IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 11 – Australia and New Zealand

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Executive Summary

Australia and New Zealand are already experiencing impacts from recent climate change: These are now evident in stresses on water supply, drought effects on agriculture, changed natural ecosystems and ice loss from New Zealand (NZ) glaciers (high confidence) [11.2.1].

There is evidence that some adaptation to observed climate changes has occurred: Examples come from sectors such as water, agriculture, horticulture and coasts, but continued vulnerability to extreme events is demonstrated by substantial economic losses caused by droughts, floods, fire, tropical cyclones and hail (high confidence) [11.2.3].

Climatic trends since 1950 are likely to accelerate: Along with warmer conditions and sea-level rise, large areas of mainland Australia and eastern New Zealand are likely to have less run-off, although western New Zealand is likely to become wetter (medium confidence) [11.3]. Increasing economic losses are very likely from higher frequencies of major floods, fires, droughts, heat waves and severe storm surges (medium confidence) [11.3].

Without further adaptation, impacts of climate change are likely to be substantial:

- *Some aspects of climate change are likely to have beneficial effects for particular sub-regions and sectors*: Up to about 2050, enhanced growing conditions from higher carbon dioxide, longer growing seasons and less frost risk are likely for agriculture, horticulture and forestry over much of New Zealand and Tasmania, provided adequate water is available (high confidence) [11.4.3, 11.4.4]. Reduced energy demand is very likely in winter, although summer demand is likely to rise (high confidence) [11.4.10]. Tourism benefits from drier and warmer weather in some areas (medium confidence) [11.4.9]. Flows in New Zealand's largest rivers are very likely to increase, benefiting hydroelectricity generation and irrigation supply (medium confidence) [11.4.1, 11.4.10].
- *Water availability problems are very likely to be exacerbated* over large areas of southern and eastern Australia, the east of New Zealand's North Island and in areas distant from major rivers in the east of the South Island, particularly those reliant on one major supply source (high confidence) [11.4.1].
- *The structure, function and species composition of many natural ecosystems are very likely to alter*: Impacts are virtually certain to exacerbate existing stresses such as invasive species, habitat loss and fragmentation, and cause a reduction in ecosystem services (e.g. for tourism, fishing, water supply) (high confidence) [11.4.2].
- *Coastal settlements are likely to be highly vulnerable:* Ongoing coastal development is very likely to exacerbate risk to lives and property from sea level rise and storms (high confidence) [11.4.5]. There is very likely to be loss of high-value land, faster road deterioration, degraded beaches, social and economic trauma, loss of items of cultural significance, and higher insurance costs (very high confidence) [11.4.5].
- *Risks to major infrastructure are likely to increase*: Design criteria for extreme events are very likely to be exceeded more frequently than under the present climate. Risks include threats to hydro dams in New Zealand, failure of floodplain protection and urban drainage/sewage, increased storm and fire damage in major cities, and more heatwaves causing higher mortality and higher peaks in summer energy demand leading to the risk of black-outs (high confidence) [11.4.1, 11.4.7, 11.4.10, 11.4.11].
- *Biosecurity threats are very likely to increase*: More invasive species and disease vectors are very likely to negatively affect human health, agriculture, forestry and natural ecosystems (high confidence) [11.4.2, 11.4.3, 11.4.4, 11.4.11].
- *Substantial shifts in agriculture and forestry are very likely*: Production is likely to be reduced over much of Australia and parts of eastern New Zealand since water supply is likely to be reduced (high confidence) [11.4.3, 11.4.4]. However, food security of the region is very likely to

remain robust (high confidence) [11.7]

Some sectors and regions are likely to be more vulnerable than others:

- *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 also very likely to limit species migration in response to shifting climatic zones (high confidence) [11.5].
- *Most human systems have considerable adaptive capacity:* The region has developed economies, supported by extensive scientific and technical capabilities and disaster mitigation strategies, but there are likely to be considerable cost and institutional constraints to implementation of adaptation options (high confidence) [11.5]. Some indigenous communities have low adaptive capacity (medium confidence) [11.4.8]. Water security, coastal communities and insurance are most vulnerable (high confidence) [11.7].
- *Vulnerability is likely to rise as a consequence of 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 in a number of identifiable hotspots*: These include eastern Queensland (Aus), south-western Australia, Murray-Darling Basin (Aus), Kakadu (Aus), Bay of Plenty (NZ), Northland (NZ), eastern lowlands (NZ), Southern Alps (NZ), Australian alps and sub-Antarctic islands (medium confidence) [11.7].
- *By the end of the century, climate change impacts are likely to be substantially greater under high emission scenarios than under low emission scenarios:* Adaptation and mitigation are both necessary to manage regional vulnerability (high 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 2005, growing at 1% per year (Statistics New Zealand 2005b). Australia's population was 20.1 million in 2004, with growth of 0.9% per year (ABS 2005a). Despite markedly different landscapes and climates, many of the social, cultural and economic aspects of the two countries are comparable. Agriculture accounts for 4-5% of GDP, industry 26-28% and services 68-70% (OECD 2006). 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. Water is a fundamental input to many systems in both countries (Allen Consulting Group 2005). Over 8% of GDP is spent on health (OECD 2006).

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

The IPCC TAR for Australia and New Zealand (Pittock; Wratt 2001). The following impacts were assessed as important:

- 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 southwest and inland Australia and eastern New Zealand are likely to make agricultural activities particularly vulnerable;
- Increasing vulnerability in coastal regions exposed to tropical cyclones, storm surges and sea-level rise;
- Increased frequency of high-intensity rainfall 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: (1) climate change is likely to add to existing stresses to conservation of terrestrial and aquatic biodiversity and to achieving sustainable land use; and (2) 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)

This chapter for the AR4 strengthens these results for the Australia and New Zealand region after review of a considerable literature published since the TAR. There is now more extensive documentation of observed changes to natural systems consistent with global warming. Significant advances have been made in understanding potential future impacts on water, natural ecosystems, agriculture, coasts, indigenous people and health. More attention is given to the role of adaptation in offsetting some of the potential impacts. This chapter assesses vulnerability in specific sectors, and hotspots where development trends and climatic trends are likely to lead to high vulnerability.

Vulnerability is a product of the exposure to climate change, the sensitivity of systems to this exposure, and their capacity to adapt. Most systems and areas have a coping range to existing climate variability. As climate begins to change, impacts may exceed this range, but these can be alleviated by adaptation. Eventually, if climate change continues, the adaptive capacity may be exceeded and the system or area and its population become vulnerable (Fig. 11.1). Sections 11.2 and 11.3 consider exposure and sensitivity, 11.4 deals with potential impacts without adaptation, 11.5 covers adaptation, 11.6 provides some case studies, 11.7 gives conclusions about vulnerability and 11.8 discusses key uncertainties and research priorities.

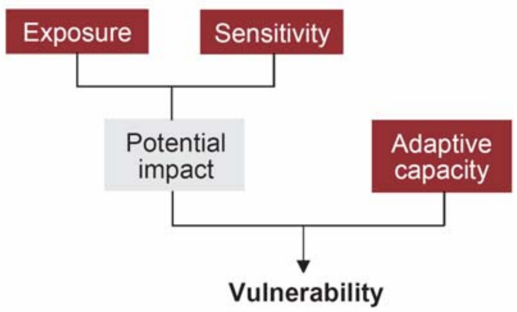

***Fig. 11.1**: Components of vulnerability (Allen Consulting Group 2005).*

11.2 Current sensitivity/vulnerability

11.2.1 Climate variability and 20th century trends

The strongest regional driver of climate variability is the El Niño/Southern Oscillation (ENSO). In New Zealand El Niño brings stronger than average south-westerly airflow, with drier conditions in the north-east of the country, and wetter conditions in the south-west (Gordon 1986:Mullan 1995). Reverse patterns occur during La Niña. El Niño tends to bring warmer and drier conditions to eastern and south-western Australia, and the converse during La Niña (Power *et al.* 1998). The positive phase of the Interdecadal Pacific Oscillation (IPO) strengthens the ENSO-rainfall links in New Zealand, and weakens links in Australia (Folland *et al.* 2005:Power *et al.* 1999:Salinger *et al.* 2004).

New Zealand mean air temperatures have risen 1.1°C from 1855-2004, but only 0.3°C since 1950 (NIWA 2005). Local sea surface temperatures have risen by 0.7°C since 1871 (Folland *et al.* 2003). From 1951-1996, the number of cold nights and frosts declined by 10-20 days (Salinger; Griffiths 2001). From 1971-2004, tropical cyclones in the southwest Pacific averaged nine/year, with no trend (Burgess 2005). The frequency and strength of extreme westerly winds has increased significantly in the south, while extreme easterly winds have decreased over land and increased to the south (Salinger *et al.* 2005a). Relative sea level rise averaged 1.6 ± 0.2 mm/year since 1900 (Hannah 2004). Rainfall has increased in the south-west and decreased in the north-east (Salinger; Mullan 1999). Pan evaporation has declined significantly at 6 out of 19 sites since the 1970s (Roderick; Farquhar 2005). There has been no trend in snow in the Southern Alps since 1930 (Owens; Fitzharris 2004).

