11

Australia and New Zealand

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Executive summary

Literature published since the IPCC Third Assessment Report confirms and extends its main findings (high confidence).

There is more extensive documentation of observed changes to natural systems, major advances in understanding potential future climate changes and impacts, more attention to the role of planned adaptation in reducing vulnerability, and assessments of key risks and benefits [11.1].

Regional climate change has occurred (very high confidence).

Since 1950, there has been 0.4 to 0.7°C warming, with more heatwaves, fewer frosts, more rain in north-west Australia and south-west New Zealand, less rain in southern and eastern Australia and north-eastern New Zealand, an increase in the intensity of Australian droughts, and a rise in sea level of about 70 mm [11.2.1].

Australia and New Zealand are already experiencing impacts from recent climate change (high confidence).

These are now evident in increasing stresses on water supply and agriculture, changed natural ecosystems, reduced seasonal snow cover, and glacier shrinkage [11.2.1, 11.2.3].

Some adaptation has already occurred in response to observed climate change (high confidence).

Examples come from sectors such as water, natural ecosystems, agriculture, horticulture and coasts [11.2.5]. However, ongoing vulnerability to extreme events is demonstrated by substantial economic losses caused by droughts, floods, fire, tropical cyclones and hail [11.2.2].

The climate of the 21st century is virtually certain to be warmer, with changes in extreme events.

Heatwaves and fires are virtually certain to increase in intensity and frequency (high confidence). Floods, landslides, droughts and storm surges are very likely to become more frequent and intense, and snow and frost are very likely to become less frequent (high confidence). Large areas of mainland Australia and eastern New Zealand are likely to have less soil moisture, although western New Zealand is likely to receive more rain (medium confidence) [11.3.1].

Potential impacts of climate change are likely to be substantial without further adaptation.

- As a result of reduced precipitation and increased evaporation, water security problems are projected to intensify by 2030 in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions (high confidence) [11.4.1].
- Ongoing coastal development and population growth, in areas such as Cairns and south-east Queensland (Australia) and Northland to Bay of Plenty (New Zealand), are projected to exacerbate risks from sea-level rise and increases in the severity and frequency of storms and coastal flooding by 2050 (high confidence) [11.4.5, 11.4.7].
- Significant loss of biodiversity is projected to occur by 2020 in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. Other sites at risk include Kakadu wetlands, south-west Australia, sub-Antarctic islands and alpine areas of both countries (very high confidence) [11.4.2].
- Risks to major infrastructure are likely to increase. By 2030, design criteria for extreme events are very likely to be exceeded more frequently. Risks include failure of floodplain protection and urban drainage/sewerage, increased storm and fire damage, and more heatwaves, causing more deaths and more blackouts (high confidence) [11.4.1, 11.4.5, 11.4.7, 11.4.10, 11.4.11].
- Production from agriculture and forestry is projected to decline by 2030 over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits to agriculture and forestry are projected in western and southern areas and close to major rivers due to a longer growing season, less frost and increased rainfall (high confidence) [11.4.3, 11.4.4].

Vulnerability is likely to increase in many sectors, but this depends on adaptive capacity.

- *Most human systems have considerable adaptive capacity:* The region has well-developed economies, extensive scientific and technical capabilities, disaster mitigation strategies, and biosecurity measures. However, there are likely to be considerable cost and institutional constraints to the implementation of adaptation options (high confidence) [11.5]. Some Indigenous communities have low adaptive capacity (medium confidence) [11.4.8]. Water security and coastal communities are the most vulnerable sectors (high confidence) [11.7].
- *Natural systems have limited adaptive capacity:* Projected rates of climate change are very likely to exceed rates of evolutionary adaptation in many species (high confidence) [11.5]. Habitat loss and fragmentation are very likely to limit species migration in response to shifting climatic zones (high confidence) [11.2.5, 11.5].
- *Vulnerability is likely to rise due to an increase in extreme events:* Economic damage from extreme weather is very likely to increase and provide major challenges for adaptation (high confidence) [11.5].
- *Vulnerability is likely to be high by 2050 in a few identified hotspots:* In Australia, these include the Great Barrier Reef, eastern Queensland, the South-West, Murray-Darling Basin, the Alps and Kakadu wetlands; in New Zealand, these include the Bay of Plenty, Northland, eastern regions and the Southern Alps (medium confidence) [11.7].

11.1 Introduction

The region is defined here as the lands and territories of Australia and New Zealand. It includes their outlying tropical, mid-latitude and sub-Antarctic islands and the waters of their Exclusive Economic Zones. New Zealand's population was 4.1 million in 2006, growing by 1.6%/yr (Statistics New Zealand, 2006). Australia's population was 20.1 million in 2004, growing by 0.9%/yr (ABS, 2005a). Many of the social, cultural and economic aspects of the two countries are comparable. Both countries are relatively wealthy and have export-based economies largely dependent on natural resources, agriculture, manufacturing, mining and tourism. Many of these are climatically sensitive.

11.1.1 Summary of knowledge from the Third Assessment Report (TAR)

In the IPCC Third Assessment Report (TAR; Pittock and Wratt, 2001), the following impacts were assessed as important for Australia and New Zealand.

- Water resources are likely to become increasingly stressed in some areas of both countries, with rising competition for water supply.
- Warming is likely to threaten the survival of species in some natural ecosystems, notably in alpine regions, south-western Australia, coral reefs and freshwater wetlands.
- Regional reductions in rainfall in south-west and inland Australia and eastern New Zealand are likely to make agricultural activities particularly vulnerable.
- Increasing coastal vulnerability to tropical cyclones, storm surges and sea-level rise.
- Increased frequency of high-intensity rainfall, which is likely to increase flood damage.
- The spread of some disease vectors is very likely, thereby increasing the potential for disease outbreaks, despite existing biosecurity and health services.

The overall conclusions of the TAR were that: (i) climate change is likely to add to existing stresses to the conservation of terrestrial and aquatic biodiversity and to achieving sustainable land use, and (ii) Australia has significant vulnerability to climate change expected over the next 100 years, whereas New Zealand appears more resilient, except in a few eastern areas.

11.1.2 New findings of this Fourth Assessment Report (AR4)

The scientific literature published since 2001 supports the TAR findings. Key differences from the TAR include (i) more extensive documentation of observed changes in natural systems consistent with global warming, (ii) significant advances in understanding potential future impacts on water, natural ecosystems, agriculture, coasts, Indigenous people and health, (iii) more attention to the role of adaptation, and (iv) identification of the most vulnerable sectors and hotspots. Vulnerability is given more attention – it is dependent on the exposure to climate change, the sensitivity of sectors to this exposure, and their capacity to adapt.

11.2 Current sensitivity/vulnerability

11.2.1 Climate variability and 20th-century trends

In this section, climate change is taken to be due to both natural variability and human activities. The relative proportions are unknown unless otherwise stated. The strongest regional driver of climate variability is the El Niño-Southern Oscillation (ENSO). In New Zealand, El Niño brings stronger and cooler south-westerly airflow, with drier conditions in the north-east of the country and wetter conditions in the south-west (Gordon, 1986; Mullan, 1995). The converse occurs during La Niña. In Australia, El Niño tends to bring warmer and drier conditions to eastern and south-western regions, and the converse during La Niña (Power et al., 1998). The positive phase of the Inter-decadal Pacific Oscillation (IPO) strengthens the ENSO-rainfall links in New Zealand and weakens links in Australia (Power et al., 1999; Salinger et al., 2004; Folland et al., 2005).

In New Zealand, mean air temperatures have increased by 1.0°C over the period 1855 to 2004, and by 0.4°C since 1950 (NIWA, 2005). Local sea surface temperatures have risen by 0.7°C since 1871 (Folland et al., 2003). From 1951 to 1996, the number of cold nights and frosts declined by 10-20 days/yr (Salinger and Griffiths, 2001). From 1971 to 2004, tropical cyclones in the south-west Pacific averaged nine/year, with no trend in frequency (Burgess, 2005) or intensity (Diamond, 2006). The frequency and strength of extreme westerly winds have increased significantly in the south. Extreme easterly winds have decreased over land but have increased in the south (Salinger et al., 2005a). Relative sea-level rise has averaged 1.6 ± 0.2 mm/yr since 1900 (Hannah, 2004). Rainfall has increased in the south-west and decreased in the north-east (Salinger and Mullan, 1999) due to changes in circulation linked to the IPO, with extremes showing similar trends (Griffiths, 2007). Pan evaporation has declined significantly at six out of nineteen sites since the 1970s, with no significant change at the other thirteen sites (Roderick and Farquhar, 2005). Snow accumulation in the Southern Alps shows considerable interannual variability but no trend since 1930 (Owens and Fitzharris, 2004).

In Australia, from 1910 to 2004, the average maximum temperature rose 0.6°C and the minimum temperature rose 1.2°C, mostly since 1950 (Nicholls and Collins, 2006). It is very likely that increases in greenhouse gases have significantly contributed to the warming since 1950 (Karoly and Braganza, 2005a, b). From 1957 to 2004, the Australian average shows an increase in hot days (≥35°C) of 0.10 days/yr, an increase in hot nights (≥20°C) of 0.18 nights/yr, a decrease in cold days (≤15°C) of 0.14 days/yr and a decrease in cold nights (≤5°C) of 0.15 nights/yr (Nicholls and Collins, 2006). Due to a shift in climate around 1950, the north-western two-thirds of Australia has seen an increase in summer monsoon rainfall, while southern and eastern Australia have become drier (Smith, 2004b). While the causes of decreased rainfall in the east are unknown, the decrease in the south-west is probably due to a combination of increased greenhouse gas concentrations, natural climate variability and land-use change, whilst the increased rainfall in the north-west may be due to increased aerosols resulting from human activity, especially in Asia (Nicholls, 2006). Droughts have become hotter since about

1973 because temperatures are higher for a given rainfall deficiency (Nicholls, 2004). From 1950 to 2005, extreme daily rainfall has increased in north-western and central Australia and over the western tablelands of New South Wales (NSW), but has decreased in the south-east, south-west and central east coast (Gallant et al., 2007). Trends in the frequency and intensity of most extreme temperature and rainfall events are rising faster than the means (Alexander et al., 2007). South-east Australian snow depths at the start of October have declined 40% in the past 40 years (Nicholls, 2005). Pan evaporation averaged over Australia from 1970 to 2005 showed large interannual variability but no significant trend (Roderick and Farquhar, 2004; Jovanovic et al., 2007; Kirono and Jones, 2007). There is no trend in the frequency of tropical cyclones in the Australian region from 1981 to 2003, but there has been an increase in intense systems (very low central pressure) (Kuleshov, 2003; Hennessy, 2004). Relative sea-level rise around Australia averaged 1.2 mm/yr from 1920 to 2000 (Church et al., 2004).

The offshore islands of Australia and New Zealand have recorded significant warming. The Chatham Islands (44°S, 177°W) have warmed 1°C over the past 100 years (Mullan et al., 2005b). Macquarie Island (55°S, 159°E) has warmed 0.3°C from 1948 to 1998 (Tweedie and Bergstrom, 2000), along with increases in wind speed, precipitation and evapotranspiration, and decreases in air moisture content and sunshine hours since 1950 (Frenot et al., 2005). Campbell Island (53°S, 169°E) has warmed by 0.6°C in summer and 0.4°C in winter since the late 1960s. Heard Island (53°S, 73°E) shows rapid glacial retreat and a reduced area of annual snow cover from 1948 to 2001 (Bergstrom, 2003).

11.2.2 Human systems: sensitivity/vulnerability to climate and weather

Extreme events have severe impacts in both countries (Box 11.1). In Australia, around 87% of economic damage due to natural disasters (storms, floods, cyclones, earthquakes, fires and landslides) is caused by weather-related events (BTE, 2001). From 1967 to 1999, these costs averaged US$719 million/yr, mostly due to floods, severe storms and tropical cyclones. In New Zealand, floods are the most costly natural disasters apart from earthquakes and droughts, and total flood damage costs averaged about US$85 million/yr from 1968 to 1998 (NZIER, 2004).

11.2.3 Natural systems: sensitivity/vulnerability to climate and weather

Some species and natural systems in Australia and New Zealand are already showing evidence of recent climate-associated change (Table 11.1). In many cases, the relative contributions of other factors such as changes in fire regimes and land use are not well understood.

11.2.4 Sensitivity/vulnerability to other stresses

Human and natural systems are sensitive to a variety of stresses independent of those produced by climate change. Growing populations and energy demands have placed stress on energy supply infrastructure. In Australia, energy consumption has increased 2.5%/yr over the past 20 years (PB Associates, 2007). Increases in water demand have placed stress on supply capacity for irrigation, cities, industry and environmental flows. Increased water demand in New Zealand has been due to agricultural intensification (Woods and Howard-Williams, 2004)

Box 11.1. Examples of extreme weather events in Australia and New Zealand*

Droughts: In Australia, the droughts of 1982-1983, 1991-1995 and 2002-2003 cost US$2.3 billion, US$3.8 billion and US$7.6 billion, respectively (Adams et al., 2002; BoM, 2006a). In New Zealand, the 1997-1998 and 1998-1999 droughts had agricultural losses of US$800 million (MAF, 1999).

Sydney hailstorm, 14 April 1999: With the exception of the droughts listed above, this is the most expensive natural disaster in Australian history, costing US$1.7 billion, of which US$1.3 billion was insured (Schuster et al., 2005).

Eastern Australian heatwave, 1 to 22 February 2004: About two-thirds of continental Australia recorded maximum temperatures over 39°C. Temperatures reached 48.5°C in western New South Wales. The Queensland ambulance service recorded a 53% increase in ambulance call-outs (Steffen et al., 2006).

Canberra fire, 19 January 2003: Wildfires caused US$261 million damage (Lavorel and Steffen, 2004; ICA, 2007). About 500 houses were destroyed, four people were killed and hundreds injured. Three of the city's four dams were contaminated for several months by sediment-laden runoff.

South-east Australian storm, 2 February 2005: Strong winds and heavy rain led to insurance claims of almost US$152 million (ICA, 2007). Transport was severely disrupted and beaches were eroded.

Tropical cyclone Larry, 20 March 2006: Significant damage or disruption to houses, businesses, industry, utilities, infrastructure (including road, rail and air transport systems, schools, hospitals and communications), crops and state forests, costing US$263 million. Fortunately, the 1.75 m storm surge occurred at low tide (BoM, 2006b; Queensland Government, 2006).

New Zealand floods: The 10 April 1968 Wahine storm cost US$188 million, the 26 January 1984 Southland floods cost US$80 million, and the February 2004 North Island floods cost US$78 million (Insurance Council of New Zealand, 2005).

