# Chapter 25. Australasia

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**Contents**

## Executive Summary

**The regional climate is changing (*very high confidence*).** The region continues to demonstrate long term trends toward higher surface air and sea-surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns. Over the past 50 years, increasing greenhouse gas concentrations have contributed to rising regional average temperature *(high confidence)* and changes to rainfall in far south-west Australia (*medium confidence*). [25.2, Table 25-1]

**Warming is projected to continue through the 21st century (*virtually certain*) along with other changes in climate.** Warming is expected to be associated with more frequent hot extremes and less frequent cold extremes (*high confidence*), and increasing extreme rainfall and flood risk in many locations (*medium confidence*). Annual average rainfall is expected to decrease in south-western Australia (*high confidence*) and elsewhere in southern Australia and the north-east South Island and northern and eastern North Island of New Zealand, and to increase in other parts of New Zealand (*medium confidence*). Tropical cyclones are projected to increase in intensity but decrease in numbers (*low confidence*), and fire weather is projected to increase in most of southern Australia (*high confidence*) and many parts of New Zealand (*medium confidence*). Regional sea level rise will *very likely* exceed the historical rate (1971-2010), consistent with global mean trends. [25.2, Table 25-1, Box 25-6, WGI 13.6]

**Uncertainty in projected rainfall changes remains large for many parts of Australia and New Zealand, which creates significant challenges for adaptation.** For example, projections for average annual runoff in far south-eastern Australia range from little change to a 40% decline for 2°C global warming. The dry end of these scenarios would have severe implications for agriculture, rural livelihoods, ecosystems and urban water supply, and would increase demands for transformative adaptation (*high confidence*). [25.2, 25.5.1, 25.6.1, 25.7.2, Box 25-2, Box 25-5]

**Recent extreme climatic events show significant vulnerability of some ecosystems and many human systems to current climate variability (*very high confidence*), and the frequency and/or intensity of such events is projected to increase in many locations (*medium* to *high confidence*).** For example, high sea surface temperatures have repeatedly bleached coral reefs in north-eastern Australia (since the late 1970s) and more recently in western Australia. Recent floods in Australia and New Zealand caused severe damage to infrastructure and settlements and 35 deaths in Queensland alone (2011); the Victorian heat wave (2009) increased heat-related morbidity and caused 374 excess deaths, and intense bushfires destroyed over 2,000 buildings and led to 173 deaths; widespread drought in south-east Australia (1997-2009) and many parts of New Zealand (2007-2009) resulted in economic losses (approximately A$7.4b in south-east Australia in 2002-03 and NZ$3.6b in direct and off-farm output in 2007-09) and mental health problems in some areas of Australia. [Table 25-1, 25.6.2, 25.8.1, Box 25-5, Box 25-6, Box 25-8]

**Without adaptation, further changes in climate, atmospheric $CO_2$ and ocean pH are projected to affect water resources, coastal ecosystems, infrastructure, agriculture, and biodiversity substantially (*high confidence*).** Freshwater resources are projected to decline in far south-west and far south-east mainland Australia (*high confidence*) and for rivers originating in the eastern and northern parts of New Zealand (*medium confidence*); rising sea levels and increasing heavy rainfall are projected to increase erosion and inundation, with consequent damages to many low-lying ecosystems, infrastructure and housing; rainfall changes and rising temperatures will shift agricultural production zones; and many endemic species will suffer from range contractions and some may face local or even global extinction. [25.5.1, 25.6.1, 25.6.2, 25.7.1, 25.7.2, 25.7.4, Box 25-1, Box 25-5, Box 25-8]

**Some sectors in some locations have the potential to benefit from projected changes in climate and increasing atmospheric $CO_2$ (*high confidence*).** Examples include reduced morbidity from winter illnesses and reduced energy demand for winter heating in New Zealand and southern parts of Australia, and forest growth in cooler regions except where soil nutrients or rainfall are limiting. Spring pasture growth in cooler regions would also increase and be beneficial for animal production if it can be utilized. [25.7.1, 25.7.2, 25.7.4, 25.8.1]

**Adaptation is already occurring and adaptation planning is becoming embedded in planning processes, albeit mostly at the conceptual rather than implementation level (*high agreement, robust evidence*).** Many solutions for reducing energy and water consumption in urban areas with co-benefits for climate change adaptation (e.g. greening cities and recycling water), are already being implemented. Planning for sea-level rise and, in Australia, reduced water availability, is becoming widely adopted, although implementation of specific policies remains piecemeal, subject to political changes, and open to legal challenges. [25.4, Box 25-1, Box 25-2, Box 25-9]

**Adaptive capacity is generally high in many human systems, but implementation faces major constraints especially for transformative responses at local and community levels (*high confidence*).** Efforts to understand and enhance adaptive capacity and adaptation processes have increased since AR4, particularly in Australia. Constraints on implementation arise from: uncertainty of projected impacts; limited financial and human resources to develop and implement effective policies and rules; limited integration of different levels of governance; lack of binding guidance on principles and priorities; different values and beliefs relating to the existence of climate change, objects and places at risk; and, attitudes towards risk. [25.4, 25.10.3, Box 25-1]

**Indigenous peoples in both Australia and New Zealand have higher than average exposure to climate change due to a heavy reliance on climate-sensitive primary industries and strong income and social connections to the natural environment, and face particular constraints to adaptation (*medium confidence*).** Social status and representation, health, infrastructure and economic issues, and engagement with natural resource industries constrain adaptation and are only partly offset by intrinsic adaptive capacity (*high confidence*). Some proposed responses to climate change may provide economic opportunities, particularly in New Zealand related to forestry. Torres Strait communities are vulnerable even to small sea level rises (*high confidence*). [25.3, 25.8.2]

**We identify eight *regional key risks* during the 21st century based on the severity of potential impacts for different levels of warming, uniqueness of the systems affected, and adaptation options (*high confidence*).** These risks differ in the degree to which they can be managed via adaptation and mitigation, and some are more likely to be realized than others, but all warrant attention from a risk-management perspective.

- Some potential impacts can be delayed but now appear very difficult to avoid entirely, even with combined globally effective mitigation and planned adaptation:
  - ***significant change in community structure of coral reef systems in Australia***, driven by increasing sea-surface temperatures and ocean acidification; the natural ability of reefs to adapt to projected changes is limited [Box CC-CR, 25.6.2, 30.5]
  - ***loss of montane ecosystems and some endemic species in Australia***, driven by rising temperatures, increased fire risk and drying trends; fragmentation of landscapes, limited dispersal and evolutionary capacity limit adaptation options [25.6.1]
- Some impacts have the potential to be severe but can be moderated or delayed significantly by globally effective mitigation combined with adaptation, with an increasing need for transformative adaptation for greater rates and magnitude of change:
  - ***increased frequency and intensity of flood damage to settlements and infrastructure in Australia and New Zealand***, driven by increasing extreme rainfall although the amount of change remains uncertain; in many locations, continued reliance on increased protection alone would become progressively less feasible [Table 25-1, 25.4.2, 25.10.3, Box 25-8]
  - ***systematic constraints on water resource use in southern Australia***, driven by rising temperatures and reduced cool-season rainfall; integrated responses encompassing management of supply, recycling, water conservation and increased efficiency across all sectors are available but face implementation constraints [25.2, 25.5.1, Box 25-2]
  - ***increasing morbidity, mortality and infrastructure damages during heat waves in Australia***, resulting from increased frequency and magnitude of extreme temperatures; vulnerable populations include the elderly, children and those with existing chronic diseases; ageing trends and prevailing social dynamics constrain effectiveness of adaptation responses [25.8.1]
  - ***increased damages to ecosystems and settlements, economic losses and risks to human life from wildfires in most of southern Australia and many parts of New Zealand***, driven by drying trends and rising temperatures; building codes, design standards, local planning mechanisms and public education can assist with adaptation and are being implemented in regions that have experienced major events [25.2, Table 25-1, 25.6.1, 25.7.1, Box 25-6]
- Some potential impacts have a low or currently unknown probability but cannot be ruled out entirely even under mitigation scenarios; these impacts would present major challenges if realized:
  - ***widespread damages to coastal infrastructure and low-lying ecosystems in Australia and New Zealand <u>if</u> sea level rise exceeds 1m***; managed retreat is a long-term adaptation strategy for human systems but options for some natural ecosystems are limited due to the rapidity of change and lack of suitable space for inland migration. Risks from sea level rise *very likely* continue to increase beyond 2100 even if temperatures are stabilised. [AR5 *WGI 13.ES;* Box 25-1, Table 25-1, 25.4.2, 25.6.1-2]
  - ***significant reduction in food production in the Murray-Darling Basin, far south-eastern Australia and some eastern and northern areas of New Zealand <u>if</u> scenarios of severe drying are realised;*** more efficient water use, allocation and trading would increase the resilience of systems in the near term but

cannot prevent significant reductions in agricultural production and severe consequences for ecosystems and some rural communities at the dry end of the projected range [25.2, 25.5.1, 25.7.2, Box 25-5]

**Significant synergies and trade-offs exist between alternative adaptation responses, and between mitigation and adaptation responses; interactions occur both within Australasia and between Australasia and the rest of the world (*very high confidence*).** Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy and biodiversity, but tools to understand and manage these interactions remain limited. Flow-on effects from climate change impacts and responses outside Australasia have the potential to outweigh some of the direct impacts within the region, particularly economic impacts on trade-intensive sectors such as agriculture (*medium confidence*), but they remain amongst the least explored issues. [25.7.5, 25.9.1, 25.9.2, Box 25-10]

**Understanding of future vulnerability of human and mixed human-natural systems to climate change remains limited due to incomplete consideration of socio-economic dimensions (*very high confidence*).** Future vulnerability will depend on factors such as wealth and its distribution across society, patterns of ageing, access to technology and information, labour force participation, societal values, and mechanisms and institutions to resolve conflicts. These dimensions have received only limited attention and are rarely included in vulnerability assessments, and frameworks to integrate social and cultural dimensions of vulnerability with bio-physical impacts and economic losses are lacking. In addition, conclusions for New Zealand in many sectors, even for bio-physical impacts, are based on limited studies that often use a narrow set of assumptions, models and data and hence have not explored the full range of potential outcomes. [25.3, 25.4, 25.11]

## 25.1. Introduction and Major Conclusions from Previous Assessments

Australasia is defined here as lands, territories, offshore waters and oceanic islands of the exclusive economic zones of Australia and New Zealand. Both countries are relatively wealthy with export-led economies. Both have Westminster-style political systems and have a relatively recent history of non-indigenous settlement (Australia in the late 18th, New Zealand in the early 19th century). Both retain significant indigenous populations.

Principal findings from the IPCC Fourth Assessment Report (AR4) for the region were (Hennessy *et al*., 2007):

- 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 sea-level rise of about 70 mm across the region; 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 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 the Australian mainland and eastern New Zealand but more rain in western New Zealand (*medium confidence*).
- Significant advances had occurred in understanding future impacts on water, ecosystems, Indigenous people and health together with an increased focus on adaptation; potential impacts would be substantial without further adaptation, particularly for water security, coastal development, biodiversity, and major infrastructure, but impacts on agriculture and forestry would be variable across the region, including potential benefits in some areas.
- Vulnerability would increase mainly due to an increase in extreme events; human systems were considered to have a higher adaptive capacity than natural systems.
- Hotspots of high vulnerability by 2050 under a medium emissions scenario included:
  - significant loss of biodiversity in areas such as 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 in areas of rapid coastal development in south-eastern Queensland and in New Zealand from Northland to the Bay of Plenty.

## 25.2. Observed and Projected Climate Change

Australasia exhibits a wide diversity of climates including moist tropical monsoonal, arid and moist temperate, including alpine conditions. Key climatic processes are the Asian-Australian monsoon and the southeast trade winds over northern Australia, and the subtropical high pressure belt and the mid-latitude storm tracks over southern Australia and New Zealand. Tropical cyclones also affect northern Australia, and, more rarely, the northernmost areas of New Zealand. Natural climatic variability is very high in the region, especially for rainfall and over Australia, with the El Nino-Southern Oscillation (ENSO) being the most important driver (McBride and Nicholls, 1983; Power *et al.*, 1998). The southern annular mode, Indian Ocean Dipole and the Pacific Decadal Oscillation are also important regional drivers (Thompson and Wallace, 2000; Cai *et al.*, 2009b). This variability poses particular challenges for detecting and projecting anthropogenic climate change and its impacts in the region. For example, changes in ENSO in response to anthropogenic climate change are uncertain (AR5 WGI Ch14) but could significantly influence rainfall and temperature extremes, droughts, fire danger, tropical cyclones, marine conditions and glacial mass balance.

Understanding of observed and projected climate change has received significant attention since AR4, particularly in Australia, with a focus on better understanding the causes of observed rainfall changes and more systematic analysis of projected changes from different models and approaches. Climatic extremes have also been a research focus. Table 25-1 presents an assessment of this body of research for observed trends and projected changes for a range of climatic variables (including extremes) relevant for regional impacts and adaptation, including examples of the magnitude of projected change where possible. Most studies are based on CMIP3 models and SRES scenarios, but CMIP5 model results are considered where available (see also AR5 WGI Chap 14 and Atlas, WGII Chapter 21).

The region has exhibited warming to the present (*very high confidence*) and is *virtually certain* to continue to do so (Table 25-1). Observed and CMIP5-modelled past and projected future annual average surface temperatures are shown in Figures 25-1 and 25-2. For further details see WGI Atlas, Figures AI.82-85.

Changes in precipitation have been observed with *very high confidence* in some areas, such as the autumn/winter decline since 1970 in south-western Australia and, since the 1990s, in south-eastern Australia, and over 1950-2004 increases in annual rainfall in the south and west of both islands of New Zealand with decreases elsewhere. Based on multiple lines of evidence, annual average rainfall is projected to decrease with at least *medium confidence* in southern Australia and in the north-east South Island and eastern and northern North Island of New Zealand, and increase in other parts of New Zealand. The direction and magnitude of rainfall change in eastern and northern Australia remains a key uncertainty (Table 25-1).

This pattern of projected rainfall change is reflected in CMIP5 model results (Figure 25-1; WGI Atlas Figures AI 86-87). Examples of the magnitude of projected annual change from 1990 to 2090 under RCP8.5 from CMIP5 are -2±21% in the Murray Darling Basin, -5±22% in Queensland and -20±13% in south-western Australia. Changes during winter and spring are more pronounced and consistent across models in many areas (see Figure 25-3), e.g. drying in the Murray Darling Basin (-16±22%, June to August) but an increase by 15% or more in the west and south of the South Island of New Zealand (Irving *et al.*, in press). Downscaled CMIP3 model projections for New Zealand indicate a stronger drying pattern in the south-east of the South Island and eastern and northern regions of the North Island in winter and spring (Reisinger *et al.*, 2010) than seen in the raw CMIP5 data; based on similar broader scale changes this pattern is expected to hold once CMIP5 data are also downscaled (Irving *et al.*, in press).

Other projected changes of at least *high confidence* include regional increases in sea surface temperature, the occurrence of hot days, extreme rainfall, mean and extreme sea level, fire danger in southern Australia, and decreases in cold days and snow extent and depth. Although changes to tropical cyclone occurrence and that of other severe storms are potentially important for future vulnerability, regional changes to these phenomena cannot be projected with at least *medium confidence* as yet.

[INSERT FIGURE 25-1 HERE
Figure 25-1: Observed and projected change in annual temperature and precipitation. For the CRU observations, differences are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.]

[INSERT FIGURE 25-2 HERE
Figure 25-2: Observed and simulated variations in past and projected future annual average temperature over land areas of Australia (left) and New Zealand (right). Black lines show several estimates from measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (68 simulations), historical changes in "natural" drivers only (30), the "RCP4.5" emissions scenario (68), and the "RCP8.5" (68). Data are anomalies from the 1986-2006 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Chapter 21.]

[INSERT FIGURE 25-3 HERE
Figure 25-3: Projected CMIP5 multi-model mean change in rainfall for 2080-2099 relative to 1980-1999, under RCP 8.5. Dots [carets] indicate where the models agree (>90% red; >67% black) that there will [will not] be a substantial increase (>10%) or decrease (< -10%). White areas indicate where the models agree (> 67%) that there will be a substantial change in rainfall (larger in magnitude than 10%) however <67% agree on the direction of this substantial change (Figure from Irving *et al*., in press).]

[INSERT TABLE 25-1 HERE
Table 25-1: Observed and projected changes in key climate variables, and (where assessed) the contribution of human activities to observed changes. For further relevant information see WGI Chapters 3, 6 (ocean changes, including acidification), 11, 12 (projections), 13 (sea level) and 14 (regional climate phenomena).]

## 25.3. Socio-Economic Trends Influencing Vulnerability and Adaptive Capacity

### *25.3.1. Economic, Demographic and Social Trends*

The economies of Australia and New Zealand rely on natural resources, agriculture, minerals, manufacturing and tourism, but the relative importance of these sectors differs between the two countries. Agriculture and mineral/energy resources accounted, respectively, for 11% and 54% (Australia) and 56% and 5% (New Zealand) of the value of total exports in 2009/2010 (ABARES, 2010; Stats NZ, 2011c). Australia and New Zealand abstracted an estimated 930 and 940 $m^3$ of water per capita in 2007, with about half used for irrigation (OECD, 2011). Between 1970 and 2011, GDP grew by an average of 3.2% p.a. in Australia and 2.4% p.a. in New Zealand, with annual GDP per capita growth of 1.8% and 1.2%, respectively (Stats NZ, 2011a; ABS, 2012b; Stats NZ, 2012). GDP is projected to grow on average by 2.5-3.5% p.a. in Australia and about 1.9% p.a. in New Zealand to 2050 (Australian Treasury, 2010; Bell *et al*., 2010) subject to significant short-term fluctuations.

The populations of Australia and New Zealand are projected to grow significantly over at least the next several decades (*very high confidence*) due to immigration and changes in mortality and fertility (ABS, 2008; Stats NZ, 2011b); Australia's population from 22.4 million in 2011 to 31-43 million by 2056 and 34-62 million by 2101 (ABS, 2008); New Zealand's population from 4.4 million in 2011 to 4.8-6.7 million by 2061 (Stats NZ, 2011b). The number of people aged 65 and over is projected to double in the next two decades (Australian Treasury, 2010; Stats NZ, 2011b). More than 20% of Australian and New Zealand residents were born overseas (OECD, 2011). More than 85% of the Australasian population lives in urban areas and their satellite communities (Stats NZ, 2004; ABS, 2008), mostly in coastal areas (DCC, 2009; Stats NZ, 2010b). Urban concentration and depletion of remote rural areas is expected to continue (Mendham and Curtis, 2010; Stats NZ, 2010c), but some coastal non-urban spaces also face increasing development pressure (Freeman and Cheyne, 2008; Gurran, 2008).

Poverty rates and income inequality in New Zealand and Australia are in the upper half of OECD countries. Both measures increased significantly in New Zealand between the mid-1980s and mid-2000s (OECD, 2011). Measurement of poverty and inequality, however, is highly contested and anticipating future changes and effects on adaptive capacity remain difficult (Peace, 2001; Scutella *et al.*, 2009).

Indigenous peoples constitute about 2% and 15% of the Australian and New Zealand populations, respectively, but are growing faster than the average and, in Australia, constitute a much higher percentage of the population in remote and very remote regions (ABS, 2009; Biddle and Taylor, 2009; ABS, 2010a; Stats NZ, 2010a). Indigenous peoples in both countries have lower than average life expectancy, income and education, implying that changes in socio-economic status and social inclusion could strongly influence their future adaptive capacity (25.8.2).

### *25.3.2. Use and Relevance of Socio-Economic Scenarios in Adaptive Capacity/Vulnerability Assessments*

Demographic, economic and socio-cultural trends influence the vulnerability and adaptive capacity of individuals and communities (see Chapters 2, 11-13, 16). A limited but growing number of studies in Australasia have attempted to incorporate such information, e.g. changes in the number of people and percentage of elderly people at risk (Preston *et al.*, 2008; Baum *et al.*, 2009; Preston and Stafford-Smith, 2009; Roiko *et al.*, 2012), the density of urban settlements and exposed infrastructure (Preston and Jones, 2008; Preston *et al.*, 2008; Baynes *et al.*, 2012), population-driven pressures on water demand (CSIRO, 2009a), and economic and social factors affecting individual coping, planning and recovery capacity (Dwyer *et al.*, 2004; Khan, 2012; Khan *et al.*, 2012; Roiko *et al.*, 2012).

Socio-economic considerations are used increasingly to understand adaptive capacity of communities (Preston *et al.*, 2008; Smith *et al.*, 2008; Fitzsimons *et al.*, 2010; Soste, 2010; Brunckhorst *et al.*, 2011; Cradock-Henry, in press) and to construct scenarios to help build regional planning capacity (CSIRO, 2006; Frame *et al.*, 2007; Pride *et al.*, 2010; Pettit *et al.*, 2011; Taylor *et al.*, 2011). Such scenarios, however, are only beginning to be used to quantify vulnerability to climate change (except e.g. Bohensky *et al.*, 2011; Baynes *et al.*, 2012; Low Choy *et al.*, 2012).

Apart from these emerging efforts, most vulnerability studies from Australasia make no or very limited use of socio-economic factors, consider only current conditions, and/or rely on postulated correlations between generic socio-economic indicators and climate change vulnerability. In many cases this limits confidence in conclusions regarding future vulnerability to climate change and adaptive capacity of human and mixed natural-human systems.

## 25.4. Cross-Sectoral Adaptation: Approaches, Effectiveness, and Constraints

### *25.4.1. Frameworks, Governance, and Institutional Arrangements*

Adaptation to climate change is motivated by experienced and expected changes in climate but also influenced by non-climate pressures, social and cultural values, perceptions of risk, and economic and political considerations. Adaptation responses depend heavily on institutional and governance arrangements that enable decision-makers to consider climate change information (see Chapters 2, 14, 15, 16, 20; Downing, 2012).

Responsibility for development and implementation of adaptation policy in Australasia is largely devolved to local governments and, in Australia, to State governments and Natural Resource Management bodies. Federal/central government supports adaptation mostly via provision of information, tools, legislation, policy guidance and (in Australia) support for pilot projects. A standard risk management paradigm has been promoted to embed adaptation into decision-making practices (AGO, 2006; MfE, 2008d; Standards Australia, 2012).

The Council of Australian Governments agreed a national adaptation policy framework in 2007 (COAG, 2007). This included establishing the collaborative National Climate Change Adaptation Research Facility (NCCARF) in 2008, which complements CSIRO's Climate Adaptation Flagship. The federal government supported a first-pass national coastal risk assessment (DCC, 2009; DCCEE, 2011), and reports addressing impacts and management options for natural and managed landscapes (Campbell, 2008; Steffen *et al*., 2009; Dunlop *et al*., 2012), National and World Heritage areas (ANU, 2009; BMT WBM, 2011), and indigenous and urban communities (Green *et al*., 2009; Norman, 2010). In New Zealand, the central government updated and expanded tools to support impact assessments and adaptation responses consistent with regulatory requirements (MfE, 2008a, d, c, 2010a), and revised key directions for coastal management (Minister of Conservation, 2010). No cross-sectoral adaptation policy framework or national-level risk assessments exist, but some departments commissioned high-level impacts assessments after the AR4 (e.g. on agriculture and on biodiversity; Wratt *et al*., 2008; McGlone and Walker, 2011).

Public and private sector organisations are potentially important adaptation actors but exhibit large differences in preparedness, linked to knowledge and belief about climate change, economic opportunities, external connections, size, familiarity with strategic planning and planning horizons (Gardner *et al*., 2010; Johnston *et al*., 2012; Murta *et al*., 2012; Taylor *et al*., 2012a). This creates challenges for achieving holistic societal outcomes (see also 25.7-25.9).

Several recent policy initiatives in Australia, while responding to broader socio-economic and environmental pressures, include goals to reduce vulnerability to climate variability and change. These include establishing the Murray-Darling Basin Authority to address over-allocation of water resources (Connell and Grafton, 2011; MDBA, 2011), removal of the interest rate subsidy during exceptional droughts (Productivity Commission, 2009), and management of bush fire risk (VBRC, 2010). These may be seen as examples of mainstreaming adaptation (Dovers, 2009), but they also demonstrate lag times in policy design and implementation and windows of opportunity presented by crises (e.g. the Millennium Drought 1997-2009, the Victorian bushfires 2009), and the challenges arising from competing interests in managing finite water resources (Botterill and Dovers, 2013; Box 25-2).

### *25.4.2. Constraints on Adaptation and Emerging Leading Practice Models*

A rapidly growing literature since the AR4 confirms, with *high confidence,* that while the adaptive capacity of society in Australasia is generally high, there are formidable environmental, economic, informational, social, attitudinal and political constraints, especially at the community level, and for small or highly fragmented industries. Reviews of public- and private-sector adaptation plans and strategies in Australia demonstrate strong efforts in institutional capacity building, but differences in assessment methods and weaknesses in translating goals into specific policies (White, 2009; Gardner *et al*., 2010; Measham *et al*., 2011; Preston *et al*., 2011; Kay *et al*., 2013). Similarly, local governments in New Zealand to date have mostly focused on impacts and climate-related hazards but few have committed to specific climate change responses (e.g. O'Donnell, 2007; Britton, 2010; Fitzharris, 2010; HRC, 2012; KCDC, 2012; Lawrence *et al*., submitted-b).

Table 25-2 lists key constraints and corresponding enabling factors for effective institutional adaptation processes identified in Australia and New Zealand. Scientific uncertainty and resources limitations are reported consistently as important constraints, particularly for smaller councils. Ultimately more powerful constraints arise, however, from current legislative, institutional and governance arrangements and the lack of consistent tools to deal with dynamic risks and uncertainty or to evaluate the success of adaptation responses (*high agreement, robust evidence*; Britton, 2010; Mukheibir *et al*., 2013; Lawrence *et al*., submitted-b; Webb *et al*., submitted; see also Chapter 16).

[INSERT TABLE 25-2 HERE
Table 25-2: Constraints and enabling factors for institutional adaptation processes in Australasia.]

Some constraints exacerbate others. There is *high confidence* that the absence of a consistent information base and binding guidelines that clarify governing principles and liabilities is a challenge particularly for small and resource-limited local authorities, which need to balance special interest advocacy with longer term community resilience. This heightens reliance on individual leadership subject to short-term political change (Smith *et al*., 2008; Brown *et al*., 2009; Norman, 2009; Britton, 2010; Preston and Kay, 2010; Rouse and Norton, 2010; Smith *et al*., 2010; Abel *et al*., 2011; McDonald, 2011; Rive and Weeks, 2011; Corkhill, 2013). In these situations, planners tend to rely more on single numbers for climate change projections that can be argued in court (Reisinger *et al*., 2011; Lawrence *et al*., submitted-b), which increases the risk of maladaptation given the uncertain and dynamic nature of climate risk (McDonald, 2010; Stafford-Smith *et al*., 2011b; Gorrdard *et al*., 2012; McDonald, 2013; Reisinger *et al*., 2013).