From 1910 to 2004, the Australian-average maximum temperature rose 0.6°C and the minimum temperature rose 1.2°C, mostly since 1950 (Nicholls; Collins 2006). It is very likely that increases in greenhouse gases and aerosols have significantly contributed to this warming in the second half of the 20th century (Karoly; Braganza 2005a: 2005b). From 1957 to 2004, the Australian-average shows an increase in hot days (35°C or more) of 0.10 days/year, an increase in hot nights (20°C or more) of 0.18 nights/year, a decrease in cold days (15°C or less) of 0.14 days/year and a decrease in cold nights (5°C or less) of 0.15 nights/year (Nicholls; Collins 2006). The north-western two-thirds of Australia has become wetter since 1950, while southern and eastern Australia has become drier (Smith 2004b). Droughts have become more intense since temperatures have risen for a given rainfall deficiency (Nicholls 2004). From 1950-2005, extreme daily rainfall has increased in north-western and central Australia and over the NSW western tablelands, but decreased in the southeast, southwest and central east-coast (Gallant *et al.* 2006). Most extreme events are changing faster than the means or more moderate extreme events (Alexander *et al.* submitted). South-east Australian snow depths at the start of October have declined 40% in the past 40 years (Nicholls 2005). Pan evaporation averaged over 30 sites from 1970-2002 decreased by 1.0 to 4.3 mm/year[2] while potential evaporation increased (Kirono *et al.* submitted:Roderick; Farquhar 2004). There is no trend in the frequency of tropical cyclones in the Australian region from 1981-2003, but an increase in intense systems (very low central pressure) (Hennessy 2004:Kuleshov 2003). Relative sea-level rise averaged 1.2 mm/year from 1920 to 2000 (Church *et al.* 2004).

New Zealand's offshore islands show significant warming with mean temperature increases of 1°C at the Chatham Islands over the past 100 years (Mullan *et al.* 2005b). South of 50°S, Macquarie Island has experienced a warming of 0.3°C in the period 1948-1998 (Tweedie; Bergstrom 2000), increased wind speed, precipitation and evapotranspiration, and decreased air moisture content and sunshine hours since 1950 (Frenot *et al.* 2005). Campbell Island has warmed by 0.6°C in summer and 0.4°C in winter since the late 1960s. Heard Island shows rapid glacial retreat and reduced area of annual snow cover (Bergstrom 2003).

11.2.2 Economic sensitivity/vulnerability to climate and weather

Extreme events have severe impacts in both countries (examples in Box 11.1). In Australia, around 87% of economic damage due to natural disasters is caused by weather-related events, excluding drought (BTE 2001). From 1967 to 1999, these costs averaged US$719 million per year, 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 flood damage averaged about US$85 million per year from 1968-1998 (BTE 2001).

Box 11.1: Extreme events

Droughts*:* In Australia, the droughts of 1982-1983, 1991-1995 and 2002-2003 cost about US$1.7 billion, US$2.8 billion and US$7.6 billion, respectively (Adams *et al.* 2002:BoM 2006). Government drought relief averaged US$76 million per year from 1992-1999 (SOE 2001). In New Zealand, the 1997-1998 El Niño and 1998-1999 La Niña events caused regional droughts, with losses of US$800 million in agricultural production.

Sydney hailstorm, April 1999*:* This storm cost US$1,700 million, of which US$1,300 million was borne by the insurance industry (Schuster *et al.* 2005). Hail caused 50% of Australian insured losses post-1967 (IDRO 2006).

Eastern Australian heatwave, 1-22 February 2004: About 2/3 of continental Australia recorded maximum temperatures over 39˚C. Temperatures peaked at 48.5˚C in western New South Wales. The Queensland ambulance service recorded a 53% increase in ambulance callouts (Steffen *et al.* 2006).

Canberra fires 2003: Wildfires caused US$261 million damage (IDRO 2006:Lavorel; Steffen 2004). About 500 houses were totally destroyed, four people were killed and hundreds injured. Three of the city's four dams were rendered useless by post-fire runoff.

Southeast Australian storm, 2 Feb 2005: Insurance claims reached almost US$152 million (IDRO 2006). Transport was severely disrupted and beaches were eroded.

Tropical Cyclone Larry (Category 5), 20 March 2006: Over 1000 people evacuated, over 1600 buildings damaged, 135,000 homes without power, up to 120,000 without clean water and sewerage, 80% of banana crop lost, and estimated damage of US$263 million (BoM 2006:Queensland Government 2006:Wikipedia 2006).

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

11.2.3 Natural systems vulnerability/sensitivity 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 poorly understood.

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

Taxa or System	Observed Change	References
Australia		
Rainforest/woodland ecotones	Expansion of rainforest at expense of eucalypt forest and grasslands in Northern Territory, Queensland and New South Wales, linked to changes in rainfall and fire regimes	(Bowman *et al.* 2001:Hughes 2003)
Subalpine vegetation	Encroachment by snow gums into sub-alpine grasslands at higher elevations	(Wearne; Morgan 2001)
Freshwater swamps and floodplains	Saltwater intrusion into freshwater swamps since 1950s in Northern Territory associated with higher than average sea levels and drier monsoonal conditions, accelerating since 1980s	(Winn *et al.* 2006)
Coral reefs	Eight mass bleaching events on the Great Barrier Reef since 1979 (1980, 1982, 1987, 1992, 1994, 1998, 2002 and 2006) associated with unusually high sea surface temperatures; no serious events known prior to 1979 (see Section 11.6)	(Berkelmans *et al.* 2004:Done *et al.* 2003b:Hoegh-Guldberg 1999)
Birds	Earlier arrival of migratory birds; range shifts and expansion of several species; high sea surface temperatures associated with reduced reproduction in Wedge-tailed Shearwaters	(Beaumont *et al.* in press:Chambers 2005:Chambers *et al.* 2005:Smithers *et al.* 2003)
Mammals	Increased penetration of feral mammals into alpine and high sub-alpine areas and prolonged winter presence of macropods	(Green; Pickering 2002)
Insects	Change in genetic constitution of *Drosophila*, equivalent to a 4° latitude shift (~400 km)	(Umina *et al.* 2005)
New Zealand		
Birds	Earlier egg laying in Welcome Swallow	(Evans *et al.* 2003)
Southern beech	Seed production increase in *Nothofagus* (1973-2002) along elevational gradient related to warming during flower development	(Richardson *et al.* 2005)
Fish	Increasing El Niño frequency associated with westward shift of Chilean jack mackerel in the Pacific and subsequent invasion into New Zealand waters in the mid-1980s	(Taylor 2002)
Glaciers	Ice volume decreased from ~100 km^3 to 64 km^3 over past century, estimated loss of at least a quarter of glacier mass since 1950	(Anderson 2004:Clare *et al.* 2002)
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:Weimerskirch *et al.* 2003:Woehler *et al.* 2002)
Vertebrates	Population increases in Fur Seals on Heard Is. and Elephant Seals on Campbell Is, linked to changes in food supply, warming, and oceanic circulation; rats moving into upland herbfields and breeding more often on Macquarie Island	(Budd 2000:Frenot *et al.* 2005:Weimerskirch *et al.* 2003)
Plant communities	Plant colonisation of areas exposed by glacial retreat on Heard Is	(Bergstrom 2003)

11.2.4 Sensitivity/vulnerability to other stresses

Population growth places stress on most resources. Growing energy demand has placed stress on power supply infrastructure. In Australia, energy consumption has been growing at 2.5% per year over the past 20 years (PB Associates 2006). Increases in water demand have placed stress on supply capacity for irrigation, cities, industry and environmental flows. Increased demand since the 1980s in New Zealand has been due to agricultural intensification (Woods; Howard-Williams 2004). The irrigated area of New Zealand has increased 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; Bright 2004). In Australia, dryland salinity, alteration of river flows, over-consumption and wasteful use of water resources, land clearing, intensification of agriculture and fragmentation of ecosystems still pose major stresses (Cullen 2002:SOE 2001). From 1985-1996/7, Australian water demand increased by 65% (NLWRA 2001). Invasive species pose significant environmental problems in both countries (MfE 2001b:SOE 2001).

11.2.5 Current adaptation

Adaptation refers to *autonomous* (or spontaneous) and *planned* adjustments in natural or human systems in response to climatic stimuli, which reduce harmful effects or exploit opportunities (see Chapter 17). The capacity for autonomous adaptation is relatively high in some sectors of the region, but 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 (Fig. 11.2). This section assesses how well Australia and New Zealand are engaged in the adaptation process.