* All costs are adjusted to 2002-2006 values.

and has seen the irrigated area of New Zealand increase by around 55% each decade since the 1960s (Lincoln Environmental, 2000). Per capita daily water consumption is 180-300 litres in New Zealand and 270 litres for Australia (Robb and Bright, 2004). In Australia, dryland salinity, alteration of river flows, over-allocation and inefficient use of water resources, land clearing, intensification of agriculture, and fragmentation of ecosystems still represent major stresses (SOE, 2001; Cullen, 2002). From 1985 to 1996, Australian water demand increased by 65% (NLWRA, 2001). Invasive plant and animal species pose significant environmental problems in both countries, particularly for agriculture and forestry (MfE, 2001; SOE, 2001); for example, *Cryptostegia grandiflora* (Kriticos et al., 2003a, b).

Table 11.1. *Examples of observed changes in species and natural systems linked to changing climate in Australia, New Zealand and their sub-Antarctic islands.*

Taxa or system	Observed change	References
Australia		
Rainforest and woodland ecotones	Expansion of rainforest at the expense of eucalypt forest and grassland in Northern Territory, Queensland and New South Wales, linked to changes in rainfall and fire regimes.	Bowman et al., 2001; Hughes, 2003
Sub-alpine vegetation	Encroachment by snow gums into sub-alpine grasslands at higher elevations.	Wearne and Morgan, 2001
Freshwater swamps and floodplains	Saltwater intrusion into freshwater swamps since the 1950s in Northern Territory accelerating since the 1980s, possibly associated with sea level and precipitation changes.	Winn et al., 2006
Coral reefs	Eight mass bleaching events on the Great Barrier Reef since 1979, triggered by unusually high sea surface temperatures; no serious events known prior to 1979 (see Section 11.6). Most widespread events appear to have occurred in 1998 and 2002, affecting up to 50% of reefs within the Great Barrier Reef Marine Park.	Hoegh-Guldberg, 1999; Done et al., 2003; Berkelmans et al., 2004
Birds	Earlier arrival of migratory birds; range shifts and expansions for several species; high sea surface temperatures associated with reduced reproduction in wedge-tailed shearwaters.	Smithers et al., 2003; Chambers, 2005; Chambers et al., 2005; Beaumont et al., 2006
Mammals	Increased penetration of feral mammals into alpine and high sub-alpine areas and prolonged winter presence of macropods.	Green and Pickering, 2002
Insects	Change in genetic constitution of *Drosophila*, equivalent to a 4° latitude shift (about 400 km).	Umina et al., 2005
New Zealand		
Birds	Earlier egg laying in the welcome swallow.	Evans et al., 2003
Southern beech	Seed production increase in *Nothofagus* (1973 to 2002) along elevational gradient related to warming during flower development.	Richardson et al., 2005
Fish	Westward shift of Chilean jack mackerel in the Pacific and subsequent invasion into New Zealand waters in the mid-1980s associated with increasing El Niño frequency.	Taylor, 2002
Glaciers	Ice volume decreased from about 100 km^3 to 53 km^3 over the past century. Loss of at least one-quarter of glacier mass since 1950. Mass balance of Franz Josef glacier decreased 0.02 m/yr from 1894 to 2005.	Chinn, 2001; Clare et al., 2002; Anderson, 2004
Sub-Antarctic Islands		
Birds	Population increases in black-browed albatross and king penguin on Heard Island; population declines on Campbell Island of rockhopper penguins, grey-headed albatross and black-browed albatross related to ocean warming and changed fishing practices.	Waugh et al., 1999; Woehler et al., 2002; Weimerskirch et al., 2003
Vertebrates	Population increases in fur seals on Heard Island and elephant seals on Campbell Island, linked to changes in food supply, warming and oceanic circulation; rats moving into upland herb-fields and breeding more often on Macquarie Island.	Budd, 2000; Weimerskirch et al., 2003; Frenot et al., 2005
Plant communities	Plant colonisation of areas exposed by glacial retreat on Heard Island; decline in area of sphagnum moss since 1992 on Macquarie Island associated with drying trend.	Whinam and Copson, 2006

11.2.5 Current adaptation

Since vulnerability is influenced by adaptation, a summary of current adaptation is given here rather than in Section 11.5 (which looks at future adaptation). Adaptation refers to planned and autonomous (or spontaneous) adjustments in natural or human systems in response to climatic stimuli. Adaptation can reduce harmful effects or exploit opportunities (see Chapter 17). An example of autonomous adaptation is the intensification of grazing in the rangelands of north-west Australia over the last 30 years, as graziers have exploited more reliable and better pasture growth following an increase in monsoon rainfall (Ash et al., 2006). However, there is currently insufficient information to comprehensively quantify this capacity. While planned adaptation usually refers to specific measures or actions, it can also be viewed as a *dynamic process* that evolves over time, involving five major pre-conditions for encouraging implementation (Figure 11.1). This section assesses how well Australia and New Zealand are engaged in the adaptation process.

Provision of knowledge, data and tools.

Since the TAR, the New Zealand Foundation for Research, Science and Technology has created a separate strategic fund for global change research (FRST, 2005). Operational research and development related to climate impacts on specific sectors have also increased over the last 10 years (e.g., agricultural impacts, decision-support systems and extension activities for integration with farmers' knowledge) (Kenny, 2002; MAF, 2006). One of Australia's four National Research Priorities is "an environmentally sustainable Australia", which includes "responding to climate change and variability" (DEST, 2004). The Australian Climate Change Science Programme and the National Climate Change Adaptation Programme are part of this effort (Allen Consulting Group, 2005). All Australian state and territory governments have greenhouse action plans that include development of knowledge, data and tools.

Risk assessments

A wide range of regional and sectoral risk assessments has been undertaken since 2001 (see Section 11.4). Both countries occasionally produce national reports that synthesise these assessments and provide a foundation for adaptation (MfE, 2001; Warrick et al., 2001; Howden et al., 2003a; Pittock, 2003). Regionally relevant guidelines are available for use in risk assessments (Wratt et al., 2004; AGO, 2006).

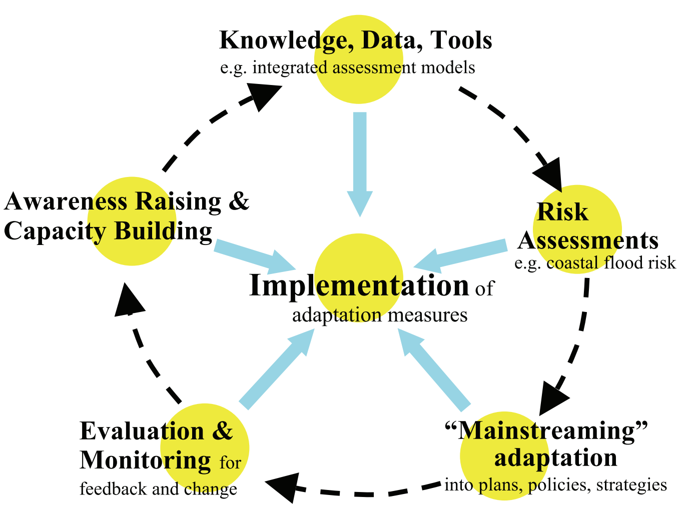

Figure 11.1. *Adaptation as a process (Warrick, 2000, 2006).*

Mainstreaming

Climate change issues are gradually being 'mainstreamed' into policies, plans and strategies for development and management. For example, in New Zealand, the Coastal Policy Statement included consideration of sea-level rise (DoC, 1994), the Resource Management (Energy and Climate Change) Amendment Act 2004 made explicit provisions for the effects of climate change, and the Civil Defence and Emergency Management Act 2002 requires regional and local government authorities (LGAs) to plan for future natural hazards. New Zealand farmers, particularly in the east, implemented a range of adaptation measures in response to droughts in the 1980s and 1990s and as a result of the removal of almost all subsidies. Increasing numbers of farmers are focusing on building long-term resilience with a diversity of options (Kenny, 2005; Salinger et al., 2005b). In Australia, climate change is included in several environmentally focused action plans, including the National Agriculture and Climate Change Action Plan (NRMMC, 2006) and the National Biodiversity and Climate Change Action Plan. A wide range of water adaptation strategies has been implemented or proposed (Table 11.2), including US$1.5 billion for the National Water Fund from 2004 to 2009 and US$1.7 billion for drought relief from 2001 to 2006.

Climate change is listed as a Key Threatening Process under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999. Climate change has been integrated into several state-based and regional strategies, such as the Queensland Coastal Management Plan, the Great Barrier Reef Climate Change Action Plan, the Victorian Sustainable Water Strategy and South Australia's Natural Resources Management Plan. The Wild Country (The Wilderness Society), Gondwana Links (Western Australia) and Nature Links (South Australia) and Alps to Atherton (Victoria, NSW, Queensland) initiatives promote connectivity of landscapes and resilience of natural systems in recognition of the fact that some species will need to migrate as climate zones shift. Guidelines prepared for the coastal and ocean engineering profession for implementing coastal management strategies include consideration of climate change (Engineers Australia, 2004).

Evaluation and monitoring

The New Zealand Climate Committee monitors the present state of knowledge of climate science, climate variability and current and future climate impacts, and makes recommendations about research and monitoring needs, priorities and gaps regarding climate, its impacts and the application of climate information (RSNZ, 2002). In Australia, the Australian Greenhouse Office (AGO) monitors and evaluates performance against objectives in the National Greenhouse Strategy. The AGO and state and territory governments commission research to assess current climate change knowledge, gaps and priorities for research on risk and vulnerability (Allen Consulting Group,

Table 11.2. *Examples of government adaptation strategies to cope with water shortages in Australia.*

Government	Strategy	Investment	Source
Australia	Drought aid payments to rural communities	US$1.7 billion from 2001 to 2006	DAFF, 2006b
Australia	National Water Initiative, supported by the Australian Water Fund	US$1.5 billion from 2004 to 2009	DAFF, 2006a
Australia	Murray-Darling Basin Water Agreement	US$0.4 billion from 2004 to 2009	DPMC, 2004
Victoria	Melbourne's Eastern Treatment Plant to supply recycled water	US$225 million by 2012	Melbourne Water, 2006
Victoria	New pipeline from Bendigo to Ballarat, water recycling, interconnections between dams, reducing channel seepage, conservation measures	US$153 million by 2015	Premier of Victoria, 2006
Victoria	Wimmera Mallee pipeline replacing open irrigation channels	US$376 million by 2010	Vic DSE, 2006
NSW	NSW Water Savings Fund supports projects which save or recycle water in Sydney	US$98 million for Round 3, plus more than US$25 million to 68 other projects	DEUS, 2006
Queensland (Qld)	Qld Water Plan 2005 to 2010 to improve water-use efficiency and quality, recycling, drought preparedness, new water pricing	Includes US$182 million for water infrastructure in south-east Qld, and US$302 million to other infrastructure programmes	Queensland Government, 2005
South Australia	Water Proofing Adelaide project is a blueprint for the management, conservation and development of Adelaide's water resources to 2025	N/A	Government of South Australia, 2005
Western Australia (WA)	State Water Strategy (2003) and State Water Plan (proposed) WA Water Corporation doubled supply from 1996 to 2006	US$500 million spent by WA Water Corporation from 1996 to 2006, plus US$290 million for the Perth desalination plant	Government of Western Australia, 2003, 2006; Water Corporation, 2006

2005). The National Land and Water Resources Audit (NLWRA, 2001) and State of the Environment Report (SOE, 2001) also have climate-change elements.

Awareness raising and capacity building

In New Zealand, efforts are underway for transferring scientific information to LGAs and facilitating exchange of information between LGAs. The New Zealand Climate Change Office has held a number of workshops for LGAs (MfE, 2002, 2004b), supported case studies of 'best practice' adaptation by LGAs, and has commissioned guidance documents for LGAs on integrating climate change adaptation into their functions (MfE, 2004c). The AGO, the Australian Bureau of Meteorology, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and most Australian state and territory governments have developed products and services for raising awareness about climate change. Government-supported capacity-building programmes, such as the Australian National Landcare Programme, enhance resilience to climate change via mechanisms such as whole-farm planning.

In general, the domestic focus of both countries has, until recently, been on mitigation, while adaptation has had a secondary role in terms of policy effort and government funding for implementation (MfE, 2004b). However, since the TAR, recognition of the necessity for adaptation has grown and concrete steps have been taken to bolster the pre-conditions for adaptation, as discussed above. Initiatives such as the Australia-New Zealand Bilateral Climate Change Partnership (AGO, 2003) explicitly include adaptation. Overall, in comparison to most other countries, New Zealand and Australia have a relatively high and growing level of adaptive capacity, which has the potential to be implemented systematically on a wide scale.

11.3 Assumptions about future trends

11.3.1 Climate

Regional climate change projections are provided in Chapter 11 of the Working Group I Fourth Assessment Report (Christensen et al., 2007). For Australia and New Zealand, these projections are limited to averages over two very broad regions: northern Australia and southern Australia (including New Zealand). More detailed regional projections are required to assess local impacts and are described below. Developed over the past five years, these are similar to those presented in the TAR, and include the full range of emissions scenarios from the IPCC Special Report on Emissions Scenarios (SRES: Nakićenović and Swart, 2000) (see Chapter 2.4.6). Some SRES scenarios have been suggested as surrogates for CO_2 concentration stabilisation scenarios: the SRES B1, B2 and A1B emissions scenarios are similar to the CO_2 stabilisation scenarios for 550 ppm by 2150, 650 ppm by 2200, and 750 ppm by 2250, respectively. Projected changes will be superimposed on continued natural variability including ENSO and the IPO. There is uncertainty about projected changes in ENSO as discussed in Chapter 10 of the Working Group I Fourth Assessment Report (Meehl et al., 2007).

In New Zealand, a warming of 0.1 to 1.4°C is likely by the 2030s and 0.2 to 4.0°C by the 2080s (Table 11.3). The mid-range projection for the 2080s is a 60% increase in the annual mean westerly component of wind speed (Wratt et al., 2004). Consequently, a tendency for increased precipitation is likely except in the eastern North Island and the northern South Island. Due to the projected increased winter precipitation over the

Table 11.3. *Projected changes in New Zealand annual precipitation and mean temperature for the 2030s and 2080s, relative to 1990. The ranges are based on results from forty SRES emission scenarios and six climate models for various locations in each region (Wratt et al., 2004).*

Temperature change (°C)	2030s	2080s
Western North Island	+0.2 to 1.3	+0.3 to 4.0
Eastern North Island	+0.2 to 1.4	+0.5 to 3.8
Northern South Island	+0.1 to 1.4	+0.4 to 3.5
Western South Island	+0.1 to 1.3	+0.2 to 3.5
Eastern South Island	+0.1 to 1.4	+0.4 to 3.4
Rainfall change (%)	**2030s**	**2080s**
Western North Island	-4 to +14	-6 to +26
Eastern North Island	-19 to +7	-32 to +2
Northern South Island	-7 to +3	-7 to +5
Western South Island	-4 to +15	+1 to +40
Eastern South Island	-12 to +13	-21 to +31

Southern Alps, it is less clear whether snow will be reduced (MfE, 2004a), although snowlines are likely to be higher (Fitzharris, 2004). By 2100, there is likely to be a 5 to 20 day decrease in frosts in the lower North Island, 10 to 30 fewer frost days in the South Island, and a 5 to 70 day increase in the number of days with temperatures over 30°C (Mullan et al., 2001). The frequency of heavy rainfall is likely to increase, especially in western areas (MfE, 2004a).