Vulnerability assessments that take mid- to late-century impacts as their starting point can inhibit actors from implementing adaptation actions, as distant impacts are easily discounted and difficult to prioritise in competition with near-term non-climate change pressures (Productivity Commission, 2012). Emerging leading practice models in Australia (Balston, 2012; HCCREMS, 2012; SGS, 2012a, b) and New Zealand (MfE, 2008e; Britton *et al*., 2011) recommend a high-level scan of sectors and locations at risk and emphasise a focus on near-term decisions that influence current and future vulnerability (which could range from early warning systems to strategic and planning responses). More detailed assessment can then focus on this more tractable subset of issues, based on explicit and iterative framing of the adaptation issue (Webb *et al*., submitted) and taking into account the full lifetime (lead- and consequence time) of the decision/asset in question (Stafford-Smith *et al*., 2011b).

Participatory processes help balance societal preferences with robust scientific information and ensure ownership by affected communities (*high confidence*), but rely on human capital and political commitment (Hobson and Niemeyer, 2011; Rouse and Blackett, 2011; Weber *et al*., 2011; Leitch and Robinson, 2012). Realising widespread and equitable participation is challenging where policies are complex, debates polarised, legitimacy of institutions contested and potential transformational changes threaten deeply held values (Gardner *et al*., 2009a; Gorrdard *et al*., 2012; Burton and Mustelin, 2013; see also 25.4.3). Regional approaches that engage diverse stakeholders, government and science providers and support the co-production of knowledge can help overcome some of these problems but require long-term institutional and financial commitments (e.g. Britton *et al*., 2011; DSEWPC, 2011; CSIRO, 2012; IOCI, 2012; Low Choy *et al*., 2012; Webb and Beh, 2013).

An emerging literature questions whether incremental adjustments of existing planning instruments, institutions and decision-making processes can deal adequately with the dynamic and uncertain nature of climate change and support transformative responses (Kennedy *et al*., 2010; Preston *et al*., 2011; Park *et al*., 2012; McDonald, 2013; Stafford-Smith, 2013; Lawrence *et al*., submitted-b). Recent studies suggest a greater focus on flexibility and matching decision-making frameworks to specific problems (Hertzler, 2007; Nelson *et al*., 2008; Dobes, 2010; Howden and Stokes, 2010; Randall *et al*., 2012). Limitations of mainstreamed and autonomous adaptation (Dovers and Hezri, 2010) and the potential need for more proactive government intervention are being explored in Australia (see Productivity Commission, 2012, including submissions), but have not yet resulted in new policy frameworks.

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**Box 25-1. Coastal Adaptation – Planning and Legal Dimensions**

Sea level rise is a significant risk to Australia and New Zealand (*very high confidence*) due to intensifying coastal development and the location of population centres and infrastructure (Freeman and Cheyne, 2008; DCC, 2009; see also 25.3). Local case studies in New Zealand (Fitzharris, 2010; Reisinger *et al*., 2013) and national reviews in Australia (DCC, 2009; DCCEE, 2011) demonstrate risks to large numbers of residential and commercial assets as well as key services. In Australia, sea level rise of 1.1 m would affect over A$226 billion of assets, including up to 274,000 residential and 8,600 commercial buildings (DCCEE, 2011), with additional intangible costs related to stress, health effects and service disruption (HCCREMS, 2010). Under expected future settlement patterns, exposure of the Australian road and rail network will increase significantly once sea level rise exceeds about 0.5 m (Baynes *et al*., 2012). While the magnitude of sea level rise during the 21$^{st}$ century remains uncertain, its persistence over many centuries implies that realization of these risks is only a question of time (AR5 WGI Chapter 13).

Responsibility for adapting to sea level rise in Australasia rests principally with local governments through spatial planning instruments. Western Australia, South Australia and Victoria have mandatory State planning benchmarks for 2100, with local governments determining how they should be implemented. Long-term benchmarks in NSW and Queensland have either been suspended or revoked, so local authorities now have broad discretion to develop their own adaptation plans. The New Zealand Coastal Policy Statement (Minister of Conservation, 2010) mandates a minimum 100-year planning horizon for assessing hazard risks, discourages protection of existing development and recommends avoidance of new development in vulnerable areas. Non-binding government guidance recommends a risk based approach, using a base value of 0.5 m sea level rise by the 2090s and at least considering implications of greater rises of 0.8 m, and 0.1 m per decade beyond 2100, where relevant (MfE, 2008c).

The incorporation of climate change impacts into local planning has evolved considerably over the past 20 years, but remains piecemeal and shows a diversity of approaches (Gibbs and Hill, 2012; Kay *et al*., 2013). Many local governments lack the resources for hazard mapping and policy design. Political commitment is variable, and legitimacy of approaches and institutions is often strongly contested (Gorrdard *et al*., 2012), including pressure on State governments to modify adaptation policies and on local authorities to compensate developers for restrictions on current or future land uses (LGNZ, 2008; Berry and Vella, 2010; McDonald, 2010; Reisinger *et al*., 2011). There is *limited evidence* but *high agreement* that incremental local coastal adaptation responses can generate a path-dependency that becomes increasingly difficult to overcome (Gorrdard *et al*., 2012; McDonald, 2013), with appreciating land values supporting ever greater emphasis on protection (Fletcher *et al*., submitted). Strategic regional-scale planning initiatives in rapidly growing regions, like southeast Queensland, allow climate change adaptation to be addressed in ways that are not typically achieved by locality- or sector-specific plans, but require effective coordination across different scales of governance (Low Choy *et al*., 2013; Smith *et al*., 2013).

Courts in both countries have played an important role in evaluating planning measures. Results of litigation have varied and, in the absence of clearer legislative guidance, more litigation is expected as rising sea levels affect existing properties and adaptation responses constrain development on coastal land (MfE, 2008c; Rive and Weeks, 2011; Verschuuren and McDonald, 2012; Corkhill, 2013).

In addition to raising minimum floor levels and creating coastal set-backs to limit further development in areas at risk, several councils have attempted to implement managed retreat policies, such as Byron Shire Council, Australia (BSC, 2010), Environment Canterbury and Kapiti Coast District Council, New Zealand (ECAN, 2005; KCDC, 2012). These policies remain largely untested in New Zealand, but experience in Australia has shown high litigation potential and opposing priorities at different levels of government, undermining retreat policies (Parliament of Australia, 2009; DCC, 2010; Abel *et al*., 2011). Mandatory disclosure of information about future risks, community engagement and policy stability are critical to support retreat, but existing-use rights, liability concerns, special interests, community resources, place attachment and divergent priorities at different levels of government present powerful barriers (*high agreement, robust evidence*; Hayward, 2008a; Berry and Vella, 2010; McDonald, 2010; Abel *et al*., 2011; Alexander *et al*., 2012; Leitch and Robinson, 2012; Reisinger *et al*., 2013).

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### *25.4.3. Socio-cultural Factors Influencing Impacts of and Adaptation to Climate Change*

Adapting to climate change relies on individuals accepting and understanding changing risks, implications, and opportunities, and responding to these risks and changes both psychologically and behaviourally within their respective spheres of influence (see Chapters 2, 16). The majority of Australasians accept the reality of climate change and less than 10% fundamentally deny its existence (high confidence; ShapeNZ, 2009; Leviston *et al*., 2011; Lewandowsky, 2011; Lewandowsky *et al*., 2012; Milfont, 2012; Reser *et al*., 2012b, c). Australians generally perceive themselves to be at higher risk from climate change than New Zealanders and citizens of many other countries, which may reflect recent climatic extremes and their impacts (Gifford *et al*., 2009; Agho *et al*., 2010; Ashworth *et al*., 2011; Milfont *et al*., 2012; Reser *et al*., 2012b). However, beliefs about climate change and the risks posed vary over time, are uneven across society and reflect media coverage and bias, political preferences, and gender (ShapeNZ, 2009; Bacon, 2011; Leviston *et al*., 2012; Milfont, 2012), which can influence the willingness of communities and businesses to consider adaptation (Gardner *et al*., 2010; Gifford, 2011; Reser *et al*., 2011; Alexander *et al*., 2012; Raymond and Spoehr, 2013).

Surveys in Australia between 2007 and 2011 show moderate to high levels of climate change concern, distress, frustration, resolve, motivation, psychological adaptation, and carbon-reducing behavioural engagement (high agreement, medium evidence; Agho *et al*., 2010; Reser *et al*., 2012b, c). About two thirds of respondents perceived global warming as likely to worsen, with about half very or extremely concerned that they or their family would be directly affected. Direct personal experience with environmental changes or events attributed to climate change, reported by 45% of respondents, was particularly significant and influential, but concern about global warming was also linked to general psychological distress levels. The extent to which distress and concern about climate change impacts translate into actual support for proactive adaptation responses has not yet been fully assessed.

Perceived levels of risk and potential losses from climate change depend on values attributed and invested by individuals to specific places, activities and objects. Examples from Australia include the value placed on winter snow cover in the Snowy Mountains (Gorman-Murray, 2008, 2010), risks to biodiversity and recreational values in coastal South Australia (Raymond and Brown, 2011), conflicts between human uses and environmental priorities in national parks (Wyborn, 2009; Roman *et al*., 2010), and alternative uses of limited water resources in rural areas (Alston, 2010; Hurlimann and Dolnicar, 2011; Kingsford *et al*., 2011). These and additional studies in Australasia addressing place connection and environmental change (e.g. Rogan *et al*., 2005; McCleave *et al*., 2006; Collins and Kearns, 2010; Gosling and Williams, 2010; Raymond *et al*., 2011) confirm the importance of place attachment in understanding psychological dimensions of climate change impacts.

Acceptable adaptation responses are similarly influenced and often constrained by social and cultural values and norms. Place attachment and differing values relating to near- versus long-term, private versus public costs and benefits, and legitimacy of institutions influence adaptation preferences, e.g. in the coastal zone (Hayward, 2008b; Agyeman *et al*., 2009; King *et al*., 2010; Gorrdard *et al*., 2012; Hofmeester *et al*., 2012) and acceptance of water recycling or pricing (Pearce *et al*., 2007; Miller and Buys, 2008; Hurlimann and Dolnicar, 2010; Kouvelis *et al*., 2010; Mankad and Tapsuwan, 2011). On the other hand, place attachment, connection, and identity can also offer substantial benefits and support with respect to adaptation challenges and impacts, including stress reduction, restoration, recreation, and continuity, and enhancement of environmental quality, subjective well being, and mental health, especially for disadvantaged and indigenous communities (Berry *et al*., 2010; see also 25.9.2).

These studies indicate that the threat of and direct and indirect experience of climate change and extreme climatic events are having appreciable psychological impacts, but also result in psychological and subsequent behavioural adaptations, reflected in high levels of acceptance and realistic concern, motivational resolve, self-reported changes in thinking, feeling and understanding of climate change and its implications, and behavioural engagement (Reser and Swim, 2011; Reser *et al*., 2012a; Reser *et al*., 2012b, c). However, adequate ongoing and standardised impact assessment strategies and systems are lacking to monitor trends and to compare impacts with bio-physical and economic impacts that dominate the climate change vulnerability literature.

## 25.5. Freshwater Resources

### *25.5.1. Projected Impacts*

Impact of climate change on water resources and river flow characteristics is a cross-cutting issue affecting people, agriculture, industries and ecosystems. The challenge of satisfying multiple demands with a limited resource is exacerbated by the high inter-annual and inter-decadal variability of river flows (Chiew and McMahon, 2002; Peel *et al*., 2004; Verdon *et al*., 2004; McKerchar *et al*., 2010) particularly in Australia.

Figure 25-4 shows estimated changes to mean annual runoff across Australia for a 1°C global average warming (Chiew and Prosser, 2011; Teng *et al*., 2012). The range of estimates arises mainly from uncertainty in projected precipitation (Table 25-1). Hydrological modelling based on CMIP3 climate models indicates that freshwater resources in far south-eastern and far south-west Australia will decline (*high confidence;* by 0-40% and 20-70%, respectively, for 2°C warming) due to the reduction in winter half-year precipitation (Table 25-1 and Figure 25-3) when most of the runoff in southern Australia occurs. The percent change in mean annual precipitation in Australia is generally amplified as a 2–3 times larger percent change in mean annual streamflow (Chiew, 2006; Jones *et al.*, 2006). This can vary, however, with unprecedented declines in flow in far south-eastern Australia in the 1997–2009 drought (Cai and Cowan, 2008; Potter *et al.*, 2010; Chiew *et al.*, 2011; Potter and Chiew, 2011). Higher temperatures and associated evaporation, tree re-growth following more frequent bushfires (Kuczera, 1987; Cornish and Vertessy, 2001; Marcar *et al.*, 2006; Lucas *et al.*, 2007), interception activities like farm dams (Van Dijk *et al.*, 2006; Lett *et al.*, 2009) and reduced surface-groundwater connectivity in long dry spells (Petrone *et al.*, 2010; Hughes *et al.*, 2012) can further accentuate declines. In the longer-term, water availability will also be affected by changes in vegetation and surface-atmosphere feedbacks from a warmer and higher $CO_2$ environment (Betts *et al.*, 2007; Donohue *et al.*, 2009; McVicar *et al.*, 2010).

[INSERT FIGURE 25-4 HERE
Figure 25-4: Estimated changes in mean annual runoff for a 1°C global average warming. Maps show changes in annual runoff (percentage change; top row) and runoff depth (millimetres; bottom row), for median, dry and wet ($10^{th}$ and $90^{th}$ percentile) range of estimates, based on hydrological modelling using CMIP3 models (Chiew *et al.*, 2009; CSIRO, 2009b; Petheram *et al.*, 2012; Post *et al.*, 2012). Projections for 2°C global average warming are about twice that shown in the maps (Post *et al.*, 2011). (Figure adapted from Chiew and Prosser, 2011; Teng *et al.*, 2012).]

In New Zealand, projected precipitation changes (Table 25-1) will generally lead to increased runoff in the west and south of the South Island and reduced runoff in the north-east of the South Island, and the east and north of the North Island (*medium confidence*). Annual flows of eastward flowing rivers with headwaters in the Southern Alps (Clutha, Waimakariri, Rangitata) are projected to increase by 5-10 % (median projection) by 2040 (Bright *et al.*, 2008; Poyck *et al.*, 2011; Zammit and Woods, 2011b, a) in response to higher alpine precipitation. Most of the projected increases occur in winter and spring, as more precipitation falls as rain and snow melts earlier. In contrast, the Ashley River, slightly north of this region, is projected to have little change in annual flows, with the increase in winter flows offset by reduced summer flows (Woods *et al.*, 2008). The retreat of glaciers is expected to have only a minor impact on river flows in the first half of the century (Chinn, 2001; Anderson *et al.*, 2008). Limited modelling studies show reduced mean annual streamflow in the east and north of the North Island: for example by 14% (median projection) by 2040 in the Waipaoa River, in response to projected precipitation decline and higher temperature (Zemansky, 2010; Collins, 2012).

Climate change will affect groundwater through changes in recharge rates and the relationship between surface waters and aquifers. Dryland diffuse recharge in most of western, central and southern Australia is projected to decrease because of the decline in precipitation, with increases in the north and some parts of the east because of projected increase in extreme rainfall intensity (*medium confidence*; Crosbie *et al.*, 2010; McCallum *et al.*, 2010; Crosbie *et al.*, 2012). There has been little research in New Zealand, with one study projecting groundwater recharge in the Canterbury Plains to decrease by about 10% by 2040 (Bright *et al.*, 2008).

### *25.5.2. Adaptation*

The 1997-2009 'Millennium' drought in south-eastern Australia and projected declines in future water resources in southern Australia are already stimulating adaptation (Box 25-2). In New Zealand, there is little evidence of this. Water in New Zealand is not as scarce generally and water policy reform is driven more by pressure to maintain water quality while expanding agricultural activities, with an increasing focus on collaborative management (Memon and Skelton, 2007; Memon *et al.*, 2010; Lennox *et al.*, 2011; Weber *et al.*, 2011) within national guidelines (LWF, 2010; MfE, 2011). Impacts of climate change on water supply, demand and infrastructure have been considered by several local authorities and consultancy reports (Jollands *et al.*, 2007; Williams *et al.*, 2008; Kouvelis *et al.*, 2010), but no explicit management changes have yet resulted.

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**Box 25-2. Adaptation through Water Resources Policy and Management in Australia**

Water policy and management in Australia is focused on allocating an often scarce resource exhibiting high seasonal, annual and decadal variability (Chiew and Prosser, 2011; Prosser, 2011). Widespread drought and projections of a drier future in south-eastern and far south-west Australia (Bates *et al*., 2010; CSIRO, 2010; Potter *et al*., 2010; Chiew *et al*., 2011) saw extensive policy and management change in both rural and urban water systems (Hussey and Dovers, 2007; Bates *et al*., 2008; Melbourne Water, 2010; DSE, 2011; MDBA, 2011; NWC, 2011; Schofield, 2011). These management changes provide examples of adaptations, building on previous policy reforms dealing with climate variability but less explicitly with climate change (Botterill and Dovers, 2013).

The broad policy framework is set out in the 2004-2014 National Water Initiative and the 2007 Commonwealth Water Act. The establishment of the National Water Commission (2004) and the Murray-Darling Basin Authority (2008) were major institutional reforms. The National Water Initiative explicitly recognises climate change as a constraint on future water allocations. Official assessments (NWC, 2009, 2011) and critiques (Connell, 2007; Grafton and Hussey, 2007; Byron, 2011; Crase, 2011; Pittock and Finlayson, 2011) have discussed progress and shortcomings of the initiative, but assessment of its overall success is made difficult by other factors such as on-going revisions to allocation plans and time lags to observable impacts.

Rural water reform in south-eastern Australia, focused on the Murray-Darling Basin, is still unfolding. The first draft Murray-Darling Basin Plan (MDBA, 2011) aims to return 2750 GL/year of consumptive water (about one fifth of current entitlements) to riverine ecosystems and develop flexible and adaptive water sharing plans to cope with current and future climates, although climate change is not factored in explicitly. The Plan recommends more than A$10 billion be spent on public buyback of entitlements, upgrading infrastructure, and improving water use efficiency. Water markets are a key policy instrument, allowing water use patterns to adapt to shifting availability and move toward higher value water (NWC, 2010; Kirby *et al*., 2012). For example, the two-thirds reduction in irrigation water use over the 1997-2009 drought in the Basin resulted in only 20% reduction in agricultural returns, mainly because water use shifted to more valuable enterprises (Kirby *et al*., 2012). Elsewhere, catchment management authorities and state agencies throughout south-eastern Australia develop water management strategies to cope with prolonged droughts and climate change (e.g. DSE, 2011). Nevertheless, if the extreme dry end of future water projections is realized (25.5.1, Figure 25-4), agriculture and ecosystems across south-eastern Australia would be threatened even with comprehensive adaptation (see 25.6.2, 25.7.2; Connor *et al*., 2009; Kirby *et al*., in press).

Many capital cities in Australia are reducing their reliance on catchment runoff and groundwater as these sources are most sensitive to climate change and drought, and are diversifying supplies by investing in desalinisation plants, water re-use and integrated water cycle management. Concurrently, demand is being reduced through water conservation and water sensitive urban design and, during severe shortfalls, through implementation of restrictions. In Melbourne, for example, planning has centred on securing new supplies that are more resilient to major climate shocks, increasing use of alternative sources like sewage recycling and stormwater for non-potable water, programs to reduce demand, and integrated planning that also considers integration with climate change impacts on flood risk and on urban stormwater and wastewater infrastructures (DSE, 2007; Skinner, 2010; DSE, 2011; Rhodes *et al*., 2012). Melbourne's water augmentation program includes a desalinisation plant with a 150 GL/year capacity (about one third of the current demand), following the lead of Perth in far south-west Australia where a desalinisation plant was established in 2006 following declining inflows since the mid-1970s (Hennessy *et al*., 2007; Bates and Hughes, 2009). Melbourne's water conservation strategies include water efficiency and rebate programs for business and industry, water smart gardens, dual flush toilets, grey water systems, rainwater tank rebates, free water-efficient showerheads and voluntary residential use targets. These conservation measures, together with water restrictions since the early 2000s, have reduced Melbourne's total per capita use by 40% (Fitzgerald, 2009; Rhodes *et al*., 2012). Similar recent programs reduced Brisbane's per capita use by about 50% (Shearer, 2011), while adoption of water recycling and rainwater harvesting resulted in up to 60% water savings in some parts of Adelaide (Barton and Argue, 2009; Radcliffe, 2010).

The success of urban water reforms in the face of drought and climate change can be interpreted in different ways. Increasing supply through desalinisation plants and water reuse schemes reduces the risk of future water shortages and helps cities cope with increasing population. Uptake of household-scale adaptation options has been significant in some locations, but their long-term sustainability or reversibility in response to changing drivers and societal attitudes is an open question (Troy, 2008; Brown and Farrelly, 2009; Mankad and Tapsuwan, 2011). In addition, desalinisation plants can be maladaptive in that they are energy intensive, and the enhancement of traditional mass supply could create a disincentive for reducing demand or increasing resilience by diversifying supply (Barnett and O'Neill, 2010; Taptiklis, 2011).

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## 25.6. Natural Ecosystems

### *25.6.1. Terrestrial and Inland Freshwater Ecosystems*

Terrestrial and freshwater ecosystems have suffered high rates of habitat loss and degradation, and species extinctions since European settlement (Kingsford *et al*., 2009; Bradshaw *et al*., 2010; McGlone *et al*., 2010; Lundquist *et al*., 2011; SoE, 2011); many reserves are small and isolated, and some key ecosystems and species under-represented (Walker *et al*., 2006; Sattler and Taylor, 2008; MfE, 2010b; SoE, 2011). Freshwater ecosystems in both countries are pressured from over-allocation, agriculture and pollution (e.g. Ling, 2010). Additional stresses include erosion, changes in nutrients and fire regimes, mining, invasive species, grazing and salinity (Kingsford *et al*., 2009; McGlone *et al*., 2010; SoE, 2011). These increase vulnerability to rapid climate change and provide challenges for both autonomous and managed adaptation (Burbidge *et al*., 2008).

#### *25.6.1.1. Observed Impacts*

In Australian terrestrial systems, some recently observed changes in the distributions, genetics and phenology of individual species, and in the structure and composition of some ecological communities can be attributed to recent climatic and atmospheric trends (*medium* to *high confidence*; see Box 25-3). Uncertainty remains regarding the role of non-climatic drivers, including changes in fire management, grazing and land-use. The 1997-2009 drought had severe impacts in freshwater systems in the eastern States and the Murray Darling Basin (Pittock and Finlayson, 2011) but in many freshwater systems, direct climate impacts are difficult to detect above the strong signal of over-allocation, pollution, sedimentation, exotic invasions and natural climate variability (Jenkins *et al*., 2011). In New Zealand, few if any impacts have been directly attributed to climate change rather than variability (Box 25-3; McGlone *et al*., 2010; McGlone and Walker, 2011). Alpine treelines in New Zealand have remained roughly stable for several hundred years (*high confidence*) despite 0.9°C average warming (McGlone *et al*., 2010; McGlone and Walker, 2011; Harsch *et al*., 2012).

#### *25.6.1.2. Projected Impacts*

Existing environmental stresses will interact with, and in many cases be exacerbated by, shifts in mean climatic conditions and associated increase in the frequency or intensity of extreme events, especially fire, drought and floods (*high confidence*; Steffen *et al*., 2009; Bradstock, 2010; Murphy *et al*., 2012). Recent drought-related mortality of amphibians in south-east Australia (Mac Nally *et al*., 2009); savannah trees in north-east Australia (Fensham *et al*., 2009; Allen *et al*., 2010); eucalypts in sub-alpine regions in Tasmania (Calder and Kirkpatrick, 2008); and mass die-offs of flying foxes and cockatoos during heatwaves (Welbergen *et al*., 2008; Saunders *et al*., 2011) provide *high confidence* that extreme heat combined with reduced water availability will be a significant driver of future population loss and increase the risk of local species extinctions (e.g. McKechnie and Wolf, 2010; see also Figure 25-5).

Species distribution modelling (SDM) consistently indicates future range contractions for Australia's native species even assuming optimistic rates of dispersal, e.g. WA *Banksia* spp. (Fitzpatrick *et al*., 2008), koalas (Adams-Hosking *et al*., 2011), northern macropods (Ritchie and Bolitho, 2008), native rats (Green *et al*., 2008b), greater gliders (Kearney *et al*., 2010b), quokkas (Gibson *et al*., 2010), platypus (Klamt *et al*., 2011) and fish (Bond *et al*., 2011). In some studies, complete loss of climatically suitable habitat is projected for some species within a few decades, and therefore increased risk of local and, perhaps, global extinction (*medium confidence*). SDM has limitations (e.g. Elith *et al*., 2010; McGlone and Walker, 2011) but is being improved through integration with physiological (Kearney *et al*., 2010b) and demographic models (Keith *et al*., 2008; Harris *et al*., 2012), and incorporation into broader risk assessments (e.g. Williams *et al*., 2008; Crossman *et al*., 2012).

In Australia, assessments of ecosystem vulnerability have been based on observed changes, coupled with projections of future climate in relation to known biological thresholds and assumptions about adaptive capacity (e.g. Laurance *et al*., 2011; Murphy *et al*., 2012). There is *very high confidence* that one of the most vulnerable Australian ecosystems is the alpine zone, from loss of snow cover, with flow on impacts such as exotic species invasions and changed species interactions (Pickering *et al*., 2008). There is also *high confidence* in substantial risks to coastal wetlands such as Kakadu National Park subject to saline intrusion (BMT WBM, 2011); tropical savannas subject to changed fire regimes (Laurance *et al*., 2011); inland freshwater and groundwater systems subject to drought, over-allocation and altered timing of floods (Lake and Bond, 2007; Pittock, 2008; Pittock *et al*., 2008; Nielsen and Brock, 2009; Balcombe *et al*., 2011; Jenkins *et al*., 2011; Morrongiello *et al*., 2011; Pratchett *et al*., 2011; Kroon *et al*., 2012); peat-forming wetlands along the east coast (Keith *et al*., 2010); and biodiversity-rich regions such as southwest Western Australia (Yates *et al*., 2010a; Yates *et al*., 2010b) and rainforests in Queensland (Stork *et al*., 2007; Shoo *et al*., 2011; Murphy *et al*., 2012).

The very few studies of climate change impacts on biodiversity in New Zealand suggest that on-going impacts of invasive species (Box 25-4) and habitat loss will dominate climate change signals in the short- to medium-term (McGlone *et al*., 2010), but that atmospheric and climatic change have the potential to exacerbate existing stresses (McGlone and Walker, 2011). There is *limited evidence but high agreement* that the rich biota of the alpine zone is at risk through increasing shrubby growth and loss of herbs, especially if combined with increased establishment of invasive species (McGlone *et al*., 2010; McGlone and Walker, 2011). Some cold water-adapted freshwater fish and invertebrates are vulnerable to warming (August and Hicks, 2008; Winterbourn *et al*., 2008; Hitchings, 2009; McGlone and Walker, 2011) and increased spring flooding may increase risks for braided-river bird species (MfE, 2008d). For some restricted native species, suitable habitat may increase with warming (e.g. native frogs; Fouquet *et al*., 2010) although limited dispersal ability will limit range expansion. Tuatara populations are at risk as warming increases the ratio of males to females (Mitchell *et al*., 2010), although the lineage has persisted during higher temperatures in the geological past (McGlone and Walker, 2011).