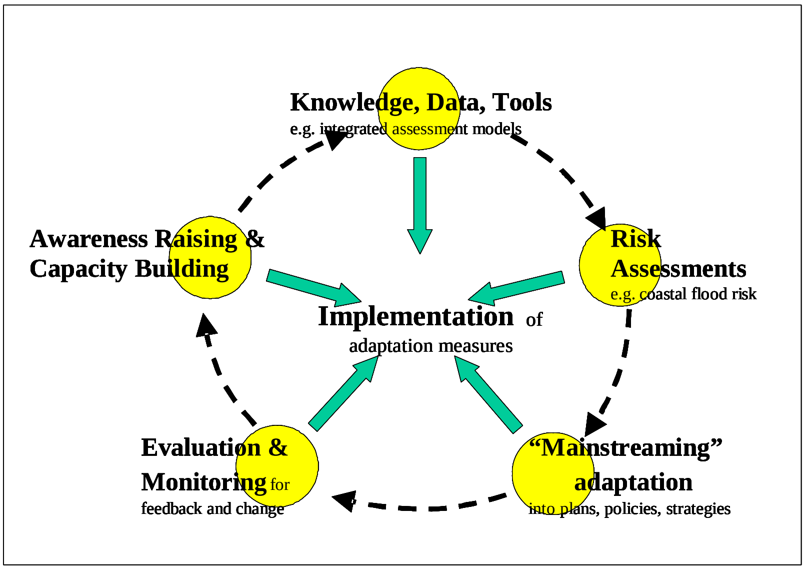

Fig. 11.2: *Adaptation as a process (MfE 2004c:Warrick 2000).*

Provision of knowledge, data and tools

There has been growing support for this in region. 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 has also increased over the last ten years (e.g. agricultural impacts, decision-support systems and extension activities for integration with farmers' knowledge) (Kenny 2002:MAF 2006). The Australian Research Council (ARC 2004) lists "responding to climate change and variability" as a priority goal under Research Priority Area 1: An Environmentally Sustainable Australia (2005-2006). The Australian Climate Change Science Program and the National Climate Change Adaptation Program are supported by the Australian Greenhouse Office (AGO) (Allen Consulting Group 2005). All Australian State and Territory governments have greenhouse action plans that include development of knowledge, data and tools.

Risk assessments

Regionally-relevant guidelines are available for use in risk assessments (Australian/New Zealand Standard for Risk Management. AS/NZS 4360:1999). Both countries regularly produce national impact assessments that provide a foundation for adaptation (e.g. (Howden *et al.* 2003c:MfE 2001a:Pittock 2003:Warrick 2001). Regional and local risk assessments including climate change are increasing (Shaw *et al.* 2005).

Mainstreaming

Climate change issues are being gradually "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 Defense 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 Action Plan for Salinity and Water Quality, the National Action Plan on Biodiversity and Climate Change, the National Water Initiative, the Queensland Coastal Management Plan and the Representative Areas Program Zoning Plan for the Great Barrier Reef Marine Park (see section 11.6). Climate change is listed as a Key Threatening Process under the federal Environment Protection and Biodiversity Conservation Act (1999) and several of the state-based acts such as the NSW Threatened Species Conservation Act (1995), the listing of which requires a Threat Abatement Plan to be drafted. The Wild Country (The Wilderness Society), Gondwana Links (Western Australia) and Nature Links (South Australia) initiatives promote connectivity of landscapes and resilience of natural systems in recognition that ecosystems will need to migrate as climate zones shift. The State Coastal Management Plan (Queensland Government 2001) states that planning must address the potential impacts of climate change. 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

It is the remit of the New Zealand Climate Committee to monitor the present state of knowledge of climate science, of climate variability on all time scales, and of current and future climate impacts" and "to make recommendations and provide advice on New Zealand research and monitoring needs, priorities and gaps regarding climate, its impacts, and the application of climate information" (RSNZ 2002). In Australia, the AGO monitors and evaluates performance against objectives in the National Greenhouse Strategy, and commissions research to assess current climate change knowledge, gaps and priorities for research on risk and vulnerability (Allen Consulting Group 2005). The National Land and Water Resources Audit (NLWRA 2001) and State of the Environment Report (SOE 2001) also have climate change elements. At regional and local levels, the capacity for climate monitoring and evaluation has not yet been well developed.

Awareness raising and capacity building

In New Zealand, substantive efforts are underway for transferring scientific information to, and facilitating exchange of information between LGAs. The New Zealand Climate Change Office has held a number of workshops for LGAs (MfE 2002: 2004c) supported case studies of "best practice" adaptation by LGAs, and commissioned guidance documents for LGAs on integrating climate change adaptation into their functions (MfE 2004a). The Australian Greenhouse Office, the Australian Bureau of Meteorology, CSIRO and most Australian State and Territory governments are developing and promoting on-line resources for raising awareness about climate change. Government-supported capacity-building programs, such as the Australian National Landcare Program, 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 2004c). However, since the TAR, the status of 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 explicitly include adaptation. Overall, in comparison to most other countries, New Zealand and Australia have a relatively high and growing level of adaptive capacity, but have yet to see that capacity systematically implemented on a wide scale.

11.3 Assumptions about future trends

11.3.1 Climate

Regional climate change scenarios with very coarse resolution are provided in Chapter 11 of the IPCC Working Group 1 report, based on recent model simulations. However, the scenarios below are based on more-detailed projections for Australia and New Zealand developed by (**CSIRO** 2001) and NIWA (Wratt *et al.* 2004), respectively.

In New Zealand, a warming of 0.2-1.3°C is likely by 2030 and 0.5-3.5°C by 2080 (Table 11.2). The mid-range projection for the 2080s is a 60% increase in the annual mean westerly winds (Wratt *et al.* 2004). Consequently, precipitation is likely to be biased toward increase except in the eastern North Island and the northern South Island. Due to the projected increased winter precipitation over the Southern Alps, it is less clear whether snow will be reduced (MfE 2004b), although snowlines are likely to be higher (Fitzharris 2004). There is likely to be a 50-100% decrease in frosts in the lower North Island, and a 50% decrease in the South Island, and a 10-100% increase in the number of days over 30°C (Mullan *et al.* 2001). The frequency of heavy rainfall is likely to increase, especially in western areas (MfE 2004b).

Table 11.2: *Projected changes in New Zealand annual precipitation and mean temperature for the 2030s and 2080s, relative to 1990. The uncertainty range is based on results from 40 SRES emission scenarios and 6 climate models (Wratt et al. 2004).*

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

Within 800 km of the Australian coast, a mean warming of 0.1 to 1.3°C is likely by the year 2020, relative to 1990, 0.3-3.4°C by 2050 and 0.4 to 6.7°C by 2080 (Table 11.3). A 5 to 50% increase in days over 35°C is likely by 2020 with a 10 to 80% decrease in days below 0°C (Suppiah *et al.* 2006). A tendency for decreased rainfall is likely over most of Australia, except Tasmania and NSW. A tendency for less run-off is also likely (see section 11.4.1).

The area of Australian snow cover is likely shrink 10-40% by 2020 and 22-85% by 2050 (Hennessy *et al.* 2003). Increases in extreme daily rainfall are likely where average rainfall increases, or decreases slightly. For example, the intensity of the 1-in-20 year daily-rainfall event increases by up to 10% in parts of South Australia by the year 2030 (McInnes *et al.* 2002), 5 to 70% by the year 2050 in Victoria (Whetton *et al.* 2002), up to 25% in northern Queensland by 2050 (Walsh *et al.* 2001) and up to 30% by the year 2040 in south-east Queensland (Abbs 2004). Under 3 × CO_2 conditions, there is a 56% increase in the number of simulated tropical cyclones over north-eastern Australia with peak winds greater than $30 ms^{-1}$ (Walsh *et al.* 2004). Decreases in hail frequency are simulated for Melbourne and Mt Gambier (Niall; Walsh 2005). However, over Sydney, a scenario for 2050 gives a 20% increase in large hail (2 cm diameter) frequency and a 40% reduction in the average recurrence interval (from 8 years to 5 years) for hail exceeding 6 cm diameter (Leslie *et al.* 2006).