In Australia, within 800 km of the coast, a mean warming of 0.1 to 1.3°C is likely by the year 2020, relative to 1990, 0.3 to 3.4°C by 2050, and 0.4 to 6.7°C by 2080 (Table 11.4). In temperate areas, this translates to 1 to 32 more days/yr over 35°C by 2020 and 3 to 84 more by 2050, with 1 to 16 fewer days/yr below 0°C by 2020 and 2 to 32 fewer by 2050 (Suppiah et al., 2007). A tendency for decreased annual rainfall is likely over most of southern and sub-tropical Australia, with a tendency for increases in Tasmania, central Northern Territory and northern NSW (Table 11.4). The 15-model average shows decreasing rainfall over the whole continent (Suppiah et al., 2007). A decline in runoff in southern and eastern Australia is also likely (see Section 11.4.1).

The area of mainland Australia with at least one day of snow cover per year is likely to shrink by 10 to 40% by 2020 and by 22 to 85% by 2050 (Hennessy et al., 2003). Increases in extreme daily rainfall are likely where average rainfall either increases or decreases slightly. For example, the intensity of the 1-in-20 year daily rainfall event is likely to increase by up to 10% in parts of South Australia by the year 2030 (McInnes et al., 2002), by 5 to 70% by the year 2050 in Victoria (Whetton et al., 2002), by up to 25% in northern Queensland by 2050 (Walsh et al., 2001) and by up to 30% by 2040 in south-east Queensland (Abbs, 2004). In NSW, the intensity of the 1-in-40 year event increases by 5 to 15% by 2070 (Hennessy et al., 2004). The frequency of severe tropical cyclones (Categories 3, 4 and 5) on the east Australian coast increases 22% for the IS92a scenario (IPCC, 1992) from 2000 to 2050, with a 200 km southward shift in the cyclone genesis region, leading to greater exposure in south-east Queensland and north-east NSW (Leslie and Karoly, 2007). For tripled pre-industrial CO_2 conditions, there is a 56% increase in the number of simulated tropical cyclones over north-eastern Australia with peak winds greater than 30 m/s (Walsh et al., 2004). Decreases in hail frequency are simulated for Melbourne and Mt. Gambier (Niall and Walsh, 2005).

Potential evaporation (or evaporative demand) is likely to increase (Jones, 2004a). Projected changes in rainfall and evaporation have been applied to water-balance models, indicating that reduced soil moisture and runoff are very likely over most of Australia and eastern New Zealand (see Section 11.4.1 and Meehl et al., 2007). Up to 20% more droughts (defined as the 1-in-10 year soil moisture deficit from 1974 to 2003) are simulated over most of Australia by 2030 and up to 80% more droughts by 2070 in south-western Australia (Mpelasoka et al., 2007). Projected increases in the Palmer Drought Severity Index for the SRES A2 scenario are indicated over much of eastern Australia between 2000 and 2046 (Burke et al., 2006). In New Zealand, severe droughts (the current 1-in-20 year soil moisture deficit) are likely to occur every 7 to 15 years by the 2030s, and every 5 to 10 years by the 2080s, in the east of both islands, and parts of Bay of Plenty and Northland (Mullan et al., 2005a). The drying of pastures in eastern New Zealand in spring is very likely to be advanced by one month, with an expansion of droughts into both spring and autumn.

An increase in fire danger in Australia is likely to be associated with a reduced interval between fires, increased fire intensity, a decrease in fire extinguishments and faster fire spread (Tapper, 2000; Williams et al., 2001; Cary, 2002). In south-east Australia, the frequency of very high and extreme fire danger days is likely to rise 4-25% by 2020 and 15-70% by 2050 (Hennessy et al., 2006). By the 2080s, 10-50% more days with very high and extreme fire danger are likely in eastern areas of New Zealand, the Bay of Plenty, Wellington and Nelson regions (Pearce et al., 2005), with increases of up to 60% in some western areas. In both Australia and New Zealand, the fire season length is likely to be extended, with the window of opportunity for controlled burning shifting toward winter.

Relative to the year 2000, the global-mean projection of sea-level rise by 2100 is 0.18 to 0.59 m, excluding uncertainties in

Table 11.4. *Projected changes in annual average rainfall and temperature for 2020, 2050 and 2080, relative to 1990, for Australia. The ranges are based on results from forty SRES emission scenarios and fifteen climate models for various locations in each region (Suppiah et al., 2007).*

Temperature change (°C)	2020	2050	2080
0 to 400 km inland of coast	+0.1 to 1.0	+0.3 to 2.7	+0.4 to 5.4
400 to 800 km inland	+0.2 to 1.3	+0.5 to 3.4	+0.8 to 6.7
Central Australia	+0.2 to 1.5	+0.5 to 4.0	+0.8 to 8.0
Rainfall change (%)	**2020**	**2050**	**2080**
Within 400 km of western and southern coasts	-15 to 0	-40 to 0	-80 to 0
Sub-tropics (latitudes 20-28°S) except west coast and inland Queensland	-10 to +5	-27 to +13	-54 to +27
Northern NSW, Tasmania and central Northern Territory (NT)	-5 to +10	-13 to +27	-27 to +54
Central South Australia, southern NSW and north of latitude 20°S, except central NT	-5 to +5	-13 to +13	-27 to +27
Inland Queensland	-10 to +10	-27 to +27	-54 to +54

carbon cycle feedbacks and the possibility of faster ice loss from Greenland and Antarctica (Meehl et al., 2007). These values would apply to Australia and New Zealand, but would be further modified by as much as ±25% due to regional differences in thermal expansion rates, oceanic circulation changes (as derived from atmosphere-ocean general circulation model experiments; Gregory et al., 2001) and by local differences in relative sea-level changes due to vertical land movements. An increase in westerly winds is probable south of latitude 45°S, with a strengthening of the East Australian Current and southern mid-latitude ocean circulation (Cai et al., 2005).

11.3.2 Population, energy and agriculture

The Australian population is projected to grow from 20 million in 2003 to 26.4 million in 2051, then stabilise (ABS, 2003a). This is under medium assumptions, including a fall in the number of children per woman from 1.75 at present to 1.6 from 2011 onward, net immigration of 100,000/yr, and a 10% increase in life expectancy by 2051 (ABS, 2003a). A greater concentration of the population is likely in Sydney, Melbourne, Perth, Brisbane and south-east Queensland. The proportion of people aged 65 and over is likely to increase from 13% in 2003 to 27% in 2051 (ABS, 2003a). Population growth is likely to intensify the urban heat island effect, exacerbating greenhouse-induced warming (Torok et al., 2001). Up to at least 2020, Australian energy consumption is projected to grow 2.1%/yr on average (ABARE, 2004). New energy sources will be needed to meet peak energy demands in Victoria, NSW, Queensland and South Australia between 2007 and 2010 (NEMMCO, 2006). Agriculture is likely to contribute about 3% of national gross domestic product (GDP).

In New Zealand, under medium assumptions, the population is likely to grow from 4.1 million in 2004 to 5.05 million in 2051 (Statistics New Zealand, 2005b). These assumptions include a net immigration of 10,000/yr, a drop in fertility rate from 2.01 in 2004 to 1.85 from 2016 onward and a 10% increase in life expectancy by 2051. The proportion aged 65 and over is likely to grow from 12% in 2004 to 25% in 2051. Total energy demand is likely to grow at an average rate of 2.4%/yr from 2005 to 2025 (Electricity Commission, 2005). Agriculture is likely to continue contributing about 5% of GDP (MFAT, 2006).

11.4 Key future impacts and vulnerabilities

This section discusses potential impacts of climate change, mostly based on climate projections consistent with those described in Section 11.3. It does not take into account adaptation; this is discussed in Section 11.5 and in more detail in Chapter 17. Conclusions are drawn from the available literature. Very little information is available on social and economic impacts. Further details on potential impacts can be found in various synthesis reports (MfE, 2001; Pittock, 2003).

11.4.1 Freshwater resources

11.4.1.1 Water security

The impact of climate change on water security is a significant cross-cutting issue. In Australia, many new risk assessments have been undertaken since the TAR (Table 11.5). The Murray-Darling Basin is Australia's largest river basin, accounting for about 70% of irrigated crops and pastures (MDBC, 2006). Annual streamflow in the Basin is likely to fall 10-25% by 2050 and 16-48% by 2100 (Table 11.5). Little is known about future impacts on groundwater in Australia.

In New Zealand, annual flow from larger rivers with headwaters in the Southern Alps is likely to increase. Proportionately more runoff is very likely from South Island rivers in winter, and less in summer (Woods and Howard-Williams, 2004). This is very likely to provide more water for hydro-electric generation during the winter peak demand period, and reduce dependence on hydro-storage lakes to transfer generation into the next winter. However, industries dependent on irrigation are likely to experience negative effects due to lower water availability in spring and summer, their time of peak demand. Increased drought frequency is very likely in eastern areas, with potential losses in agricultural production. The effects of climate change on flood and drought frequency are virtually certain to be modulated by phases of the ENSO and IPO (McKerchar and Henderson, 2003; see Section 11.2.1). The groundwater aquifer for Auckland City has spare capacity to accommodate recharge under all scenarios

Table 11.5. *Impacts on Australian water security. SRES scenarios are specified where possible.*

Year	Impacts
2030	• Change in annual runoff: -5 to +15% on the north-east coast, ±15% on the east coast, a decline of up to 20% in the south-east, ±10% in Tasmania, a decline of up to 25% in the Gulf of St Vincent (South Australia), and -25 to +10% in the south-west (Chiew and McMahon, 2002). • Decline in annual runoff: 6-8% in most of eastern Australia and 14% in south-west Australia in the period 2021 to 2050 relative to 1961 to 1990 for the A2 scenario (Chiew et al., 2003). • Burrendong dam (NSW): inflows change by +10% to 30% across all SRES scenarios, but the 90% confidence interval is 0% to -15% (Jones and Page, 2001). • Victoria: runoff in 29 catchments declines by 0-45% (Jones and Durack, 2005).
2050	• Murray Darling Basin: for B1, streamflow drops 10-19% and salinity changes -6 to +16%; for A1, streamflow drops 14-25% and salinity changes -8 to +19% (Beare and Heaney, 2002). • Melbourne: a risk assessment using ten climate models (driven by the SRES B1, A1B and A1FI scenarios) indicated that average streamflow is likely to decline 7-35% (Howe et al., 2005); however, planned demand-side and supply-side actions are likely to alleviate water shortages through to 2020 (Howe et al., 2005).
2070	• Burrendong Dam (NSW): inflows change by +5 to -35% across all SRES scenarios, for the 90% confidence interval (Jones and Page, 2001).
2100	• Murray-Darling Basin: for B1, streamflow declines 16 to 30%, salinity changes -16 to +35%, agricultural costs US$0.6 billion; for A1, streamflow declines 24 to 48%, salinity changes -25 to +72%, agricultural costs US$0.9 billion (Beare and Heaney, 2002).

examined (Namjou et al., 2005). Base flows in principal streams and springs are very unlikely to be compromised unless many dry years occur in succession.

11.4.1.2 Flood and waste water management

Little quantitative information is available about potential changes in flood risk in Australia. Sufficient capacity exists within the Melbourne sewerage and drainage systems to accommodate moderate increases (up to 20%) in storm rainfall totals with minimal surcharging (Howe et al., 2005). For the Albert-Logan Rivers system near the Gold Coast in Queensland, each 1% increase in rainfall intensity is likely to produce a 1.4% increase in peak runoff (Abbs et al., 2000). However, increases in runoff and flooding are partially offset by a reduction in average rainfall, which reduces soil wetness prior to storms. A high-resolution atmospheric model of storm events coupled with a non-linear flood event model has been applied to flooding around the Gold Coast caused by tropical cyclone Wanda in 1974. If the same event occurred in 2050 with a 10 to 40 cm rise in mean sea level, the number of dwellings and people affected is likely to increase by 3 to 18% (Abbs et al., 2000).

In New Zealand, rain events are likely to become more intense, leading to greater storm runoff, but with lower river levels between events. This is likely to cause greater erosion of land surfaces, more landslides (Glade, 1998; Dymond et al., 2006), redistribution of river sediments (Griffiths, 1990) and a decrease in the protection afforded by levees. Increased demands for enhancement of flood protection works are likely, as evidenced by the response to large floods in 2004 (MCDEM, 2004; CAE, 2005). Flood risk to Westport has been assessed using a regional atmospheric model, a rainfall-runoff model for the Buller River, projected sea-level rise and a detailed inundation model. Assuming the current levee configuration, the proportion of the town inundated by a 1-in-50 year event is currently 4.3%, but rises to 13 to 30% by 2030, and 30 to 80% by 2080 (Gray et al., 2005). Peak flow increases 4% by 2030 and 40% by 2080. In contrast, a flood risk study for Auckland using 2050 climate scenarios with 1 to 2°C global warming indicated only minor increases in flood levels (Dayananda et al., 2005). Higher flows and flood risk are likely in the Wairau catchment in North Shore City (URS, 2004).

11.4.1.3 Water quality

In Australia, there is a 50% chance by 2020 of the average salinity of the lower Murray River exceeding the 800 EC threshold set for desirable drinking and irrigation water (MDBMC, 1999). There are no integrated assessments of the impacts of climate change on runoff quantity and quality, salt interception and revegetation policies, and water pricing and trading policies. Eutrophication is a major water-quality problem (Davis, 1997; SOE, 2001). Toxic algal blooms are likely to become more frequent and to last longer due to climate change. They can pose a threat to human health, for both recreation and consumptive water use, and can kill fish and livestock (Falconer, 1997). Simple, resource-neutral, adaptive management strategies, such as flushing flows, can substantially reduce their occurrence and duration in nutrient-rich, thermally stratified water bodies (Viney et al., 2003).

In New Zealand, lowland waterways in agricultural catchments are in a relatively poor state and these streams are under pressure from land-use intensification and increasing water abstraction demands (Larned et al., 2004). There is no literature on impacts of climate change on water quality in New Zealand.