#### *25.6.1.3. Adaptation*

High levels of endemism in both countries (Lindenmayer, 2007; Lundquist *et al*., 2011) are associated with narrow geographic ranges and associated climatic vulnerability, although there is greater scope for adaptive dispersal to higher elevations in New Zealand than in Australia. Anticipated rates of climate change, together with fragmentation of remaining habitat and limited migration options in many regions (Steffen *et al*., 2009; Morrongiello *et al*., 2011), will limit *in situ* adaptive capacity and distributional shifts to more climatically suitable areas for many species (*high confidence*). Significant local and global losses of species and ecosystem services, and large scale changes in ecological communities, are anticipated (e.g. Dunlop *et al*., 2012; Murphy *et al*., 2012).

There is increasing recognition in Australia that rapid climate change has fundamental implications for traditional conservation objectives (e.g. Steffen *et al*., 2009; Prober and Dunlop, 2011; Dunlop *et al*., 2012; Murphy *et al*., 2012). Research on impacts and adaptation in terrestrial and freshwater systems has been guided by the National Adaptation Research Plans (Hughes *et al*., 2010; Bates *et al*., 2011). Climate change adaptation plans developed by many levels of government and Natural Resource Management (NRM) bodies, supported by substantial federal government funding, have identified priorities that include: identification and protection of climatic refugia (Shoo *et al*., 2011); restoration of riparian zones to reduce stream temperatures (Davies, 2010; Jenkins *et al*., 2011);

construction of levees to protect wetlands from saltwater intrusion (Jenkins *et al*., 2011); reduction of non-climatic threats such as invasive species to increase ecosystem resilience (Kingsford *et al*., 2009); ecologically-appropriate fire regimes (Driscoll *et al*., 2010); restoration of environmental flows in major rivers (Kingsford and Watson, 2011; Pittock and Finlayson, 2011); protecting and restoring habitat connectivity in association with expansion of the protected area network (Dunlop and Brown, 2008; Mackey *et al*., 2008; Taylor and Philp, 2010; Prowse and Brook, 2011); and active interventionist strategies such as assisted colonisation (Burbidge *et al*., 2011; McIntyre, 2011). The effectiveness of these measures cannot yet be assessed. Biodiversity research and management in New Zealand to date has taken little account of climate change-related pressures and continues to focus largely on managing pressures from invasive species and predators, freshwater pollution, exotic diseases, and halting the decline in native vegetation, although a number of specific recommendations have been made to improve ecosystem resilience to future climate threats (McGlone *et al*., 2010; McGlone and Walker, 2011).

Climate change responses in other sectors may have beneficial as well as adverse impacts on biodiversity, but few tools to assess risks from an integrated perspective have been developed (25.9.1, Box 25.10).

### *25.6.2. Coastal and Ocean Ecosystems*

Australia's 60,000 km coastline spans tropical waters in the north to cool temperate waters off Tasmania and the sub-Antarctic islands with sovereign rights over ~8.1 million $km^2$, excluding the Australian Antarctic Territory (Richardson and Poloczanska, 2009). New Zealand has ~18,000 km of coastline, spanning subtropical to sub-Antarctic waters, and the world's fifth largest Exclusive Economic Zone at 4.2 million $km^2$ (Gordon *et al*., 2010). The marine ecosystems of both are considered hotspots of global marine biodiversity with many rare, endemic and commercially important species (Hoegh-Guldberg *et al*., 2007; Blanchette *et al*., 2009; Gordon *et al*., 2010; Gillanders *et al*., 2011; Lundquist *et al*., 2011). The increasing density of coastal populations (25.3) and stressors such as pollution and sedimentation from settlements and agriculture will intensify non-climate stressors in coastal areas (*high confidence*; e.g. Russell *et al*., 2009). Coastal habitats also store carbon, particularly seagrass, saltmarsh and mangroves, which could become increasingly important for mitigation (e.g. Irving *et al*., 2011). Coastal ecosystems occupy <1% of the land mass but may account for 39% of Australia's average national annual carbon burial (estimated total: 466 millions tonnes $CO_2$-eq per year; Lawrence *et al*., 2012).

#### *25.6.2.1. Observed Impacts*

There is *high confidence* that climate change is already affecting the oceans around Australia (Pearce and Feng, 2007; Poloczanska *et al*., 2007; Lough and Hobday, 2011) and warming the Tasman sea in northern New Zealand (Sutton *et al*., 2005; Lundquist *et al*., 2011); average climate zones have shifted south by more than 200 km along the northeast and about 100 km along the northwest Australian coasts (Lough, 2008). The rate of warming is even faster in southeast Australia, with a poleward advance of the East Australia Current of ~350 km over the past 60 years (Ridgway, 2007; Wu *et al*., 2012). Based on elevated rates of ocean warming, southwest and southeast Australia are recognized as global warming hotspots (Wernberg *et al*., 2011; Wu *et al*., 2012).

Observed impacts on marine species around Australia have been reported from a range of trophic levels (Box 25-3) and include changes in phytoplankton productivity (Thompson *et al*., 2009; Johnson *et al*., 2011); species abundance of macroalgae (Johnson *et al*., 2011); growth rates of abalone (Johnson *et al*., 2011), southern rock lobster (Pecl *et al*., 2009; Johnson *et al*., 2011), coastal fish (Neuheimer *et al*., 2011) and coral (De'ath *et al*., 2009); life cycles of southern rock lobster (Pecl *et al*., 2009) and seabirds (Cullen *et al*., 2009; Chambers *et al*., 2011); and distribution of subtidal seaweeds (Johnson *et al*., 2011; Wernberg *et al*., 2011; Smale and Wernberg, 2013), plankton (McLeod *et al.,* 2012), fish (Figueira *et al*., 2009; Figueira and Booth, 2010; Last *et al*., 2011; Madin *et al*., 2012), sea urchins (Ling *et al*., 2009) and intertidal invertebrates (Pitt *et al*., 2010).

Habitat-related impacts are more prevalent in northern Australia (Pratchett *et al*., 2011), while distribution changes are reported more often in southern waters (Madin *et al*., 2012), particularly south-east Australia, where warming has been greatest. The 2011 marine heat wave in Western Australia caused the first-ever reported bleaching at

Ningaloo reef, as well as reports of southern range extensions of many marine species, and declines in local abundance (Wernberg *et al*., 2013). About 10% of the observed 50% decline in coral cover on the Great Barrier Reef has been attributed to bleaching, the remainder to cyclones and predators (De'ath *et al*., 2012). Changes in distribution and abundance of marine species in New Zealand are primarily linked to ENSO-related variability that dominates in many time series (Clucas, 2011; Lundquist *et al*., 2011; McGlone and Walker, 2011; Schiel, 2011), although water temperature is also important (e.g. Beentjes and Renwick, 2001). New Zealand fisheries export some $1.4 billion worth of product and variability in ocean circulation and temperature plays an important role in local fish abundance (e.g. Chiswell and Booth, 2005; Dunn *et al*., 2009), but no climate change impacts have been reported at this stage (Dunn *et al*., 2009).

### *25.6.2.2. Projected Impacts*

Even though evidence to date of climate impacts on coastal habitats is limited, *confidence* is *high* that negative impacts will arise with continued climate change (Lovelock *et al*., 2009; McGlone and Walker, 2011; Traill *et al*., 2011). Some coastal habitats such as mangroves are projected to expand further landward, driven by sea-level rise and exacerbated by soil subsidence if rainfall declines (*medium confidence*; Traill *et al*., 2011), although this may be at the expense of saltmarsh and constrained in many regions by the built environment (DCC, 2009; Lovelock *et al*., 2009; Rogers *et al*., 2012). Estuarine habitats will be affected by changing rainfall or sediment discharges, as well as connectivity to the ocean (*high confidence*; Gillanders *et al*., 2011). Loss of coastal habitats and declines in iconic species will result in substantial impacts on coastal settlements and infrastructure from direct impacts such as storm surge, and tourism (*medium confidence*; 25.7.5).

Change in temperature and rainfall, and sea level rise, are expected to lead to secondary effects, including erosion, landslips, and flooding, affecting coastal habitats and their dependent species, e.g. loss of habitat for nesting birds (*high confidence*; Chambers *et al*., 2011). Increasing ocean acidification is expected to affect many taxa (*medium confidence*; see also Box CC-OA) including corals (Fabricius *et al*., 2011), coralline algae (Anthony *et al*., 2008), calcareous plankton (Richardson *et al*., 2009; Thompson *et al*., 2009; Hallegraeff, 2010), reef fishes (Munday *et al*., 2009; Nilsson *et al*., 2012), bryozoans and other benthic calcifiers (Fabricius *et al*., 2011). Deep-sea scleractinian corals off New Zealand and Australia are also expected to decline with ocean acidification (Miller *et al*., 2011).

The AR4 identified the Great Barrier Reef (GBR) as highly vulnerable to warming and acidification (Hennessy *et al*., 2007). Recent observations of bleaching and reduced calcification in both the GBR and other reef systems (Cooper *et al*., 2008; De'ath *et al*., 2009; Cooper *et al*., 2012), along with model and experimental studies (Hoegh-Guldberg *et al*., 2007; Anthony *et al*., 2008; Veron *et al*., 2009) confirm this vulnerability (see also Box CC-CR). There is *high confidence* that the combined impacts of warming and acidification associated with atmospheric $CO_2$ concentrations in excess of 450-500 ppm will be associated with increased frequency and severity of coral bleaching, disease incidence and mortality, leading to dominance by macroalgae (Hoegh-Guldberg *et al*., 2007; Veron *et al*., 2009). Bleaching frequency is expected to increase and become decoupled from the 4-7 year El Niño cycle (Veron *et al*., 2009). Other stresses, including rising sea levels, increased cyclone intensity, and nutrient-enriched runoff, will exacerbate these impacts (*high confidence*; Hoegh-Guldberg *et al*., 2007; Veron *et al*., 2009). Thermal thresholds and the ability to recover from bleaching events vary geographically and between species (e.g. Diaz-Pulido *et al*., 2009) but evidence of the ability of corals to adapt to rising temperatures and acidification is limited and appears insufficient to offset the detrimental effects of warming and acidification (*robust evidence, medium agreement*; Hoegh-Guldberg et al., 2007; Veron et al., 2009).

Under all SRES scenarios and a range of CMIP3 models, pelagic fishes such as sharks, tuna and billfish are projected to move further south on the east and west coasts of Australia (*high confidence*; Hobday, 2010). These changes depend on sensitivity to water temperature, and may lead to shifts in species-overlap with implications for by-catch management (Hartog *et al*., 2011). Poleward movements are also projected for coastal fish species in Western Australia (Cheung *et al*., 2012). A strengthening East Auckland Current in northern New Zealand is expected to promote establishment of tropical or sub-tropical species that currently occur as vagrants in warm La Niña years (Willis *et al*., 2007). Such shifts suggest potentially substantial changes in production and profit of both wild fisheries (Norman-Lopez *et al*., 2011) and aquaculture species such as salmon, mussels and oysters (*medium* *confidence*; Hobday *et al*., 2008; Hobday and Poloczanska, 2010). Ecosystem models also project changes to habitat and fisheries production (*low confidence*; Fulton, 2011; Watson *et al*., 2012).

#### *25.6.2.3. Adaptation*

In Australia, research on marine impacts and adaptation has been guided by the National Adaptation Research Plan for Marine Biodiversity and Resources (Mapstone *et al*., 2010). Planned adaptation options include removal of human barriers to landward migration of species, beach nourishment, management of environmental flows to maintain estuaries (Jenkins *et al*., 2010), habitat provision (Hobday and Poloczanska, 2010), translocation of seagrass and species such as turtles (e.g. Fuentes *et al*., 2009) and burrow modification for nesting seabirds (Chambers *et al*., 2011). For southern species on the continental shelf, options are more limited because suitable habitat will not be present – the next shallow water to the south is Macquarie Island. There is *low confidence* about the adequacy of autonomous rates of adaptation by species, although recent experiments with coral reef fish suggest that some species may adapt to the projected climate changes (Miller *et al*., 2012).

Management actions to increase coral reef resilience include reducing fishing pressure on herbivorous fish, protecting top predators, managing runoff quality, and minimizing other human disturbances, especially through marine protected areas (Hughes *et al*., 2007; Veron *et al*., 2009; Wooldridge *et al*., 2012). There is *high confidence* that such actions will slow, but not prevent, long-term degradation of reef systems once critical thresholds of ocean temperature and acidity are exceeded, and so novel options, including translocation and shading critical reefs, have been proposed (Rau *et al*., 2012). Forecasting can also prepare managers for bleaching events (Spillman, 2011).

Adaptation by the fishing industry to shifting distributions of target species is considered possible by most stakeholders (e.g. southern rock lobster fishery; Pecl *et al*., 2009). Translocation to maintain production in the face of declining recruitment may also be possible for some high value species, and has been trialled for the southern rock lobster (Green *et al*., 2010a). Options for aquaculture include disease management, alternative site selection, and selective breeding (Battaglene *et al*., 2008), although implementation is only in preliminary stages for both Australia and New Zealand. Marine protected area planning is not explicitly considering climate change in either country, but reserve performance will be affected by the projected environment shifts and novel combinations of species, habitats and human pressures (Hobday, 2011).

_____ START BOX 25-3 HERE _____

**Box 25-3. Impacts of a Changing Climate in Natural and Managed Ecosystems**

Observed changes in species, and in natural and managed ecosystems (25.6.1, 25.6.2, 25.7.2) provide multiple lines of evidence of the impacts of a changing climate[1]. Examples of observations published since the AR4 are shown in Table 25-3. At present only one study describes a climate-related change in a managed ecosystem (wine grape ripening in Australia; Webb *et al*., 2012a). It remains unclear whether this imbalance is due to confounding factors or a lack of published research.

[INSERT TABLE 25-3 HERE
Table 25-3: Examples of detected changes in species, natural and managed ecosystems, consistent with a climate change[1] signal, published since the AR4. Confidence in detection of change is based on the length of study, and the type, amount and quality of data in relation to the natural variability in the particular species or system. Confidence in the role of climate as a major driver of the change is based on the extent to which the detected change is consistent with that expected under climate change, and to which other confounding or interacting non-climate factors have been considered and been found insufficient to explain the observed change.]

[FOOTNOTE 1: Consistent with the IPCC definition, a change in climate refers to any statistically detectable signal, it does not necessarily imply a human cause. See Glossary, Table 25-1 and 25.2.]

_____ END BOX 25-3 HERE _____

## 25.7. Major Industries

### *25.7.1. Production Forestry*

Australia has about 149 Mha forests (includes woodlands, 2 Mha plantations, 9.4 Mha multiple-use native forests; MPIGA, 2008; Gavran and Parsons, 2010), and forestry contributes around $7 billion annually to GDP (ABARES, 2011a). New Zealand's plantation estate comprises about 1.7 Mha (90% *Pinus radiata*), with recent contractions due to increased profitability of dairying (MfE, 2008b; NZPFI, 2012).

#### *25.7.1.1. Observed and Projected Impacts*

Existing climate variability and other confounding factors have so far prevented the detection of climate change impacts on forests. Modelled projections are based on ecophysiological responses of forests to $CO_2$, water and temperatures. In Australia, potential changes in water availability will be most important (*very high confidence*). Modelling future distributions or growth rates indicate that plantations in south-west Western Australia are most at risk due to declining rainfall, and there is *high confidence* that plantation growth will be reduced by temperature increases in hotter regions, especially where species are grown at the upper range of their temperature tolerances (Medlyn *et al*., 2011a). There is *limited evidence* and *medium agreement* that moderate reductions in rainfall and increased temperature could be offset by fertilisation from increasing $CO_2$ (Simioni *et al*., 2009). In cool regions where water is not limiting, higher temperatures could benefit production (Battaglia *et al*., 2009). In New Zealand, temperatures are mostly sub-optimal for forest growth and water relations are generally less limiting (Kirschbaum and Watt, 2011). Warming is expected to increase *P. radiata* growth in the cooler south (*very high confidence*). In the warmer north, temperature increases can reduce productivity, but $CO_2$ fertilisation may offset this (*medium confidence*; Kirschbaum *et al*., 2012).

Modelling studies are limited by their reliance on key assumptions which are difficult to verify experimentally, e.g. either no or strong down-regulation of photosynthesis under elevated $CO_2$ (Battaglia *et al*., 2009). Most studies also exclude impacts of pests, diseases, weeds, fire and wind damage that may change adversely with climate. Fire, for instance, poses a significant threat in Australia and is expected to worsen with climate change (see Box 25.6), especially for the commercial forestry plantations in the southern winter-rainfall regions (Williams *et al*., 2009; Clarke *et al*., 2011). In New Zealand, changes in biotic factors are particularly important as they already affect plantation productivity. *Dothistroma* blight, for instance, is a serious pine disease with a temperature optimum that coincides with New Zealand's warmer, but not warmest, pine-growing regions (Watt *et al*., 2011a). Under climate change, its severity is, therefore, expected to reduce in the warm central North Island but increase in the cooler South Island (*high confidence*) where it could offset temperature-driven improved plantation growth. There is *medium evidence* and *high agreement* of similar future southward shifts in the distribution of existing plantation weed, insect pest and disease species in Australia (see review in Medlyn *et al*., 2011b).

#### *25.7.1.2. Adaptation*

Adaptation strategies include changes to species or provenance selection, and adopting different silvicultural options, e.g. fertilizer management or modified stand stocking (White *et al*., 2009; Booth *et al*., 2010). Depending on the extent of climate changes, and plant responses to increasing $CO_2$, the above studies (25.7.1.1) provide *limited evidence* but *high agreement* of potential net increased productivity in many areas, but only where soil nutrients are not limiting. The rotation time of plantation forests of about 30 years or more makes proactive adaptation important but also challenging. There is *medium evidence* and *high agreement* that the greatest barriers to long-term adaptation planning are incomplete knowledge of plant responses to $CO_2$ concentration and uncertainty in regionally-specific climate change scenarios (Medlyn *et al*., 2011b).

### *25.7.2. Agriculture*

Australia produces 93% of its domestic food requirements yet still exports 76% of agricultural production (11.9% of total exports; DAFF, 2010). New Zealand agriculture contributes about 56% of total export value of which dairy products contribute 30% (Stats NZ, 2011c); 95% of all New Zealand dairy products are exported and these account for about 35% of world trade. Agricultural production is sensitive to climate (in particular to drought; see Box 25-5) but also to many non-climate factors, which thus far has limited detection or attribution of climate-related changes (7.2, although see Webb et al., 2012a). In New Zealand, the importance of agriculture makes the economy very sensitive to climate, for example an increase in soil moisture deficit has an immediate negative effect on domestic output and a consequent effect on GDP (Buckle *et al*., 2002)

#### *25.7.2.1. Projected Impacts and Adaptation – Livestock Systems*

Livestock grazing dominates land use by area in the region. At the Australian national level, the net effect of a 3°C temperature increase is expected to be a 4% reduction in gross value of the beef, sheep and wool sector due to declining rainfall and rising temperatures (McKeon et al., 2008). Dairy output is projected to decline in all regions of Australia other than Tasmania under a 1°C increase by 2030 (Hanslow *et al*., submitted). Projected changes in national pasture production for dairy, sheep and beef pastures in New Zealand range from an average reduction of 4% across climate scenarios for the 2030s (Wratt et al., 2008) to increases of up to 4% for two scenarios in the 2050s (Baisden *et al*., 2010), with increases based on more recent process-based models that incorporate $CO_2$ fertilisation and nitrogen feedbacks. An analysis of the impact of a 0.9-1.2°C increase on dairy systems across five sites in New Zealand found little change in operating profit over the period 2030-2049 (Lee et al., 2012).

Studies modelling seasonal (rather than annual average) changes in fodder supply show greater sensitivity in animal production to climate change and elevated $CO_2$ than previously anticipated and are expected to occur even under modest warming (*high confidence*) in both New Zealand (Lieffering *et al*., 2012) and Australia (Moore and Ghahramani, 2013). Across 25 sites in southern Australia (an area covering 85% of sheep and 40% of beef production regions), modelled profitability declined at most sites by the 2050s because of a shorter growing season (Moore and Ghahramani, 2013). Increasing soil fertility (largely using phosphate fertiliser) was an adequate adaptation until about 2050 but, thereafter, transformational change, such as enterprise choice, would be required to maintain incomes (Ghahramani and Moore, submitted). In New Zealand, projected changes in seasonal pasture growth drove changes in animal production at four sites representing the main areas of sheep production (Lieffering *et al*., 2012). In Hawke's Bay, changes in stock number were able to maintain farm income for a period in the face of variable forage supply but transformational adaptation would be required to maintain farm income in the longer term. In Southland and Waikato, projected increases in early spring pasture growth posed management problems in maintaining pasture quality, yet, if these were met, animal production could be maintained or increased.

Rainfall is a key determinant of inter-annual variability in production and profitability of pastures and rangelands (Radcliffe and Baars, 1987; Steffen *et al*., 2011) yet remains the most uncertain change. Savannahs that are currently water-limited are expected to show greater sensitivity to temperature and rainfall changes than nitrogen-limited ones (Webb *et al*., 2012b). The 'water-sparing' effect of elevated $CO_2$ (offsetting reduced water availability through reduced rainfall and increased temperatures) is invoked in many impact studies but reduced stomatal conductance does not always translate into production benefits (Kamman *et al*., 2005; Newton *et al*., 2006; Stokes and Ash, 2007; Wan *et al*., 2007). The impacts of elevated $CO_2$ on forage production, quality, nutrient cycling and water availability remains the major uncertainty in modelling system responses (McKeon *et al*., 2009). New Zealand agro-ecosystems are subject to erosion processes strongly driven by climate; greater certainty in projections of rainfall, particularly storm frequency, are needed to better understand climate change impacts on erosion (Basher et al., 2012).

#### *25.7.2.2. Projected Impacts and Adaptation – Cropping*

Experiments (Fitzgerald *et al*., 2010) and modelling for wheat in Australia (Crimp *et al*., 2008; Luo *et al*., 2009; O'Leary *et al*., 2010) and New Zealand (Teixeira *et al*., 2012) support the AR4 conclusion (Hennessy *et al*., 2007) that adaptation, particularly altering sowing dates and cultivars, can sustain or increase yields past 2050 except under the most extreme low rainfall scenarios (*high confidence*). Although yields may increase in New Zealand with current management (Teixeira *et al*., 2012), adaptation will be essential in Australia to avoid yield reductions in some regions (Luo *et al*., 2009). Under the more severe climate scenarios and without adaptation, Australia could become a net importer of wheat (Howden *et al*., 2010).

Rice production in Australia is largely dependent on irrigation and climate change impacts will strongly depend on water availability and price (Gaydon *et al*., 2010). Sugarcane is also strongly water dependent (Carr and Knox, 2011); yields may increase where rainfall is unchanged or increased, but rising temperatures could drive up evapotranspiration and increase water use (*medium confidence*; Park *et al*., 2010).

Observed trends and modelling for wine-grapes suggest that climate change will lead to earlier budburst, ripening and harvest for most regions and scenarios (*high confidence*; Grace *et al*., 2009; Sadras and Petrie, 2011; Webb *et al*., 2012a). Without adaptation, reduced quality is expected in all Australian regions (*high confidence*; Webb *et al*., 2008). Change in cultivar suitability in specific regions is expected (Clothier *et al*., 2012), with potential for development of cooler or more elevated sites within some regions (Tait, 2008; Hall and Jones, 2009) and/or expansion to new regions, with some growers in Australia already relocating (e.g. to Tasmania; Smart, 2010).

Climate change and elevated $CO_2$ impacts on weeds, pests and diseases are highly uncertain (see Box 25.4). Future performance of currently effective resistance mechanisms under elevated $CO_2$ and temperature is particularly important (Melloy *et al*., 2010; Chakraborty *et al*., 2011) as is the future efficacy of biocontrol (Gerard *et al*., 2012), which is widely used in the region. Australia is ranked second and New Zealand fourth in the world in the number of biological control agent introductions (Cock *et al*., 2010).

#### *25.7.2.3. Integrated Adaptation Perspectives*

Future water demand by the sector is critical for planning (Box 25.2). Even though dryland agriculture dominates in Australia (DAFF, 2010), irrigation takes 50% of total water consumption (70% in the Murray-Darling Basin; Quiggin *et al*., 2008), and generates 30% of the gross value of Australian agriculture (Robertson, 2010). Reduced inflow under a non-mitigation scenario is predicted to reduce the value of agricultural production in the Basin by 12-44% to 2030 and 49-72% to 2050 (A1FI; Garnaut, 2008). Water availability also constrains agricultural expansion: 17 Mha in northern Australia could support cropping but only 1% has appropriate water availability (Webster *et al*., 2009). In New Zealand, the irrigated area has risen by 82% since 1999 to over 1 Mha; 76% is on pasture (Rajanayaka *et al*., 2010). The New Zealand dairy herd doubled between 1980-2009 moving from high rainfall zones (>2000 mm annual) to drier, irrigation-dependent areas (600-1000 mm annual); this dependence will increase with expansion (Robertson, 2010), which is being supported by the Government's Irrigation Acceleration Fund.

Many adaptation options such as flexible water allocation, irrigation and seasonal forecasting support managing risk in the current climate (Howden *et al*., 2008; Botterill and Dovers, 2013) and adoption is often high (Hogan *et al*., 2011a; Kenny, 2011). However, incremental on-farm adaptation has limits (Stafford-Smith *et al*., 2011a; Park *et al*., 2012) and may hinder transformational change such as diversification of land use or relocation (see Box 25-5) if it encourages persistence where climate change may take current systems beyond their response capacity (Marshall, 2010; Park *et al*., 2012; Rickards and Howden, 2012). In many cases, transformational change requires a greater level of commitment, access to more resources, and greater integration across levels of decision-making that encompass both on- and off-farm knowledge, processes and values (Marshall, 2010; Rickards and Howden, 2012).

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**Box 25-4. Biosecurity**

Biosecurity is a high priority for Australia and New Zealand given the economic importance of biologically-based industries and risks to endemic species and iconic ecosystems. There is *high confidence* that the biology and potential risk from invasive and native pathogenic species will be altered by climate change (Roura-Pascual *et al.*, 2011), but impacts may be positive or negative depending on the particular system.

[INSERT TABLE 25-4 HERE
Table 25-4: Examples of potential consequences of climate change for invasive and pathogenic species relevant to Australia and New Zealand, with consequence categories based on Hellman et al. (2008).]

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**Box 25-5. Climate Change Vulnerability and Adaptation in Rural Areas**

Rural communities in Australasia have higher proportions of older and unemployed people than urban populations (Mulet-Marquis and Fairweather, 2008). Employment and economic prospects depend heavily on the physical environment and hence are highly exposed to climate (averages, variability and extremes) as well as changing commodity prices. These interact with other economic, social and environmental pressures, such as changing government policies (e.g. on drought, carbon pricing; Productivity Commission, 2009; Nelson *et al.*, 2010) and access to water resources. The vulnerability of rural communities differs within and between countries reflecting differences in financial security, environmental awareness, policy and social support, strategic skills and capacity for diversification (Bi and Parton, 2008; Marshall, 2009; Nelson *et al.*, 2010; Hogan *et al.*, 2011b; Kenny, 2011).