Table 11.3: *Projected changes in annual average rainfall and temperature for 2020, 2050 and 2080, relative to 1990, for Australia. The range of uncertainty is based on results from 40 SRES emission scenarios and 18 climate models (Suppiah et al. 2006).*

Temperature change (°C)	2020	2050	2080
0-400 km inland of coast	0.1 to 1.0	0.3 to 2.7	0.4 to 5.4
400-800 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 coast north of latitude 20°S	-9 to +4	-22 to +11	-45 to +22
Sub-tropics (latitudes 20-28°S) except west coast	-13 to +9	-34 to +22	-67 to +45
Northern and eastern New South Wales	-9 to +9	-22 to +22	-45 to +45
Within 400 km of western & southern coasts	-13 to +4	-34 to +11	-67 to +22
Tasmania	-4 to +9	-11 to +22	-22 to +45

Potential evaporation (or evaporative demand) is likely to increase (Kirono *et al.* submitted). Projected changes in rainfall and evaporation have been applied to water balance models, indicating that reduced soil moisture and runoff is very likely over most of Australia and eastern New Zealand, (see section 11.4.1 and Chapter 10 of the IPCC Working Group 1 report). Two climate models simulate up to 20% more droughts (defined as soil moisture in lowest 10% from 1974-2003) over most of Australia by 2030 and up to 80% more droughts by 2070 in south-western Australia (Mpelasoka *et al.* 2005). By the 2080s in New Zealand, severe droughts (the current one-in-twenty year soil moisture deficit) are likely to occur at least twice to four times as often 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 a month, with an expansion of droughts into spring and autumn.

An increase in fire danger in Australia is likely to be associated with a reduced interval between fires, increased fire-line intensity, a decrease in fire extinguishments and faster fire spread (Cary 2002:Tapper 2000:Williams *et al.* 2001). 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% (6-18) 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 1-5 days in some western areas. Fire season length is likely to be extended, starting earlier in August and finishing in May in many parts of New Zealand, compared with the current October to April season.

Sea-level in the region is likely to rise 0.02-0.12 m by 2020, 0.04-0.36 m by 2050 and 0.06-0.74 m by 2080, relative to 1990 (Gregory *et al.* 2001). These projections take account of both global-mean projections from IPCC SRES emissions and the non-uniform spatial distribution of sea-level change (related to ocean circulation and thermal expansion components of change) as produced by climate simulations. They do not include vertical land movement components of relative sea-level change, which can be large and locally important.

11.3.2 Population, energy and agriculture

In Australia, under medium assumptions (ABS 2003b), the population is likely to grow from 20 million in 2003 to 26.4 million in 2051, then stabilise. These assumptions include a fall in the number of children per woman (fertility rate) from 1.75 at present to 1.6 from 2011 onward, net overseas migration of 100,000 per year, and a 10% increase in life expectancy by 2051 (ABS 2003b). A greater concentration of the population is likely in Sydney, Melbourne, Brisbane, Perth and south-east Queensland. The proportion of Australians aged 65+ is likely to increase from 13% in 2003 to 27% in 2051 (ABS 2003b). Up to at least 2020, Australian energy consumption is projected to grow 2.1% per year on average (PB Associates 2006). Agriculture is likely to continue contributing about 3% of national 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 2005a). These assumptions include a net immigration of 10,000 per annum, 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 share of the population aged 65+ is likely to grow from 12% in 2004 to 25% in 2051. Total energy demand is likely to grow at an average rate of 0.6% per year from 2000-2025 (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, without adaptation. Some SRES emissions scenarios have been suggested as surrogates for CO_2 concentration stabilization scenarios: emissions under the SRES B1 pathway for those required to achieve stabilization at 550 ppm, emissions under SRES B2 for the 650 ppm stabilisation pathway, and emissions under SRES A1B for the 750 ppm stabilisation pathway. Further detail on potential impacts is available in various synthesis reports (MfE 2001b:Pittock 2003).

11.4.1 Freshwater resources

11.4.1.1 Water security

The Murray-Darling Basin is the largest river basin in Australia, accounting for about 70% of irrigated crops and pastures (MDBC 2006). Changes in streamflow and salinity in five parts of the Murray-Darling Basin were examined for two mid-range SRES scenarios (A1-mid and B1-mid) with mid-range climate sensitivity (Beare; Heaney 2002). By 2050, modelled streamflow dropped 10 to 19% (B1) or 14 to 25% (A1) and salinity changed -6 to +16 (B1) or -8 to +19% (A1). By 2100, modelled streamflow dropped 16 to 30% (B1) or 24 to 48% (A1) and salinity changed -16 to +35% (B1) or -25 to +72% (A1). Estimated agricultural costs are US$0.6 billion (B1) to US$0.9 billion (A1).

By 2030, inflows to Burrendong dam (Macquarie Basin, NSW) are likely to change by +10% to -30% across all SRES scenarios, but the interval covering 90% of all possible outcomes is 0% to -15% (Jones; Page 2001). In 2070, 90% of possible outcomes fall within the interval +5 to -35%. If upland tree cover is increased by 10% for the purposes of sequestering carbon and ameliorating dryland and stream salinity, inflows to Burrendong dam are likely to decrease by 17% on a long-term basis, excluding climate change impacts (Herron *et al.* 2002). A mid-case climate change scenario for 2030 gives an additional 5% reduction.

Using climate projections for 2030 (CSIRO 2001), changes in Australian annual runoff are likely to be -5 to +15% on the northeast coast, ±15% on the east coast, a decline of up to 20% in the southeast, ±10% in Tasmania, a decline of up to 25% in the Gulf of St Vincent region of South Australian, and -25 to +10% on the southwest coast (Chiew; McMahon 2002). A second study, involving six small catchments and an ensemble of five transient runs (1871-2100) of the CSIRO Mark 2 model for the SRES A2 scenario, indicated a decrease in mean annual runoff of 6-8% in most of eastern Australia and 14% in southwest Australia in the period 2021-2050 relative to 1961-1990 (Chiew *et al.* 2003). Run-off in 29 Victorian catchments is likely to fall by 0-45% by 2030 (Jones; Durack 2005). For Melbourne, a probabilistic risk assessment using ten climate models driven by the SRES B1, A1B and A1F scenarios indicated that average streamflow is likely to drop 3-11% by 2020, and 7-35% by 2050 (Howe *et al.* 2005). Planned demand-side and supply-side actions are likely to alleviate water shortages through to 2020. Little is known about impacts on groundwater in Australia.

In New Zealand, proportionately more runoff is likely from South Island rivers in winter, and less in summer (Woods; Howard-Williams 2004). This could 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 could experience negative effects due to lower water availability in their time of peak demand. Increased drought frequency is likely in eastern areas of the country, with potential losses in agricultural production. The effects of climate change on flood and drought frequency are virtually certain to be enhanced or suppressed by the phases of the ENSO and IPO (McKerchar; Henderson 2003) see section 11.2.1). Future scenarios of groundwater behaviour for Auckland City (Namjou *et al.* 2005) indicate that the aquifer has spare capacity to accommodate recharge under all scenarios examined. Base flows in principal streams and springs are very unlikely 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 sewerage and drainage systems to accommodate moderate increases (up to 20%) in storm rainfall totals with minimal surcharging (Howe *et al.* 2005). A rainfall-runoff model was applied to three different catchments upstream of Sydney and Canberra under doubled CO_2 conditions (Schreider *et al.* 2000), showing increases in the magnitude and frequency of flood events. 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.* 2001). However, increases in runoff and flooding are partially offset by a reduction in average rainfall, which reduces soil wetness prior to storms. An integrated modelling system which couples a high-resolution atmospheric model of storm events with a non-linear flood event model has been applied to the historic case of flooding around the Gold Coast by tropical cyclone Wanda in 1974. If the same event occurred with a 10-40 cm rise in mean sea-level by the year 2050, the number of dwellings and people affected would increase by 3-18% (Abbs *et al.* 2001).

In New Zealand, rain events are likely to become more intense, leading to greater runoff during storms, with lower river levels between events. This may result in greater erosion of land surfaces, the redistribution of river sediments (Griffiths 1990), and a decrease in the protection afforded by stop-banks. This is likely to increase demands for enhancement of flood protection works, evidenced by the response to floods in 2004 (CAE 2005:MCDEM 2004). Flood risk to Westport has been assessed using a regional atmospheric model, a rainfall-runoff model and a detailed inundation model, assuming the current stop-bank configuration. The proportion of the Westport region inundated by a 1-in-50 year event is currently 4.3%, rising to 13-30% by 2030, and 30-80% by 2080 (Gray *et al.* 2005). Peak flow increased 4% by 2030 and 40% by 2080. In contrast, a flood risk study using 2050 climate scenarios assuming 1-2°C global warming downscaled for Auckland indicated only minor flood level differences (Dayananda *et al.* 2005). Higher flows and flood risk are likely in the Wairau catchment in North Shore City (URS 2004). Although increased flows and volumes are likely in Timaru, the increases are not significant enough to cause damage (Optus 2004). A major issue is finding practical ways of capturing large volumes of high intensity stormwater.