11.4.2 Natural ecosystems

The flora and fauna of Australia and New Zealand have a high degree of endemism (80 to 100% in many taxa). Many species are at risk from rapid climate change because they are restricted in geographical and climatic range. Most species are well-adapted to short-term climate variability, but not to longer-term shifts in mean climate and increased frequency or intensity of extreme events. Many reserved areas are small and isolated, particularly in the New Zealand lowlands and in the agricultural areas of Australia. Bioclimatic modelling studies generally project reductions and/or fragmentation of existing climatic ranges. Climate change will also interact with other stresses such as invasive species and habitat fragmentation. The most vulnerable include the Wet Tropics and Kakadu wetlands, alpine areas, tropical and deep-sea coral reefs, south-east Tasman Sea, isolated habitats in the New Zealand lowlands, coastal and freshwater wetlands and south-west Australian heathlands (Table 11.6). There is little research on the impacts of climate change on New Zealand species or natural ecosystems, with the exception of the alpine zone and some forested areas.

Major changes are expected in all vegetation communities. In the Australian rangelands (75% of total continental land area), shifts in rainfall patterns are likely to favour establishment of woody vegetation and encroachment of unpalatable woody shrubs. Interactions between CO_2, water supply, grazing practices and fire regimes are likely to be critical (Gifford and Howden, 2001; Hughes, 2003). In New Zealand, fragmented native forests of drier lowland areas (Northland, Waikato, Manawatu) and in the east (from East Cape to Southland) are likely to be most vulnerable to drying and changes in fire regimes (McGlone, 2001; MfE, 2001). In alpine zones of both countries, reductions in duration and depth of snow cover are likely to alter distributions of communities, for example favouring an expansion of woody vegetation into herbfields (Pickering et al., 2004). More fires are likely in alpine peatlands (Whinam et al., 2003). Alpine vertebrates dependent on snow cover for hibernation are likely to be at risk of extinction (Pickering et al., 2004). In regions such as south-western Australia, many narrow-ranged endemic species will be vulnerable to extinction with relatively small amounts of warming (Hughes, 2003). Saltwater intrusion as a result of sea-level rise, decreases in river flows and increased drought frequency, are very likely to alter species composition of freshwater habitats, with consequent impacts on estuarine and coastal fisheries (Bunn and Arthington, 2002; Hall and Burns, 2002; Herron et al., 2002; Schallenberg et al., 2003). In marine ecosystems, ocean acidification is likely to decrease productivity and diversity of plankton communities around Australia, while warmer oceans are likely to lead to further southward movement of fish and kelp communities (Poloczanska et al., 2007).

Table 11.6. *Examples of projected impacts on species and ecosystems, relative to 1990.*

Year	Potential Impacts	Source
2020	Bleaching and damage to the Great Barrier Reef equivalent to that in 1998 and 2002 in up to 50% of years.	Berkelmans et al., 2004; Crimp et al., 2004
	60% of the Great Barrier Reef regularly bleached.	Jones, 2004b
	Habitat lost for marine invertebrates currently confined to cool waters (>10% of Victoria's total).	O'Hara, 2002; Watters et al., 2003
	63% decrease in golden bowerbird habitat in northern Australia.	Hilbert et al., 2004
	50% decrease in montane tropical rainforest area in northern Australia.	Hilbert et al., 2001
2030	58 to 81% of the Great Barrier Reef bleached every year.	Jones, 2004b
	Hard coral reef communities widely replaced by algal communities.	Wooldridge et al., 2005
	88% of Australian butterfly species' core habitat decreases.	Beaumont and Hughes, 2002
	97% of Wet Tropics endemic vertebrates have reduced core habitat.	Williams et al., 2003
2050	97% of the Great Barrier Reef bleached every year.	Jones, 2004b
	92% of butterfly species' core habitat decreases.	Beaumont and Hughes, 2002
	98% decrease in golden bowerbird habitat in northern Australia.	Hilbert et al., 2004
	80% loss of freshwater wetlands in Kakadu for a 30 cm sea-level rise.	Hare, 2003
2080	Catastrophic mortality of coral species annually.	Jones, 2004b
	95% decrease in distribution of Great Barrier Reef species.	Jones et al., 2004
	65% loss of Great Barrier Reef species in the Cairns region.	Crimp et al., 2004
	46% of Wet Tropics endemic vertebrates lose core habitat.	Williams et al., 2003
	200 to 300 indigenous New Zealand alpine plant species may become extinct.	Halloy and Mark, 2003
	Reduced calcification for 70% of the area where deep sea corals occur, loss of endemic species.	Poloczanska et al., 2007

On the sub-Antarctic Islands, likely impacts include increased mortality of burrowing petrels, increased invasions by disturbance-tolerant alien plants such as *Poa annua*, increased abundance of existing rats, mice and rabbits on islands, and reduced distribution of *Sphagnum* moss (Bergstrom and Selkirk, 1999; Frenot et al., 2005).

11.4.3 Agriculture

11.4.3.1 Cropping

Since the TAR, there has been further assessment of potential impacts of climate and CO_2 changes at local, regional and national scales in both Australia and New Zealand. Overall, these emphasise the vulnerability of cropping and the potential for regional differences. Impacts of climate change on pests, diseases and weeds, and their effects on crops, remain uncertain, since few experimental or modelling studies have been performed (Chakraborty et al., 2002).

In New Zealand, for C_3 crops such as wheat, the CO_2 response is likely to more than compensate for a moderate increase in temperature (Jamieson et al., 2000) (see Section 5.4). The net impact in irrigation areas depends on the availability of water (Miller and Veltman, 2004). For maize (a C_4 crop), reduction in growth duration reduces crop water requirements, providing closer synchronisation of development with seasonal climatic conditions (Sorensen et al., 2000).

In Australia, the potential impacts of climate change on wheat vary regionally, as shown by a study which used the full range of CO_2 and climate change in the IPCC SRES scenarios (Howden and Jones, 2004), in conjunction with a crop model recently validated for its CO_2 response for current wheat varieties (Reyenga et al., 2001; Asseng et al., 2004). South-western Australian regions are likely to have significant yield reductions by 2070 (increased yield very unlikely). In contrast, regions in north-eastern Australia are likely to have moderate increases in yield (unlikely to have substantial yield reductions). Nationally, median crop yields dropped slightly. There is a substantial risk to the industry as maximum potential increases in crop value are limited (to about 10% or US\$0.3 billion/yr) but maximum potential losses are large (about 50% or US\$1.4 billion/yr) (Figure 11.2). However, adaptation through changing planting dates and varieties is likely to be highly effective: the median benefit is projected to be US\$158 million/yr but with a range of US\$70 million to over US\$350 million/yr (Howden and Jones, 2004) (Figure 11.2).

Climate change is likely to change land use in southern Australia, with cropping becoming non-viable at the dry margins if rainfall is reduced substantially, even though yield increases from elevated CO_2 partly offset this effect (Sinclair et al., 2000; Luo et al., 2003). In contrast, cropping is likely to expand into the wet margins if rainfall declines. In the north of Australia, climate change and CO_2 increases are likely to enable cropping to persist (Howden et al., 2001a). Observed warming trends are already reducing frost risk and increasing yields (Howden et al., 2003b).

Grain quality is also likely to be affected. Firstly, elevated CO_2 reduces grain protein levels (Sinclair et al., 2000). Significant increases in nitrogenous fertiliser application or increased use of pasture legume rotations would be needed to maintain protein levels (Howden et al., 2003c). Secondly, there is increased risk of development of undesirable heat-shock proteins in wheat grain in both northern and southern cropping zones with temperature increases greater than 4°C (Howden et al., 1999d).

Land degradation is likely to be affected by climate change. Elevated atmospheric CO_2 concentrations slightly reduce crop evapotranspiration. This increases the risk of water moving below the root zone of crops (deep drainage), potentially exacerbating three of Australia's most severe land degradation problems across agricultural zones: waterlogging, soil acidification and dryland salinity. In Western Australia, deep drainage is simulated to increase 1 to 10% when CO_2 is raised to 550 ppm, but deep drainage decreases 8 to 29% for a 3°C warming (van Ittersum et al., 2003). Deep drainage is reduced by

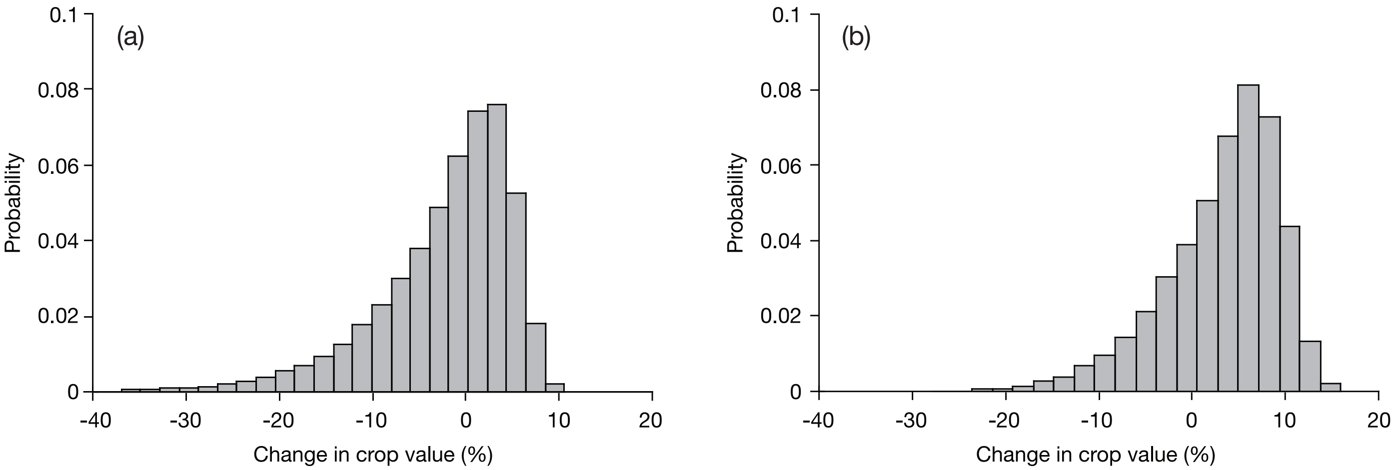

Figure 11.2: *Change in national gross value of wheat from historical baseline values (%) for 2070 as a result of increases in CO_2 and changes in temperature and rainfall: (a) without adaptation and (b) with adaptations of changed planting dates and varieties (Howden and Jones, 2004).*

up to 94% in low precipitation scenarios. However, the changes in deep drainage were not correlated with changes in productivity or gross margin.

11.4.3.2 Horticulture

Australian temperate fruits and nuts are all likely to be negatively affected by warmer conditions because they require winter chill or vernalisation. Crops reliant on irrigation are likely to be threatened where irrigation water availability is reduced. Climate change is likely to make a major horticultural pest, the Queensland fruit fly *Bactrocera tryoni*, a significant threat to southern Australia. Warming scenarios of 0.5, 1.0 and 2.0°C suggest expansion from its endemic range in the north and north-east across most of the non-arid areas of the continent, including the currently quarantined fruit fly-free zone (Sutherst et al., 2000). Apple, orange and pear growers in endemic Queensland fruit fly areas are likely to have cost increases of 42 to 82%, and 24 to 83% in the current fruit fly-free zone (Sutherst et al., 2000).

In New Zealand, warmer summer temperatures for Hayward kiwifruit are likely to increase vegetative growth at the expense of fruit growth and quality (Richardson et al., 2004). Kiwifruit budbreak is likely to occur later, reducing flower numbers and yield in northern zones (Hall et al., 2001). Production of current kiwifruit varieties is likely to become uneconomic in Northland by 2050 because of a lack of winter chilling, and be dependent on dormancy-breaking agents and varieties bred for warmer winter temperatures in the Bay of Plenty (Kenny et al., 2000). In contrast, more areas in the South Island are likely to be suitable (MfE, 2001). Apples, another major crop, are very likely to flower and reach maturity earlier, with increased fruit size, especially after 2050 (Austin et al., 2000). New Zealand is likely to be more susceptible to the establishment of new horticultural pests. For example, under the current climate, only small areas in the north are suitable for the oriental fruit fly, but by the 2080s it is likely to expand to much of the North Island (Stephens et al., 2007).

Viticulture has expanded rapidly in both countries. Earlier ripening and reductions in grape quality and value are likely by 2030, e.g., in Australia, price per tonne drops 4 to 10% in the Yarra Valley and 16 to 52% in the Riverina (Webb et al., 2006). In cooler Australian climates, warming is likely to allow alternative varieties to be grown. With warming and a longer growing season in New Zealand, red wine production is increasingly likely to be practised in the south, with higher yields (Salinger et al., 1990). Higher CO_2 levels increase vine vegetative growth, and subsequent shading is likely to reduce fruitfulness. Distribution of vines is likely to change depending upon suitability compared with high-yield pasture and silviculture, and with future irrigation water availability and cost (Hood et al., 2002).

11.4.3.3 Pastoral and rangeland farming

In western, southern and higher-altitude areas of New Zealand, higher temperatures, a longer growing season, higher CO_2 concentrations and less frost are very likely to increase annual pasture production by 10 to 20% by 2030, although gains may decline thereafter (MfE, 2001). In eastern New Zealand and Northland, pasture productivity is likely to decline by 2030 due to increased drought frequency (see Section 11.3.1). Sub-tropical pastoral species with lower feed quality such as *Paspalum* are likely to spread southwards, reducing productivity (Clark et al., 2001), particularly in the Waikato district. The range and incidence of many pests and diseases are likely to increase. Drought and water security problems are likely to make irrigated agriculture vulnerable, e.g., intensive dairying in Canterbury (Jenkins, 2006).

In Australia, a rise in CO_2 concentration is likely to increase pasture growth, particularly in water-limited environments (Ghannoum et al., 2000; Stokes and Ash, 2006; see also Section 5.4). However, if rainfall is reduced by 10%, this CO_2 benefit is likely to be offset (Howden et al., 1999d; Crimp et al., 2002). A 20% reduction in rainfall is likely to reduce pasture productivity by an average of 15% and liveweight gain in cattle by 12%, substantially increasing variability in stocking rates and reducing farm income (Crimp et al., 2002). Elevated concentrations of CO_2 significantly decrease leaf nitrogen content and increase non-structural carbohydrate, but cause little change in digestibility (Lilley et al., 2001). In farming systems with high nitrogen forage (e.g., temperate pastures), these effects are likely to increase energy availability, nitrogen processing in the rumen and productivity. In contrast, where nitrogen is deficient (e.g., rangelands), higher temperatures are likely to exacerbate existing problems by decreasing non-structural carbohydrate concentrations and digestibility, particularly in tropical C_4 grasses (see Section 5.4.3). Doubled CO_2 concentrations and warming are likely to result in only limited changes in the distributions of native C_3 and C_4 grasses (Howden et al., 1999b).