Climate change will affect rural industries and communities through impacts on resource availability and distribution, particularly water. Decreased availability and/or increased demand, or price, in response to climate change will increase tensions among agricultural, mining, urban and environmental water users (*very high confidence*), with implications for governance and participatory adaptation processes to resolve conflicts (see 25.4.2, 25.4.3, 25.6.1, 25.7.2, 25.7.3, Box 25-2, Box 25-10). Communities will also be affected through direct impacts on primary production, extraction activities, critical infrastructure, population health and recreational and culturally significant sites (see 25.7, 25.8; Kouvelis *et al.*, 2010; Balston *et al.*, 2012).

Altered production and profitability risks and/or land use will translate into complex and interconnected effects on rural communities, particularly income, employment, service provision, and reduced volunteerism (Stehlik *et al.*, 2000; Bevin, 2007; Kerr and Zhang, 2009). The prolonged drought in Australia during the early 2000s, for example, had many interrelated negative social impacts in rural communities, including farm closures, increased poverty, increased off-farm work and, hence, involuntary separation of families, increased social isolation, rising stress and associated health impacts, including suicide (especially of male farmers), accelerated rural depopulation and closure of key services (*high agreement, robust evidence*; Alston, 2007; Edwards and Gray, 2009; Alston, 2010, 2012; Hanigan *et al.*, 2012). Positive social change also occurred, however, including increased social capital through interaction with community organisations (Edwards and Gray, 2009). While social and cultural changes have the potential to undermine the adaptive capacity of communities (Smith *et al.*, 2011b), robust ongoing engagement between farmers and the local community can contribute to a strong sense of community and enhance potential for resilience (McManus *et al.*, 2012).

The economic impact of droughts on rural communities and the entire economy can be substantial. The 2002-03 drought in Australia, for example, significantly reduced agricultural income and employment and subtracted around 1% from GDP (equivalent to A$7.4 billion; ABS, 2004), but the full impact may have been as high as 1.6% when indirect impacts are included (Horridge *et al.*, 2005). Widespread drought in New Zealand during 2007-2009 affected many regions not traditionally impacted by drought, such as the Waikato, resulting in an estimated reduction of NZ$3.6 billion in direct and off-farm output (Butcher, 2009). Drought frequency and severity are projected to increase in many parts of the region (Table 25-1).

The decisions of rural enterprise managers have significant consequences for and beyond rural communities (Pomeroy, 1996; Clark and Tait, 2008). Many current responses are incremental, responding to existing climate variability (Kenny, 2011), but transformational change has occurred where industries and individuals are relocating part of their operations, e.g. rice (Gaydon *et al*., 2010), wine-grapes (Park *et al*., 2012), peanuts (Thorburn *et al*., 2012) or changing and diversifying land use *in situ* (e.g. the recent switch from grazing to cropping in South Australia; Howden *et al*., 2010) in response to recent and/or expectations of future climate or policy change (Kenny, 2011; see also Box 25-10). Such transformational changes are expected to become more frequent and widespread with a changing climate (*high confidence*; 25..6.2), with positive or negative implications for the wider communities in origin and destination regions.

Although stakeholders within rural communities differ in their vulnerabilities and adaptive capacities, they are bound by similar dependence upon critical infrastructure and resources, economic conditions, government policy direction, and societal expectations (Loechel *et al*., 2013). Consequently, adaptation to climate change will require an approach that devolves decision-making to the level where the knowledge for effective adaptations resides, using open communication, interaction and joint-planning (Nelson *et al*., 2008).

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_____ START BOX 25-6 HERE _____

**Box 25-6. Climate Change and Fire**

Fire during hot, dry and windy summers in southern Australia can cause loss of life and substantial property damage (Cary *et al*., 2003; Adams and Attiwill, 2010). The 'Black Saturday' bushfires in Victoria in February 2009, for example, burnt over 4,500 km$^2$, caused 173 deaths, destroyed over 2,000 buildings and caused damages of A$4billion (Cameron *et al*., 2009; VBRC, 2010). This fire occurred toward the end of a 13-year drought (CSIRO, 2010) and after an extended period of consecutive days over 40°C (Tolhurst, 2009).

Climate change is expected to increase the number of days with very high and extreme fire weather (Table 25-1), with greater changes where fire is weather-constrained (most of southern Australia; many, in particular eastern and northern, parts of New Zealand) than where it is constrained by fuel load and ignitions (tropical savannas in Australia). Fire season length will be extended in many already high-risk areas (*high confidence*) and so reduce opportunities for controlled burning (Lucas *et al*., 2007). Higher $CO_2$ will also generally enhance fuel loads except where moisture is limiting (Donohue *et al*., 2009; Williams *et al*., 2009; Bradstock, 2010; Hovenden and Williams, 2010; King *et al*., 2011).

Climate change and fire will have complex impacts on vegetation communities and biodiversity, with negative or positive implications in different regions (Williams *et al*., 2009). The greatest impacts on biodiversity in Australia are expected in the sclerophyll forests of the south-east and south-west (Williams *et al*., 2009). Most New Zealand native ecosystems have limited exposure but also limited adaptation to fire (Ogden *et al*., 1998; McGlone and Walker, 2011). There is *high confidence* that increased incidence of fires in southern Australia will increase risk to people, property and infrastructure such as electricity transmission lines (Parsons Brinkerhoff, 2009; O'Neill and Handmer, 2012; Whittaker *et al*., 2013) and in parts of New Zealand where urban margins expand into rural areas (Jakes *et al*., 2010; Jakes and Langer, 2012); exacerbate some respiratory conditions such as asthma (Johnston *et al*., 2002; Beggs and Bennett, 2011); and increase economic risks to plantation forestry (Watt *et al*., 2008; Pearce *et al*., 2011). Forest regeneration following wildfires also reduces water yields (Brown *et al*., 2005; MDBC, 2007), while reduced vegetation cover increases erosion risk and material washoff to waterways with implications for water quality (Shakesby *et al*., 2007; Wilkinson *et al*., 2009; Smith *et al*., 2011a).

In Australia, fire management will become increasingly challenging under climate change (*high confidence*; O'Neill and Handmer, 2012; Whittaker *et al*., 2013). Current initiatives centre on planning and regulations, building design to reduce flammability, fuel management, early warning systems, and fire detection and suppression (Handmer and Haynes, 2008; Preston *et al*., 2009; VBRC, 2010; O'Neill and Handmer, 2012). Some Australian authorities are taking climate change into account when rethinking approaches to managing fire to restore ecosystems while protecting human life and properties (Preston *et al*., 2009; Adams and Attiwill, 2010). Improved understanding of climate-drivers of fire risks is assisting fire management agencies, landowners and communities in New Zealand

(Pearce *et al*., 2008; Pearce *et al*., 2011), although changes in management to date show little evidence of being driven by climate change.

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### *25.7.3. Mining*

Australia is the world's largest exporter of coking coal and iron ore and has the world's largest resources of brown coal, nickel, uranium, lead and zinc (ABS, 2012a). Recent events demonstrated significant vulnerability to climate extremes: the 2011 floods reduced coal exports by 25-54 million tonnes and led to A$5-9bn in lost revenue in that year (ABARES, 2011b; RBA, 2011). Impacts were exacerbated by regulatory constraints on mine discharges, highlighting tensions among industry, social and ecological management objectives (QRC, 2011).

Projected changes in climate extremes imply increasing sector vulnerability without adaptation (*high confidence*; Hodgkinson *et al*., 2010a; Hodgkinson *et al*., 2010b). Stakeholders perceive the adaptive capacity of the industry to be high (Hodgkinson *et al*., 2010a; Loechel *et al*., 2010; QRC, 2011), but costs and broader benefits are yet to be explored along the value-chain and evaluated for community support. On-going and open challenges include competition for energy and water, climate scepticism, avoiding maladaptation, and mining-community relations regarding response options, acceptable mine discharges and post-mining rehabilitation (Loechel *et al*., 2013).

### *25.7.4. Energy Supply, Demand and Transmission*

Primary energy demand is projected to grow by 0.5-1.3% per annum in Australasia over the next few decades (MED, 2011; Syed, 2012). Australia's predominantly thermal power generation is vulnerable to drought-induced water restrictions, which could require dry-cooling and increased water use efficiency where rainfall declines (Graham *et al*., 2008; Smart and Aspinall, 2009). Depending on carbon price and technology costs, renewable electricity generation in Australia is projected to increase from 10% in 2010/11 to 19-50% by 2030 (Hayward *et al*., 2011; Stark *et al*., 2012; Syed, 2012), but few studies have explored the climate vulnerability of these new energy sources (Bryan *et al*., 2010; Crook *et al*., 2011; Odeh *et al*., 2011).

New Zealand's predominantly hydroelectric power generation is vulnerable to precipitation variability. Increasing winter precipitation and snow melt, and a shift from snowfall to rainfall will reduce this vulnerability (*medium confidence*) as winter/spring inflows to main hydro lakes are projected to increase by 5-10% over the next few decades (McKerchar and Mullan, 2004; Poyck *et al*., 2011). Further reductions in seasonal snow and glacial melt as glaciers diminish, however, would compromise this benefit (Chinn, 2001; Renwick *et al*., 2009; Srinivasan *et al*., 2011). Increasing wind power generation (MED, 2011) would benefit from projected increases in mean westerly winds but face increased risk of damages and shut-down during extreme winds (Renwick *et al*., 2009).

Climate warming would reduce annual average peak electricity demands by 1-2% per °C across New Zealand and 2(±1)% in New South Wales, but increase by 1.1(±1.4) and 4.6(±2.7)% in Queensland and South Australia due to air conditioning demand (Stroombergen *et al*., 2006; Jollands *et al*., 2007; Thatcher, 2007; Chen and Lie, 2010). Increased summer peak demand (see also Figure 25-5) will place additional stress on networks, particularly in Australia (*very high confidence*; Jollands *et al*., 2007; Thatcher, 2007; Howden and Crimp, 2008; Wang *et al*., 2010a). During the 2009 Victorian heat wave, for example, demand rose by 24% but electrical losses from transmission lines increased by 53% due to higher peak currents (Nguyen *et al*., 2010), and successive failures of the overloaded network temporarily left more than 500,000 people without power (QUT, 2010). Various adaptation options to limit increasing urban energy demand exist and some are being implemented (see Box 25-9).

There is *limited evidence* but *high agreement* that without additional adaptation, distribution networks in most Australian states will be at high risk of failure by 2031-2070 under non-mitigation scenarios due to increased bushfire risk and potential strengthening and southward shift of severe cyclones in tropical regions (Maunsell and CSIRO, 2008; Parsons Brinkerhoff, 2009). Adaptation costs have been estimated at A$2.5 billion to 2015, with more than half to meet increasing demand for air conditioning and the remainder to increase resilience to climate-related hazards; underground cabling would reduce bushfire risk but has large investment costs (not included above; Parsons Brinkerhoff, 2009). Decentralised ownership of assets constitutes a significant adaptation constraint (ATSE, 2008; Parsons Brinkerhoff, 2009). In New Zealand, increasing high winds and temperatures have been identified qualitatively as the most relevant risks to transmission (Jollands *et al*., 2007; Renwick *et al*., 2009).

### *25.7.5. Tourism*

Tourism contributes 2.6-4% of GDP to the economies of Australia and New Zealand (ABS, 2010b; Stats NZ, 2011a). The net present value of the Great Barrier Reef alone over the next 100 years has been estimated at A$51.4 billion (Oxford Economics, 2009). Most Australasian tourism is exposed to climate variability and change, and some destinations are highly sensitive to extreme events (Becken and Hay, 2012). The 2011 floods and Cyclone Yasi, for example, cost the Queensland tourism industry about A$590 million, mainly due to cancellations and damage to the Great Barrier Reef (PWC, 2011), and drought in the Murray-Darling Basin caused an estimated A$70 million loss in 2008 due to reduced visitor days (TRA, 2010).

#### *25.7.5.1. Projected Impacts*

Future impacts on tourism have been modelled for several Australian destinations. The Great Barrier Reef is expected to degrade under all climate change scenarios (Box CC-CR, 25.6.2, 30.5), reducing its attractiveness (Marshall and Johnson, 2007; Bohensky *et al*., 2011; Wilson and Turton, 2011). Ski tourism is expected to decline in the Australian Alps due to snow cover reducing more rapidly than in New Zealand (Pickering *et al*., 2010; Hendrikx *et al*., in press) and greater perceived broad attractiveness of New Zealand (Hopkins *et al*., 2012). Higher temperature extremes in the Northern Territory are projected with *high confidence* to increase heat stress and incur higher costs for air conditioning (Turton *et al*., 2009). Sea level rise places pressures on shorelines and long-lived infrastructure but implications for tourist resorts have not been quantified (Buckley, 2008).

Economic modelling suggests that the Australian alpine region would be most negatively affected in relative terms due to limited alternative activities (Pham *et al*., 2010), whereas the competitiveness of some destinations (e.g. Margaret River in Western Australia) could be enhanced by higher temperatures and lower rainfall (Jones *et al*., 2010; Pham *et al*., 2010). An analogue-based study suggests that, in New Zealand, warmer and drier conditions mostly benefit but wetter conditions and extreme climate events undermine tourism (Wilson and Becken, 2011). *Confidence* in outcomes is *low* due to uncertain future tourist behaviour (Scott *et al*., 2012; also 25.9.2).

#### *25.7.5.2. Adaptation*

Both New Zealand and Australia have adaptation strategies for tourism (Becken and Clapcott, 2011; Zeppel and Beaumont, 2011); promoted preparation for extreme events (Tourism Queensland, 2007, 2010; Tourism Victoria, 2010); and are strengthening ecosystem resilience to maintain destination attractiveness (GBRMPA, 2009). Snow-making is already broadly adopted to increase reliability of skiing (Bicknell and McManus, 2006; Hennessy *et al*., 2008b), but its future effectiveness depends on location. In New Zealand, even though warming will significantly reduce the number of days suitable for snow-making (Hendrikx and Hreinsson, 2012), sufficient snow could be made in all years until the end of the 21st century to maintain current minimum operational skiing conditions. Options for resorts in Australia's Snowy Mountains are far more limited (Hendrikx *et al*., in press), where maintaining skiing conditions until at least 2020 would require A$100 million in capital investment into 700 snow guns and 2.5-3.3 GL of water per month (Pickering and Buckley, 2010).

Short investment horizons, high substitutability and a high proportion of human capital compared with built assets give *high confidence* that the adaptive capacity of the tourism industry is high overall, except for destinations where climate change is projected to degrade core natural assets and diversification opportunities are limited (Evans *et al*., 2011; Morrison and Pickering, 2011). Strategic adaptation decisions are constrained by uncertainties in regional climatic changes (Turton *et al*., 2010), limited concern (Bicknell and McManus, 2006), lack of leadership and limited coordinated forward planning (Sanders *et al*., 2008; Turton *et al*., 2009; Roman *et al*., 2010; White and Buultjens, 2012). An integrated assessment of tourism vulnerability in Australasia is not yet possible due to limited understanding of future changes in tourism and community preferences (Scott *et al*., 2012), including the flow-on effects of changing travel behaviour and tourism preferences in other world regions (see 25.9.2).

## 25.8. Human Society

### *25.8.1. Human Health*

#### *25.8.1.1. Observed Impacts*

Life expectancy in Australasia is high, but shows substantial ethnic and socio-economic inequalities (Anderson *et al*., 2006b). There is *high agreement and robust evidence* that mortality increases in hot weather (Bi and Parton, 2008; Vaneckova *et al*., 2008) with air pollution exacerbating this association. Exceptional heatwave conditions in Australia have been associated with substantial increases in mortality and hospital admissions in several capital cities (*high confidence*; Khalaj *et al*., 2010; Loughnan *et al*., 2010; Tong *et al*., 2010a; Tong *et al*., 2010b). In January and February 2009, for example, south-eastern Australia experienced record maximum temperatures and consecutive hot days in many locations (BoM, 2009). Over this period, total emergency cases increased by 25% and by 46% over the three hottest days. Direct heat-related health problems increased 34-fold, 61% of these being people aged 75 years or older. There were 374 excess deaths, a 62% increase in all-cause mortality (Victorian Government, 2009a). Mental health admissions increased by 7.3% in metropolitan South Australia during heatwaves (1993-2006), with increases across all age groups (Hansen *et al*., 2008). Mortality attributed to mental and behavioural disorders increased in the 65 to 74-year age group and in persons with schizophrenia, schizotypal, and delusional disorders (Hansen *et al*., 2008). Experience of extreme events also correlates strongly with general concern about climate change and psychological well-being (see 25.4.3).

#### *25.8.1.2. Projected Impacts*

Projected increases in heatwaves (see Figure 25-5) will increase both heat-related deaths and hospitalizations, especially among the elderly, compounded by population growth and ageing (*high confidence*). This may be partly offset by reduced deaths from cold at least for modest rises in temperature in the southern states of Australia and parts of New Zealand (*low confidence*; Bambrick *et al*., 2008; Kinney, 2012). Relative to a baseline that allowed for demographic change but no climate change after 2005, the annual net change across Australia was 943 (-11%) *fewer* deaths in 2070 and 924 (-11%) fewer in 2100 in a strongly mitigated 450 ppm scenario, or an *additional* 1250 (+14%) deaths in 2070 and 8628 (+100%) in 2100 in a hot, dry A1FI scenario (Bambrick *et al*., 2008). In this study, which accounted for changes in the mean but not variability of temperatures, net results were driven almost entirely by increased mortality in the north, especially Queensland, consistent with Huang *et al*., (2012) who projected temperature-related years of life lost in Brisbane. In a separate study, which did account for increased daily temperature variability, a substantial increase in heat-related deaths was estimated for Sydney (Gosling *et al*., 2009): using the HadCM3 climate model for both recent past and future climates, without adaptation, annual heat-related deaths per 100,000 people were projected to increase nearly threefold, from 2.5 in 1961-1990 to 7.4 in 2070-2099 for the A2 emissions scenario, and from 2.6 to 6.8 for the B2 scenario. The annual number of temperature-related hospital admissions in South Australia under the A1FI scenario is projected to increase 110% by 2100 (Bambrick *et al*., 2008). The number of hot days when physical labor in the sun becomes dangerous is also projected to increase substantially in Australia by 2070, leading to economic costs from lost productivity, increased hospitalisations and occasional deaths (*medium confidence*; Hanna *et al*., 2011; Maloney and Forbes, 2011).

Water- and food-borne diseases are projected to increase, but the complexity of their relationship to climate and non-climate drivers means there is *low confidence* in specific projections. For Australia, 205,000-335,000 new cases of bacterial gastroenteritis by 2050, and 239,000-870,000 cases by 2100, were projected under a range of emission scenarios (Bambrick *et al*., 2008; Harley *et al*., 2011). Water-borne zoonotic diseases such as cryptosporidiosis have more complex relationships with climate (Lal *et al*., 2012), while water treatment systems help to prevent outbreaks related to heavy rainfall or flooding (Britton *et al*., 2010b, a).

Current empirical models assess the combined effects of climate change and socio-economic development on the distribution of vector borne diseases. The area climatically suitable for transmission of dengue is projected to expand under A1FI scenarios in Australia (*high confidence*; Bambrick *et al*., 2008). This expansion may be limited or even reversed depending on socio-economic development (*low confidence*; Åström *et al*., 2013). Australasia is projected to remain malaria free under the A1B emission scenario until at least 2050 (Béguin *et al*., 2011) and sporadic cases could be treated effectively. The impacts of climate change on Ross River and other arboviruses with more complex transmission cycles that involve multiple host species have not been modelled in this region. However, the combined effects of climate change, frequent travel within and outside the region, and recent incursions of exotic mosquito species suggest that the geographic range of arboviruses could expand (*medium confidence*; Derraik and Slaney, 2007; Derraik *et al*., 2010).

A growing literature since the AR4 has focused on the psychological impacts of climate change, based on impacts of recent climate variability and extremes (Doherty and Clayton, 2011; 25.4.3). These studies indicate significant mental health risks associated with climate-related disasters, in particular persistent and severe drought, floods and storms, and that impacts may be especially acute in rural communities where climate change places additional stresses on livelihoods (*high confidence*; Edwards *et al*., 2011; see also Box 25.5). Projected population growth and urbanization could further increase health risks indirectly via climate-related stress on housing, transport and energy infrastructure and water supplies (*low confidence*; Howden-Chapman, 2010).

[INSERT FIGURE 25-5 HERE
Figure 25-5: Projected changes in exposure to heat under a high emissions scenario (A1FI). Maps show the average number of days with peak temperatures >40°C for Australian statistical local areas, for ~1990 (based on available meteorological station data for the period 1975-2004), ~2050 and ~2100. Bar charts show the change in population heat exposure, expressed as person-days exposed to peak temperatures >40°C, aggregated by State/Territory and including projected population growth for a default scenario. Future temperatures are based on simulations by the GFDL-CM2 global climate model (Meehl *et al*., 2007), re-scaled to the A1FI scenario; simulations based on other climate models could give higher or lower results. Data from Baynes *et al*. (2012).]

*25.8.1.3. Adaptation*

Research since the AR4 has mainly focused on health impacts. Some adaptation strategies have received attention in Australia, however, including reshaping government policy, improving healthcare services, social support for those most at risk, improving community awareness to reduce adverse exposures, and developing early warning and emergency response plans (Wang and McAllister, 2011). In New Zealand, central Government health policies show no specific measures to adapt to climate change (Wilson, 2011).

A review of the southern Australian heatwave of 2009 identified communication failures 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 (Kiem *et al*., 2010). Emergency and services infrastructure were underprepared and relied on reactive solutions (QUT, 2010). Charging more for energy during peak times would reduce risk to infrastructure overload (see 25.7.4), but leave low-income residents more vulnerable to heat waves (Strengers and Maller, 2011). The Victorian government has since developed a heatwave plan to coordinate a state-wide response, maintain consistent community-wide understanding through a Heat Health alert system, build capacity of councils to support communities most at risk from heat-related impacts, support and fund health services and a Heat Health Intelligence surveillance system, and distribute public health information (Victorian Government, 2009b). As a longer term strategy, greening cities reduces the urban heat island effect which in turn reduces heat health risks (Bambrick *et al*., 2011; see Box 25-9). The increased risk of dengue from domestic water tanks suggests a risk of maladaptive outcomes unless climate-related risks are taken into account in their installation and maintenance (Kearney *et al*., 2009).

### *25.8.2. Indigenous Peoples*

#### *25.8.2.1. Aboriginal and Torres Strait Islanders*

Australia's Indigenous population is small (2.5%), widely dispersed and rapidly growing (ABS 2009) yet controls more than 25% of the Australian land area (Altman *et al*., 2007; NNTT, 2013). Key work since the AR4 includes a national Indigenous adaptation research action plan (Langton *et al*., 2012), regional risk studies (Green *et al*., 2009; DoNP 2010; TSRA 2010) and scrutiny from an Indigenous rights perspective (ATSISJC 2009).

Socio-economic disadvantage and poor health (SCRGSP 2011) indicate a disproportionate climate change vulnerability of Indigenous Australians (McMichael *et al*., 2009) although there are no detailed assessments. In urban and regional areas, where 75% of the Indigenous population lives, assessments have not specifically addressed risks to Indigenous people (e.g. Guillaume *et al*., 2010). In other regions, all remote, there is limited empirical evidence of vulnerability (Maru *et al*., 2012). However, there is *high agreement* and *medium evidence* for significant future impacts from increasing heat stress, extreme events and increased disease (Campbell *et al*., 2008; Spickett *et al*., 2008; Green *et al*., 2009).

There is also *high agreement* but *limited evidence*, that: natural resource dependence (e.g. Bird *et al*., 2005; Gray *et al*., 2005a; Kwan *et al*., 2006; Buultjens *et al*., 2010) increases Indigenous exposure and sensitivity to climate change (Green *et al*., 2009); climate change-induced dislocation, attenuation of cultural attachment to place and loss of agency will disadvantage Indigenous mental health and community identity (Fritze *et al*., 2008; Hunter, 2009; McIntyre-Tamwoy and Buhrich, 2011); and, housing, infrastructure, services and transport, often already inadequate for Indigenous needs especially in remote Australia (ABS 2010c), will be further stressed (Taylor and Philp, 2010). Torres Strait island communities and livelihoods are vulnerable to major impacts from even small sea level rises (*high confidence*; DCC, 2009; Green *et al*., 2010b; TSRA 2010).

Little adaptation of Indigenous communities to climate change is apparent to date (but see Burroughs, 2010; GETF 2011). Institutions external to Indigenous communities can constrain their adaptive capacity (Ellemor, 2005; Petheram *et al*., 2010; Veland *et al*., 2010; Langton *et al*., 2012) and designing and communicating adaptation strategies is challenged by multiple stressors. Adaptation planning would benefit from a robust typology (Maru *et al*., 2011) across the diversity of Indigenous life experience (McMichael *et al*., 2009). Indigenous re-engagement with environmental management (e. g. Hunt *et al*., 2009; Ross *et al*., 2009) can promote health (Burgess *et al*., 2009) and may increase adaptive capacity (Berry *et al*., 2010; Davies *et al*., 2011). There is emerging interest in integrating Indigenous observations of climate change (Green *et al*., 2010c; Petheram *et al*., 2010) and developing inter-cultural communication tools (Prober *et al*., 2011; Woodward *et al*., 2012). Extensive land ownership in northern and inland Australia and land management traditions mean that Indigenous people are well situated to provide greenhouse gas abatement and carbon sequestration services that may also support their livelihood aspirations (Whitehead *et al*., 2009; Heckbert *et al*., 2012).

#### *25.8.2.2. New Zealand Māori*

The projected impacts of climate change on Māori society are expected to be highly differentiated reflecting complex economic, social, cultural, environmental and political factors (*high confidence*). Since the AR4, studies have been either sector-specific (e.g. Insley, 2007; Insley and Meade, 2008; Harmsworth *et al*., 2010; King *et al*., 2012) or more general, inferring risk and vulnerability based on exploratory engagements with varied stakeholders and existing social, economic, political and ecological conditions (e.g. MfE, 2007b; Te Aho, 2007; King *et al*., 2010).

The Māori economy depends on climate-sensitive primary industries with vulnerabilities to climate conditions (*high confidence*; Packman *et al*., 2001; NZIER, 2003; Cottrell *et al*., 2004; TPK, 2007; Tait *et al*., 2008b; Harmsworth *et al*., 2010; King *et al*., 2010; Nana *et al*., 2011a). Much of Māori-owned land is steep (>60%) and susceptible to damage from high intensity rainstorms, while many lowland areas are vulnerable to flooding and sedimentation (Harmsworth and Raynor, 2005; King *et al*., 2010). Land in the east and north is also drought prone, and this increases uncertainties for future agricultural performance, product quality and investment (*medium confidence*; Cottrell *et al*., 2004; Harmsworth *et al*., 2010; King *et al*., 2010). The fisheries and aquaculture sector faces substantial risks (and uncertainties) from changes in ocean temperature and chemistry, potential changes in species composition, condition and productivity levels (*medium confidence*; King *et al*., 2010; see also 25.6.2). At the community and individual level, Māori regularly utilize the natural environment for hunting and fishing, recreation, the maintenance of traditional skills and identity, and collection of cultural resources (King and Penny, 2006; King *et al*., 2012). Many of these activities are already compromised due to resource-competition, degradation and modification (Woodward *et al*., 2001; King *et al*., 2012). Climate change driven shifts in natural ecosystems will further challenge the capacities of some Māori to cope and adapt (*medium confidence*; King *et al*., 2012).

