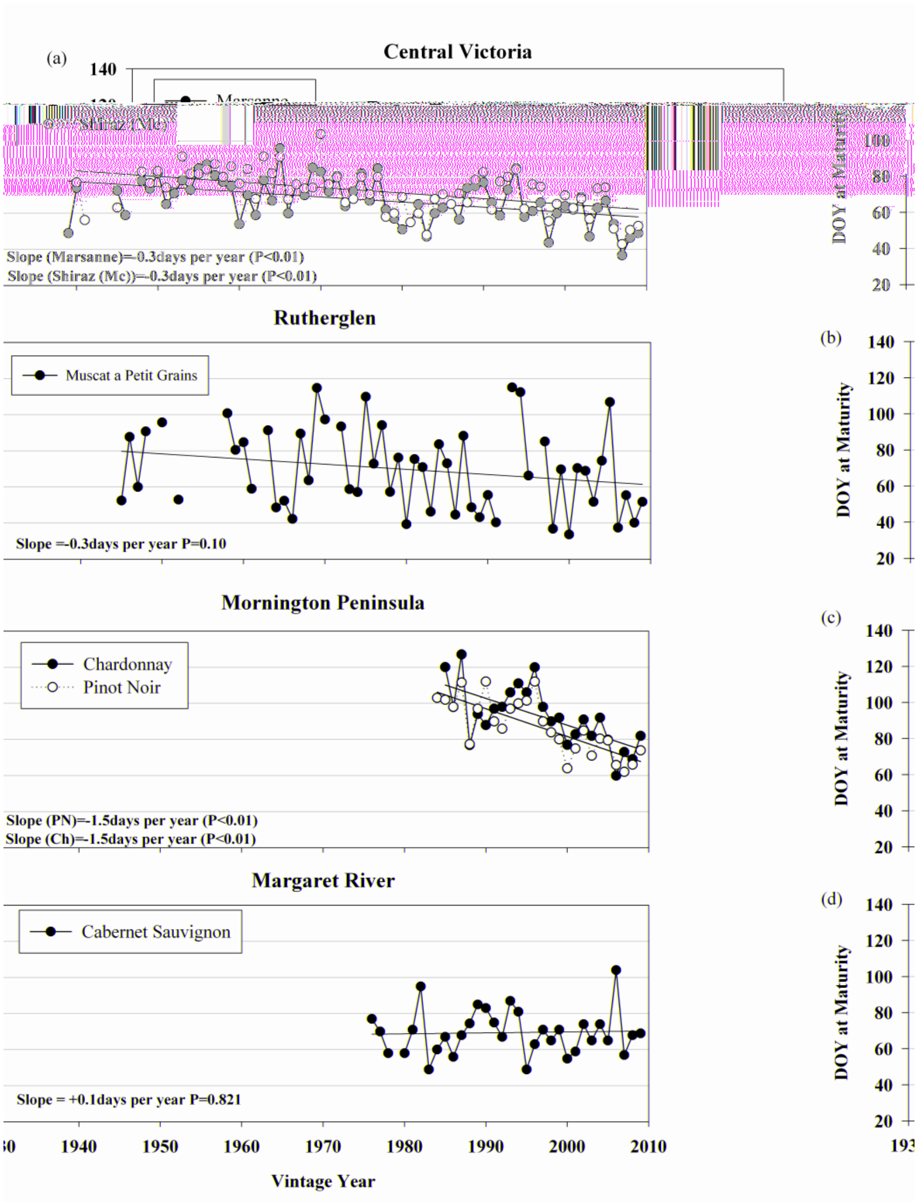


Figure 25-9: The observed day of year (DOY) at maturity recorded for six blocks from four regions in Australia (a) Central Victoria: Marsanne (1939-2009) (solid circles), Shiraz (Mc) (1940–2009) (open circles) and (b) Rutherglen (Vic.): Muscat a Petit Grains (1945–2009) (c) Mornington Peninsula (Vic.): Chardonnay (1985–2009) (solid circles) and Pinot Noir (1984–2009) (open circles) and (d) Margaret River (WA): Cabernet Sauvignon (1973–2009). The best fit linear regression indicates the average trend in the maturity day.

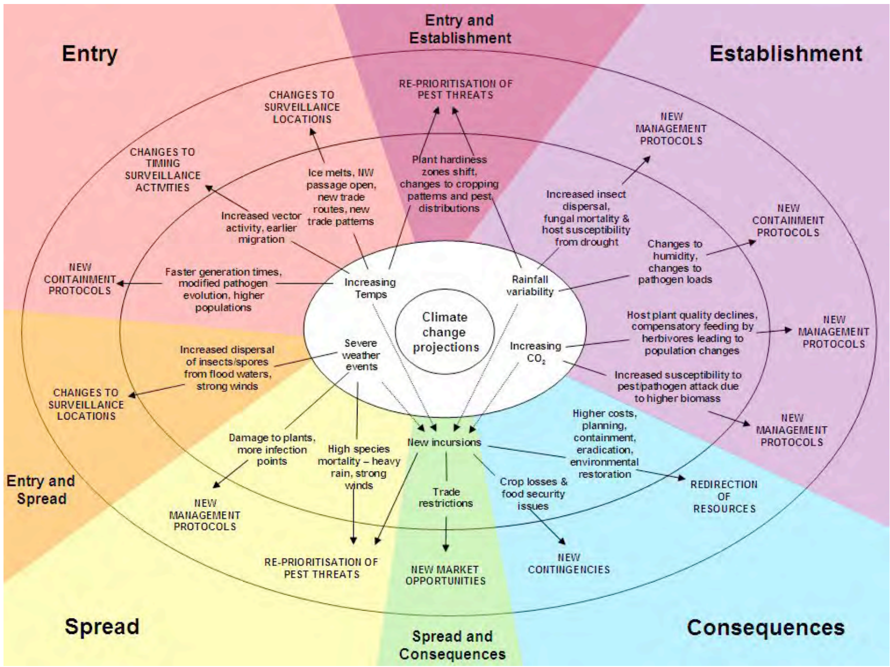


Figure 25-10: Biosecurity and climate change and the implications for policy (Luck et al.).