11.4.1.3 Water quality

By 2020, the average salinity of the lower Murray River in Australia is likely to exceed the 800 EC threshold set for desirable drinking water about 50% of the time (MDBMC 1999). However, the impacts of climate change have not been assessed for Adelaide's water supply, salt interception policies for ameliorating salinity, revegetation policies for ameliorating salinity and sequestering carbon, and water pricing and trading policies on water resources. Eutrophication is a major water quality problem in Australia (Davis 1997:SOE 2001). Toxic algal blooms can pose a threat to human health, for both recreation and consumptive water use, and can kill fish and livestock (Falconer 1997). These blooms are likely to become longer and more frequent due to climate change, but simple, resource-neutral, adaptive management strategies, such as flushing flows, have the potential to 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). No research has been published to date on climate change impacts 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 (80-100% in many taxa), and many species are already restricted in geographic and climatic range predisposing them to risk under rapid climate change. Many species are well-adapted to short-term climate variability, but not to longer-term shifts in mean climate. 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 future reductions and or fragmentation of existing climatic ranges Climate change will also interact with other stresses such as invasive species and habitat fragmentation. Natural ecosystems/regions identified as being most vulnerable in the short to medium term include the Wet Tropics and Kakadu World Heritage Areas, alpine areas, coral reefs, south-west Australian heathlands, isolated habitats in the New Zealand lowlands and both coastal and freshwater wetlands (Table 11.4). There is little research on the potential impacts of climate change on New Zealand species or natural ecosystems, with the exception of the alpine zone and some forested areas.

***Table 11.4**: Examples of potential impacts of climate change on species and natural systems. See further details and examples in (Chambers et al. 2005:Howden et al. 2003c:Hughes et al. 2003:Preston; Jones 2006).*

System / taxa	Potential Impacts	Source
Forests	*Australia:* Distribution of rainforest types in North Queensland Wet Tropics projected to either increase or decrease with warming, depending on direction of rainfall changes; *New Zealand:* Fragmented native forests of drier lowland environments in Northland, Waikato, Manuwatu, and in the east from East Cape to Southland likely to be most vulnerable, any increases in fire frequency are likely to have significant impacts because few New Zealand species have adaptations to survive or tolerate fire.	(Hilbert *et al.* 2001:McGlone 2001:MfE 2001b)
Rangelands	Major changes in vegetation composition of Australian rangelands (75% of total land area) likely to occur via shifts in rainfall pattern; changes in distribution of runoff likely to favour establishment of woody vegetation and encroachment of unpalatable woody shrubs; interactions between CO_2 and water supply likely to be critical, as well as grazing practices and fire regimes.	(Gifford; Howden 2001:Hughes 2003)
Alpine regions	*Australia:* species vulnerable due to limited extent of high altitude refuge and sensitivity to snow cover duration and depth; likely expansion of woody vegetation into herbfields; changed fire regimes in alpine peatlands likely due to drying; some alpine vertebrates likely to be at risk due to dependence on snow cover during hibernation; greater reliance on artificial snow making likely to have negative impacts on some species. *New Zealand:* 3^{o}C warming likely to result in loss of many indigenous vascular plant taxa; warming may lower frost resistance in plants but may also reduce overall incidence of frosts.	(Bannister *et al.* 2005:Halloy; Mark 2003:Pickering *et al.* 2004:Whinam *et al.* 2003)
Freshwater systems, wetlands and estuaries	Saltwater intrusion and decreases in river flows very likely to alter species composition of freshwater habitats; low relief coastal wetlands such as Kakadu National Park at risk from sea level rise and changes to river flows; increased drought frequency highly likely to reduce river flows with consequent impacts on freshwater biota; these effects likely to interact with existing stresses such as salinity, increased nutrient input and altered flows.	(Bunn; Arthington 2002:Hall; Burns 2002:Herron *et al.* 2002:Schallenberg *et al.* 2003)
Narrow-ranged endemic species - general	Narrow geographic and climatic ranges of many endemic plant and animal species very likely to increase vulnerability to even modest (0.5-1^{o}C) warming eg upland endemic vertebrates in Queensland Wet Tropics projected to lose most or all of bioclimatic range with 1-3.5^{o}C warming; impact of warming on predators likely to have flow on effects for native species such as NZ long-tailed bat	(Hughes 2003:Pryde *et al.* 2005:Shoo *et al.* 2005:Williams *et al.* 2003)
Marine species & systems	Warming oceans and changes to currents such as the East Australian Current very likely to have cascading effects on marine food chains; coral reefs such as the Great Barrier Reef (see Section 11.6) and Ningaloo Reef in Western Australia very likely to be negatively affected by temperature changes, changes in ocean chemistry and sea level rise; up to 14% of marine invertebrates in southern Australia confined to cool temperate waters and therefore vulnerable to a 1-2^{o}C increase	(Berkelmans *et al.* 2004:Done *et al.* 2003b:Lyne *et al.* 2005:O'Hara 2002:Watters *et al.* 2003)
Sub-Antarctic Islands	Increased mortality of burrowing petrels; increased invasions by disturbance-tolerant alien plants such as *Poa annua*; increased abundance of rats, mice and rabbits likely on islands where already present.	(Bergstrom; Selkirk 1999:Frenot *et al.* 2005)

11.4.3 Agriculture

11.4.3.1 Cropping

Since the TAR, additional studies have assessed potential impacts of climate and CO_2 changes at site, regional and national scales. Overall, these emphasise the vulnerability of cropping as well as the potential for regional differences.

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 temperatures (Jamieson *et al.* 2000) (see Chapter 5.4), but the net impact in irrigation areas depends on availability of irrigation water (Sorensen *et al.* 2000). For maize production (a C_4 crop), reduction in growth duration reduces crop water requirements, providing closer synchronisation of development with annual climatic variations (van Ittersum *et al.* 2003). Impacts of climate change on pests, diseases and weeds of Australian or New Zealand crops remain uncertain since few experimental or modeling studies have been performed.

A risk assessment of climate change for the Australian wheat industry was undertaken for the full range of CO_2 and climate IPCC SRES scenarios (Howden; Jones 2004) in conjunction with the APSIM crop simulation framework (Keating *et al.* 2003) recently validated for its CO_2 response for current wheat varieties (Asseng *et al.* 2004:Reyenga *et al.* 2001). Regional impacts varied markedly, with Western Australian regions likely to have significant yield reductions by 2070 (increased yield very unlikely). In contrast, regions in north-eastern Australia were likely to have moderate increases in yield (unlikely to have substantial yield reductions). Nationally, while median crop yields dropped slightly (without adaptation) 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 p.a.) but maximum potential losses are large (about 50% or US$1.4 billion p.a.). Adaptation through changing planting dates and varieties is likely to be highly effective: the median benefit was about US$158 million p.a. but with a range of US$70 million to over US$350 million p.a (Fig. 11.3).

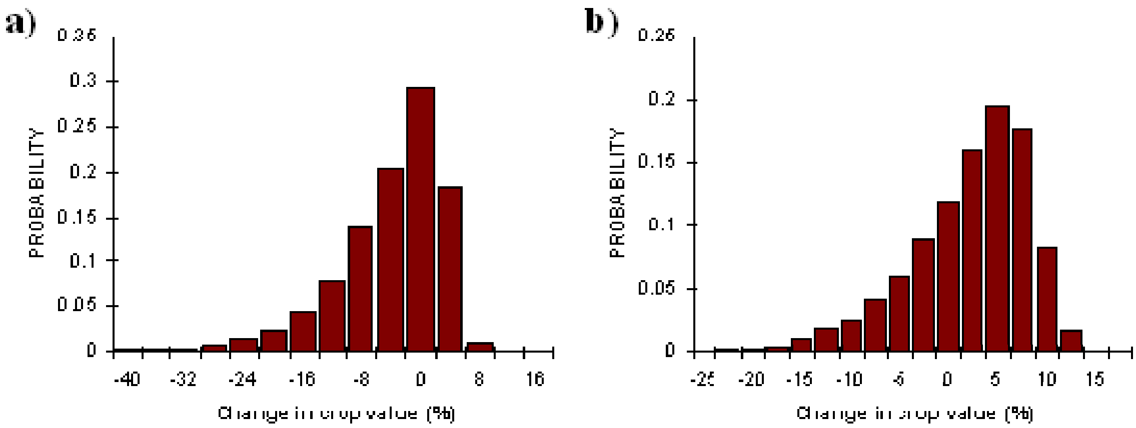

Fig. 11.3: *Change in national gross value of wheat from historical baseline values (%) for 2070 as a result of increase in CO_2 and change in temperature and rainfall a) without adaptation and b) with adaptations of changed planting windows and varieties.*

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

Grain quality is also likely to be affected. Firstly, increased levels of CO_2 reduce grain protein levels (Sutherst *et al.* 2000) requiring significant increases in nitrogenous fertiliser application or increased use of pasture legume rotations to maintain grain protein levels (Howden *et al.* 2003a). Secondly, there is increased risk of development of undesirable heat shock proteins in wheat grain in the northern cropping zones and in the southern cropping zones with temperature increases greater than 4^oC (Howden *et al.* 1999a).