Māori organizations have sophisticated business structures, governance (e.g. trusts, incorporations) and networks (e.g. Iwi leadership groups) across the state and private sectors (Harmsworth *et al*., 2010; Insley, 2010; Nana *et al*., 2011b), critical for managing and adapting to climate change risks (Harmsworth *et al*., 2010; King *et al*., 2012). Some tribal organizations are developing options in response to the New Zealand Government's Emissions Trading Scheme (Insley, 2010). Future opportunities will depend on partnerships in business, science, research and government (*high confidence*; Harmsworth *et al*., 2010; King *et al*., 2010) as well as innovative technologies and new land management practices to better suit future climates (Carswell *et al*., 2002; Harmsworth, 2003; Funk and Kerr, 2007; Insley and Meade, 2008; Tait *et al*., 2008b; Penny and King, 2010).

Māori knowledge of environmental processes and hazards (King *et al*., 2005; King *et al*., 2007) as well as strong social-cultural networks are vital for adaptation and on-going risk management (King *et al*., 2008); however, choices and actions continue to be constrained by insufficient resourcing, shortages in social capital, and competing values (King *et al*., 2012). Combining traditional ways and knowledge with new and untried policies and strategies will be key to the long-term sustainability of climate-sensitive Māori communities, groups and activities (*high confidence*; Harmsworth *et al*., 2010; King *et al*., 2012).

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**Box 25-7. Insurance as Climate Risk Management Tool**

Insurance helps spread the risk from extreme events across communities and over time and therefore enhances the resilience of society to disasters (see 10.7). In Australia, insured losses are dominated by meteorological hazards, including the 2011 Queensland floods and the 1999 Sydney hailstorm (ICA, 2012) with estimated claims of A$3 billion p.a. (IAA, 2011a). In New Zealand, floods and storms are the second most costly natural hazards after earthquakes (ICNZ, 2013). Even though the number of damaging insured events (up to a certain loss value) has increased significantly in the Oceania region since 1980 (Schuster, 2013), normalised insured losses in Australia show no significant trend from 1967 to 2006 (Crompton and McAneney, 2008; see also Table 10.4).

There is *high confidence* that without adaptive measures, projected increases in extremes (Table 25-1) and uncertainties in these projections will lead to increased insurance premiums, exclusions and non-coverage in some locations (IAG, 2011), which will reshape the distribution of vulnerability, e.g., through unaffordability or unavailability of cover in areas at highest risk (IAA, 2011a, b; NDIR, 2011; Booth and Williams, 2012). Restriction of cover occurred in some locations following recent flood events in Queensland (Suncorp, 2013).

Insurance can positively contribute to risk reduction by providing incentives to policy holders to reduce their risk profile (O'Neill and Handmer, 2012), e.g. through resilience ratings given to buildings (TGA, 2009; Edge Environment, 2011; IAG, 2011). Apart from constituting an autonomous private sector response to extreme events, insurance can also be framed as a form of social policy to manage climate risks, similar to New Zealand's government insurance scheme to manage geological risk (Glavovic *et al*., 2010); government measures to reduce or avoid risks also interact with insurance companies' willingness to provide cover (Booth and Williams, 2012). Insurance can also act as a barrier to adaptation, however, where those living in climate-risk prone localities pay discounted or cross-subsidised premiums, or if policies fail to encourage betterment after damaging events by requiring replacement of 'like for like', constituting a missed opportunity for risk reduction (NDIR, 2011; QFCI, 2012; Reisinger *et al*., 2013; see also 10.7).

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**Box 25-8. Changes in Flood Risk and Management Responses**

Floods are the most costly natural disaster in Australia (BTE, 2001) and the second-most costly insured disaster in New Zealand, after earthquakes (ICNZ, 2013). Nonetheless, flood damages across eastern Australia and both main islands of New Zealand in 2010 and 2011 revealed a significant adaptation deficit (ICA, 2012; ICNZ, 2013). For example, the Queensland floods in January 2011 resulted in 35 deaths, three quarters of the State including Brisbane declared a disaster zone, and damages in excess of AUD$2 billion (Queensland Government, 2011). These floods were associated with a strong monsoon and the strongest La Niña on record (Cai *et al*., 2012; CSIRO and BoM, 2012; Evans and Boyer-Souchet, 2012). Floods exhibit strong decadal variability in their frequency and severity but no significant long-term trend to date (Kiem *et al*., 2003; Smart and McKerchar, 2010; Ishak *et al*., in press).

Flood risk is projected to increase in many regions due to more intense extreme rainfall events driven by a warmer and wetter atmosphere (*medium confidence*; Table 25-1). High resolution downscaling (Griffiths, 2007; Carey-Smith *et al*., 2010), and dynamic catchment hydrological and river hydraulic modelling in New Zealand (Gray *et al*., 2005b; McMillan *et al*., 2010; MfE, 2010a; Ballinger *et al*., 2011; Duncan and Smart, 2011; McMillan *et al*., 2012) indicate that the 50-year and 100-year flood peaks for rivers in many parts of the country will increase by 10-20% by 2050 and more (and greater variation between models and scenarios) by 2100, with a corresponding decrease in return periods for design floods. Studies for Queensland show similar results (DERM *et al*., 2010). In Australia, flood risk is expected to increase more in the north (driven by convective rainfall systems) than in the south (where more intense extreme rainfall may be compensated by drier antecedent moisture conditions), consistent with confidence in heavy rainfall projections (Table 25-1; Alexander and Arblaster, 2009; Rafter and Abbs, 2009a).

Flood risk near river mouths will be exacerbated by storm surge associated with higher sea level and potential change in wind speeds (McInnes *et al*., 2005; MfE, 2010a; Wang *et al*., 2010b). Higher rainfall intensity and peak flow will also increase erosion and sediment loads in waterways (Nearing *et al*., 2004) and exacerbate problems from aging stormwater and wastewater infrastructure in cities (Howe *et al*., 2005; Jollands *et al*., 2007; CCC, 2010; WCC, 2010). However, moderate flooding also has benefits through filling reservoirs, recharging groundwater and replenishing natural environments (Hughes, 2003; Chiew and Prosser, 2011; Oliver and Webster, 2011).

Adaptation to increased flood risks from climate change is starting to happen (Wilby and Keenan, 2012) through updating guidelines for design flood estimation (MfE, 2010a; Westra, 2012), improving flood risk management (O'Connell and Hargreaves, 2004; NFRAG, 2008; Queensland Government, 2011), enhancing coping capacity for buildings in flood prone areas (options include raising floor levels, using strong piled foundations, using water-resistant insulation materials and ensuring weather tightness), and risk reduction and avoidance through spatial planning and managed relocation (Trotman, 2008; Glavovic *et al*., 2010; LVRC, 2012; QFCI, 2012). Adaptation options in urban areas include retaining floodplains and floodways and retrofitting existing systems to attenuate flows (Box 25.9; Howe *et al*., 2005; Skinner, 2010; WCC, 2010).

The recent flooding in eastern Australia and the projected increase in future flood risk have resulted in changes to reservoir operations to mitigate floods (van den Honert and McAneney, 2011; QFCI, 2012) and insurance practice to cover flood damages (NDIR, 2011; Phelan, 2011). However, the magnitude of potential future changes in flood risks and limits to incremental adaptation responses in urban areas suggest that more transformative and structural approaches based on altering land-use and avoidance of exposure to future flooding may be needed in some locations, especially if changes in the upper range of projections are realised (*high confidence*; Lawrence and Allan, 2009; DERM *et al*., 2010; Glavovic *et al*., 2010; Wilby and Keenan, 2012; Lawrence *et al*., submitted-a).

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**Box 25-9. Opportunities, Constraints, and Challenges to Adaptation in Urban Spaces**

Considerable opportunities exist for Australasian cities and towns to reduce climate change impacts and, in some regions, benefit from projected changes such as warmer winters and more secure water supply (Fitzharris, 2010; Australian Government, 2012). Many tools and practices developed for sustainable resource management or disaster risk reduction in urban areas are co-beneficial for climate change adaptation, and vice versa, and can be integrated with mitigation objectives (Hamin and Gurran, 2009). Despite the abundance of potential adaptation options, however, social, cultural, institutional and economic factors frequently constrain their implementation (*robust evidence* and *high agreement*; see also 25.4.2). The form and longevity of cities and towns, with their concentration of hard and critical infrastructure such as housing, transport, energy transmission, waste, telecommunications and public facilities provide additional challenges (see also Chapters 8 and 10, Boxes 25-1, 25-2, 25-8, 25.7.4, 25.8.1). Table 25-5 summarises some adaptation options, co-benefits and constraints on their adoption in Australasia.

Overall, the implementation of climate change adaptation policy for urban settlements in Australia and New Zealand has been mixed. The Australian National Urban Policy encourages adaptation, and many urban plans include significant adaptation policies (City of Melbourne, 2009; City of Port Phillip, 2010; e.g. ACT Government, 2012; City of Adelaide, 2012). New Zealand also promotes urban adaptation through strategies, plans and guidance documents (MfE, 2008a; CCC, 2010; WCC, 2010; Auckland Council, 2012). Many examples of incremental urban adaptation exist already (see Box 25-2, Table 25-5), particularly where these include co-benefits and respond to other stressors, like prolonged drought in southern Australia and recurrent floods. Experience is much scarcer with transformative changes, such as managed relocation or more flexible land-uses that could disrupt existing settlement patterns and development trends, and where maintaining flexibility to address long-term climate risks can run against near-term development pressures (see Boxes 25-2, 25-8). Decision-making models that support adaptive and transformative change (25.4.2) have not yet been implemented widely in urban contexts; increased coordination among different levels of government may be required to spread costs and balance public and private, near- and long-term and local and regional benefits (Norman, 2009; Britton, 2010; Norman, 2010; Abel *et al*., 2011; McDonald, 2013; Palutikof *et al*., 2013; Reisinger *et al*., 2013; Lawrence *et al*., submitted-a).

[INSERT TABLE 25-5 HERE
Table 25-5: Examples of co-beneficial climate change adaptation options for urban areas and barriers to their adoption. Options in italics are already widely implemented in Australia and New Zealand urban areas.]

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## 25.9. Interactions among Impacts, Adaptation, and Mitigation Responses

The AR4 found that individual adaptation responses can entail synergies or trade-offs with other adaptation responses and with mitigation, but that integrated assessment tools were lacking in Australasia (Hennessy *et al*., 2007). Subsequent studies provide detail on such interactions and can inform a balanced portfolio of climate change responses, but evaluation tools remain limited, especially for local decision-making (Park *et al*., 2011). A review of 25 specific climate change-associated land-use plans from Australia, for example, found that 12 exhibited potential for conflict between mitigation and adaptation (Hamin and Gurran, 2009).

### *25.9.1. Interactions among Local-Level Impacts, Adaptation, and Mitigation Responses*

Table 25-6 shows examples of adaptation responses that are either synergistic or entail trade-offs with other impacts and/or adaptation responses and goals. Adapting proactively to projected climate changes, particularly extremes such as floods or drought, can increase near-term resilience to climate variability and be a motivation for adopting adaptation measures (Productivity Commission, 2012). However, exclusive reliance on near-term benefits can increase trade-offs and result in long-term maladaptation (*high confidence*). For example, enhancing protection measures after major flood events, combined with rapid re-building, accumulates fixed assets that can become increasingly costly to protect as climate change continues, with attendant loss of amenity and environmental values (Glavovic *et al*., 2010; Gorrdard *et al*., 2012; McDonald, 2013). Similarly, deferring adoption of increased design wind speeds in cyclone-prone areas delays near-term investment costs but also reduces the long-term benefit/cost ratio of the strategy (Stewart and Wang, 2011).

[INSERT TABLE 25-6 HERE
Table 25-6: Examples of interactions between impacts and adaptation measures in different sectors. In each case, impacts or responses in one sector have the potential to cause negative impacts or have co-benefits with impacts or responses in another sector, or with another type of response in the same sector.]

Mitigation actions can contribute to but also counteract local adaptation goals. Energy efficient buildings, for example, reduce network and health risks during heat waves, but urban densification to reduce transport energy demand intensifies urban heat islands and, hence, heat-related health risks (25.7.4, 25.8.1). Specific adaptations can also make achievement of mitigation targets harder or easier. Increased use of air conditioning, for example, increases energy demand, but reducing heat exposure through energy efficiency and building design reduces demand (25.7.4, Box 25-9). Table 25-7 gives further examples, and Box 25-10 explores the multiple and complex benefits and trade-offs in changing land-use simultaneously to adapt to and mitigate climate change.

[INSERT TABLE 25-7 HERE
Table 25-7: Examples of interactions between adaptation and mitigation measures (green rows denote synergies where multiple benefits may be realized, orange rows denote potential tradeoffs and conflicts; grey row gives an example of complex, mixed interactions). The primary goal may be adaptation or mitigation.]

_____ START BOX 25-10 HERE _____

**Box 25-10. Land-based Interactions Among Climate, Energy, Water, and Biodiversity**

Climate, water, biodiversity, food and energy production and use are intertwined through complex feedbacks and trade-offs (see also Box CC-WE). This could make alternative uses of natural resources within rural landscapes increasingly contested, yet decision support tools to manage competing objectives are limited (PMSIEC, 2010).

Various policies in Australasia support increased biofuel production and biological carbon sequestration via, for example, mandatory renewable energy targets and incentives to increase carbon storage. Impacts of increased biological sequestration activities on biodiversity depend on their implementation. Benefits arise from reduced erosion, additional habitat, and enhanced ecosystem connectivity, while risks or lost opportunities are associated with large-scale monocultures especially if replacing more diverse landscapes (Brockerhoff *et al*., 2008; Giltrap *et al*., 2009; Steffen *et al*., 2009; Todd *et al*., 2009; Bradshaw *et al*., submitted).

Photosynthesis transfers water to the atmosphere, so increased sequestration is projected to reduce catchment yields particularly in southern Australia and affect water quality negatively (Botkin *et al*., 2007; CSIRO, 2008; Schrobback *et al*., 2011; Bradshaw *et al*., submitted). Accounting for this water use in water allocations for sequestration activities would increase their cost and limit the potential of sequestration-driven land-use change (Polglase *et al*., 2011; Stewart *et al*., 2011). Large-scale land-cover changes also affect regional climate through changing albedo, evapotranspiration and surface roughness, but these feedbacks have rarely been integrated with direct water demands (McAlpine *et al*., 2009; Kirschbaum *et al*., 2011b).

Biological carbon sequestration in New Zealand is less water-challenged than in Australia, except where catchments are projected to become drier and/or are already completely allocated (MfE, 2007a; Rutledge *et al*., 2011). Carbon sequestration would mostly improve water quality through reduced erosion (Giltrap *et al*., 2009). Policies to protect water quality by limiting nitrogen discharge from agriculture have reduced livestock production and greenhouse gas emissions in the Lake Taupo catchment and supported land-use change towards sequestration (Yeo *et al*., 2012).

Trade-offs between biofuel and food production and ecosystem services depend strongly on the type of sequestration activity and their management relies on use of consistent principles to evaluate externalities and benefits of alternative land-uses (PMSIEC, 2010). First-generation biofuels have been modelled in Australia as directly competing with agricultural production (Bryan *et al*., 2010). In contrast, production of woody biofuels in New Zealand is projected to occur on marginal land, not where the most intense agriculture occurs (Todd *et al*., 2009). Falling costs and increasing efficiency of solar energy may limit future biofuel demand, given the limited efficiency of plants in converting solar energy into usable fuel (e.g. Reijnders and Huijbregts, 2007).

_____ END BOX 25-10 HERE _____

### *25.9.2. Intra- and Inter-Regional Flow-On Effects Among Impacts, Adaptation and Mitigation*

Recent studies strengthen conclusions from the AR4 (Hennessy *et al*., 2007) that flow-on effects from climate change impacts occurring in other world regions can exacerbate or counteract projected impacts in Australasia.

Modelling suggests Australia's terms of trade would deteriorate by about 0.23% in 2050 and 2.95% in 2100 as climate change impacts reduce economic activity and demand for coal, minerals and agricultural products in other world regions (A1FI scenario; Harman *et al*., 2008). As a result, Australian Gross National Product (GNP) is expected to decline more strongly than GDP due to climate change, especially towards the end of the 21$^{st}$ century (Gunasekera *et al*., 2008). These conclusions, however, merit only *medium confidence*, because they rely on simplified assumptions about global climate change impacts, economic effects and policy responses.

For New Zealand, there is *limited evidence* but *high agreement* that higher global food prices driven by adverse climate change impacts on global agriculture and some international climate policies would increase commodity prices and hence producer returns. Agriculture and forestry producer returns, for example, are estimated to increase by 14.6% under the A2 scenario by 2070 (Saunders *et al*., 2010) and real gross national disposable income by 0.6-2.3% under a range of non-mitigation scenarios (Stroombergen, 2010) relative to baseline projections in the absence of global climate change. Some climate policies such as biofuel targets and agricultural mitigation in other regions would also increase global commodity prices and hence returns to New Zealand farmers (Saunders *et al*., 2009; Reisinger *et al*., 2012). Depending on global implementation, these could more than offset projected average domestic climate change impacts on agriculture (Tait *et al*., 2008a). In contrast, higher international agricultural commodity prices appear insufficient to compensate for the more severe effects of climate change on agriculture in Australia (see 25.7.2; Gunasekera *et al*., 2007; Garnaut, 2008).

Climate change could affect international tourism to Australasia through international destination and activity preferences (Kulendran and Dwyer, 2010; Rosselló-Nadal *et al*., 2011; Scott *et al*., 2012), climate policies, and oil prices (Mayor and Tol, 2007; Becken, 2011; Schiff and Becken, 2011). These potentially significant effects remain poorly quantified, however, and are not well integrated into local vulnerability studies (Hopkins *et al*., 2012).

Climate change has the potential to change migration flows within Australasia, particularly due to coastal changes (e.g. from the Torres Straits islands to mainland Australia), although reliable estimates of such movements do not yet exist (see Chapter 12.4; Green *et al*., 2010b; McNamara *et al*., 2011; Hugo, 2012). Migration within countries, and from New Zealand to Australia, is largely economically driven and sustained by transnational networks, though the perceived more attractive current climate in Australia is reportedly a factor in migration from New Zealand (Goss and Lindquist, 2000; Green *et al*., 2008a; Poot, 2009). The impacts of climate change in the Pacific may contribute to an increase in the number of people seeking to move to nearby countries (Bedford and Bedford, 2010; Hugo, 2010; McAdam, 2010; Farbotko and Lazrus, 2012) and affect political stability and geopolitical rivalry within the Asia-Pacific region, although there is no clear evidence of this to date and causal theories are scarce (Dupont, 2008; Pearman, 2009; see Chapter 12.5). There is *high agreement* and *robust evidence* that increasing climate-driven disasters, disease and border control will stimulate operations other than war for Australasia's armed forces, and that integration of security into adaptation and development assistance for Pacific island countries can play a key role in moderating the influence of climate change on forced migration and conflict (Dupont and Pearman, 2006; Bergin and Townsend, 2007; Dupont, 2008; Sinclair, 2008; Barnett, 2009; Rolfe, 2009).

## 25.10. Synthesis and Regional Key Risks

### *25.10.1. Economy-wide Impacts and the Potential of Mitigation to Reduce Risks*

Globally effective mitigation could reduce or delay some of the risks associated with climate change and make adaptation more feasible beyond about 2050, when projected climates begin to diverge substantially between mitigation and non-mitigation scenarios (see also 19.7). However, literature quantifying these benefits for Australasia is sparse. Economy-wide net costs for Australia are modelled to be substantially greater in 2100 under unmitigated climate change (A1FI; GNP loss 7.6%) than under globally effective mitigation (GNP loss less than 2% for stabilization at 450 or 550 ppm $CO_2$-eq, including residual impacts and costs of mitigation; Garnaut, 2008). These estimates, however, are highly uncertain and depend strongly on valuation of non-market impacts, treatment of potentially catastrophic outcomes, and specific assumptions about autonomous adaptation, global changes and flow-on effects for Australia, and effectiveness and implementation of global mitigation efforts (Garnaut, 2008). No integrated estimates of climate change costs across the entire economy exist for New Zealand.

The benefits of mitigation in terms of reduced risks have been quantified for some individual sectors in Australia, e.g. for irrigated agriculture in the Murray-Darling Basin (Quiggin *et al*., 2008; Quiggin *et al*., 2010; Valenzuela and Anderson, 2011; Scealy *et al*., 2012) and for net health outcomes (Bambrick *et al*., 2008). Although quantitative estimates from individual studies are highly assumption-dependent, multiple lines of evidence (see 25.7-8) give *very high confidence* that globally effective mitigation would significantly reduce many long-term risks from climate change to Australia. Benefits differ, however, between States for some issues, e.g. heat and cold mortality (Bambrick *et al*., 2008). Few studies consider mitigation benefits explicitly for New Zealand, but scenario-based studies give *high confidence* that mitigating emissions from a high (A2) to at least a medium-low (B1) emissions scenario would markedly lower the projected increase in flood risks (Ballinger *et al*., 2011; McMillan *et al*., 2012) and reduce risks to livestock production in the most drought prone regions (Tait *et al*., 2008a; Clark *et al*., 2011b). Mitigation would also reduce the projected benefits to production forestry, however, though amounts depend on the response to $CO_2$ fertilization (Kirschbaum *et al*., 2011a; 25.7.1).

### *25.10.2. Regional Key Risks as a Function of Mitigation and Adaptation*

The Australia/New Zealand Chapter of the AR4 (Hennessy *et al*., 2007) concluded with an assessment of aggregated vulnerability for a range of sectors as a function of global average temperature. Building on recent additional insights, Table 25-8 shows eight key risks within those sectors that can be identified with *high confidence* for the 21$^{st}$ century, based on the multiple lines of evidence presented in the preceding sections and selected using the framework for identifying key risks set out in Chapter 19. This combines consideration of biophysical impacts, their likelihood, timing and persistence, with vulnerability of the affected system, based on exposure, magnitude of harm, significance of the system and its ability to cope with or adapt to projected biophysical changes. These key risks differ in the extent to which they can be managed through adaptation and mitigation, and some are more likely than others, but all warrant attention from a risk-management perspective.

[INSERT TABLE 25-8 HERE
Table 25-8: Key regional risks during the 21st century from climate change for Australia and New Zealand. Colour bars indicate risk as a function of global mean temperature relative to pre-industrial, based on the studies assessed and expert judgment, for the current (top bar) and a hypothetical fully adapted state (bottom bar). For each risk, relevant climate variables and trends are indicated by symbols, in approximate order of priority. Where relevant climate projections span a particularly wide range even for a given amount of global mean temperature change, risks are shown in two pairs for low and high end projections, each without and with effective adaptation.]

One set of risks comprises damages to natural ecosystems (significant change in coral reefs and decline of some montane and low-lying ecosystems) that can be moderated by globally effective mitigation but to which some damage now seems inevitable. For some species and ecosystems, there is *high confidence* that climatically constrained ecological niches, fragmented habitats and limited adaptive movement collectively present hard limits to adaptation to further climate change (see also 25.10.3). A second set of key risks (increase in wild fire, heat waves, water scarcity and flood risk) comprises damages that could be severe but can be moderated or delayed by a portfolio of adaptation measures together with mitigation, and where the need for transformative adaptation increases with the rate and amount of climate change (see also 25.10.3). A third set of key risks (coastal damages from sea level rise, and loss of food production from severe drying) comprises potential impacts that are particularly uncertain within the 21st century, even for a given global temperature change, and where alternative scenarios for changes in other climate drivers materially affect levels of concern and adaptation needs. Even though scenarios of severe drying or rapid sea level rise have low or currently unknown probabilities, the associated impacts would so severely challenge adaptive capacity, including transformational changes, that they constitute important risks.

A first comparative assessment of exposure and damages from different hazards for Australia up to 2100 indicates that inland flooding will continue to be the most costly source of direct damages to infrastructure, even though the largest value of assets is exposed to bush fire. Exposure to and damages from coastal inundation are currently smaller, but would rise most rapidly beyond mid-century once sea level rise exceeds 0.5 m (Baynes *et al*., 2012).

An *emerging risk* is the compounding of extreme events, none of which would constitute a *key* risk in its own right, but that collectively and cumulatively across space, time and governance scales could stretch emergency response and recovery capacity and hamper regional economic development, including through impacts on insurance markets or multiple concurrent needs for major infrastructure upgrades (NDIR, 2011; Phelan, 2011; Baynes *et al*., 2012; Booth and Williams, 2012; Karoly and Boulter, 2013). Efforts are underway to better understand the potential importance of cumulative impacts and responses (CSIRO, 2011; Leonard *et al*., submitted) but evidence is as yet too limited to identify this as a *key risk* consistent with the definitions adopted in this report (see Chapter 19).

Climate change is projected to bring benefits to some sectors and parts of Australasia, at least under limited warming scenarios associated with globally effective mitigation (*high confidence*). Examples include an extended growing season for agriculture and forestry in cooler parts of New Zealand and Tasmania, reduced winter energy demand and illnesses in most of New Zealand and southern States of Australia, and increased winter hydropower potential in New Zealand's South Island (25.7.1, 25.7.2, 25.7.4, 25.8.1).

The literature supporting this assessment of key risks is uneven among sectors and between Australia and New Zealand; for the latter, conclusions in many sectors are based on limited studies that often use a narrow set of assumptions, models, and data and which, accordingly, have not explored the full range of potential outcomes.

### *25.10.3. Challenges to Adaptation in Managing Key Risks, and Limits to Adaptation*

Two key and related challenges for regional adaptation are apparent: to identify when and where a move from incremental to transformative adaptation measures is needed; and, where specific interventions are needed to overcome adaptation constraints, in particular to support proactive and transformative responses that require coordination across different spheres of governance and decision-making (Palutikof *et al*., 2013). The magnitude of climate change, especially under scenarios of limited mitigation, and constraints to adaptation suggest that incremental and autonomous responses will not deliver the full range of adaptation options available, or to ensure natural and human systems can still function even if some key risks are realized (*high confidence*; see also 25.4).