Climatic changes are likely to increase major land-degradation problems such as erosion and salinisation (see Section 11.4.3.1). They are also likely to increase the potential distribution and abundance of exotic weeds, e.g., *Acacia nilotica* and *Cryptostegia grandiflora* (Kriticos et al., 2003a, b) and native woody species, e.g., *A. aneura* (Moore et al., 2001). This is likely to increase competition with pasture grasses, reducing livestock productivity. However, the same CO_2 and climate changes are likely to provide increased opportunities for woody weed control through increased burning opportunities (Howden et al., 2001b). A warming of 2.5°C is likely to lead to a 15 to 60% reduction in rabbit populations in some areas via the impact on biological control agents, e.g., myxomatosis and rabbit haemorrhagic disease virus (Scanlan et al., 2006).

Heat stress already affects livestock in many Australian regions, reducing production and reproductive performance and enhancing mortality (see Section 5.4.3). Increased thermal stress on animals is very likely (Howden et al., 1999a). In contrast, less cold-stress is likely to reduce lamb mortality in both countries. Impacts of the cattle tick (*Boophilus microplus*) on the Australian beef industry are likely to increase and move southwards (White et al., 2003). If breakdown of quarantine occurs, losses in live-weight gain from tick infestation are projected to increase 30% in 2030 and 120% in 2100 (in the absence of adaptation). The net present value of future tick losses is estimated as 21% of farm cash income in Queensland, the state currently most severely affected.

11.4.4 Forestry

In Australia, the value of wood and wood products in 2001-2002 was US$5 billion/yr. About 164 million ha are classified as forest, with 1% as plantation forests and 7% available for timber production in state-managed, multiple-use native forests (BRS, 2003). New Zealand's indigenous forests cover 6.4 million ha, with 1.7 million ha of planted production exotic forests, the latter providing substantial export income (MAF, 2001). Research since the TAR confirms that climate change is likely to have both positive and negative impacts on forestry in both countries. Productivity of exotic softwood and native hardwood plantations is likely to be increased by CO_2 fertilisation effects, although the amount of increase will be limited by projected increases in temperature, reductions in rainfall and by feedbacks such as nutrient cycling (Howden et al., 1999c; Kirschbaum, 1999a, b).

Where trees are not water-limited, warming expands the growing season in southern Australia, but pest damage is likely to negate some gains (see Section 5.4.5). Reduction in average runoff in some regions (see Section 11.4.1) and increased fire risk (see Section 11.3.1) are very likely to reduce productivity, whilst increased rainfall intensity is likely to exacerbate soil erosion problems and pollution of streams during forestry operations (Howden et al., 1999c). In *Pinus radiata* and *Eucalyptus* plantations, fertile sites are likely to have increased productivity for moderate warming, whereas infertile sites are likely to have decreased production (Howden et al., 1999c).

In New Zealand, the growth rates for plantation forestry (mainly *P. radiata*) are likely to increase in response to elevated CO_2 and wetter conditions in the south and west. Studies of pine seedlings confirm that the growth and wood density of *P. radiata* are enhanced during the first two years of artificial CO_2 fertilisation (Atwell et al., 2003). Tree growth reductions are likely for the east of the North Island due to projected rainfall decreases and increased fire risk (see Section 11.3.1). However, uncertainties remain regarding increased water-use efficiency with elevated CO_2 (MfE, 2001), and whether warmer and drier conditions could increase the frequency of upper mid-crown yellowing and winter fungal diseases (MfE, 2001).

11.4.5 Coasts

Over 80% of the Australian population lives in the coastal zone, with significant recent non-metropolitan population growth (Harvey and Caton, 2003). About 711,000 addresses (from the National Geo-coded Address File) are within 3 km of the coast and less than 6 m above sea level, with more than 60% located in Queensland and NSW (Chen and McAneney, 2006). These are potentially at risk from long-term sea-level rise and large storm surges.

Rises in sea level, together with changes to weather patterns, ocean currents, ocean temperature and storm surges are very likely to create differences in regional exposure (Walsh, 2002; MfE, 2004a; Voice et al., 2006). In New Zealand, there are likely to be more vigorous and regular swells on western coasts (MfE, 2004a). In northern Australia, tropical cyclones are likely to become more intense (see Section 11.3). The area of Cairns at risk of inundation by a 1-in-100 year storm surge is likely to more than double by 2050 (McInnes et al., 2003). Major impacts are very likely for coral reefs, particularly the Great Barrier Reef (see Section 11.6).

Future effects on coastal erosion include climate-induced changes in coastal sediment supply and storminess. In Pegasus Bay (New Zealand), shoreline erosion of up to 50 m is likely between 1980 and 2030 near the Waipara River if southerly waves are reduced by 50%, and up to 80 m near the Waimakariri River if river sand is reduced by 50% (Bell et al., 2001). In New Zealand, emphasis has been placed on providing information, guidelines and tools such as zoning and setbacks to local authorities for risk-based planning and management of coastal hazards affected by climate change and variability (Bell et al., 2001; MfE, 2004a) (see Section 11.6). In Australia, linkages between the IPO, ENSO and changes in coastal geomorphology have been demonstrated for the northern NSW coast (Goodwin, 2005; Goodwin et al., 2006) and between historic beach erosion and ENSO for Narabeen Beach (NSW) (Ranasinghe et al., 2004).

Sea-level rise is virtually certain to cause greater coastal inundation, erosion, loss of wetlands and salt-water intrusion into freshwater sources (MfE, 2004a), with impacts on infrastructure, coastal resources and existing coastal management programmes. Model simulations indicate that the loss of wetlands and mangroves in Spencer Gulf due to sea-level rise is influenced largely by elevation and exposure (Bryan et al., 2001). At Collaroy/Narrabeen beach (NSW), a sea-level rise of 0.2 m by 2050 combined with a 50-year storm event leads to coastal recession exceeding 110 m and causing losses of US$184 million (Hennecke et al., 2004). Investigations for metropolitan coasts reveal increased costs of protection for existing management systems (Bell et al., 2001). Mid-range sea-level rise projections for 2005 to 2025 are likely to increase the cost of sand replenishment on the Adelaide metropolitan coast by at least US$0.94 million/yr (DEH, 2005). Uncertainties in projected impacts can be managed through a risk-based approach involving stochastic simulation (Cowell et al., 2006). Coasts are also likely to be affected by changes in pollution and sediment loads from changes in the intensity and seasonality of river flows, and future impacts of river regulation (Kennish, 2002). In the next 50 to 100 years, 21% of the Tasmanian coast is at risk of erosion and significant recession from predicted sea-level rise (Sharples, 2004).

11.4.6 Fisheries

In Australia, the gross value of fisheries production is US$1.7 billion annually, of which 68% is wild-catch and 32% is aquaculture. In New Zealand, the combined value of fisheries production is US$0.8 billion, of which 80% is from the commercial catch and 20% from the growing aquaculture sector (Seafood Industry Council, 2006), which continues to grow. Little research has been completed on impacts of climate change on freshwater fisheries and aquaculture.

Marine fisheries around the world are threatened by over-exploitation. In Australia, of 74 stocks considered in 2005, 17 were over-fished, 17 were not over-fished, and 40 were of uncertain status (ABARE, 2005). In New Zealand, of 84 stocks of demersal fish where landings were greater than 500 tonnes/yr, 5 were regarded as over-fished, 24 were assessed as not over-fished, and 55 were of uncertain status (Ministry of Fisheries Science Group, 2006). Climate change will be an additional stress (Hobday and Matear, 2005). The key variables expected to drive impacts on marine fisheries are changes in ocean temperature, currents, winds, nutrient supply, acidification and rainfall. Changes in four emergent biological properties are likely as a result of climate change, the first of which is best understood: (i) distribution and abundance of impacted species, (ii) phenology, (iii) community composition, and (iv) community structure and dynamics (including productivity). Few climate-change impact studies have been undertaken, so this assessment mostly relies on extrapolation of observed relationships between climate variability and fisheries. With sea-level rise, increasing marine intrusions are highly likely to affect coastal fisheries and inshore sub-tidal breeding and nursery areas (Schallenberg et al., 2003). Overall, future climate-change impacts are likely to be greater for temperate endemics than for tropical species (Francis, 1994, 1996) and on coastal and demersal fisheries relative to pelagic and deep-sea fisheries (Hobday and Matear, 2005).

Changes in sea surface temperature or currents are likely to affect the distribution of several commercial pelagic (e.g., tuna) fisheries in the region (Lehodey et al., 1997; Lyne, 2000; Sims et al., 2001; Hobday and Matear, 2005). In particular, circulation changes may increase the availability of some species and reduce others, as has been demonstrated in Western Australia for the Leeuwin Current. Different management regimes are likely to be required: fishers will be faced with relocation or face reduced catches *in situ*. Recruitment is likely to be reduced in cool-water species. For example, for New Zealand species such as red cod, recruitment is correlated with cold autumn and winter conditions associated with El Niño events (Beentjes and Renwick, 2001; Annala et al., 2004). In contrast, for snapper, relatively high recruitment and faster growth rate of juveniles and adults are correlated with warmer conditions during La Niña events (Francis, 1994; Maunder and Watters, 2003), with decreases in larval recruitment during El Niño events (Zeldis et al., 2005). A similar pattern of recruitment exists for gemfish (Renwick et al., 1998). Regarding physiological changes, temperature has a major influence on the population genetics of ectotherms, selecting for changes in abundance of temperature-sensitive alleles and genotypes and their adaptive capacity. For New Zealand snapper, differences in allele frequencies at one enzyme marker are found among year classes from warm and cold summers (Smith, 1979). If species cannot adapt to the pace of climate change, then major changes in distribution are likely, particularly for species at the edges of suitable habitats (Richardson and Schoeman, 2004; Hampe and Petit, 2005).

Projected changes in Southern Ocean circulation (see Section 11.3.1) are likely to affect fisheries. Seasonal to interannual variability of westerly winds and strong wind events are associated with recruitment and catch rates in several species (Thresher et al., 1989, 1992; Thresher, 1994). A decline in wind due to a poleward shift in climate systems underlies recent stock declines off south-eastern Australia and western Tasmania, and these are linked to changes in larval growth rates and recruitment of juveniles in two fish species around Tasmania (Koslow and Thresher, 1999; Thresher, 2002). Reductions in upwelling of nutrients and extension of warm water along the east Australian coast are likely to reduce krill and jack mackerel abundance, upon which many other species are reliant, including tuna, seals and seabirds (CSIRO, 2002).

11.4.7 Settlements, industry and societies

Settlements, industry and societies are sensitive to extreme weather events, drought and sea-level rise (see Chapter 7). Many planning decisions for settlements and infrastructure need to account for new climatic conditions and higher sea-levels, but little research has been done on climate change impacts. The planning horizon for refurbishing major infrastructure is 10 to 30 years, while major upgrades or replacements have an expected lifetime of 50 to 100 years (PIA, 2004). Substantial infrastructure is at risk from projected climate change. About US$1,125 billion of Australia's wealth is locked up in homes, commercial buildings, ports and physical assets, which is equivalent to nine times the current national budget or twice the GDP (Coleman et al., 2004). In New Zealand, homes are valued at about US$280 billion, which is equivalent to about triple the national GDP (QVL, 2006). The average life of a house is 80 years and some last for 150 years or more (O'Connell and Hargreaves, 2004).

For infrastructure, design criteria for extreme events are very likely to be exceeded more frequently. Increased damage is likely for buildings (e.g., concrete joints, steel, asphalt, protective cladding, sealants), transport structures (e.g., roads, railways, ports, airports, bridges, tunnels), energy services (see Section 11.4.10), telecommunications (e.g., cables, towers, manholes), and water services (see Section 11.4.1) (PIA, 2004; BRANZ, 2007; Holper et al., 2007). In Victoria, water infrastructure is at significant risk for the B1 scenario by 2030, while power, telecommunications, transport and buildings are all at significant risk for the A1FI emission scenario by 2030 (Holper et al., 2007).

Climate change is very likely to affect property values and investment through disclosure of increased hazards and risk, as well as affecting the price and availability of insurance. In many Australian jurisdictions, flood hazard liability is not mandatory, or is poorly quantified (Yeo, 2003). Governments sometimes provide financial relief to the uninsured from large natural disasters (Box 11.1) and such costs are likely to rise. Insurance costs are very likely to rise in areas with increased risk. Hail damage accounts for 50% of the 20 highest insurance payouts in Australia (ICA, 2007), but there is limited information about potential changes in hail frequency (see Section 11.3).

Despite the economic significance of mining in Australia (5% of GDP and 35% of export earnings; ABS, 2005c), there is little information regarding climate change impacts on mining. However, in northern Australia, projected increases in extreme events, such as floods and cyclones, have the potential to increase erosion, slow down re-vegetation, shift capping materials and expose tailings in the area that includes Ranger and Jabiluka mines. These impacts have not been adequately considered in long-term mine planning (Wasson et al., 1988; Parliament of Australia, 2003). The traditional owners, the Mirrar, are concerned that these impacts may detrimentally affect land between Madjinbardi Billabong and the East Alligator River and the lowlands on the floodplain margins that lie downstream from these mine sites (Kyle, 2006).

There are major implications for amenities, cultural heritage, accessibility, and health of communities. These include costs, injury and trauma due to increased storm intensity and higher extreme temperatures, damage to items and landscapes of cultural significance, degraded beaches due to sea-level rise and larger storm surges, and higher insurance premiums (PIA, 2004). Increased demand for emergency services is likely. By 2100, costs of road maintenance in Australia are estimated to rise 31% for the SRES A2 scenario in a CSIRO climate simulation (Austroads, 2004).

Climate change may contribute to destabilising unregulated population movements in the Asia-Pacific region, providing an additional challenge to national security (Dupont and Pearman, 2006; Preston et al., 2006). Population growth and a one-metre rise in sea-level are likely to affect 200-450 million people in the Asia-Pacific region (Mimura, 2006). An increase in migrations from the Asia-Pacific region to surrounding nations such as New Zealand and Australia is possible (Woodward et al., 2001). Displacement of Torres Strait Islanders to mainland Australia is also likely (Green, 2006b).

11.4.8 Indigenous people

Indigenous people comprise about 15% of the New Zealand population (Statistics New Zealand, 2005a) and 2.4% of the Australian population (including about 30% of the Northern Territory population) (ABS, 2002).