Land degradation is likely to be affected by climate change. Elevated atmospheric CO_2 concentrations slightly reduces crop evapotranspiration, increasing the risk of water moving below the root zone of crops (deep drainage) so potentially exacerbating three of Australia's most severe land degradation problems across agricultural zones: waterlogging, soil acidification and dryland salinity. Scenarios of changes in climate and CO_2 for Western Australia show that deep drainage is likely to increase slightly (1 to10% at 550ppm CO_2) under elevated CO_2 concentrations, but when higher temperatures (+3^oC) were also simulated this was reversed (-8 to -29%) (van Ittersum *et al.* 2003). Deep drainage was greatly reduced (by up to 94%) in the low precipitation scenarios. However, the changes in deep drainage were not necessarily correlated with changes in productivity or gross margin and so scenarios had a range of beneficial or negative outcomes depending on the focus.

11.4.3.2 Horticulture

Australian temperate fruits and nuts are all likely to be negatively affected by prospective climate changes identified in section 11.3.1 because they require winter chill or vernalisation. Like tropical fruit, they are also strongly affected by disease and severe hail, wind and rain damage. 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 scenario 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 42–82%. These increases may be 24–83% 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 regions (Hall *et al.* 2001). Production of current kiwifruit varieties is likely to become uneconomic in Northland and Bay of Plenty by 2050 because of 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, dry matter proportion is likely to increase in southern regions (MfE 2001b). Apples, another major New Zealand crop, are very likely to flower and reach maturity earlier, with increased fruit size, especially after 2050 (Austin *et al.* 2000).

Viticulture is rapidly expanding in both countries. Earlier ripening dates and possible reductions in grape quality are likely (Webb *et al.* 2006). In cooler Australian climates, warming is likely to allow alternative varieties to be grown. Distribution of vines is likely to change depending upon suitability compared with high yield pasture and silviculture, and with irrigation water availability and cost (Hood *et al.* 2002). With warming in New Zealand, red wine production is likely to spread south, with higher yields (Salinger 1990), but higher CO_2 levels increase vine growth and shading may reduce fruitfulness.

11.4.3.3 Pastoral and rangeland farming

In cool areas of New Zealand, higher temperatures and CO_2 concentrations and less frost are very likely to increase annual pasture production by 10 to 20% by 2030, although gains decline after that (MfE 2001b). Increased frequency of drought has already decreased pasture growth for dryland farms, and this is very likely to continue. Subtropical pastoral species with lower feed-quality such as *Paspalum* are likely to continue spreading steadily southwards, reducing productivity (Clark *et al.* 2001), particularly around Waikato. Warming is likely to increase the range and incidence of many pests and diseases.

A rise in CO_2 concentration is likely to increase pasture growth in Australia, particularly in water-limited environments (e.g. Ghannoum *et al.* 2001; Chapter 5.3.2). However, if rainfall is reduced by 10% then this is likely to offset the CO_2 effect nationally (Crimp *et al.* 2004:Howden *et al.* 1999a). A 20% reduction in rainfall is likely to reduce pasture productivity by an average of 15% and live-weight gain in cattle by 12% and substantially increase variability in stocking rates, so reducing farm income (Crimp *et al.* 2004). The nutritional value of pastures is likely to alter as elevated concentrations of CO_2 significantly decrease leaf N-content, increase non-structural carbohydrate, but cause little change in digestibility (Lilley *et al.* 2001). In production 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 chronically deficient such as rangelands, higher temperatures are likely to exacerbate existing problems by decreasing non-structural carbohydrate concentrations and digestibility, particularly in tropical (C_4) grasses (Chapter 5.4.2). Doubled CO_2 concentrations and increased temperature are likely to result in only limited changes in native C_3 and C_4 grass distributions (Howden *et al.* 1999d).

Climatic changes are likely to increase major land degradation problems such as erosion and salinisation (section 11.4.3.1) and increase the potential distribution and abundance of exotic weeds (e.g. *Acacia nilotica* and *Cryptostegia grandiflora*; (Kriticos *et al.* 2003a:Kriticos *et al.* 2003b)) 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.* 2001a).

Heat stress already affects livestock in many Australian regions, reducing production and reproductive performance and enhancing mortality (section 5.3.2). Increased thermal stress on animals is very likely (Howden *et al.* 1999b). In contrast, reduced cold-stress is likely to reduce lamb mortality in both countries (Chapter 5.4.2). 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, in the absence of adaptation measures, losses in live weight gain from tick infestation are projected to increase by 20% in 2030 and by 230% in 2100. The net present value of future tick losses was estimated to be about 21% of farm cash income in Queensland, the State most affected.

11.4.4 Forestry

In Australia, the value of wood and wood products in 2001-2002 was US$5 billion (1% of GDP). About 164 million hectares are classified as forest, with 1% as plantation forests and 7% as native forest for timber production (BRS 2003). Plantation forestry is expanding rapidly in Australia (i.e. over 50,000 hectares per year) adding to the current but declining native forest area of 18M ha (NGGI 2000). Additional plantings are occurring to ameliorate land degradation problems such as erosion, waterlogging, and salinisation. In New Zealand, new plantations have declined to almost zero (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 feedbacks such as nutrient cycling (Howden *et al.* 1999c:Kirschbaum 1999a: 1999b).

Where trees are not water-limited, warming expands the growing season in southern Australia, but increases fire hazard (section 11.3.1) and pest damage is likely to negate some gains (Chapter 5.4.4). The anticipated reduction in average run-off in some regions (section 11.4.1) and increased fire risk (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).

For plantation forestry (mainly *P. radiata)* in New Zealand, the growth rates of these trees are likely to increase with carbon fertilization and wetter conditions in the south and west. Studies of pine seedlings confirm growth and wood density of *P. radiata* were enhanced under increased CO_2 during the first two years (Attwell 2003). East coast areas of the North Island are likely to experience growth reductions under projected rainfall decreases. However, it is uncertain whether this could be offset by increased water use efficiency with elevated CO_2 (MfE 2001b). It is also uncertain whether warmer and drier conditions could increase the frequency of upper mid-crown yellowing and winter fungal diseases (MfE 2001b).

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). A significant sea level rise of 6 m would inundate about 700,000 national addresses within 3km of the coast, and more than 60% of these vulnerable addresses are located in Queensland and NSW (Chen; McAneney 2006). The majority of the New Zealand population is within 30 km of the coast (WRI 2005). This has created a regional demand for coastal infrastructure which is virtually certain to be placed under further pressure with climate change-induced impacts.

The likely rise in sea-level, and changes to weather patterns, ocean currents, ocean temperature and storm surges will create differences in regional exposure (MfE 2004b:Walsh 2002) such as more vigorous and regular swells on the west coast of New Zealand (MfE 2004b). In northern Australia, tropical cyclones are likely to become more intense (section 11.3). The average area of Cairns (Australia) at risk of inundation by a 1 in 100 year storm surge event is likely to more than double by 2050 (McInnes *et al.* 2003) (see Chapter 6). Major impacts are 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. Modelling shows that between 1980-2030 in Pegasus Bay (New Zealand), shoreline erosion of up to 50m could occur near the Waipara River with 50% less southerly waves, and up to 80m near the Waimakariri River with 50% less river sand (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 2004b). 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 2004b); section 11.4.1), in addition to impacts on infrastructure, coastal resources, and existing coastal management programs. Distributive process modelling indicates the coastal impacts of sea-level rise on wetlands and mangroves in Spencer Gulf, South Australia (Bryan *et al.* 2001). At Collaroy/Narrabeen beach (NSW), a sea level rise of 0.2m by 2050 combined with a 50-year storm leads to coastal recession exceeding 110m, resulting in a loss of US$184 million (Hennecke *et al.* 2004). Investigations for metropolitan coasts reveal the increased cost of protection on existing management systems (Bell *et al.* 2001). In Australia, for example, it has been estimated that mid-range sea-level rise projections for 2005-2025 are likely to increase the cost of the sand replenishment program on the Adelaide metropolitan coast by at least US$0.94 million per annum (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 sediment loads from changes in the intensity and seasonality of river flows carrying pollution and sediment, and future impacts of river regulation (Kennish 2002).

Australian and New Zealand studies on coastal vulnerability have underlined some of the problems with the suitability of the original IPCC approach to a ‘Common Methodology’ for coastal vulnerability assessment (Harvey *et al.* 1999). Subsequently, there has been very little use of globally applicable vulnerability assessment methods in the region, although they have contributed to the use of local and regional studies and scaling-up techniques (McLean 2001). At the regional and local level there has been a number of coastal vulnerability studies in both countries, particularly through local government (AGO 2006:MfE 2006). For example, 21% of the Tasmanian coast is at risk to erosion and significant recession from predicted sea-level rise in the next 50-100 years (Sharples 2004).

11.4.6 Fisheries

In Australia, the gross value of fisheries production is US$1.7 billion (1% of GDP), of which 68% is wild-catch and 32% is aquaculture. In New Zealand, the combined value of fisheries production is $US0.8 billion (1% of GDP), of which 80% is from the commercial catch, and 20% from aquaculture (Seafood Industry Council 2006) which continues to grow.