Most incremental adaptation measures in natural ecosystems focus on reducing other non-climate stresses (25.6.1, 25.6.2) but, even with scaled-up efforts, conserving the current state and composition of natural ecosystems most at risk appears increasingly infeasible. Maintenance of key ecosystem functions and services and individual species requires a radical reassessment of conservation values and practices related to translocation of species and the values placed on "introduced" species (Steffen *et al*., 2009). Divergent views regarding intrinsic and service values of individual species and ecosystems imply that a proactive discussion is necessary to enable effective decision-making and resource allocation. In human systems, incremental adjustments of current tools, planning approaches and early warning systems for floods, fire, drought, water resources and coastal hazards will increase resilience to climate variability and could be sufficient under scenarios of limited climate change (*medium confidence*; Stafford-Smith, 2013). A purely incremental approach, however, which generally aims to preserve current management objectives, governance and institutional arrangements, creates a path-dependency that becomes increasingly constraining and costly to overcome once more transformative changes are needed (*high agreement, medium evidence*; e.g. Howden *et al*., 2010; Park *et al*., 2012; McDonald, 2013, and 25.4.2). Examples include: managed retreat from eroding coasts that are increasingly difficult or costly to protect; the transformation of some rural and remote communities; translocation of some industries and economic activities in response to increasing drought, flood and fire risks or water scarcity; and re-balancing protection from and accommodation or avoidance of flood risk (Boxes 25-1, -2, 5-9; Linnenluecke *et al*., 2011; Kiem and Austin, 2012; O'Neill and Handmer, 2012; Fletcher *et al*., submitted).

Consideration of transformative adaptation becomes critical where long life- or lead-times are involved, and where high up-front costs or multiple interdependent actors across a range of scales create barriers that require coordinated and proactive interventions (Stafford-Smith *et al*., 2011b; Palutikof *et al*., 2013). In these situations, deferring adaptation decisions due to limited knowledge about the future will not necessarily minimize costs or ensure adequate flexibility for future responses (Stewart and Wang, 2011; Gorrdard *et al*., 2012; McDonald, 2013).

Nonetheless, thresholds and any need for policy support for transformative adaptation inevitably depend upon social, institutional and cultural values and objectives. Whether transformative responses are seen as success or failure of adaptation depends on the extent to which actors accept a change in, or wish to maintain current activities and management objectives, and the degree to which the values and institutions underpinning the transformation are shared or contested across stakeholders (Park *et al*., 2012; Stafford-Smith, 2013). These views will differ not only between communities and industries but also from person to person depending on their individual value systems, perceptions of and attitude to risk, and ability to capitalize on opportunities (see also 25.4.3).

## 25.11. Filling Knowledge Gaps to Improve Management of Climate Risks

The wide range of projected rainfall changes (averages and extremes) and their hydrological amplification are key uncertainties affecting the scale and urgency of adaptation in agriculture, forestry, water resources, some ecosystems, and wildfire and flood risks. For ecosystems, agriculture and forestry, these uncertainties are compounded by limited knowledge of responses of vegetation to elevated $CO_2$, changes in ocean pH, and interactions with changing climatic conditions. The uncertainties in future impacts are most critical for decisions with long lifetimes, such as capital infrastructure investment or large-scale changes in land- and water-use. Uncertainties about the rate of sea level rise, and changes in storm paths and intensity, add to challenges for infrastructure design. The use of multi-model means and a narrow set of emissions scenarios in many past studies implies that the full set of climate-related risks and management options remains incompletely explored.

Understanding of ecological and physiological thresholds that, once exceeded, would result in rapid changes in species, ecosystems and their services, is still very limited. The literature is noticeably sparse in New Zealand and for arid Australia. These knowledge gaps are compounded by limited information about the effect of global climate change on patterns of natural climate variability, such as ENSO. Better understanding the effect of evolving natural climate variability and long-term trends on both invasive species and native and managed ecosystems could support more robust ecosystem-based adaptation strategies.

Vulnerability of human and managed systems depends critically on future socio-economic characteristics. Research into psychological, social and cultural dimensions of vulnerability, adaptive capacity and underpinning values remains limited and poorly integrated with bio-physical studies, which reduces confidence in conclusions regarding future vulnerabilities and the feasibility and effectiveness of adaptation strategies.

These multiple, persistent and structural uncertainties imply that, in most cases, adaptation requires an iterative risk management process. While decision-support frameworks are being developed, it remains unclear to what extent existing governance and institutional arrangements will be able to support more transformational responses, particularly where competing public and private interests and particularly vulnerable groups are involved. The enabling or constraining influences on adaptation from interactions among market forces, institutions, governance, policy and regulatory environments have only recently begun to attract research attention, mostly in Australia.

Climate change impacts, adaptation and mitigation responses in other world regions will affect Australasia, but our understanding of this remains very limited. Existing studies suggest transboundary effects, mediated mostly via trade but potentially also migration, can be of similar if not larger scale than direct domestic impacts of climate change for economically important sectors such as agriculture and tourism. However, scenarios used in such studies tend to be highly simplified. Effective management of risks and opportunities in these sectors would benefit from better integration of relevant global scenarios of climatic and socio-economic changes into studies of local impacts, vulnerabilities and adaptation options.

## Frequently Asked Questions

***FAQ 25-1: How can we adapt to climate change while projected future changes remain so uncertain?***

A focus on distant impacts and their uncertainties can make adaptation to climate change appear an impossible task. However, a different approach can mitigate this perceived problem (Figure 25-6). First, many climate changes are reasonably certain, especially in the short to medium term (i.e. to mid-century). Examples include rising air and sea surface temperatures (including a related increase in heatwaves and moisture evaporation), rising atmospheric $CO_2$, increasing ocean acidification, and rising sea-levels. These changes are no more uncertain than other changes such as future population, economic development or exchange rates that also concern decision-makers.

Second, for adaptation, our attention should focus on decisions that can and will be made in the near future, on the 'lifetime' of those decisions, and the risk posed by climate change during that lifetime. Thus the choice of next year's annual crop, even though it is greatly affected by climate, only matters for a year or two and can be adjusted within a few years. When the adaptation challenge is reframed as implications for near-term decisions, many decisions are not greatly affected by climate change, or do not require a dedicated adaptation response. Third, there are, of course, decisions such as those about long-lived infrastructure and spatial planning which must take longer-term climate change into account, and in some cases these do need to be addressed in light of significant uncertainty. Even then, techniques exist and are widely used in other areas to reduce challenges for decision-making – including the precautionary principle, real options, adaptive management, no regrets strategies, or risk hedging. These can be matched to the type of uncertainty.

Last, adaptation is not a one-off action; change will be on-going and adaptation will take place along an evolving pathway, in which decisions are updated and revisited as the future unfolds and more information comes to hand (see Figure 25-6). While this creates an opportunity for learning, successive short-term decisions need to be monitored to avoid unwittingly creating an adaptation path that is not be sustainable as climate change continues, also referred to as maladaptation. Changing pathways (e.g. from a paradigm that favours protection from risks, to one that seeks to accommodate or avoid risks) can be challenging and may require new collaborations and interactions between decision-makers at various levels and the people affected by those decisions.

[INSERT FIGURE 25-6 HERE
Schematic illustration of adaptation as an iterative risk management process. Each individual adaptation decision comprises well known aspects of risk assessment and management (top left panel). Each such decision occurs within and exerts its own sphere of influence, determined by the lead- and consequence time of the decision, and the broader regulatory and societal influences on the decision (top right panel). A sequence of adaptation decisions creates an adaptation pathway (bottom panel). There is no single correct adaptation pathway, although some decisions, and sequences of decisions, are more likely to result in long-term maladaptive outcomes than others, but the judgment of outcomes depends strongly on societal values, expectations and goals.]

***FAQ 25-2: Why and where does climate change matter to Australia and New Zealand?***

Climate change will produce rises in temperatures, atmospheric $CO_2$ and sea levels as well as changes in rainfall and other precipitation patterns and some extreme weather events. Ecosystems have developed and many aspects of human society, including large-scale infrastructure, been designed to function under *current* climate conditions. The projected changes, accordingly, will affect water resources, coasts, infrastructure, agriculture, health and biodiversity in Australia and New Zealand.

For the range of plausible climate changes over the 21st century, key risks exist for Australia and New Zealand. These differ both in their likelihood and the degree to which they can be managed by adaptation and mitigation.

Some potential impacts, such as significant change in coral reef systems and loss of higher-altitude ecosystems, are very difficult to avoid entirely even if climate change is limited by mitigation. Some impacts, such as increased flood damage to settlements and infrastructures, increased health impacts, and infrastructure failure during heat waves, increasing water scarcity in some regions and increased damages to ecosystems and risk to human life, properties and infrastructure from wildfires, have the potential to be severe but can be moderated by effective mitigation combined with regional adaptation measures - although the degree and nature of adaptation required will depend on the amount of climate change. Other impacts are very uncertain but could arise even if global mitigation actions are effective. These include significant region-wide damages to coastal infrastructure and low-lying ecosystems from sea level rise, or a severe decline in water availability resulting in significant reduction in food production, e.g. in the Murray-Darling Basin. In spite of their uncertainty, the severe consequences of such extreme scenarios warrants their consideration in current risk management.

**Cross-Chapter Box**

**Box CC-WE. The Water-Energy-Food Nexus as Linked to Climate Change**

[Douglas J. Arent (USA), Petra Döll (Germany), Ken Strzepek (UNU/USA), FerencToth (IAEA/Hungary), Blanca Elena Jimenez Cisneros (Mexico), Taikan Oki (Japan)]

Water, energy, and food are linked through numerous interactive pathways and subject to a changing climate, as depicted in Figure CC-WE-1. The depth and intensity of those linkages vary enormously between regions and production systems. Some energy technologies (biofuels, hydropower, thermal power plants), transportation fuels and modes and food products (from irrigated crops, in particular animal protein produced by feeding irrigated crops) require more water than others (Chapter 3.7.2, 7.3.2, 10.2,10.3.4, McMahon and Price, 2011, Macknick et al, 2012a, Cary and Weber 2008). In irrigated agriculture, climate, crop choice and yields determine water requirements per unit of produced crop, and in areas where water must be pumped or treated, energy must be provided (Kahn and Hajra 2009, Gertenet al. 2011). While food production and transport require large amounts of energy (Pelletier et al 2011), a major link between food and energy as related to climate change is the competition of bioenergy and food production for land and water (7.3.2, Diffenbaugh et al 2012, Skaggs et al, 2012).

[INSERT FIGURE WE-1 HERE
Figure WE-1: The water-energy-food nexus as related to climate change.]

Most energy production methods require significant amounts of water, either directly (e.g. crop-based energy sources and hydropower) or indirectly (e.g., cooling for thermal energy sources or other operations) (Chapter 10.2.2 and 10.3.4, and Davies et al 2013, van Vliet et al 2012). Water is also required for mining, processing, and residue disposal of fossil fuels. Water for biofuels, for example, has been reported by Gerbens-Leenes et al. 2012 who computed a scenario of water use for biofuels for transport in 2030 based on the Alternative Policy Scenario of the IEA. Under this scenario, global consumptive irrigation water use for biofuel production is projected to increase from 0.5% of global renewable water resources in 2005 to 5.5% in 2030, resulting in increased pressure on freshwater resources, with potential negative impacts on freshwater ecosystems. Water for energy currently ranges from a few percent to more than 50% of freshwater withdrawals, depending on the region and future water requirements will depend on electric demand growth, the portfolio of generation technologies and water management options employed (WEC 2010, Sattler et al., 2012). Future water availability for energy production will change due to climate change (Chapter 3.5.2.2).

Water may require significant amounts of energy for lifting, transport and distribution, treatment or desalination. Non-conventional water sources (wastewater or seawater) are often highly energy intensive. Energy intensities per $m^3$ of water vary by about a factor of 10 between different sources, e.g. locally produced or reclaimed wastewater vs. desalinated seawater (Plappally and Lienhard 2012, Macknick et al, 2012b). Groundwater (35% of total global water withdrawals, with irrigated food production being the largest user, Döll et al. 2012) is generally more energy intensive than surface water – in some countries, 40% of total energy use is for pumping groundwater. Pumping from greater depth (following falling groundwater tables) increases energy demand significantly– electricity use (kWhr/$m^3$) increases by a factor of 3 when going from 35 to 120 m depth (Plappally and Lienhard 2012). A lack of water security can lead to increasing energy demand and vice versa, e.g. over-irrigation in response to electricity or water supply gaps.

Other linkages through land use and management, e.g. afforestation, can affect water as well as other ecosystem services, climate and water cycles (4.4.4, Box 25-10). Land degradation often reduces efficiency of water and energy use (e.g. resulting in higher fertilizer demand and surface runoff), and many of these interactions can compromise food security (3.7.2, 4.4.4). Only a few reports have begun to evaluate the multiple interactions among energy, food, land, and water (McCornick *et al.,* 2008, Bazilian *et al.,* 2011, Bierbaum and Matson, 2013), addressing the issues from a security standpoint and describing early integrated modeling approaches. The interaction among each of these factors is influenced by the changing climate, which in turn impacts energy demand, bioproductivity and other factors (see Figure WE-1 and Wise et al, 2009), and has implications for security of supplies of energy, food and water, adaptation and mitigation pathways, air pollution reduction as well as the implications for health and economic impacts as described throughout this Assessment Report.

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Table 25-1: Observed and projected changes in key climate variables, and (where assessed) the contribution of human activities to observed changes. For further relevant information see WGI Chapters 3, 6 (ocean changes, including acidification), 11, 12 (projections), 13 (sea level), and 14 (regional climate phenomena).

(*) *medium confidence*, (**) *high confidence*, (***) *very high confidence*, (****) *virtually certain*

| ***Climate variable*** | ***Observed change*** | ***Direction of projected change*** | ***Examples of projected magnitude of change*** *(relative to 1990, unless otherwise stated)* | ***Additional comments*** |
|---|---|---|---|---|
| **Mean air temperature** | ***Aus:*** Increased by 0.09 ± 0.03°C per decade since 1911[1] (***)<br>***NZ:*** Increased by 0.09 ± 0.03°C per decade since 1909[2] (***) | ***Aus and NZ:*** Increase [3-7](****); greatest over inland Aus and least in coastal areas and NZ[3, 4, 7, 8] (***) | ***Aus:*** 0.5-1.5°C (2030 A1B), 1.0-2.5°C (2070 B1), 2.2-5.0°C (2070 A1FI)[5]<br>***NZ:*** 0.3-1.4°C (2040 A1B), 0.7-2.3°C (2090 B1), 1.6-5.1°C (2090 A1FI)[7]<br>*CMIP5 RCP4.5, rel. to 1995[9]:*<br>***N Aus:*** 0.2-1.9°C (2035), 0.9-3.4°C (2065)<br>***S Aus & NZ:*** 0.1-1.2°C (2035), 0.6-2.2°C (2065) | ***Aus****:* A significant contribution to observed change attributed to anthropogenic climate change[10] (**) with some regional variations attributed to atmospheric circulation variations[11, 12]<br>***NZ:*** Observed change partially attributed to anthropogenic climate change[13](*) |
| **Sea surface temperature** | ***Aus:*** Increased by about 0.12°C per decade for NW&NE Aus and by about 0.2°C per decade for E Aus since 1950[14-16](***)<br>***NZ:*** Increased by about 0.07°C per decade from 1909-2009[2] (***) | **Aus and NZ:** Increase[3-5, 17](***) with greater increase in the Tasman sea region (*) [3-5, 17] | ***Aus:*** 0.6-1.0°C (2070 B1) and 1.6-2.0°C (2070 A1FI) for southern coastal and 1.2-1.5°C (2070 B1) and 2.2-2.5°C (2070 A1FI) elsewhere[5]<br>***NZ:*** Similar to projected changes in mean air temperature for coastal waters[7, 18] | |
| **Air temperature extremes** | ***Aus and NZ:*** Significant trend since 1950: cool extremes have become rarer and hot extremes more frequent and intense[19-22] (**) | ***Aus and NZ:*** Hot days and nights more frequent and cold days and cold nights less frequent during the 21st century[5, 7, 18, 23-25](**) | ***Aus:*** Hot days in Melbourne (>35°C max.) increase by 20-40% (2030 A1B), 30-90% (2070 B1) and 70-190% (2070 A1FI)[5]<br>***NZ:*** Spring and autumn frost-free land to increase by around 16% by 2080s; up to 60 more hot days (>25°C max.) for northern areas by 2090[7] | ***Aus****:* Observed trend partly attributable to anthropogenic climate change[21-23, 26](**), although other factors may have contributed high extremes during droughts[27-29] |
| **Precipitation** | ***Aus:*** Late autumn/winter decreases in SW Aus since the 1970s and in SE Aus since the mid 1990s, and annual increases in NW Aus since the 1950s[30-32](***)<br>***NZ:*** Mean annual rainfall increased over 1950-2004 in the south and west of both islands and decreased elsewhere[33] (***) | ***Aus:*** Annual decline in SW Aus (**) and elsewhere in southern Aus (*) with the reductions strongest in the winter half year[5, 6, 34-36] (**). Direction of annual change elsewhere is uncertain[5, 36, 37] (Figure 25.2) (**)<br>***NZ:*** In the South Island, annual increase in the west and south and decrease in north-east. In the North Island, increase in the west and decrease in eastern and northern regions [7, 35, 38] (Figure 25.2) (**) | ***Aus:*** For 2030 A1B, annual changes of-15% to +10% (N&E Aus) and -10% to 0% (S Aus), for 2070 B1, -15% to +7.5% (N&E Aus) and -15% to 0% (S Aus), and for 2070 A1FI, -30% to +20% (N&E Aus) and -30% to +5% (S Aus), with larger changes seasonally[5]<br>***NZ:*** For 2040 A1B, -5 to +15% (S&W) and -15% to +10% (N&E) and for 2090 A1B, -10% to +25% (S&W) and -20% to +15% (N&E) based on downscaled projections with larger changes seasonally[7, 38] | ***Aus:*** Observed decline in SW is related to atmospheric circulation changes[39-41] (***), other factors[42], and partly attributable to anthropogenic climate change[41-44](***). The recent SE rainfall decline is also related to circulation changes[32, 45-47] (**), with some evidence of an anthropogenic component[48]<br>***NZ:*** Observed trends related to increased westerly winds[33]. Projected annual trends dominated by winter and spring trends related to increased westerlies[7] |
| **Precipitation extremes** | ***Aus:*** Indices of annual daily extremes (e.g. 95th and 99th percentile rainfalls) show mixed or insignificant trends[23, 49], but significant increase is evident in recent decades for shorter duration (sub-daily) events[50, 51] (**).<br>***NZ:*** Extreme annual 1-day rainfall decrease in north and east and increase in west since 1930 (*). | ***Aus and NZ:*** Increase in most regions in the intensity of rare daily rainfall extremes (i.e. current 20 year return period events) and in short duration (sub-daily) extremes (*) and an increase in the intensity of 99 percentile daily extremes (*low confidence*)[4, 7, 23, 52-56] | ***Aus:*** For 2090 A2, CMIP3 give increases in the intensity of the 20 year daily extreme of +200% to -25% depending on region and model[53]<br>***NZ:*** Increases of daily extreme rainfalls of 8% per degree C are projected but with significant regional variations[7, 57] | ***Aus and NZ:*** The sign of observed trends mostly reflects trends in mean rainfall (e.g. there is a decrease in mean and daily extremes in SW Aus)[23, 33, 50]. Similarly, future increases in intensity of extreme daily rainfall are more likely where mean rainfall is projected to increase[5] |

| | | | | |
|---|---|---|---|---|
| **Drought** | ***Aus:*** Defined using rainfall only, drought occurrence over the period 1900-2007 has not changed significantly[58](**)<br>***NZ:*** Defined using a soil water balance model, there has been no trend in drought occurrence since 1972[59] (*) | ***Aus and NZ:*** Drought frequency is projected to increase in southern Australia [4, 55, 58, 60, 61](*) and in eastern and northern New Zealand[59, 62] (*) | ***Aus:*** Occurrence under 2070 A1B ranges from a halving to 3 times more frequent in N. Aus, and 0-5 times more frequent in southern Aus[61]<br>***NZ:*** Time spent in drought in eastern and northern New Zealand is projected to double or triple by 2040[62] | ***Aus:*** Regional warming may have led to an increase in hydrological drought (*low confidence*)[63, 64] |
| **Winds** | ***Aus:*** Significant decline in storminess over SE Aus since 1885[65](*), but inconsistent trends in wind observations since 1975[66, 67]<br>***NZ:*** Mean westerly flow increased during the late 20th century (1978–1998), associated with the positive phase of the IPO[68, 69] | ***Aus:*** Increases in winds in 20-30°S band, with little change to decrease elsewhere, except for winter increases over Tasmania. Decrease to little change in extremes (99th percentile) over most of Australia except Tasmania in winter[70] (*).<br>***NZ:*** Mean westerly winds and extreme winds (based on projected changes in circulation patterns) are projected to increase, especially in winter[7, 71](*) | ***Aus:*** Magnitude of simulated changes are around 10% under A1B for 2081-2100 relative to 1981-2000[70]<br>***NZ:*** Westerlies to increase by approximately 10% by 2090[7] | ***Aus and NZ:*** Many of past and projected changes in mean wind speed can be related to changes in atmospheric circulation[44, 68, 69]<br>***NZ:*** Extreme westerlies and southerlies have slightly increased while extreme easterlies have decreased since 1960[13, 72] |
| **Mean sea level** | ***Aus:*** From 1920-2011 the average rate of relative sea level rise (SLR) was 1.6±0.1.4 mm/yr[73] (***)<br>***NZ:*** The average rate of relative SLR was 1.7±0.1 mm/yr over 1900-2009[74](***) | ***Aus and NZ:*** Regional sea level rise will *very likely* exceed the 1971-2000 historical rate, consistent with global mean trends[75]. Mean sea level will continue to rise for at least several more centuries[75] (***). | ***Aus and NZ:*** Off shore eastern Australian regional sea level rise, may exceed 10% more than global SLR, see AR5 WGI Chap13, Figure 13.15[75] | ***Aus****:* Satellite estimates of regional SLR for 1993-2009 are significantly higher than those for 1920-2000, partly reflecting atmospheric circulation changes[73, 74, 76, 77]<br>***NZ:*** Allowing for glacial isostatic adjustment, absolute observed SLR is around 2.0mm/yr[74, 78] |
| **Extreme sea level** | ***Aus:*** Extreme sea levels have risen at a similar rate to global SLR[79] | ***Aus and NZ:*** Projected mean SLR will lead to large increases in the frequency of extreme sea level events (***), with changes in storm surges playing a lesser role[80-83] | ***Aus:*** An increase of mean sea level by 0.1m increases the frequency of an extreme sea level event by a factor of between 5 and 10[80-82], depending on location | |
| **Fire weather** | ***Aus:*** Increased since 1973(**) with 24 out of 38 sites showing increases in the 90$^{th}$ percentile of the McArthur Forest Fire Danger index[84] | ***Aus:*** Fire weather is expected to increase in most of southern Australia due to hotter and drier conditions (**), based on explicit model studies carried out for SE Australia [85-88] , and change little or decrease in NE[88] (*)<br>***NZ:*** Fire danger is projected to increase in many areas[89](*) | ***Aus:*** Very high and extreme fire danger increase 2-30% (2020), 10-100% (2050) (using B1 and A2 and two climate models, and 1973-2007 base)[85]<br>***NZ:*** Very high and extreme fire danger days increase 0 to 400% (2040), 0 to 600% (2090) (using A1B,16 CMIP3 GCMs )[89] | ***Aus:*** For the example of Canberra, the projected changes represent the current 17 days per year increasing to 18-23 days in 2020 and 20-33 days in 2050[85] |
| **Tropical cyclones and other severe storms** | ***Aus:*** No regional change in the number of tropical cyclones (TCs) or in the proportion of intense TCs over 1981-2007[90](*), but landfall in NE Aus has declined significantly since the 19$^{th}$ Century[91] and east-west distribution changed since 1980[92] | ***Aus:*** Tropical cyclones are projected to increase in intensity, but stay similar or decrease in numbers[9, 93] (*low confidence*)<br>***NZ:*** Projected increase in the average intensity of cyclones in the south during winter, but a decrease elsewhere[71] (*) | ***Aus:*** Modelling study shows a 50% reduction in TC occurrence for 2051-2090 relative to 1971-2000 but increases in intensity of the modelled storms[93]<br>***NZ:*** Occurrence of conditions conducive to convective storm development is projected to increase by 3–6% by 2070-2100 (A2), relative to 1970-2000, with the largest increases over the South Island[71] | ***Aus:*** Single studies project decreased cool-season tornadoes in southern Australia[94], and hail increases in Sydney[95] |
| **Snow and ice** | ***Aus****:* Late season significant snow depth decline at three out of four Snowy mountain sites over 1957-2002[96](**)<br>***NZ:*** Ice volume declined by almost 50% during the 20th century, with glacier volume reducing by at least 25% since 1950[97-100] (**). | ***Aus:*** Both snow depth and area are projected to decline[96] (***)<br>***NZ:*** Snowline elevations are projected to rise, and winter snow volume and the duration of days with low elevation snow lying are projected to decrease[7, 101, 102] (**) | ***Aus:*** Area with at least 30 days cover annually projected to decline 14-54% (2020) and 30-93% (2050) [96]<br>***NZ:*** By 2090, peak snow accumulation is projected to decline by 32-79% at 1000m and by 6-51% at 2000m[102] | ***NZ:*** Atmospheric circulation variations can enhance or outweigh multi-decadal trends in ice volume over time scales of up to two decades[103, 104] |