Changes in New Zealand's climate over the next 50 to 100 years are likely to challenge the Māori economy and influence the social and cultural landscapes of Māori people (Packman et al., 2001). Some Māori have significant investment in fishing, agriculture and forestry and the downstream activities of processing and marketing (NZIER, 2003), as well as being important stakeholders in New Zealand's growing tourist industry (McIntosh, 2004) and in the energy sector. Economic performance and opportunities in these primary industries are likely to be influenced by climate-induced changes to production rates, product quality, pest and disease prevalence, drought, fire-risk and biodiversity, which, in turn, will affect the ability to raise development capital in these industries (MAF, 2001; Cottrell et al., 2004). While the majority of Māori live in urban environments, they also occupy remote and rural areas where the economy and social and cultural systems are strongly tied to natural environmental systems (e.g., traditional resource use, tourism), and where vital infrastructure and services are vulnerable to extreme weather events (e.g., flooding, landslides) (Harmsworth and Raynor, 2005). The capacity of the Māori people to plan and respond to threats of climate change to their assets (i.e., buildings, farms, forests, native forest, coastal resources, businesses) varies greatly, and is likely to be limited by access to funds, information and human capital, especially in Northland and on the East Coast, where there are large populations of Māori (TPK, 2001) and increased risks of extreme weather are likely (Mullan et al., 2001). Other pressures include the unclear role of local authorities with regard to rules, regulations and strategies for adaptation; multiple land-ownership and decision-making processes can be complex, often making it difficult to reach consensus and implement costly or non-traditional adaptation measures; and the high spiritual and cultural value placed on traditional lands/resources that can restrict or rule out some adaptation options such as relocation (NZIER, 2003). Many rural Māori also rely on the use of public and private land and coastal areas for hunting and fishing to supplement household food supplies, recreation, and the collection of firewood and cultural resources. The distribution and abundance of culturally important flora and fauna is likely to be adversely influenced by climate change, so the nature of such activities and the values associated with these resources are likely to be adversely affected, including spiritual well-being and cultural affirmation (NIWA, 2006). These challenges compound the sensitivity of the Māori to climate change.

Indigenous communities in remote areas of Australia often have inadequate infrastructure, health services and employment (Braaf, 1999; Ring and Brown, 2002; IGWG, 2004; Arthur and Morphy, 2005). Consequently, many of these communities show features of social and economic disadvantage (Altman, 2000; ABS, 2005b). Existing social disadvantage reduces coping ability and may restrict adaptive capacity (Woodward et al., 1998; Braaf, 1999), affecting these communities' resilience to climate hazards

(Watson and McMichael, 2001; Ellemor, 2005). Many of these communities strongly connect the health of their 'country' to their cultural, mental and physical well-being (Smith, 2004a; Jackson, 2005). Direct biophysical impacts, such as increases in temperature, rainfall extremes or sea-level rise, are likely to have significant indirect impacts on the social and cultural cohesion of these communities. There is recent recognition of the untapped resource of Indigenous knowledge about past climate change (Rose, 1996; Lewis, 2002; Orlove, 2003) which could be used to inform adaptation options. However, the oral tradition of recording this knowledge has, until recently, largely hindered non-Indigenous scientists from using this expertise to inform their science (Webb, 1997; Hill, 2004). Climate-change impacts identified for remote Indigenous communities include increases in the number of days of extreme heat, which may affect disease vectors, reproduction and survival of infectious pathogens, and heat stress (Green, 2006a; McMichael et al., 2006); extreme rainfall events and flooding, causing infrastructure damage (Green and Preston, 2006); salt inundation of freshwater aquifers and changes in mangrove ecology (UNEP-WCMC, 2006); changing fire regimes; sea-level rise and coastal erosion (Bessen Consulting Services, 2005; Green and Preston, 2006). King tides[1] in 2005 and 2006 in the Torres Strait have highlighted the need to revisit short-term coastal protection and long-term relocation plans for up to 2,000 Australians living on the central coral cays and north-west islands (Mulrennan, 1992; Green, 2006b).

11.4.9 Tourism and recreation

Tourism contributes 4.5% of Australian GDP and represents 11.2% of exports (Allen Consulting Group, 2005), and even more in New Zealand (about 5% of GDP and 16% of exports). The main tourism centres are the Gold Coast and tropical north Queensland in Australia, and Queenstown and Rotorua in New Zealand. Most tourism and recreation in Australia and New Zealand rely on resources of the natural environment. In Australia's Wet Tropics, the value of ecosystem goods and services, including tourism, is about US$132 to 148 million/yr (Curtis, 2004).

Few regional studies have assessed potential impacts on tourism, but elsewhere there is evidence that climate change has direct impacts (Agnew and Palutikof, 2001; Maddison, 2001). Some tourist destinations may benefit from drier and warmer conditions, e.g., for beach activities, viewing wildlife and geothermal activity, trekking, camping, climbing, wine tasting and fishing. However, greater risks to tourism are likely from increases in hazards such as flooding, storm surges, heatwaves, cyclones, fires and droughts (World Tourism Organisation, 2003; Scott et al., 2004; Becken, 2005; Hall and Higham, 2005; Becken and Hay, 2007). These adversely affect transport, personal safety, communication, water availability and natural attractions such as coral reefs, beaches, freshwater wetlands, snow, glaciers and forests. Changes in species distribution and ecosystems in National Parks (see Section 11.4.2) are likely to alter their tourism appeal. Tropical Australian destinations are particularly vulnerable to climate impacts (Allen Consulting Group, 2005). Queensland tourism is likely to be negatively affected by more intense tropical cyclones and by degradation of the Great Barrier Reef (see Section 11.6) and beaches (PIA, 2004).

Skiing attracts many tourists to New Zealand and south-eastern Australia. For the full range of SRES scenarios, by 2020 in south-east Australia, there are likely to be 5 to 40 fewer days of snow cover per year, a rise in the snowline of 30 to 165 m, and a reduction in the total snow-covered area of 10 to 40% (Hennessy et al., 2003). By 2050, the duration of snow cover reduces by 15 to 100 days, the maximum snow depth reduces by 10 to 99%, the snowline rises 60 to 570 m and the total area of snow cover shrinks by 20 to 85%. Similarly, in New Zealand, changes in seasonal snow cover are likely to have a significant impact on the ski industry. The snow line is likely to rise by 120 to 270 m based on scenarios for the 2080s (Fitzharris, 2004). Tourist flows from Australia to New Zealand might grow as a result of the relatively poorer snow conditions in Australia. Numerical modelling of the Franz Josef glacier reveals that temperature is the dominant control on glacier length for New Zealand's maritime glaciers (Anderson and Mackintosh, 2006). Noticeable shrinkage and retreat is very likely for even small temperature increases (Anderson, 2004; Anderson et al., 2006), and is likely to reduce visitor flows through tourism-dependent towns such as Fox and Franz Josef.

11.4.10 Energy

Energy consumption is projected to grow due to demographic and socio-economic factors (see Section 11.3.2). However, average and peak energy demands are also linked to climatic conditions. Increases in peak energy demand due to increased air-conditioner use are likely to exceed increases for base load. The risk of line outages and blackouts is likely to increase (PB Associates, 2007). More peak generating capacity is likely to be needed beyond that for underlying economic growth (Howden and Crimp, 2001). For a 2°C warming, *peak* demand increases 4% in Brisbane and 10% in Adelaide, but decreases 1% in Melbourne and Sydney (Howden and Crimp, 2001). About 10% of the existing asset levels may be required to allow for climate-related increases in peak demand by 2030 (PB Associates, 2007). However, *annual total* demand may be less sensitive to warming; a likely reduction in winter heating demand counteracts the increasing summer demand, e.g., New Zealand electricity demand decreases by 3%/°C increase in mean winter temperature (Salinger, 1990).

Climate change is likely to affect energy infrastructure in Australia and New Zealand through impacts of severe weather events on wind power stations, electricity transmission and distribution networks, oil and gas product storage and transport facilities, and off-shore oil and gas production (see Chapter 7). There are also likely to be costs and damages that can be avoided by adaptation and mitigation (see Section 18.4). An assessment of potential risks for Australia (PB Associates, 2007) found (i) increased peak and average temperatures are likely to reduce electricity generation efficiency, transmission line capacity, transformer capacity and the life of switchgear and other components; (ii) if climate changes gradually, both the generation utilities and the equipment manufacturers are likely to have enough time to adjust their standards and specifications; and (iii)

[1] King tide: any high tide well above average height.

vulnerability to the above impacts is low, but there is medium vulnerability to a decline in water supply for large-scale coal, hydro and gas turbine power generation.

In New Zealand, increased westerly wind speed is very likely to enhance wind generation and spill-over precipitation into major South Island hydro catchments, and to increase winter rain in the Waikato catchment (Wratt et al., 2004). Warming is virtually certain to increase snow melt, the ratio of rainfall to snowfall, and river flows in winter and early spring. This is very likely to assist hydroelectric generation at the time of highest energy demand for heating.

11.4.11 Human health

One of the most significant health impacts of climate change is likely to be an increase in heat-related deaths. Assuming no planned adaptation, the number of deaths is likely to rise from 1,115/yr at present in Adelaide, Melbourne, Perth, Sydney and Brisbane to 2,300 to 2,500/yr by 2020, and 4,300 to 6,300/yr by 2050, for all SRES scenarios, including demographic change (McMichael et al., 2003). In Auckland and Christchurch, a total of 14 heat-related deaths occur per year in people aged over 65, but this is likely to rise to 28, 51 and 88 deaths for warmings of 1, 2 and 3°C, respectively (McMichael et al., 2003). Demographic change is likely to amplify these figures. By 2100, the Australian annual death rate in people aged over 65 is estimated to increase from a 1999 baseline of 82 per 100,000 to 131-246 per 100,000, for the SRES B2 and A2 scenarios and the 450 ppm stabilisation scenario (Woodruff et al., 2005). Australian temperate cities are likely to experience higher heat-related deaths than tropical cities, and the winter peak in deaths is likely to be overtaken by heat-related deaths in nearly all cities by 2050 (McMichael et al., 2003). In New Zealand, the winter peak in deaths is likely to decline.

There are likely to be alterations in the geographical range and seasonality of some mosquito-borne infectious diseases. Fewer but heavier rainfall events are likely to affect mosquito breeding and increase the variability in annual rates of Ross River disease, particularly in temperate and semi-arid areas (Woodruff et al., 2002, 2006). The risk of establishment of dengue fever is likely to increase through changes in climate and population sensitivity in both tropical and temperate latitudes (Sutherst, 2004). Dengue is a substantial threat in Australia: the climate of the far north already supports *Aedes aegypti* (the major mosquito vector of the dengue virus); and outbreaks of dengue have occurred with increasing frequency and magnitude in far-northern Australia over the past decade. Projected climate changes in north-eastern Australia, combined with population growth, are likely to increase the average annual number of people living in areas suitable for supporting the dengue vector (an additional 0.1 to 0.3 million exposed in 2020, and 0.6 to 1.4 million in 2050) (McMichael et al., 2003). Malaria is unlikely to become established unless there is a dramatic deterioration in the public health response (McMichael et al., 2003). In New Zealand, parts of the North Island are likely to become suitable for breeding of the major dengue vector, while much of the country becomes receptive to other less-efficient vector species (De Wet et al., 2001; Woodward et al., 2001). The risk of dengue in New Zealand is likely to remain below the threshold for local transmission beyond 2050 (McMichael et al., 2003).

Warmer temperatures and increased rainfall variability are likely to increase the intensity and frequency of food-borne (D'Souza et al., 2004) and water-borne (Hall et al., 2002) diseases in both countries. Indigenous people living in remote communities are likely to be at increased risk due to their particular living conditions and poor access to services. The annual number of diarrhoeal hospital admissions among Aboriginal children living in central Australia is likely to increase 10% by 2050, assuming no change in current health standards (McMichael et al., 2003). The relationship between drought, suicide and severe mental health impacts in rural communities (Nicholls et al., 2006) suggests that parts of Australia are likely to experience increased mental health risks in future. Impacts on aeroallergens and photochemical smog in cities remain uncertain. High concentrations of bushfire smoke play a role in increasing hospital presentations of asthma (Johnston et al., 2002), so projected increases in fire risk may lead to more asthma.

11.4.12 Synthesis

Climate change adds new dimensions to the challenges already facing communities, businesses, governments and individuals. Assessment of the information given in this section leads to the conclusion that climate change is likely to give rise to six key *risks* in specific sectors (Table 11.7): natural systems, water security, coastal communities, agriculture and forestry, major infrastructure and health. Some extreme events can trigger multiple and simultaneous impacts across systems, e.g., heatwaves leading to heat-related deaths, fires, smoke pollution, respiratory illness, blackouts, and buckling of railways. There are also four key *benefits* for particular sectors: (i) in New Zealand, initial benefits to agriculture and forestry are projected in western and southern areas and close to major rivers due to a longer growing season, less frost and increased rainfall; (ii) reduced energy demand is very likely in winter; (iii) tourism is likely to directly benefit from drier and warmer weather in some areas; and (iv) flows in New Zealand's larger mountain-fed rivers are likely to increase, benefiting hydroelectricity generation and irrigation supply. Adaptation can alleviate or delay vulnerability in some sectors, as well as allowing benefits to accrue more rapidly (see Section 11.5).

11.5 Adaptation constraints and opportunities

Planned adaptation can greatly reduce vulnerability (see examples in Chapter 17). Since the TAR, Australia and New Zealand have taken notable steps in building adaptive capacity (see Section 11.2.5) by increasing support for research and knowledge, expanding assessments for decision makers of the risks of climate change, infusing climate change into policies and plans, promoting awareness, and better dealing with climate issues. However, there remain formidable environmental,

Table 11.7. *Six key risks in Australia (Aus) and New Zealand (NZ) (assuming no new adaptation). Underlying climate projections (see Section 11.3) include higher temperatures, sea-level rise, heavier rainfall, greater fire risk, less snow cover, reduced runoff over southern and eastern Australia and in the smaller lowland rivers of eastern New Zealand, more intense tropical cyclones and larger storm surges.*

System	Impacts	Identified hotspots
Natural systems	Damage to coral reefs, coasts, rainforests, wetlands and alpine areas. Increased disturbance, loss of biodiversity including possible extinctions, changed species ranges and interactions, loss of ecosystem services (e.g., for tourism and water). Potentially catastrophic for some systems (e.g., reefs may be dominated by macroalgae by 2050, extinctions of endemic vertebrates in Queensland Wet Tropics). Shrinking glaciers create slope instability.	Aus: Great Barrier Reef, Kakadu, east Queensland, alpine zones, Murray-Darling Basin (MDB) and south-western Aus; NZ: Southern Alps and their National Parks, eastern lowlands
Water security	Reduction in water supply for irrigation, cities, industry and riverine environment in those areas where streamflow declines, e.g., in the Murray-Darling Basin, annual mean flow may drop 10 to 25% by 2050 and 16 to 48% by 2100.	Southern and eastern Aus; Northland and parts of eastern lowlands of NZ
Coastal communities	Greater coastal inundation and erosion, especially in regions exposed to cyclones and storm surges. Coastal development is exacerbating the climate risks.	Tropical and south-east Queensland (Aus) and from Bay of Plenty to Northland in NZ
Agriculture and forestry	Reduced crop, pastoral and rangeland production over much of southern and eastern Australia and parts of eastern New Zealand. Reduced grain and grape quality. A southward shift of pests and disease vectors. Increased fire risk for forests.	Southern and eastern Aus and eastern NZ
Major infrastructure	Design criteria for extreme climatic events, floods and storm surges very likely to be exceeded more frequently. Increased damage likely for buildings, transport structures, telecommunications, energy services and water services.	Large cities, floodplains of major rivers, coastal communities, north-eastern parts of both countries
Health	By 2050, 3,200 to 5200 more heat-related deaths/yr, and 0.6 to 1.4 million more people exposed to dengue fever.	Large cities of both countries

economic, informational, social, attitudinal and political barriers to the implementation of adaptation.