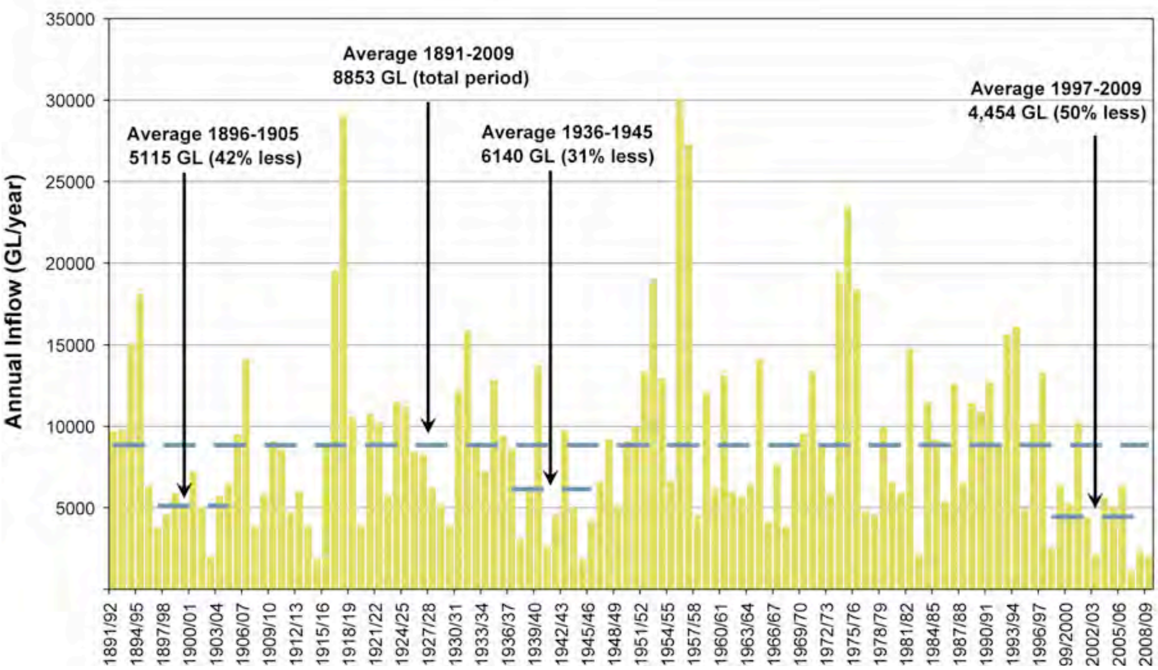


Figure 25-11: Annual series of total inflow into the Murray River showing the high inter-annual and inter-decadal variability and the low inflow over 1997-2009. (Source: Murray-Darling Basin Authority)

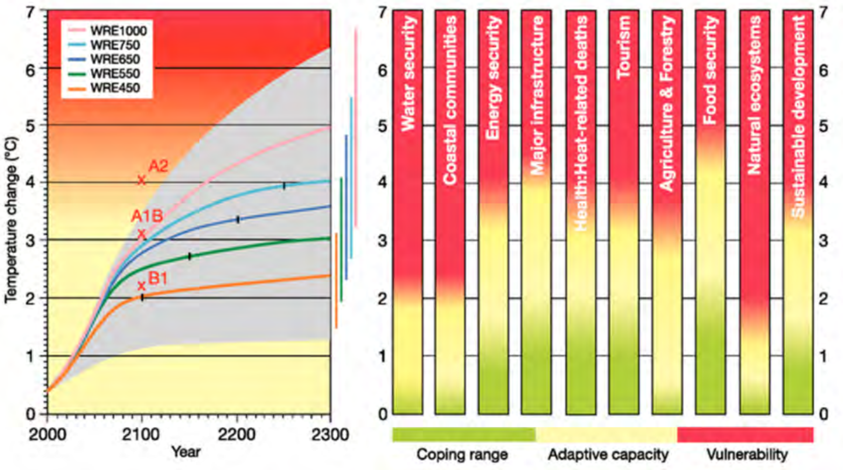


Figure 11.4. Vulnerability to climate change aggregated for key sectors in the Australia and New Zealand region, allowing for current coping range and adaptive capacity. Right-hand panel is a schematic diagram assessing relative coping range, adaptive capacity and vulnerability. Left-hand panel shows global temperature change taken from the TAR Synthesis Report (Figure SPM-6). The coloured curves in the left panel represent temperature changes associated with stabilisation of CO_2 concentrations at 450 ppm (WRE450), 550 ppm (WRE550), 650 ppm (WRE650), 750 ppm (WRE750) and 1,000 ppm (WRE1000). Year of stabilisation is shown as black dots. It is assumed that emissions of non-CO_2 greenhouse gases follow the SRES A1B scenario until 2100 and are constant thereafter. The shaded area indicates the range of climate sensitivity across the five stabilisation cases.

The narrow bars show uncertainty at the year 2300. Crosses indicate warming by 2100 for the SRES B1, A1B and A2 scenarios.

Figure 25-12
(This is the figure that was used in the AR4 Australasia chapter to summarise key vulnerabilities)