References: 1: Fawcett, *et al*. (2012); 2: Mullan, *et al*. (2010); 3: AR5-WGI-Ch11; 4: AR5-WGI-Ch12; 5: CSIRO and BoM (2007); 6: Moise and Hudson (2008); 7: MfE (2008); 8: AR5-WGI-Atlas; 9: AR5-WGI-Ch14; 10: Karoly and Braganza (2005); 11: Hendon, *et al*. (2007); 12: Nicholls, *et al*. (2010); 13: Dean and Stott (2009); 14: BoM (2011); 15: Lough (2008); 16: Lough and Hobday (2011); 17: AR5-WGI-Atlas-AI68-69; 18: Tait (2008); 19: Chambers and Griffiths (2008); 20: Gallant and Karoly (2010); 21: Nicholls and Collins (2006); 22: Trewin and Vermont (2010); 23: Alexander and Arblaster (2009); 24: Tryhorn and Risbey (2006); 25: Griffiths, *et al*. (2005); 26: Alexander, *et al*. (2007); 27: Deo, *et al*. (2009); 28: McAlpine, *et al*. (2007); 29: Cruz, *et al*. (2010); 30: Hope, *et al*. (2010); 31: Jones, *et al*. (2009); 32: Gallant, *et al*. (2012); 33: Griffiths (2007); 34: Timbal and Jones (2008); 35: AR5-WGI-Atlas-AI70-71; 36: Irving, *et al*. (in press); 37: Watterson (2012); 38: Reisinger, *et al*. (2010); 39: Bates, *et al*. (2008); 40: Frederiksen and Frederiksen (2007); 41: Hope, *et al*. (2006); 42: Timbal, *et al*. (2006); 43: Cai and Cowan (2006); 44: Frederiksen, *et al*. (2011); 45: Cai, *et al*. (2011); 46: Nicholls (2010); 47: Smith and Timbal (2010); 48: Timbal, *et al*. (2010a); 49: Gallant, *et al*. (2007); 50: Westra and Sisson (2011); 51: Jakob, *et al*. (2011); 52: Abbs and Rafter (2009); 53: Rafter and Abbs (2009); 54: Kharin, *et al*. (submitted); 55: IPCC-SREX-Chapter-3; 56: Westra, *et al*. (2013); 57: Carey-Smith, *et al*. (2010); 58: Hennessy, *et al*. (2008a); 59: Mullan, *et al*. (2005); 60: Kirono and Kent (2010); 61: Kirono, *et al*. (2011); 62: Clark, *et al*. (2011a); 63: Cai and Cowan (2008); 64: Nicholls (2006); 65: Alexander, *et al*. (2011); 66: McVicar, *et al*. (2008); 67: Troccoli, *et al*. (2012); 68: Parker, *et al*. (2007); 69: Mullan, *et al*. (2001); 70: McInnes, *et al*. (2011a); 71: Mullan, *et al*. (2011); 72: Salinger, *et al*. (2005); 73: Burgette, *et al*. (submitted); 74: Hannah and Bell (2012); 75: AR5-WGI-Ch13; 76: CSIRO and BoM (2012); 77: Meyssignac and Cazenave (2012); 78: Hannah (2004); 79: Menendez and Woodworth (2010); 80: McInnes, *et al*. (2009); 81: McInnes, *et al*. (2011); 82: McInnes, *et al*. (2012); 83: Harper, *et al*. (2009); 84: Clarke, *et al*. (2012); 85: Lucas, *et al*. (2007); 86: Hasson, *et al*. (2009); 87: Cai, *et al*. (2009a); 88: Clarke, *et al*. (2011); 89: Pearce, *et al*. (2011); 90: Kuleshov, *et al*. (2010); 91: Callaghan and Power (2011); 92: Hassim and Walsh (2008); 93: Abbs (2012); 94: Timbal, *et al*. (2010b); 95: Leslie, *et al*. (2008); 96: Hennessy, *et al*. (2008); 97: Anderson, *et al*. (2006a); 98: Anderson and Mackintosh (2006); 99: Chinn, *et al*. (2012); 100: Clare, *et al*. (2002); 101: Fitzharris (2004); 102: Hendrikx, *et al*. (2012); 103: Purdie, *et al*. (2011); 104: Willsman, *et al*. (2010)

Table 25-2: Constraints and enabling factors for institutional adaptation processes in Australasia.*

| Constraint | Enabling factors | References |
|---|---|---|
| Uncertainty of projections | Improved guidance and tools to manage uncertainty and support adaptive management<br>Increased focus on lead and consequence time of decisions and link with current climate variability<br>Increased communication between practitioners and scientists to identify and provide decision-relevant data | (Reisinger *et al*., 2011; Stafford-Smith *et al*., 2011b; Johnston *et al*., 2012; Murta *et al*., 2012; Park *et al*., 2012; Productivity Commission, 2012; Randall *et al*., 2012; Verdon-Kidd *et al*., 2012; Stafford-Smith, 2013; Webb *et al*., submitted) |
| Availability and cost of data and models | Central provision of relevant core climate and non-climate data, including regional scenarios projected changes<br>National first-pass risk assessments | (DCC, 2009; Smith *et al*., 2010; DCCEE, 2011; Baynes *et al*., 2012; Roiko *et al*., 2012; Mukheibir *et al*., 2013; Webb and Beh, 2013; Lawrence *et al*., submitted-b) |
| Limited financial and human capability and capacity; time lag in developing expertise | Support for pilot projects<br>Building capacity through institutional commitment and learning<br>Central databases on guidance, tools, methodologies, case studies<br>Regional partnerships and collaborations, knowledge networks | (Smith *et al*., 2008; Gardner *et al*., 2010; Preston and Kay, 2010; DSEWPC, 2011; Johnston *et al*., 2012; Low Choy *et al*., 2012; Murta *et al*., 2012; Park *et al*., 2012; Yuen *et al*., 2012; Webb and Beh, 2013; Lawrence *et al*., submitted-b; Mustelin *et al*., submitted; Webb *et al*., submitted) |
| Unclear problem definition and goals; unclear standards for choices in risk assessment methodologies and decision support tools; limited monitoring and evaluation | Explicit but iterative framing and scoping of adaptation challenge, to reflect alternative entry points for stakeholders while meeting expectations of project sponsors to ensure long-term support<br>Tailoring decision-making frameworks to specific problems<br>Criteria and tools to monitor and evaluate adaptation success | (Nelson *et al*., 2008; Preston *et al*., 2008; Preston and Stafford-Smith, 2009; Rouse and Norton, 2010; Britton *et al*., 2011; Maru *et al*., 2011; Fünfgeld *et al*., 2012; Randall *et al*., 2012; Verdon-Kidd *et al*., 2012; Mukheibir *et al*., 2013; Webb and Beh, 2013; Webb *et al*., submitted) |
| Unclear or contradictory legislative frameworks and responsibilities, unclear liabilities | Clear and coordinated legislative frameworks<br>Defined responsibilities for public and private actors, including liabilities from acting and failure to act<br>Legally binding guidance on the incorporation of climate change in planning mechanisms | (Smith *et al*., 2008; Norman, 2009; Parliament of Australia, 2009; McDonald, 2010; Minister of Conservation, 2010; Rouse and Norton, 2010; Abel *et al*., 2011; McDonald, 2011; Rive and Weeks, 2011; Corkhill, 2013; McDonald, 2013; Lawrence *et al*., submitted-b) |
| Static planning mechanisms and practice; competing mandates and fragmentation of policies; disciplinary voids or single approaches | Whole-of-council approach to climate adaptation<br>Long-term policy commitments and implementation support<br>Increased policy coherence across sectors<br>Strengthening multi-disciplinarity across professional fields | (Smith *et al*., 2008; CSIRO, 2011; Measham *et al*., 2011; Preston *et al*., 2011; Reisinger *et al*., 2011; Rive and Weeks, 2011; Webb and Beh, 2013; Lawrence *et al*., submitted-b; Mustelin *et al*., submitted) |
| Lack of political leadership; short election cycles; limited community support, participation and awareness for adaptation | Legally binding guidance and clarification of liabilities and duty of care to reduce dependence on individual leadership<br>Consistent communication of current and potential future vulnerability and implications for community values<br>Comprehensible communication of and access to response options, and their consistency with wider development plans<br>Clearly identified entry points for public participation | (Smith *et al*., 2008; Gardner *et al*., 2009a; Britton *et al*., 2011; Hobson and Niemeyer, 2011; Rouse and Blackett, 2011; Alexander *et al*., 2012; Burton and Mustelin, 2013; Keys *et al*., 2013) |

* Note: The relevance of each constraint varies among organisations, sectors and location. Some enabling factors are only beginning to be implemented or have only been suggested in the literature, hence their effectiveness cannot yet be evaluated. Entries exclude issue-specific responses, such as early warning systems and their funding and operation, or funding mechanisms for capital infrastructure upgrades or retreat schemes.

Table 25-3: Examples of detected changes in species, natural and managed ecosystems, consistent with a climate change[1] signal, published since the AR4. Confidence in detection of change is based on the length of study, and the type, amount and quality of data in relation to the natural variability in the particular species or system. Confidence in the role of climate being a major driver of the change is based on the extent to which the detected change is consistent with that expected under climate change, and to which other confounding or interacting non-climate factors have been considered and been found insufficient to explain the observed change.

| Type of change and nature of evidence | Examples | Time scale of observations | Confidence in the detection of biological change | Potential climate change driver(s) [1] | Confidence in the role of climate vs other drivers |
|---|---|---|---|---|---|
| **Morphology**<br><br>*Limited evidence*<br>(1 study) | Declining body size of southeast Australian passerine birds, equivalent to ~7º latitudinal shift (Gardner *et al*., 2009b) | ~100 years | ***medium***<br>trend significant for 4 out of 8 species, two other species show same trend but not statistically significant | Warming air temperatures ~1.0ºC over same period | ***medium***<br>Nutritional cause discounted |
| **Geographic distribution**<br><br>*High agreement, robust evidence* for many marine species & mobile terrestrial species | Southerly range extension of the barrens-forming sea urchin *Centrostephanus rodgersii* from the NSW coast to Tasmania; flow on impacts to marine communities including lobster fishery; shift of 160 km per decade over 30 years (Ling, 2008; Ling *et al*., 2008), (Ling *et al*., 2009; Banks *et al*., 2010) | ~30-50 years (first recorded in Tasmania late 1970s) | ***high*** | Increased sea surface temperature (SST), Ocean warming in SE Australia, increased southerly penetration of the East Australian Current (EAC), 350 km over 60 years | ***high*** |
| | Forty-five fish species, representing 27 families (about 30% of the inshore fish families occurring in the region), exhibited major distributional shifts in Tasmania (Last et al 2011) | distributions from late 1880s, 1980s and present (1995-now) | ***high*** | Increased SST SE Australia, increased southerly penetration of EAC | ***medium***<br>Changed fishing practices have potentially contributed to trends |
| | Southward range shift of intertidal species (average minimum distance 116 km) off west coast of Tasmania; 55% species recorded at more southerly sites, only 3% species expanded to more northerly sites (Pitt *et al*., 2010) | ~50 years<br>Sites resampled 2007-2008, compared with 1950s | ***medium*** | Increased SST in SE Australia (average 0.22ºC per decade), increased southerly penetration of the EAC, 350 km over 60 years | ***medium*** |
| **Life cycles**<br><br>*Robust evidence, medium agreement*; increasing documentation of | Significant advance in mean emergence date of 1.5 days per decade (1941-2005) in the Common Brown butterfly *Heteronympha merope* in Australia (Kearney *et al*., 2010a) | 65 years | ***high*** | Increase in local air temperatures of 0.16ºC per decade (1945-2007) | ***high***<br>Advance consistent with physiologically based model of temperature influence on development |

| | | | | | |
|---|---|---|---|---|---|
| advances in phenology in some species (mainly migration and reproduction in birds, emergence in butterflies, flowering in plants) but also significant trends towards later life cycle events in some taxa | Earlier wine-grape ripening at 9 of 10 sites in Australia (Webb *et al*. 2012) | Multiple time periods up to 64 years (average 41 years) | ***high*** | Increased length of growing season, increased average temperature and reduced soil moisture | ***medium*** Changed husbandry techniques, resulting in lower crop yields, may have contributed to trend |
| | Timing of migration of glass eels, *Anguilla* spp. advanced by several weeks in Waikato River, North island, New Zealand (Jellyman *et al*., 2009) | 30 years (2004-2005 compared to 1970s) | ***medium*** | Warming water temperatures in spawning grounds | ***low*** Changes in discharge discounted as contributing factor |
| **Marine productivity** *Limited evidence, medium agreement* | Otolith ("ear stone") analyses in long-lived Pacific fish indicates significantly increased growth rates for shallow-water species (<250 m) (3 of 3 species), reduced growth rates of deep-water (>1000 m) species (3 of 3 species); no change observed in the 2 intermediate-depth species (Thresher *et al*., 2007) | Birth years ranged 1861-1993 (fish 2-128 years old) | ***high*** | Increasing growth rates in species in top 250m associated with warming SST, declining growth rates in species >1000m associated with long-term cooling (as indicated by Mg/Ca ratios and delta$^{18}$O in deep water corals) | ***medium*** Changed fishing pressure may have contributed to trend |
| | ~50% decline in growth rate and biomass of spring phytoplankton bloom in western Tasman Sea (Thompson *et al*., 2009) | 60 years (1997-2007) | ***high*** | Increased SST and extension EAC associated with reduced nutrient availability | ***medium*** |
| **Vegetation change** *Limited agreement & evidence*; interacting impacts of changed land practices, altered fire regimes, increasing atmospheric $CO_2$ concentration and climate trends difficult to disentangle | Expansion of monsoon rainforest at expense of eucalypt savanna and grassland in Northern Territory, Australia (Banfai and Bowman, 2007) (Bowman *et al*., 2010) | ~40 years | ***medium*** | Increases in rainfall and atmospheric $CO_2$ | ***medium*** Changes in fire regimes and land management practices may have contributed to trend |
| | Net increase in mire wetland extent (10.2%) and corresponding contraction of adjacent eucalypt woodland in seven sub-catchments in south east Australia (Keith *et al*., 2010) | Weather data covers 40 years; vegetation mapping from 1961-1998 | ***medium*** | Decline in evapo-transpiration | ***low*** Resource exploitation, fire history and autogenic mire development discounted |

| | | | | | |
|---|---|---|---|---|---|
| **Freshwater communities**<br><br>*Limited evidence*<br>(1 study) | Decline in families of macroinvertebrates that favour cooler, faster-flowing habitats in NSW streams and increase in families favouring warmer and more lentic conditions (Chessman, 2009) | 13 years (1994-2007) | ***medium*** | Increasing water temperatures and declining flows | ***low***<br>Variation in sampling, changes in water quality, impacts of impoundment and water extraction may have contributed to trends |
| **Disease**<br><br>*Limited evidence, robust agreement* | Emergence and increased incidence of coral diseases including white syndrome (since 1998), and black band disease (since 1993-4) (Bruno *et al.*, 2007), (Sato *et al.*, 2009), (Dalton *et al.*, 2010) | 1998 onwards | ***medium*** | Increasing SST | ***high*** |
| **Coral reefs**<br><br>*Robust evidence & high agreement* | Multiple mass bleaching events since 1979 (see 25.6.2, 30.5) | 1979 onwards | ***high*** | Increasing SST | ***high*** |
| | Calcification of *Porites* on GBR declined 21% (1971-2003) (n=4 reefs); (Cooper *et al.*, 2008), 14.2% (1990-2005) (n=69 reefs) (De'ath *et al.*, 2009) | 1971-2003; 1961-2005 | ***high*** | Increasing SST | ***high***<br>Changes in water quality discounted |

Table 25-4: Examples of potential consequences of climate change for invasive and pathogenic species relevant to Australia and New Zealand, with consequence categories based on Hellman et al. (2008).

| Consequence | Projected | Organism/Ecosystem affected | Reference |
|---|---|---|---|
| **altered mechanisms of transport and introduction** | Increased risk of introduction of Asiatic Citrus Psyllid, (*Diaphorina citri*), vector of the disease huanglongbing | Australian citrus industry and native citrus and other rutaceaous species and endemic psyllid fauna | (Finlay *et al*., 2009) |
| **altered distribution of existing invasive & pathogenic species** | *Nassella neesiana* (Chilean needle grass): increased droughts favour establishment | Managed pasture in New Zealand | (Bourdôt *et al*., 2012) |
| | Warming and drying may encourage the spread of existing invasives such as *Pheidole megacephala* and provide suitable conditions for other exotic ant species if they invade | Human health and potentially agricultural and natural ecosystems | (Harris and Barker, 2007) |
| | Reduced climatic suitability for exotic invasive grasses in Australia (11 species including *Nassella* sp.) | Australian rangeland | (Gallagher *et al*., 2012) |
| | Range of the invasive weed *Lantana camara* (lantana) projected to extend from Northern Australia to Victoria, South Australia and Tasmania. | Multiple | (Taylor *et al*., 2012b) |
| | Projected increases in the range of three recently naturalised sub-tropical plants (*Archontophoenix cunninghamiana*, *Psidium guajava*, *Schefflera actinophylla*) | Native ecosystems in New Zealand | (Sheppard, 2012) |
| **altered climatic constraints on invasive & pathogenic species** | Queensland fruit fly (*Bactrocera tryoni*) moving southwards | Horticulture | (Sutherst *et al*., 2000) |
| | Significant association between amphibian declines in upland rainforests of North QLD and three consecutive years of warm weather suggests future warming could increase the vulnerability of frogs to chytridiomycosis caused by the chytrid fungus *Batrachochytrium dendrobatadis* | Native frogs | (Laurance, 2008) |
| **altered impact of existing invasive & pathogenic species** | *Fusarium pseudograminearum* causing crown rot increases under elevated $CO_2$ | Wheat | (Melloy *et al*., 2010) |
| | Increased abundance of the root-feeding nematode *Longidorus elongatus* under elevated $CO_2$ | New Zealand pasture | (Yeates and Newton, 2009) |
| | Increased severity of Swiss needle cast disease caused by *Phaeocryptopus gaeumannii* | Douglas fir plantations in New Zealand, impact more severe in North Island | (Watt *et al*., 2011b) |
| **altered effectiveness of management strategies** | Light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera:Tortricidae) reduction in natural enemies due to asynchrony and loss of host species | Australian horticulture | (Thomson *et al*., 2010) |
| | Projected changes in the efficacy of five biological control systems demonstrating a range of potential disruption mechanisms | Pastoral and horticultural systems in New Zealand | (Gerard *et al*., 2012) |

Table 25-5: Examples of co-beneficial climate change adaptation options for urban areas and barriers to their adoption. Options in italics are already widely implemented in Australia and New Zealand urban areas.

| **Climate impact** | **Adaptation options** | **Co-benefits** | **Barriers to adoption** | **References** |
|---|---|---|---|---|
| Hot days and heatwaves | Greening cities/roofs; *more green spaces*; well-designed energy efficient buildings; occupant behavioural change; standards for new and retrofitting of existing infrastructure and assets | Energy efficiency; reduced risk of blackouts; fewer health impacts; resilient infrastructure and assets | Lack of standards; high installation costs; limited understanding of benefits; high individual discount rate; split of private costs and public benefits | (BRANZ, 2007; Coutts *et al*., 2010; Stephenson *et al*., 2010; Williams *et al*., 2010; Tables 25-5, 25-6; Moon and Han, 2011; Ren *et al*., 2012) |
| Decreased water supply and drought | Supply augmentation (*water recycling*, *rainwater harvesting*, *increased storage*, desalinisation); *demand management*; *infrastructure upgrades*; *integrated urban sensitive design* | Water self-sufficiency for current and future demand/population; less pipe/storage leakage; reduced environmental impacts from abstraction | Potential health impacts of recycled water; lower than expected uptake of demand options and relaxation after crises; trade-offs between supply and demand management | See Box 25-2 for more detail; also Table 25-5 |
| River and local flooding, coastal erosion and inundation | *Building and infrastructure (e.g. drainage) improvements*; *upgrades of protection systems*; buffers from hazard-prone areas; *raising minimum floor levels*; rezoning/ relocation; integrated urban sensitive design | Reduced damages to homes and infrastructure and loss of life; decreased insurance premiums | High implementation cost especially if retrospective on existing stock; rezoning/ relocation can affect property prices and are highly contested | See Boxes 25-1 and 25-8 for more detail |
| Severe storms and tropical cyclones | New building design to withstand higher wind pressures; rezoning/relocation | Reduced damages to homes and infrastructure and loss of life; decreased insurance premiums | High implementation cost; rezoning/ relocation can affect property prices and are highly contested | (Mason and Haynes, 2010; Wang *et al*., 2010b; Stewart and Wang, 2011; Mason *et al*., 2013) |
| Corrosion from increased atmospheric $CO_2$ levels | Improved standards for construction using concrete; application of coatings for existing building stock | Reduced rates of carbonation-induced corrosion of concrete | Effectiveness of coatings varies with age and condition of concrete | (Stewart *et al*., 2012; Wang *et al*., 2012) |

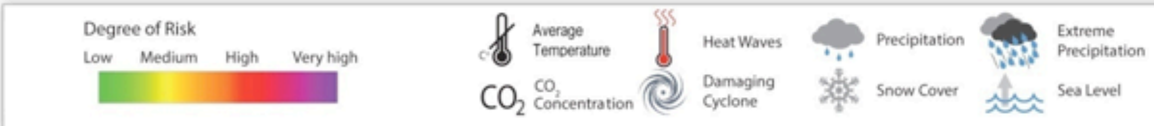
Table 25-6: Examples of interactions between impacts and adaptation measures in different sectors. In each case, impacts or responses in one sector have the potential to conflict (cause negative impacts) or be synergistic (have co-benefits) with impacts or responses in another sector, or with another type of response in the same sector.

| Primary goal | Sector(s) affected | Examples of interactions between impacts and adaptation responses |
|---|---|---|
| **Reduction of bushfire risk in natural landscapes** | Biodiversity, tourism | Potential for greater conflict between conservation managers and other park users in Kosciuszko National Park if increasing fire incidence causes park closures, either to reduce risk, or to rehabilitate vegetation after fires (Wyborn, 2009), e.g. Objectives of the Wildfire Management Overlay (WMO) in Victoria conflicts with vegetation conservation (Hughes and Mercer, 2009). |
| **Reduction of risk to energy transmission from bushfires** | Biodiversity, energy | Underground cabling would reduce both the susceptibility of transmission networks to fire and ignition sources for wild fires, thus reducing risks to ecosystems and settlements; constraints include significant investment cost, diverse ownership of assets and lack of an overarching national strategy (ATSE, 2008; Parsons Brinkerhoff, 2009; Linnenluecke *et al*., 2011). |
| **Protection of coastal infrastructure** | Biodiversity, tourism | Seawalls may provide habitat but these communities have different diversity and structure to those developing on natural substrates (Jackson *et al*., 2008); groynes potentially alter beach fauna diversity and community structure (Walker *et al*., 2008); continuing hard protection against sea level rise results in long-term loss of coastal amenities (Gorrdard *et al*., 2012). |
| **Avoidance of risks from sea level rise via relocation** | Indigenous communities | Relocation can avoid increasing local pressures on communities from sea level rise but raises complex cultural, land rights, legal and economic issues, e.g. potential relocation of Torres Strait islander communities (Green *et al*., 2010b; McNamara *et al*., 2011). |
| **Allocating scarce water resources via market instruments** | Rural areas, agriculture, mining | Market based instruments such as water trading help allocation of scarce water resources to the highest value uses. The negative implications of this include potential loss of access to lower value users, which in some areas includes agriculture and drinking water supplies, with potentially significant social, environmental and wider economic consequences (Kiem and Austin, 2012). |
| **Increased water security via water storage and irrigation for urban and agricultural systems** | Biodiversity, water demand management | Water storage can buffer urban settlements and agricultural systems via irrigation against low runoff and high variability in river flow. Altered flow regimes have significant negative impacts on freshwater ecosystems (Bond *et al*., 2008; Pittock *et al*., 2008; Kingsford, 2011). Discharge from desalination plants (e.g. in Perth and Sydney) can lead to substantial local increases in salinity and temperature, and the accumulation of metals, hydrocarbons and toxic anti-fouling compounds in receiving waters (Roberts *et al*., 2010) and reduce the effectiveness of measures to reduce water demand (Barnett and O'Neill, 2010). |

Table 25-7: Examples of interactions between adaptation and mitigation measures (green rows denote synergies where multiple benefits may be realized, orange rows denote potential tradeoffs and conflicts; grey row gives an example of complex, mixed interactions). The primary goal may be adaptation or mitigation.

| Primary goal | Sector(s) affected | Examples of interactions between adaptation and mitigation responses |
|---|---|---|
| Adaptation to decreasing snowfall | Biodiversity, energy use, water use | Snowmaking in the Australian Alps would require large additional energy and water resources by 2020 of 2500-3300 ML of water per month, more than half the average monthly water consumption by Canberra in 2004-05. Increased snowmaking negatively affects vegetation, soils and hydrology of subalpine-alpine areas (Pickering and Buckley, 2010; Morrison and Pickering, 2011; ABS, 2012c). |
| Air conditioning for heat stress | Health, energy use | Rising temperatures degrade building energy efficiency (Wang *et al.*, 2010a) and increase energy demand and associated $CO_2$ emissions if summer cooling needs are met by increased air conditioning (Stroombergen *et al.*, 2006; Thatcher, 2007; Wang *et al.*, 2010a). |
| Renewable wind energy production | Biodiversity | Wind-farms can have localised negative effects on bats and birds. 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 (Smales, 2006). |
| Urban densification | Biodiversity, water, health | Higher urban density to reduce energy consumption from transport and infrastructure can result in loss of permeable surfaces and tree cover, intensify flood risks, and exacerbate discomfort and health impacts of hotter summers (Hamin and Gurran, 2009). |
| Water supply from desalination | Energy demand | Meeting increasing urban water demand via desalination plants increases energy demand and $CO_2$ emissions if this demand is met by increased fossil fuel energy generation (Barnett and O'Neill, 2010; Stamatov and Stamatov, 2010). |
| Secure food production in a warming climate | Nitrous oxide and methane emissions | Net greenhouse gas emissions intensity from dairy systems in southern Australia have been estimated to increase in future in several locations due to a changing climate and management responses (Cullen and Eckard, 2011; Eckard and Cullen, 2011). A shift towards perennial C4 grasses would increase methane emissions from grazing ruminants due to lower feed quality, but studies in south-west Australia suggest this could be more than offset by increased soil carbon storage (Thomas *et al.*, 2012; Bradshaw *et al.*, submitted). |
| Housing design to reduce peak energy demand | Energy use, infrastructure, health | Reducing peak energy demand through building design and demand management reduces vulnerability of electricity networks and transmission losses during heat waves (Parsons Brinkerhoff, 2009; Nguyen *et al.*, 2010), reduces heat stress during summer and provides health benefits during winter (Strengers, 2008; Howden-Chapman, 2010; Strengers and Maller, 2011; Ren *et al.*, 2012). |
| Energy from second-generation biofuels | Biodiversity, rural areas, 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 (essential oils, charcoal, bio-char, biofuels), and providing ecosystem services including reducing erosion (Cocklin and Dibden, 2009; Giltrap *et al.*, 2009; McHenry, 2009). |
| Reduction of emissions from fires | Biodiversity, livelihoods | Improved management of savanna fires to reduce the extent of high intensity late season fires could substantially reduce emissions as well as having significant benefits for biodiversity and indigenous employment (Russell-Smith *et al.*, 2009; Bradshaw *et al.*, submitted). |
| Reduce methane emissions from feral camels | Biodiversity, agriculture | Feral camels in Australia are projected to double from 1 to 2 million by 2020. Control of exotic vertebrate pests to reduce methane emissions could have significant biodiversity benefits (NRMMC, 2010; Bradshaw *et al.*, submitted). Economic benefits of reduced grazing competition, infrastructure damage and greenhouse gases could outweigh costs of camel reductions (Drucker *et al.*, 2010). |

Table 25-8 | Key regional risks during the 21st century from climate change for Australia and New Zealand. Colour bars indicate risk as a function of global mean temperature relative to pre-industrial, based on the studies assessed and expert judgement, for the current (top bar) and a hypothetical fully adapted state (bottom bar). For each risk, relevant climate variables and trends are indicated by symbols, in approximate order of priority. Where relevant climate projections span a particularly wide range even for a given amount of global mean temperature change, risks are shown in two pairs for high and low end projections, each without and with effective adaptation*.