Marine fisheries around the world are threatened by over-exploitation. In Australia, for example, of 74 stocks considered in 2005, 17 were over-fished, 17 were not over-fished and 40 were of uncertain status (ABARE 2005). Climate change will be an additional stress on this sector (Hobday; Matear 2005). The key variables expected to drive climate change impacts on marine fisheries are changes in ocean temperature, currents, winds, nutrient supply, acidification and rainfall. Four biological attributes are likely to be affected by climate change, the first of which is best understood: (1) distribution and abundance of exploited species, (2) phenology, (3) community composition, and (4) 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:Francis 1996) and on coastal fisheries relative to deep-sea fisheries (Hobday; 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 (Hobday; Matear 2005:Lehodey *et al.*

1997:Lyne 2000:Sims *et al.* 2001). In particular, circulation changes may increase or decrease the availability of some species and reduce others, as has been demonstrated in Western Australia with Leeuwin current relationships and ENSO. Fishers will have to respond with relocation or face reduced catches *in situ*. Recruitment is likely to be reduced in cool-water species based on evidence for New Zealand species such as hoki (Bull; Livingston 2001) and red cod (Annala *et al.* 2004:Beentjes; Renwick 2001); where recruitment has been correlated with cold autumn and winter conditions associated with El Niño events. In contrast, relatively high recruitment and faster growth rate of juvenile and adult snapper have been correlated with warmer conditions during La Niña events (Francis 1994:Maunder; Watters 2003). A similar pattern of recruitment has been found for gemfish (Renwick *et al.* 1998). Regarding physiological changes, temperature has a major influence on the population genetics of cold-blooded animals, selecting for changes in abundance of temperature-sensitive alleles and genotypes and their adaptive capacity. In New Zealand snapper, differences in allele frequencies at one enzyme marker have been 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 edge of suitable habitat (Hampe; Petit 2005:Richardson; Schoeman 2004).

Fish productivity is also linked to wind regimes and ocean currents. Seasonal to interannual variability of westerly winds and strong wind events relate to recruitment and catch rates in several species (Thresher 1994:Thresher *et al.* 1989:Thresher *et al.* 1992). A decline in wind due to a poleward shift in climate systems underlies recent stock declines off south-east Australia and western Tasmania, and are linked to larval growth rates and/or recruitment of juveniles in two fish species around Tasmania (Koslow; Thresher 1999:Thresher 2002). This implies that if westerly winds strengthen, stocks are likely to increase if quota management regimes are in place. With regard to productivity, reductions in upwelling of nutrients and extension of warm water along the east Australian coast may reduce krill and jack mackerel abundance, upon which many other species, including tuna, seals and seabirds are reliant (CSIRO 2002:McInnes *et al.* 2003).

11.4.7 Settlements, industry and society

Settlements, industry, and society are mainly sensitive to extreme weather events rather than to gradual climate change, although sea-level rise is also a major coastal issue. Many planning decisions involve settlements and infrastructure that may persist well into times of markedly different climatic conditions and higher sea levels. The planning horizon for refurbishing major infrastructure is 10-30 years, while major upgrades or replacement have an expected lifetime of 50 to 100 years (PIA 2004). About A$1,500 billion of Australia's wealth is locked up in homes, commercial buildings, ports and physical assets. This is equivalent to nine times the current national budget or twice the GDP (Coleman *et al.* 2004). In New Zealand, there are 1.4 million homes valued at about NZ$0.3 million each, 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; Hargreaves 2004). Higher extreme temperatures, more intense rainfall, and stronger winds are likely to produce intense heat wave episodes that affect millions of urban people, increased flooding of settlements and damage to buildings.

Despite the economic significance of mining in Australia (5% of GDP and 35% of export earnings (ABS 2005b)), little information exists regarding climate change impacts on mining. However, potential hazards have been noted for the Ranger Uranium Mine area, where the Traditional Owners (the Mirrar) are concerned that projected increases in extreme rainfall may inundate the Jabiluka billabong country and the lowlands on the floodplain margins (Kyle 2006). The Mirarr could lose a significant part of their estate. Projected increases in extreme events, such as floods and cyclones, also have the potential to increase erosion, slow re-vegetation, shift capping materials, and expose tailings and other contaminated wastes.

Ongoing growth of settlements and infrastructure near coasts occurs in both countries, but is markedly increasing exposure to climate hazards. This trend of rising risk is likely to continue. For example, the number of people living in exposed coastal areas in Australia and New Zealand is estimated to double in the next 50 years (McMichael *et al.* 2003). Risk to coastal property and infrastructure is very likely to be exacerbated by sea-level rise, higher storm intensity, more extreme flooding larger storm surges, and resulting erosion (CSIRO 2002:Hardy 2003:McInnes *et al.* 2003:PIA 2004). Design criteria for extreme events are very likely to be exceeded more frequently than under the present climate. Potential impacts include damage to buildings (e.g. water and foundation problems, higher wind loading), communication structures (e.g. roads, railways, bridges, telecommunications), critical services (e.g. transmission lines, stormwater systems, amenity values) and possible failure of some large structures (e.g. dams, flood levees, sea walls, jetties) (BRANZ 2006:PIA 2004).

Climate change is very likely to affect property values and investment through disclosure of increased hazards, 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), and governments sometimes provide disaster relief to the uninsured from large natural disasters (see Box 11.1). 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 (IDRO 2006), but there is limited information about potential changes in hail (see section 11.3).

Climate change is very likely to have 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 the year 2100, for the SRES A2 scenario in a CSIRO climate simulation, costs for road maintenance for Australia are predicted to rise 31% in real terms (Austroads 2004). About 60,000-90,000 people from the Pacific islands may be exposed to flooding from sea-level rise each year by the 2050s (McMichael *et al.* 2003). This would place pressure internally on these countries and on surrounding nations (such as New Zealand and Australia) to help sustain communities or to consider emergency immigrants (Woodward *et al.* 2001). Displacement of Torres Strait Islanders to mainland Australia is also likely to occur within this time frame.

11.4.8 Indigenous people

Indigenous peoples comprise about 15% of the New Zealand population (Statistics New Zealand, 2005a) and 2.4% of the Australian population (ABS 2002). Changes in New Zealand's climate over the next 50-100 years are likely to challenge the Maori economy and influence the social and cultural landscapes of Maori people (Packman *et al.* 2001). Some Maori have significant investment in fishing, agriculture and forestry and down-stream activities of processing and marketing (NZIER 2003). Economic performance and opportunities in these primary industries are likely to be influenced by climatic induced changes to production rates, product quality, pest and disease prevalence, drought, fire-risk and biodiversity (Cottrell *et al.* 2004:MAF 2001). While the majority of Maori 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, landslips).The capacity of Maori to plan and respond to threats of climate change on their assets (i.e. buildings, farms, forests, native forest, coastal resources) 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 increased risks of extreme weather are predicted (Mullan *et al.* 2001). Other pressures include the unclear role of local authorities with regard to adaptation; multiple land-ownership and decision-making processes which can complicate implementation of costly or non-traditional adaptation measures; and the high spiritual and cultural value placed on traditional lands/resources that can restrict or rule out adaptation options such as relocation. Many rural Maori rely on the use of public and private land and coastal resources for hunting and fishing to supplement household food supplies, for recreation and the collection of cultural resources. The distribution and abundance of culturally important flora and fauna is likely to be adversely influenced by climate change and therefore the nature of such activities is likely to be adversely affected, including cultural tourism. These challenges compound the sensitivity of Maori to climate change.

Indigenous communities in remote areas of Australia have inadequate infrastructure, health services and employment opportunities (Arthur; Morphy 2005:Braaf 1999a:IGWG 2004:Ring; Brown 2002). Consequently, many of these communities show features of social and economic disadvantage (ABS 2005c:Altman 2000). This social context is highly significant in terms of these communities' resilience to climate hazards (Ellemor 2005:Watson; McMichael 2001) because existing social disadvantage reduces coping ability and may restrict the capacity to adapt (Braaf 1999b:Woodward *et al.* 1998). Compounding this issue is the reality that many of these communities strongly connect the health of their 'country' to their cultural, mental and physical wellbeing (Jackson 2005:Smith 2004a). Therefore, direct biophysical impacts such as increases in temperate, rainfall extremes or sea level rise, may have significant indirect impacts on the social and cultural cohesion of these communities. There is a recent recognition of the untapped resource of indigenous knowledge about past climate change (Lewis 2002:Rose 1996:Strauss; Orlove 2003) which could be used to inform adaptation options for these communities. However, as with many indigenous peoples elsewhere, the oral tradition of recording this knowledge has, until recently, largely hindered non-indigenous scientists from appreciating the significance of this expertise for informing their science (Hill 2004:Webb 1997). Particular climate change impacts identified for remote indigenous communities include: increases in the number of days of extreme heat which may affect disease vectors, replication and survival of infectious pathogens, and heat stress (McMichael *et al.* 2006:Tait; Green 2006); extreme rainfall events and flooding causing infrastructure damage (Green; 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 2005a: 2005b:Green; Preston 2006). King tides 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 two thousand Australians living on the central coral cays and North West mud islands (Green 2006:Mulrennan 1992).