For many natural ecosystems, impacts have limited reversibility. Planned adaptation opportunities for offsetting potentially deleterious impacts are often limited due to fixed habitat regions (e.g., the Wet Tropics and upland rainforests in Australia and the alpine zone in both Australia and New Zealand). One adaptive strategy is to provide corridors to facilitate migration of species under future warming. This will require changes in land tenure in many regions, with significant economic costs, although schemes to promote such connectivity are already under way in some Australian states (see Section 11.2.5). Another strategy is translocation of species. This is a very expensive measure, but it may be considered desirable for some iconic, charismatic or particularly vulnerable species.

For water, planned adaptation opportunities lie in the inclusion of risks due to climate change on both the demand and supply side (Allen Consulting Group, 2005; Table 11.2). In urban catchments, better use of storm and recycled water can augment supply, although existing institutional arrangements and technical systems for water distribution constrain implementation. Moreover, there is community resistance to the use of recycled water for human consumption (e.g., in such cities as Toowoomba in Queensland and Goulburn in NSW). Desalination schemes are being considered in some Australian capital cities. Installation of rainwater tanks is another adaptation response and is now actively pursued through incentive policies and rebates. For rural activities, more flexible arrangements for allocation are required, via the expansion of water markets, where trading can increase water-use efficiency (Beare and Heaney, 2002). Existing attitudes toward water pricing and difficulties with structural adjustment are significant barriers.

For agriculture, there are opportunities for planned adaptation via improvements in crop varieties (Figure 11.2), rotations, farm technology, farm practices and land-use mix. Cropping can be extended to historically wetter regions. Implementation will require new investment and significant managerial changes (Howden et al., 2003a). Farmers in eastern New Zealand are engaging in local discussion of risks posed by future climate change and how to enhance adaptation options (Kenny, 2005). They stress the need for support and education for 'bottom-up' adaptation (Kenny, 2007). Farming of marginal land at the drier fringe is likely to be increasingly challenging, especially in those regions of both countries with prospective declines in rainfall.

In coastal areas, there is solid progress in risk assessments and in fashioning policies and plans at the local and regional level in New Zealand. However, there remain significant challenges to achieving concrete actions that reduce risks. Consistent implementation of adaptation measures (e.g., setback lines, planned retreat, dune management (Dahm et al., 2005), building designs, prohibition of new structures and siting requirements that account for sea-level rise) has been difficult. Differences in political commitment, lack of strong and clear guidelines from government, and legal challenges by property owners are major constraints (MfE, 2003).

Considering all sectors, four broad barriers to adaptation are evident.

1. A lack of methods for integrated assessment of impacts and adaptation that can be applied on an area-wide basis. While sector-specific knowledge and tools have steadily progressed, the vulnerability of water resources, coasts, agriculture and ecosystems of local areas and regions are interconnected and need to be assessed accordingly (see Section 11.8).
2. Lack of well-developed evaluation tools for assessing planned adaptation options, such as benefit-cost analysis, incorporating climate change and adapted for local and regional application.

3. Ongoing scepticism about climate change science, uncertainty in regional climate change projections, and a lack of knowledge about how to promote adaptation. This is despite 87% of Australians being more concerned about climate change impacts than terrorism (Lowy Institute, 2006). Application of risk-based approaches to adaptation (e.g., upgrading urban storm-water infrastructure design; Shaw et al., 2005) demonstrate how developments can be 'climate-proofed' (ADB, 2005). While a risk-based method for planned adaptation has been published for Australia (AGO, 2006), there are few examples of where it has been applied.
4. Weak linkages between the various strata of government, from national to local, regarding adaptation policy, plans and requirements. Stronger guidance and support are required from state (in Australia) and central government (in New Zealand) to underpin efforts to promote adaptation locally. For example, the New Zealand Coastal Policy Statement recommends that regional councils should take account of future sea-level rise. But there is a lack of guidance as to how this should be accomplished and little support for building capacity to undertake the necessary actions. As a consequence, regional and local responses have been limited, variable and inconsistent.

11.6 Case studies

The following case studies (Boxes 11.2 to 11.4) illustrate regions where climate change has already occurred, impacts are evident and planned adaptation is being considered or implemented.

Box 11.2. Adaptation of water supplies in cities

In capital cities such as Perth, Brisbane, Sydney, Melbourne, Adelaide, Canberra and Auckland, concern about population pressures and the impact of climate change is leading water planners to implement a range of adaptation options (Table 11.2). For example, the winter rainfall-dominated region of south-west Western Australia has experienced a substantial decline in May to July rainfall since the mid-20th century. The effects of the decline on natural runoff have been severe, as evidenced by a 50% drop in annual inflows to reservoirs supplying the city of Perth (Figure 11.3). Similar pressures have been imposed on groundwater resources and wetlands. This has been accompanied by a 20% increase in domestic usage in 20 years, and a population growth of 1.7%/yr (IOCI, 2002). Climate simulations indicate that at least some of the observed drying is due to the enhanced greenhouse effect (IOCI, 2002). To ensure water security, a US$350 million programme of investment in water source development was undertaken by the WA Water Corporation (WA Water Corporation, 2004) from 1993 to 2003. In 2004, the continuation of low streamflow led to the decision to construct a seawater desalination plant, which will provide 45 Gl of water each year, at a cost of US$271 million. Energy requirements (24 MW) will be met by 48 wind turbines.

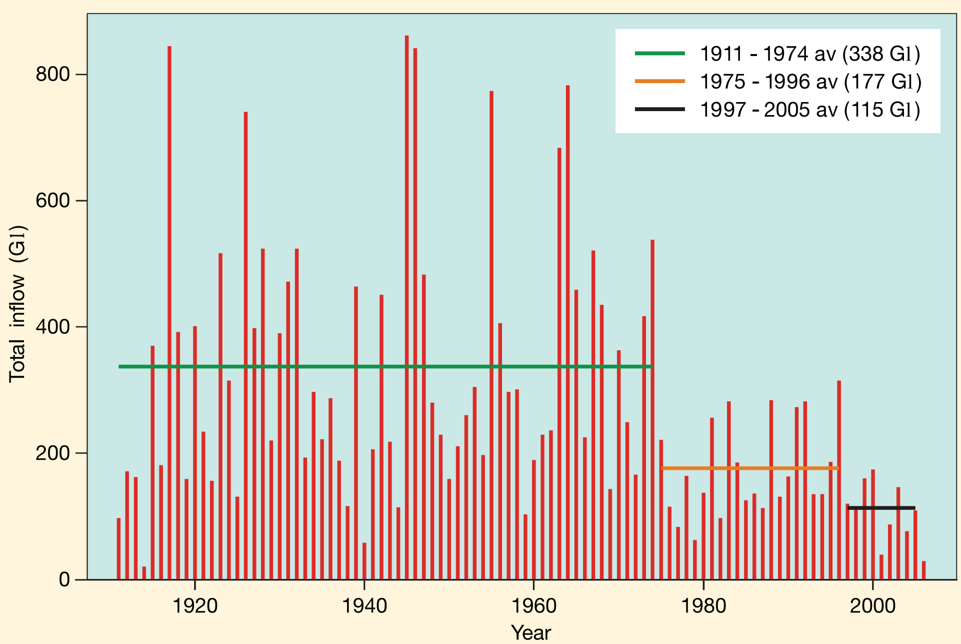

Figure 11.3. *Annual inflow to Perth Water Supply System from 1911 to 2005. Horizontal lines show averages. Source: www.watercorporation.com.au/D/dams_streamflow.cfm. Courtesy of the Water Corporation of Western Australia.*

Box 11.3. Climate change and the Great Barrier Reef

The Great Barrier Reef (GBR) is the world's largest continuous reef system (2,100 km long) and is a critical storehouse of Australian marine biodiversity and a breeding ground for seabirds and other marine vertebrates such as the humpback whale. Tourism associated with the GBR generated over US$4.48 billion in the 12-month period 2004/5 and provided employment for about 63,000 full-time equivalent persons (Access Economics, 2005). The two greatest threats from climate change to the GBR are (i) rising sea temperatures, which are almost certain to increase the frequency and intensity of mass coral bleaching events, and (ii) ocean acidification, which is likely to reduce the calcifying ability of key organisms such as corals. Other factors, such as droughts and more intense storms, are likely to influence reefs through physical damage and extended flood plumes (Puotinen, 2006).

Sea temperatures on the GBR have warmed by about 0.4°C over the past century (Lough, 2000). Temperatures currently typical of the northern tip of the GBR are very likely to extend to its southern end by 2040 to 2050 (SRES scenarios A1, A2) and 2070 to 2090 (SRES scenarios B1, B2) (Done et al., 2003). Temperatures only 1°C above the long-term summer maxima already cause mass coral bleaching (loss of symbiotic algae). Corals may recover but will die under high or prolonged temperatures (2 to 3°C above long-term maxima for at least 4 weeks). The GBR has experienced eight mass bleaching events since 1979 (1980, 1982, 1987, 1992, 1994, 1998, 2002 and 2006); there are no records of events prior to 1979 (Hoegh-Guldberg, 1999). The most widespread and intense events occurred in the summers of 1998 and 2002, with about 42% and 54% of reefs affected, respectively (Done et al., 2003; Berkelmans et al., 2004). Mortality was distributed patchily, with the greatest effects on near-shore reefs, possibly exacerbated by osmotic stress caused by floodwaters in some areas (Berkelmans and Oliver, 1999). The 2002 event was followed by localised outbreaks of coral disease, with incidence of some disease-like syndromes increasing by as much as 500% over the past decade at a few sites (Willis et al., 2004). While the impacts of coral disease on the GBR are currently minor, experiences in other parts of the world suggest that disease has the potential to be a threat to GBR reefs. Effects from thermal stress are likely to be exacerbated under future scenarios by the gradual acidification of the world's oceans, which have absorbed about 30% excess CO_2 released to the atmosphere (Orr et al., 2005; Raven et al., 2005). Calcification declines with decreasing carbonate ion concentrations, becoming zero at carbonate ion concentrations of approximately 200 μmol/kg (Langdon et al., 2000; Langdon, 2002). These occur at atmospheric CO_2 concentrations of approximately 500 ppm. Reduced growth due to acidic conditions is very likely to hinder reef recovery after bleaching events and will reduce the resilience of reefs to other stressors (e.g., sediment, eutrophication).

Even under a moderate warming scenario (A1T, 2°C by 2100), corals on the GBR are very likely to be exposed to regular summer temperatures that exceed the thermal thresholds observed over the past 20 years (Done et al., 2003). Annual bleaching is projected under the A1FI scenario by 2030, and under A1T by 2050 (Done et al., 2003; Wooldridge et al., 2005). Given that the recovery time from a severe bleaching-induced mortality event is at least 10 years (and may exceed 50 years for full recovery), these models suggest that reefs are likely to be dominated by non-coral organisms such as macroalgae by 2050 (Hoegh-Guldberg, 1999; Done et al., 2003). Substantial impacts on biodiversity, fishing and tourism are likely. Maintenance of hard coral cover on the GBR will require corals to increase their upper thermal tolerance limits at the same pace as the change in sea temperatures driven by climate change, i.e. about 0.1-0.5°C/decade (Donner et al., 2005). There is currently little evidence that corals have the capacity for such rapid genetic change; most of the evidence is to the contrary (Hoegh-Guldberg, 1999, 2004). Given that recovery from mortality can be potentially enhanced by reducing local stresses (water quality, fishing pressure), management initiatives such as the Reef Water Quality Protection Plan and the Representative Areas Programme (which expanded totally protected areas on the GBR from 4.6% to over 33%) represent adaptation options to enhance the ability of coral reefs to endure the rising pressure from rapid climate change.

Box 11.4. Climate change adaptation in coastal areas

Australia and New Zealand have very long coastlines with ongoing development and large and rapidly growing populations in the coastal zone. This situation is placing intense pressure on land and water resources and is increasing vulnerability to climatic variations, including storm surges, droughts and floods. A major challenge facing both countries is how to adapt to changes in climate, reduce vulnerability, and yet achieve sustainable development. Two examples illustrate this challenge.

Bay of Plenty, North Island, New Zealand. This bay is characterised by a narrow coastal zone with two of the fastest-growing districts of New Zealand. Combined population growth was 13.4% over the period 1996 to 2001, centred on the cities of Tauranga and Whakatane. By 2050, the population is projected to increase 2 to 3 times. Beachfront locations demand the highest premiums on the property market, but face the highest risks from storm surge flooding and erosion. Substantial efforts have been made to reduce the risks. For the purpose of delineation of hazard zones and design of adaptation measures, the Environment Bay of Plenty regional council explicitly included IPCC projections of sea-level rise in its Regional Coastal Environment Plan. This identified 'areas sensitive to coastal hazards within the next 100 years'. Implementation of such policy and plans by local government authorities has been repeatedly challenged by property developers, commercial interests and individual homeowners with different interpretations of the risks.

Sunshine Coast and Wide Bay-Burnett, Queensland, Australia. Between 2001 and 2021, the Sunshine Coast population is projected to grow from 277,987 to 479,806 (QDLGP, 2003), and the Wide Bay-Burnett population is projected to grow from 236,500 to 333,900 (ABS, 2003b). Sandy beaches and dunes are key biophysical characteristics of this coastline, including Fraser Island which is the largest sand island in the world. These natural features and the human populations they attract are vulnerable to sea-level rise, flooding, storm surges and tropical cyclones. Many estuaries and adjacent lowlands have been intensively developed, some as high-value canal estates. Local government is clearly becoming aware of climate-change risks. This topic is included in the agenda of the Sea-Change Taskforce, made up of coastal councils throughout Australia. At the regional planning level, climate change was recently embedded at a policy level into the strategic planning processes for the Wide Bay-Burnett region.

11.7 Conclusions: implications for sustainable development

An assessment of aggregate vulnerability for key sectors of the region is given in Figure 11.4, as a function of potential global warming. It synthesises relevant information in Sections 11.2 to 11.5 about current sensitivity, coping ranges, potential impacts, adaptive capacity and vulnerability. It follows similar diagrams and concepts published elsewhere (Jones et al., 2007) and emulates the 'Reasons for Concern' diagram (Figure SPM-3) in the TAR Synthesis Report. Since most impact assessments in the available literature do not allow for adaptation, the yellow band in Figure 11.4 is indicative only. In line with Chapter 19, vulnerability is assessed using criteria of: magnitude of impact, timing, persistence and reversibility, likelihood and confidence, potential for planned adaptation, geographical distribution and importance of the vulnerable system. Ecosystems, water security and coastal communities of the region have a narrow coping range. Even if adaptive capacity is realised, vulnerability becomes significant for 1.5 to 2.0°C of global warming. Energy security, health (heat-related deaths), agriculture and tourism have larger coping ranges and adaptive capacity, but they become vulnerable if global warming exceeds 3.0°C. The three key vulnerability factors identified in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) – natural ecosystems, sustainable development and food security – are also shown in Figure 11.4.