Arrows show projected future changes in key drivers under a range of climate and mitigation scenarios. Arrows pointing in both directions indicate that the direction of change (indicated by red and blue colours) is uncertain. Narrow horizontal bars indicate the range of potential changes, with more bars indicating greater uncertainty. Thick bars are used where the direction of change is highly certain and some amount of further change over the 21st century is virtually unavoidable even under mitigation scenarios.

| Key Regional Risk | | Risk for current and hypothetical fully adapted state | Key Climate Drivers and Trends | Key adaptation issues / prospects |
|---|---|---|---|---|
| Impacts that can be delayed but now appear very difficult to avoid entirely, even with globally effective mitigation and proactive adaptation | Significant change in community structure of coral reef systems in Australia [25.6.2, 30.5, Box CC-CR] | current / adapted; 0 °C 2 °C 4 °C 6 °C | Average Temperature; $CO_2$; Damaging Cyclone | Limited evidence for autonomous genetic adaptation of corals; other adaptation options are limited to reducing other stresses, mainly enhancing water quality and limiting pressures from tourism and fishing |
| | Loss of montane ecosystems and some endemic species in Australia [25.6.1] | current / adapted; 0 °C 2 °C 4 °C 6 °C | Average Temperature; Snow Cover; Precipitation | Direct adaptation options are limited, but reducing other stresses such as pests, diseases and predator control and enhancing connectivity of habitats provides immediate co-benefits; need to consider translocation and migration |
| Impacts that have the potential to be severe but can be moderated or delayed significantly by globally effective mitigation and a portfolio of available adaptation measures | Wild fire damages to ecosystems and settlements and risks to human life in southern Australia and many parts of New Zealand [Table 25-1, Box 25-6] | current / adapted; 0 °C 2 °C 4 °C 6 °C | Average Temperature; Heat Waves; Precipitation | Part of integrated landscape management; trade-offs exist between different management objectives and settlement patterns and goals |
| | Systematic constraints on water resource use in southern Australia [25.5.1, Box 25-2, 25-9] | current / adapted; 0 °C 2 °C 4 °C 6 °C | Precipitation; Average Temperature | Water resources already struggling to meet unlimited demand in many locations and exacerbated by projected population growth; effective adaptation relies on combination of demand and supply mechanisms |
| | Increase in morbidity and mortality and infrastructure failure during heat waves in Australia [25.7.4, 25.8.1] | current / adapted; 0 °C 2 °C 4 °C 6 °C | Heat Waves | Linked to social dynamics and ageing population in cities; transport and power infrastructure already at coping limit in many regions, with significant financial costs from future upgrades |
| | Increased frequency and intensity of flood damage to infrastructure and settlements in Australia and New Zealand [25.2, Table 25-1, Box 25-8, 25-9] | current / adapted; 0 °C 2 °C 4 °C 6 °C | Extreme Precipitation | Significant adaptation deficit in some regions to current flood risk; effective adaptation includes land-use controls and relocation as well as protection and accommodation of increased risk to ensure flexibility |
| Impacts that have a low or currently unknown probability but cannot be ruled out even with globally effective mitigation, and would present major challenges if realized | Significant reduction in food production in the Murray-Darling Basin, far south-east Australia and eastern and northern parts of New Zealand [25.2, Table 25-1, 25.6.1, 25.7.2, Box 25-2, 25-5] | Wet: current / adapted; Dry: current / adapted; 0 °C 2 °C 4 °C 6 °C | Precipitation; Average Temperature; Heat Waves | Immediate co-benefits from improved management of over-allocated water resources and balancing competing demands, but the extreme dry end would threaten agricultural production as well as ecosystems and some rural communities |
| | Widespread damages to coastal infrastructure and low-lying ecosystems in Australia and New Zealand [Table 25-1, 25.6.1, 25.6.2, Box 25-2, 25-9] | Low: current / adapted; High: current / adapted; 0 °C 2 °C 4 °C 6 °C | Sea Level; Damaging Cyclone | Adaptation deficit in some locations to current coastal erosion and flood risk; successive building and protection cycles constrain flexible responses; effective adaptation includes land-use controls and ultimately relocation as well as protection and accommodation |

* For rainfall and its impact on food production, wet and dry scenarios represent approximately the 10 and 90 percentile range of current model projections and RCP emissions scenarios. For sea level, the low scenario is a 0.39 m rise by 2100 (mid-range model projections, RCP 2.6); the high scenario is a 1.5 m rise by 2100 (semi-empirical models, RCP 8.5). See AR5 WGI Chap 13 for more details. Under either scenario, sea level would continue to rise beyond 2100, but the focus of the risk assessment here is for risks that could be realised during the 21st century.

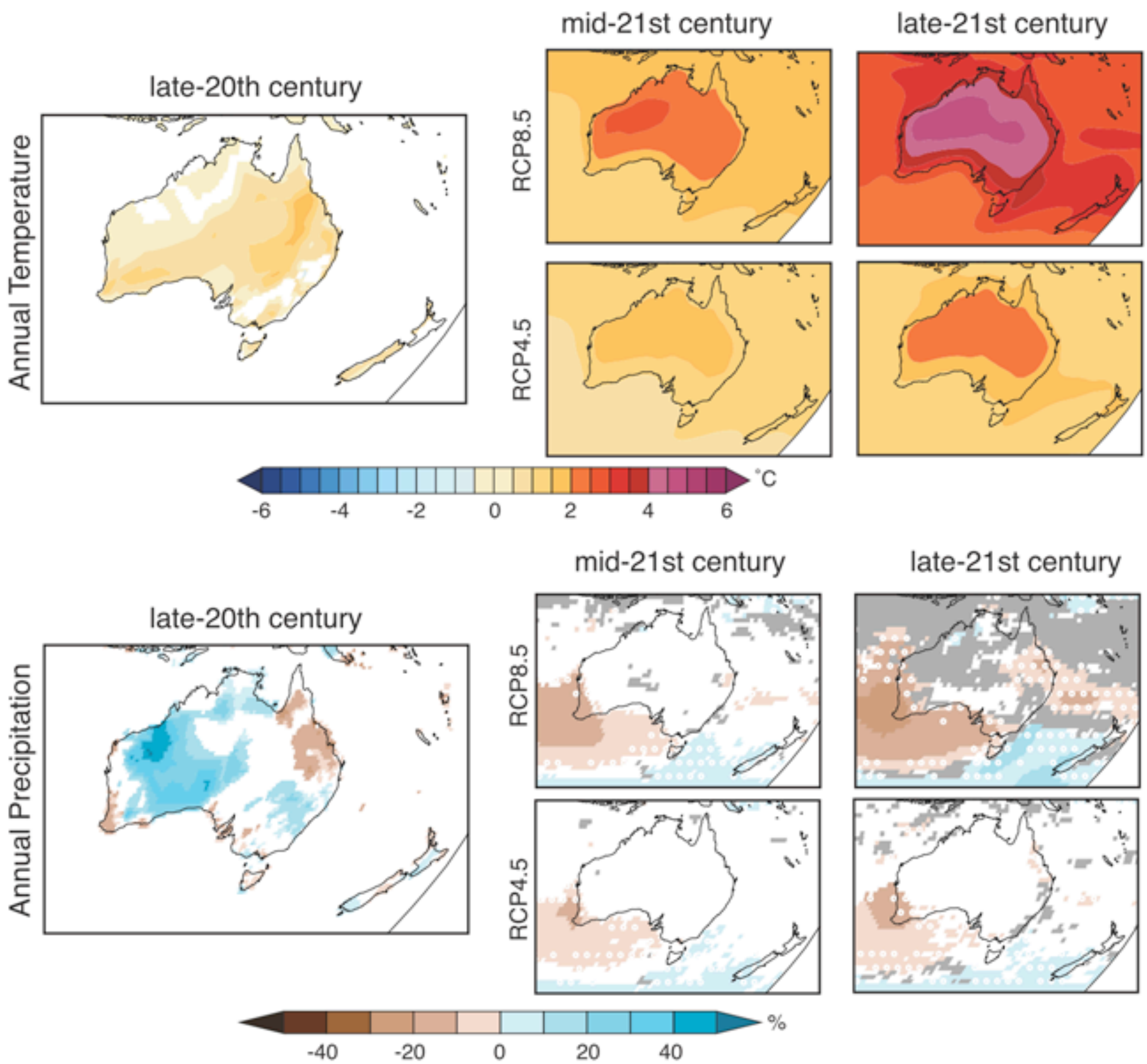



Figure 25-1: Observed and projected change in annual temperature and precipitation.

Maps: Change in annual temperature and precipitation. For the CRU observations, differences are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.

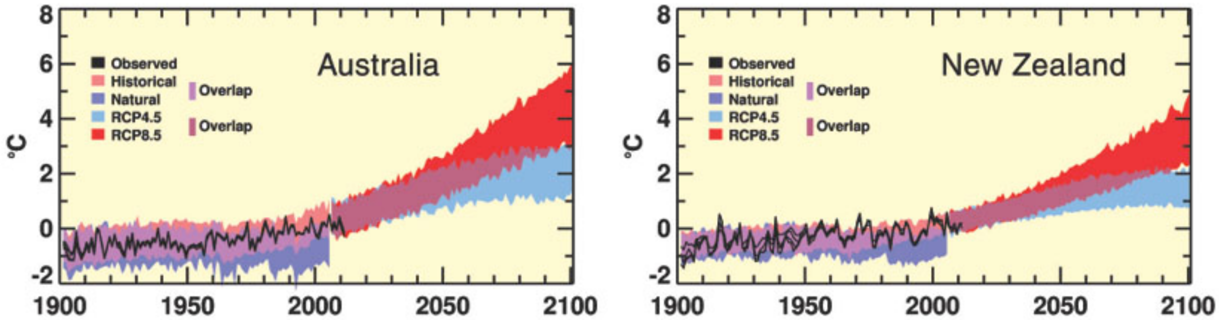



Figure 25-2: Observed and simulated variations in past and projected future annual average temperature over land areas of Australia (left) and New Zealand (right). Black lines show several estimates from measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (68 simulations), historical changes in "natural" drivers only (30), the "RCP4.5" emissions scenario (68), and the "RCP8.5" (68). Data are anomalies from the 1986-2006 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Chapter 21.

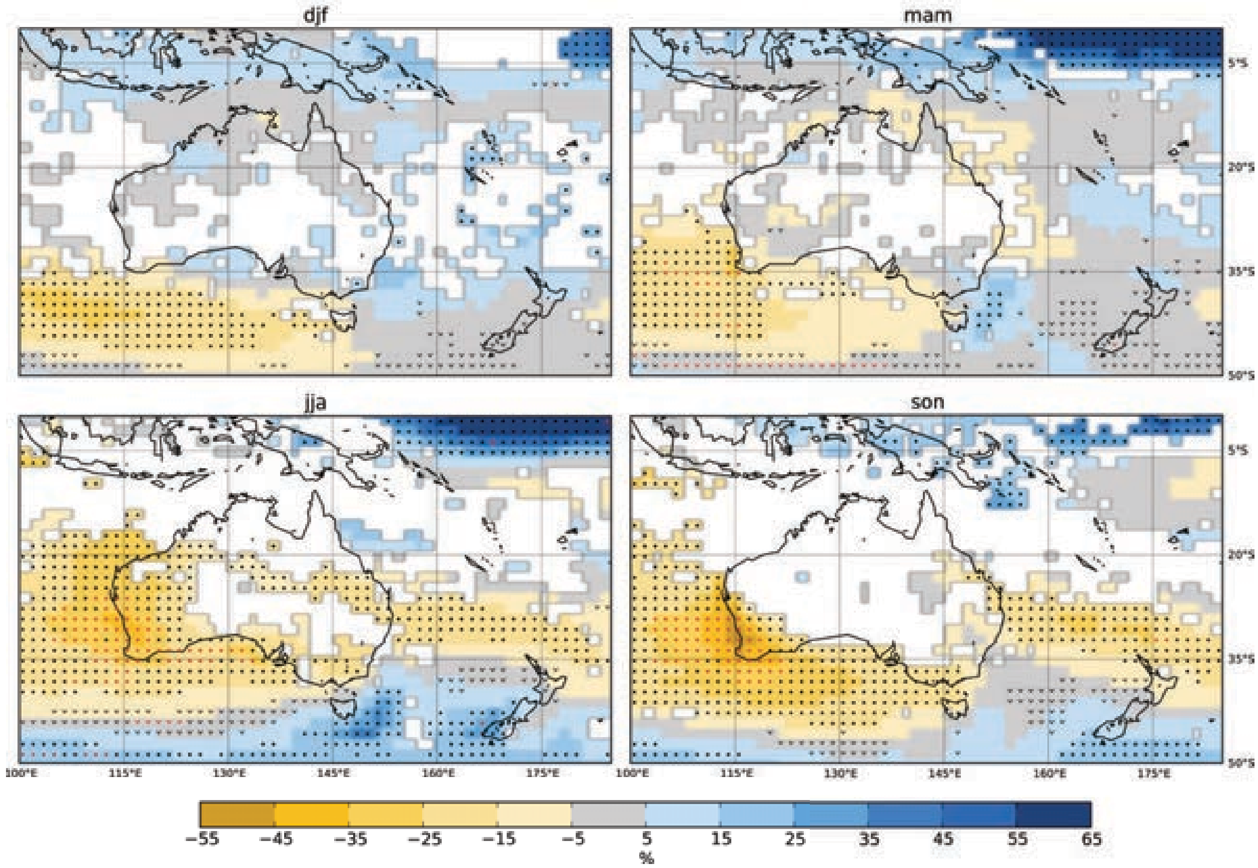



Figure 25-3: Projected CMIP5 multi-model mean change in rainfall for 2080-2099 relative to 1980-1999, under RCP 8.5. Dots [carets] indicate where the models agree (>90% red; >67% black) that there will [will not] be a substantial increase (>10%) or decrease (< -10%). White areas indicate where the models agree (> 67%) that there will be a substantial change in rainfall (larger in magnitude than 10%) however <67% agree on the direction of this substantial change (Figure from Irving *et al*., in press).

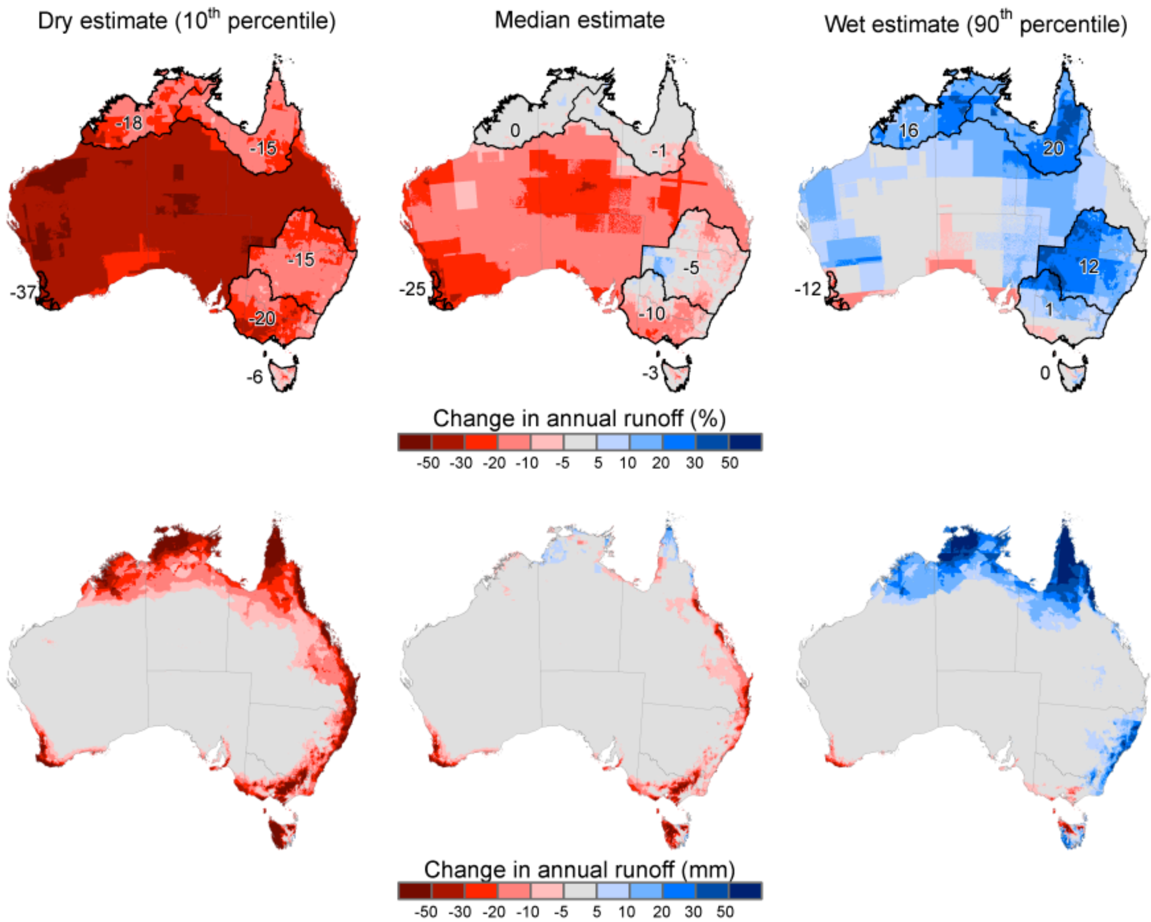



Figure 25-4: Projected changes in mean annual runoff for a 1°C global average warming. Figures show changes in annual run-off (percentage change; top row) and run-off depth (millimetres; bottom row), for median, dry and wet (10th and 90th percentile) range of estimates, based on hydrological modelling using catchment-scale climate data downscaled from AR4 GCMs (Chiew *et al.*, 2009; CSIRO, 2009b; Petheram *et al.*, 2012; Post *et al.*, 2012). Projections for a 2°C global average warming are about twice that shown in the plots (Post *et al.*, 2011). Figure adapted from (Chiew and Prosser, 2011; Teng *et al.*, 2012).

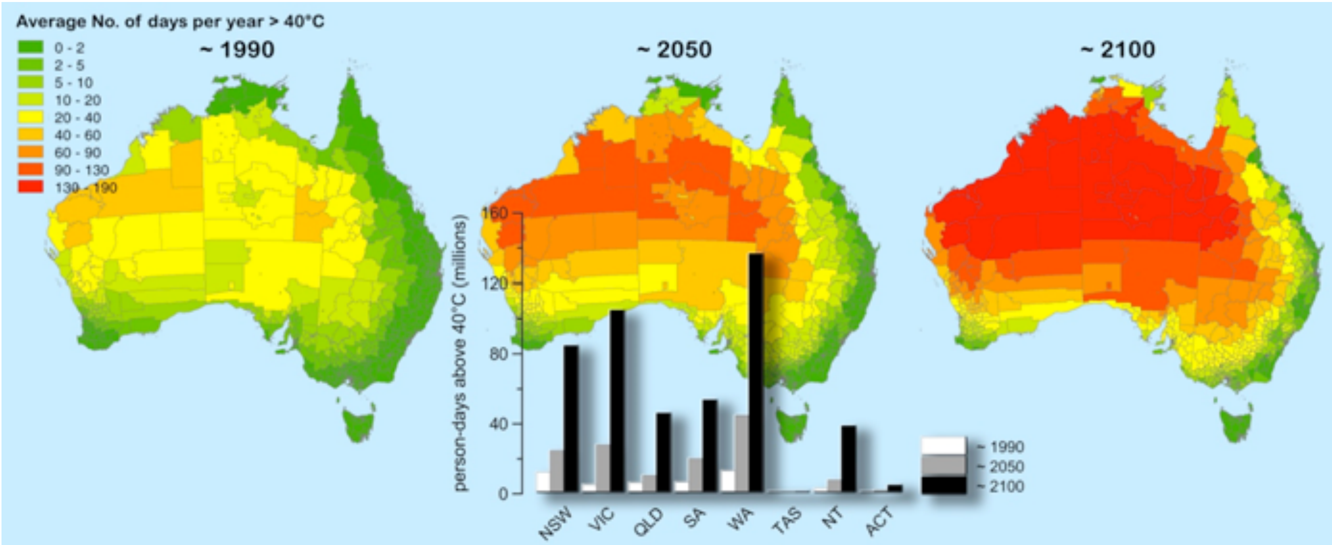



Figure 25-5: Projected changes in exposure to heat under a high emissions scenario (A1FI). Maps show the average number of days with peak temperatures >40°C for Australian statistical local areas, for ~1990 (based on available meteorological station data for the period 1975-2004), ~2050 and ~2100. Bar charts show the change in population heat exposure, expressed as person-days exposed to peak temperatures >40°C, aggregated by State/Territory and including projected population growth for a default scenario. Future temperatures are based on simulations by the GFDL-CM2 global climate model (Meehl *et al.*, 2007), re-scaled to the A1FI scenario; simulations based on other climate models could give higher or lower results. Data from Baynes *et al.* (2012).

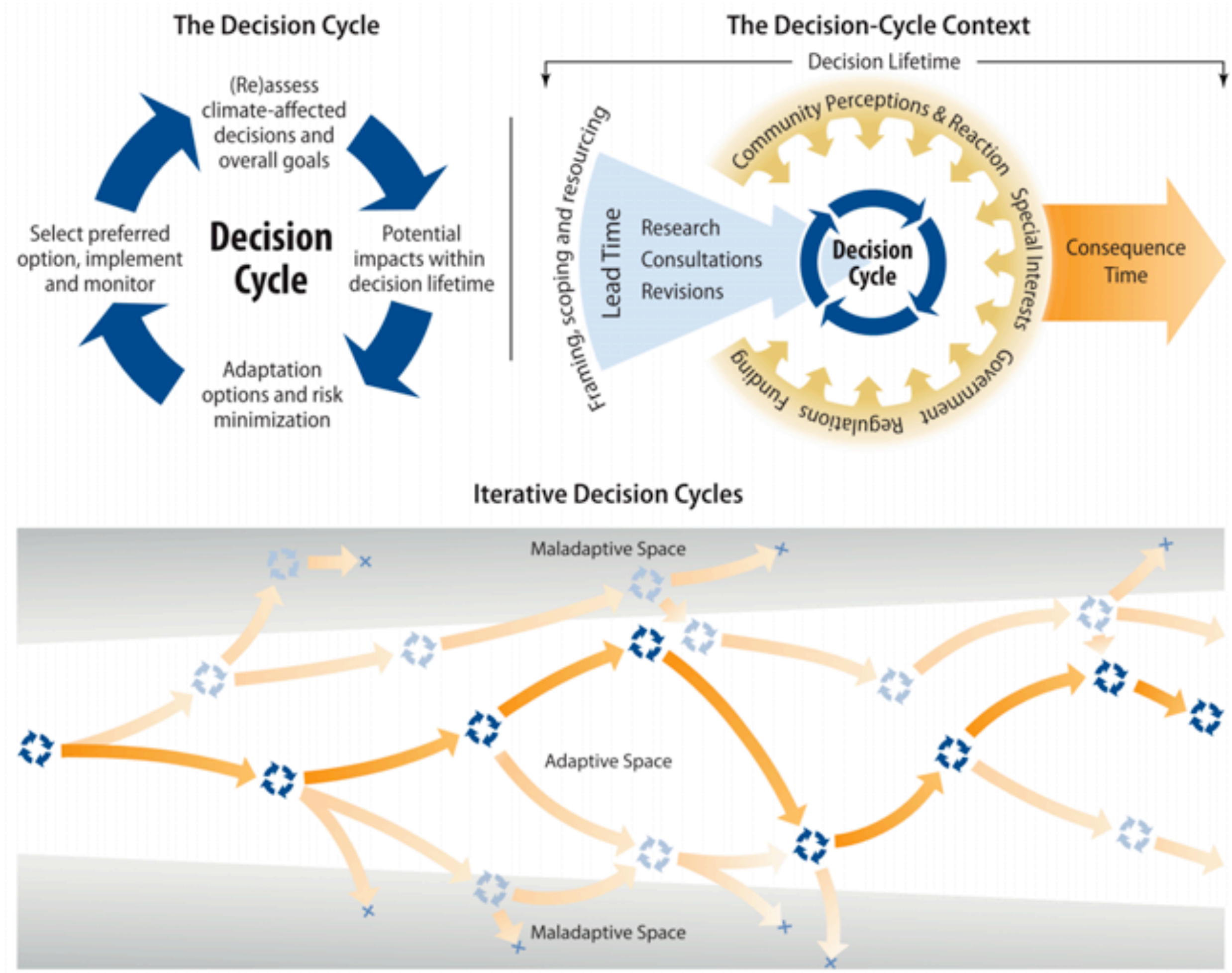



Figure 25-6: Schematic illustration of adaptation as an iterative risk management process. Each individual adaptation decision comprises well known aspects of risk assessment and management (top left panel). Each such decision occurs within and exerts its own sphere of influence, determined by the lead- and consequence time of the decision, and the broader regulatory and societal influences on the decision (top right panel). A sequence of adaptation decisions creates an adaptation pathway (bottom panel). There is no single correct adaptation pathway, although some decisions, and sequences of decisions, are more likely to result in long-term maladaptive outcomes than others, but the judgment of outcomes depends strongly on societal values, expectations and goals.

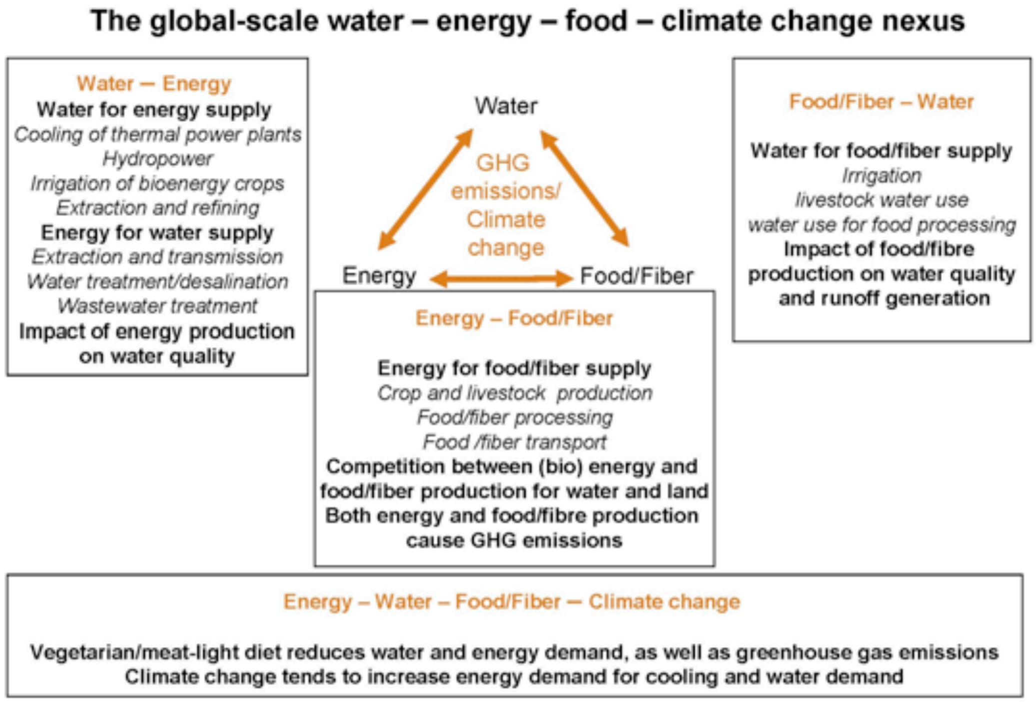



Figure WE-1: The water-energy-food nexus as related to climate change.