When these climate change impacts are combined with other non-climate trends (see Section 11.3.2), there are some serious implications for sustainability in both Australia and New Zealand. Climate change is very likely to threaten natural ecosystems, with extinction of some species. There are limited planned adaptation options, but the resilience of many ecosystems can be enhanced by reducing non-climatic stresses such as water pollution, habitat fragmentation and invasive species. In river catchments, where increasing urban and rural water demand has already exceeded sustainable levels of supply, ongoing and proposed adaptation strategies (see Section 11.2.5) are likely to buy some time. Continued rates of coastal development are likely to require tighter planning and regulation if they are to remain sustainable. Climate change is very likely to increase peak energy demand during heatwaves, posing challenges for sustainable energy supply. A substantial public health and community response is likely to be needed in order to avoid an increase of several thousand heat-related deaths per year.

Large shifts in the geographical distribution of agriculture and its services are very likely. Farming of marginal land in drier regions is likely to become unsustainable due to water shortages, new biosecurity hazards, environmental degradation and social disruption. In areas that are likely to become wetter and less frosty, it may be possible to grow new crops or those displaced from other regions. Adaptation has the capacity to capture these benefits; they are unlikely to accrue without investment in the adaptation process. Food security is very likely to remain robust,

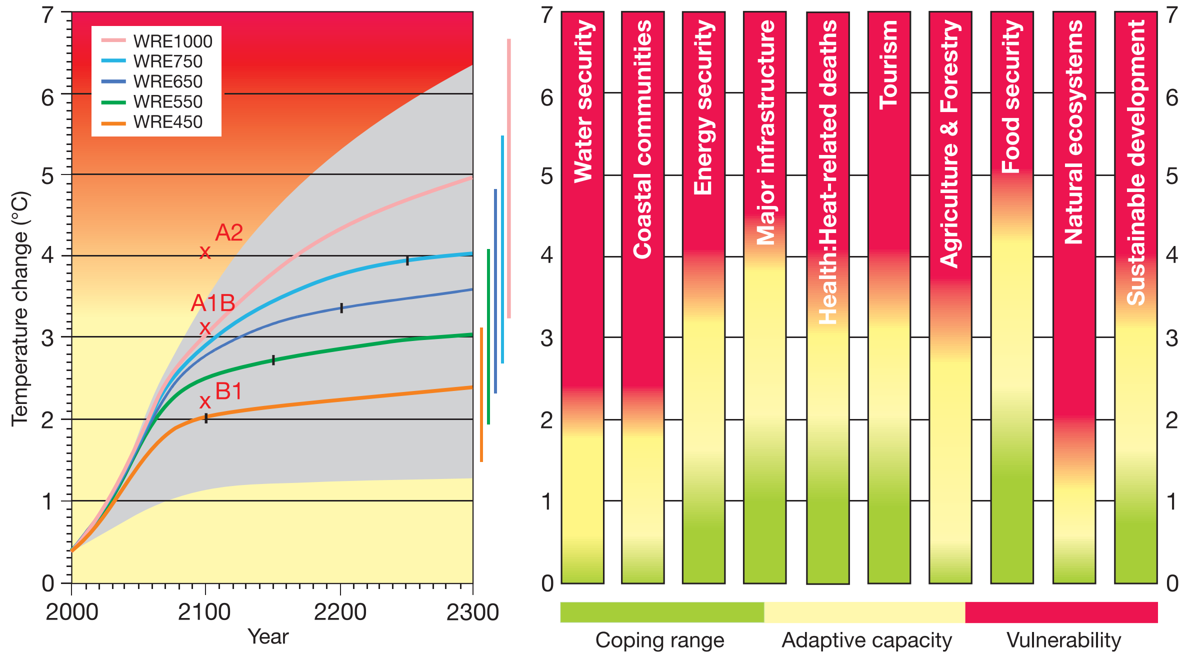

Figure 11.4. *Vulnerability to climate change aggregated for key sectors in the Australia and New Zealand region, allowing for current coping range and adaptive capacity. Right-hand panel is a schematic diagram assessing relative coping range, adaptive capacity and vulnerability. Left-hand panel shows global temperature change taken from the TAR Synthesis Report (Figure SPM-6). The coloured curves in the left panel represent temperature changes associated with stabilisation of CO_2 concentrations at 450 ppm (WRE450), 550 ppm (WRE550), 650 ppm (WRE650), 750 ppm (WRE750) and 1,000 ppm (WRE1000). Year of stabilisation is shown as black dots. It is assumed that emissions of non-CO_2 greenhouse gases follow the SRES A1B scenario until 2100 and are constant thereafter. The shaded area indicates the range of climate sensitivity across the five stabilisation cases. The narrow bars show uncertainty at the year 2300. Crosses indicate warming by 2100 for the SRES B1, A1B and A2 scenarios.*

with both countries able to produce more food than they require for internal consumption, although imports of selected foods may be needed temporarily to cover shortages due to extreme events. Climate changes are also likely to bring benefits in some areas for hydro-generation, winter heating requirements and tourism.

Figure 11.5 assesses key hotspots identified for the region, where vulnerability to climate change is likely to be high. Their selection is based on the following criteria: large impacts, low adaptive capacity, substantial population, economically important, substantial exposed infrastructure and subject to other major stresses (e.g., continued rapid population growth, ongoing development, ongoing land degradation, ongoing habitat loss, threats from rising sea level). Their development at current rates and accustomed supply of ecosystem services are unlikely to be sustainable with ongoing climate change, unless there is considerable planned adaptation.

For Australia and New Zealand, the magnitude of investment in adaptation is overshadowed by that in mitigation. The latter is intended to slow global warming. However, there is unlikely to be any noticeable climate effect from reducing greenhouse gases until at least 2040 (see Chapter 18). In contrast, the benefits of adaptation can be immediate, especially when they also address climate variability. Many adaptation options can be implemented now for Australia and New Zealand at personal, local and regional scales. Enhancing society's response capacity through the pursuit of sustainable development pathways is one way of promoting both adaptation and mitigation (see Chapter 18).

11.8 Key uncertainties and research priorities

Assessment of impacts is hampered because of uncertainty in climate change projections at the local level (e.g., in rainfall, rate of sea-level rise and extreme weather events). Research priorities for these are identified in the IPCC Working Group I Fourth Assessment Report (IPCC, 2007). Other uncertainties stem from an incomplete knowledge of natural and human system dynamics, and limited knowledge of adaptive capacity, constraints and options (Allen Consulting Group, 2005). More needs to be done to assess vulnerability within a risk-assessment framework. Based on the information presented in this Chapter, the main research priorities are assessed to fall into four categories:

11.8.1 Assessing impacts of climate change and vulnerability for critical systems

- *Water:* Impacts and optimum adaptation strategies for projected changes in drought and floods, and implications for water security within an integrated catchment framework. This includes impacts on long-term groundwater levels, water quality, environmental flows and future requirements for hydroelectricity generation, irrigation and urban supply.
- *Natural ecosystems:* Identification of thresholds including rates at which autonomous adaptation is possible; identification of the most vulnerable species (including key

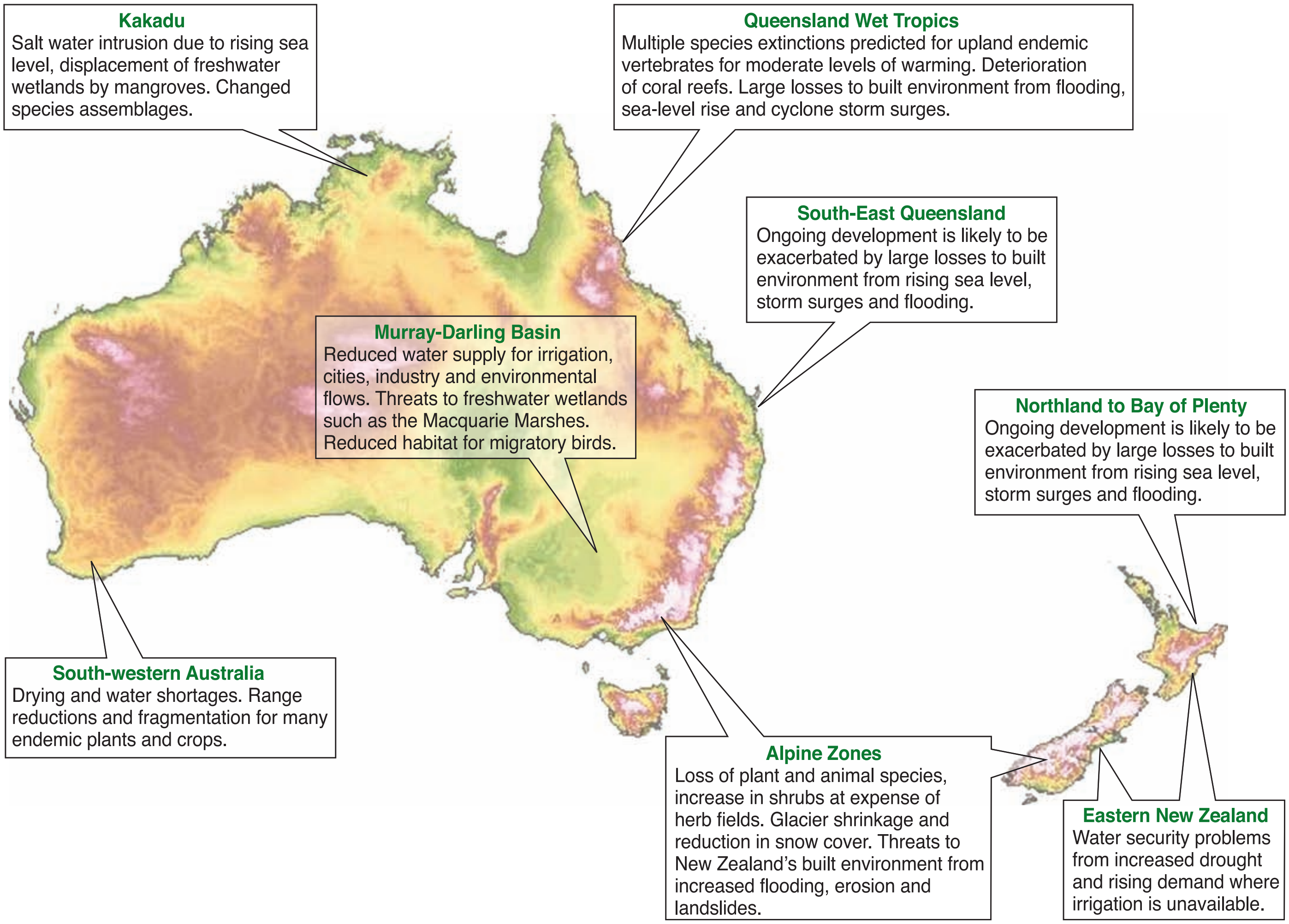

Figure 11.5. *Key hotspots identified for Australia and New Zealand, assuming a medium emissions scenario for 2050.*

indicator species), long-term monitoring; modelling of potential impacts on key ecosystems; interactions with stresses such as invasive species; improved bioclimatic modelling; and management options to reduce vulnerability.

- *Agriculture:* Impacts and adaptation strategies for a complete range of farming systems, including both costs and benefits for rural livelihoods. Analyses should address changes in the industry supply chain and regional land use, and the threat of new pests and diseases.
- *Oceans and fisheries:* Potential impacts of changes in climate, ENSO and IPO on physical oceanography, marine life and fish stocks in the waters that surround Australia and New Zealand.
- *Settlements, especially coastal communities:* Comprehensive assessments of vulnerability and adaptation options so as to provide improved guidance for planning and hazard management. Investigation of local and regional costs of projected changes in extreme weather events and adaptation planning for scenarios of sea-level rise beyond 2100.
- *Climate extremes and infrastructure:* Risks to building, transport, water, communication, energy and mining infrastructure, and insurance protection from an increase in extreme weather events. A re-evaluation is required of probable maximum precipitation and design floods[2] for dams, bridges, river protection, major urban infrastructure and risks of glacier outburst floods.
- *Tourism:* Improved understanding as to how direct and indirect impacts of climate change affect human behaviour with respect to recreation patterns and holiday destination choice.
- *Climate surprises:* Impacts of abrupt climate change, faster than expected sea-level rise and sudden changes in ocean circulation. Little is known about potential impacts and vulnerability on the region beyond 2100.

11.8.2 Fostering the process of adaptation to climate change

Australia and New Zealand have few integrated regional and sectoral assessments of impacts, adaptation and socio-economic risk. More are desirable, especially when set within the wider context of other multiple stresses. Methods to incorporate adaptation into environmental impact assessments and other regional planning and development schemes need to be

[2] A hypothetical flood representing a specific likelihood of occurrence, e.g., the 100-year or 1% probability flood.

developed. More research is required as to how local communities can shape adaptation (Kenny, 2005) and of adaptation options for Māori and Indigenous Australian communities, especially for those on traditional lands. Priority should be given to reducing the vulnerability of 'hotspot' areas through:

- identification of mechanisms that governments might use to reduce vulnerability,
- better understanding of societal preparedness and of the limitations and barriers to adaptation,
- better definition of costs and benefits of adaptation options, including benefits of impacts avoided, co-benefits, side effects, limits and better modelling,
- analyses of various options for social equity and fairness, the impacts of different discount rates, price incentives, delayed effects and inter-generational equity.

11.8.3 Assessing risks and opportunities of climate change for different scenarios

Impact scenarios underpin policy decisions about adaptation options and emission reduction targets. The following analyses are required for the full range of SRES and CO_2 stabilisation scenarios:

- definition of the probabilities of exceeding critical biophysical and socio-economic thresholds and assessment of consequent vulnerability or new opportunities,
- assessment of net costs and benefits for key economic sectors and for each country,
- better modelling of land-use change as climatic boundaries shift, and assessment of the implications for regional development, social change, food security and sustainability.

11.8.4 Analysing global trade, immigration and security for climate change outcomes

Impacts of climate change and adaptation elsewhere in the world are very likely to change global interactions, and especially trade in commodities. The implications are large for the strongly export-based economies of Australia and New Zealand. Further studies are needed in order to assess the impacts of climate change on the region's competitiveness and export mix. In the Asia-Pacific region, adverse effects on food, disease, water, energy and coastal settlements are likely (Dupont and Pearman, 2006), but implications for immigration and security in Australia and New Zealand are poorly understood.

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