11.4.9 Tourism and recreation

Tourism contributes 4.2% to Australian GDP and 11.2% of exports (Allen Consulting Group 2005), and slightly more in New Zealand (about 5% of GDP and 16% of exports). Tourism concentrates around key regions such as 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 relies on the natural environment, including climatic conditions. Climate change is likely to lead to winners and losers, depending on adaptive capacity but few regional studies have assessed potential impacts. Building on global research (Becken 2005:Becken; Hay 2006:Hall; Higham 2005:Scott 2004:World Trade Organisation 2003), tourism is at risk from changes in weather and climate hazards like flooding, storm surges, heatwaves, cyclones, fires and droughts. These adversely affect transport, beach erosion, personal safety, communication, water availability and natural attractions like coral reefs, freshwater wetlands, snow, glaciers and forests. Changes in species distribution and ecosystems in National Parks (see

11.4.1) are likely to alter their tourism appeal. 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.

Tropical and alpine destinations are particularly vulnerable to climate impacts (Allen Consulting Group 2005). Tourism in tropical Queensland is likely to be affected by more intense cyclones with major consequences for tourist safety and well-being, and in areas where tourism is dependent on the health of the Great Barrier Reef (see section 11.6) and beaches (PIA 2004). Coral bleaching and ocean acidification are likely to accelerate death of corals and their replacement by algae-based ecosystems which are less attractive. The total value of ecosystem goods and services, including tourism, in the Wet Tropics World Heritage Area in Australia is about US$132-148 million per year, as at June 2002 (Curtis 2004).

Ski resorts range from marginal to reliable. For the SRES scenarios, by 2020 in south-east Australia, there is likely to be 5-40 fewer days of snow-cover per year, a rise in the snowline of 30-165 metres, and a reduction in the total snow-covered area of 10-40% (Hennessy *et al.* 2003). By 2050, the duration of snow cover reduces by 15-100 days, the maximum snow depth reduces by 10-99%, the snowline rises 60-570 m and the total area of snow cover shrinks by 20-85%. 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 120-270 m based on scenarios for 2080 (Fitzharris 2004). Shrinkage of New Zealand's glaciers (Anderson 2004) is likely for moderate temperature increases. Tourist flows from Australia to New Zealand might grow as a result of the relatively poorer snow conditions in Australia.

11.4.10 Energy

Energy consumption in the region is projected to grow due to demographic and socio-economic factors (see section 11.3.2). However, average and peak energy demand is also linked to climatic conditions. In the warmer parts of both countries, increases in peak energy demand due to increased air conditioner use are likely to exceed those for base load, suggesting that there will be a need to install additional generating capacity over and above that needed to cater for underlying economic growth (Howden and Crimp 2001). However, annual total demand may be less affected by warmer temperatures as there is likely to be a reduction in winter heating demand counteracting the increasing summer demand, e.g. New Zealand electricity demand changes by 3% per 1°C departure in mean winter temperature (Salinger, 1990). The net effect on demand is likely to be less for some cities (e.g. Melbourne, Sydney, Christchurch and Dunedin) than for others (e.g. Brisbane, Adelaide and Auckland).

There are a range of potential impacts of climate change that may affect energy infrastructure in Australian and New Zealand, including possible impacts of severe weather events on wind power stations, electricity transmission and distribution networks, oil and gas product storage facilities, and off-shore oil and gas production (see Chapter 7). An assessment of potential risks for Australia (PB Associates 2006) made the following conclusions. In addition to the risk of increased storm damage, increased peak and average temperature are also likely to reduce electricity generation efficiency, transmission line capacity, transformer capacity, and the life of switchgear and other components. Reduced output from wind farms is possible in southern Australia due to lower average wind speeds, and excessively high peak wind speeds. Liquid natural gas (LNG) is produced in tropical Australia, where a warming of 1°C is likely to reduce production capacity by about 0.2% and reduce capacity of pipelines. Increasing extreme wind speeds and wave heights projected for this region are likely to delay berthing, cargo transfer and de-berthing large LNG carriers, and increase the risk of grounding or collision. If climate changes gradually, both the generation utilities and the equipment manufacturers are likely to have enough time to adjust their standards and specifications. Vulnerability to the above impacts is considered to be 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 intensity is very likely to enhance wind generation and spill-over precipitation into major South Island hydro catchments and give more winter rain in the Waikato catchment (Wratt *et al.* 2004). Furthermore, increased temperatures are virtually certain to increase melting of snow and add to the higher river flows in winter. This is very likely to assist hydroelectric generation at the time of peak energy demand for heating.

11.4.11 Human Health

Assuming no adaptation, the projected increase in temperatures by 2020 is likely to cause a net increase in heat-related deaths in Australian capital cities (McMichael *et al.* 2003). By 2100, the 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, depending on the greenhouse gas emission scenario (Woodruff *et al.* 2005). By the end of the century, the population size and structure will change substantially, and the proportion of people aged over 65 will increase 2.5 to 4.7 times relative to the baseline. 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 additional heat-related deaths in nearly all cities by 2050 (McMichael *et al.* 2003).

There are likely to be alterations in the geographic range and seasonality of certain mosquito-borne infectious diseases. Fewer but heavier rainfall events will affect mosquito breeding and may increase the variability in annual rates of Ross River disease, particularly in temperate and semi-arid areas (Woodruff *et al.* in press:Woodruff *et al.* 2002). 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 to Australia: the climate of the far north already supports *Aedes aegypti* (the 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. Increasing population in northern Australia is likely to increase the relative risk of dengue (an estimated total of 0.3-0.5 million cases in 2020, and 0.8-1.6 million in 2050) (McMichael *et al.* 2003). Malaria may re-emerge in Australia, however, it 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 the 2050s (McMichael *et al.* 2003).

Warmer temperatures and increased rainfall variability are likely to increase the intensity and frequency of summer-time (salmonella) food-borne (D'Souza *et al.* 2004) and water-borne diseases (Hall *et al.* 2002) in both countries. Indigenous people living in remote communities are likely to be at increased risk due to their particular living conditions and access to services. An increase of 10% in the annual number of diarrhoeal admissions among Aboriginal children living in the central Australian region is likely by 2050, assuming no change in other circumstances (McMichael *et al.* 2003). The relationship between drought and severe mental health impacts in rural communities (Nicholls *et al.* 2005) suggests that parts of Australia is likely to be at increased risk in future. The impacts on aeroallergens and photochemical smog in cities are uncertain. There is some evidence that high concentrations of bushfire smoke play a role in increasing hospital presentations of asthma (Johnston *et al.* 2002).

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 impacts, assuming no adaptation (Table 11.5). Impacts are likely to reach a "critical level" once local warming exceeds 1 or 2°C from a 1990 baseline. Critical levels are defined in Chapter 19, using criteria of: magnitude of impact; rate of change; persistence and reversibility; likelihood and confidence; and importance of the vulnerable system. Depending on the SRES scenario used, critical levels are likely to be exceeded as early as 2050 or as late as 2100 (Table 11.6). However, adaptation has the potential to alleviate or delay vulnerability in some sectors (see section 11.5). Some parts of the region are likely to be more affected than others, because of the specific nature of the impacts, the nature of economic activity and/or presence of large populations. These "hotspots" are shown in Table 11.5 and discussed further in section 11.7. If warming to 2100 exceeds 3°C, it would be more rapid than that experienced at the end of the last glacial maximum and substantially more rapid than natural climate changes over the last millenium. It would likely exceed the natural adaptive capacity of all natural and human systems (see section 11.5) and include some abrupt changes when critical threshold conditions are crossed, as identified in the TAR (Pittock; Wratt 2001).

Table 11.5: *Six key impacts in Australia and New Zealand (assuming no adaptation).*

System	**Climate scenarios**	**Impacts**	**Hot spots**
Natural systems	Higher temperatures, sea level rise, more extreme weather events, reduced run-off over southern & eastern Australia and eastern NZ	Significant impacts on coral reefs, rainforests, wetlands, coasts and alpine areas. Increased disturbance, loss of biodiversity, changed species ranges and interactions, extinctions, loss of ecosystem services (e.g. for tourism and water supply). Potentially catastrophic for some systems (e.g. reefs may be dominated by non-coral organisms such as macroalgae by 2050).	Kakadu (Aus), east Queensland (Aus), alpine zones, Murray Darling Basin (MDB) (Aus), south-western Australia
Water security	Reduced run-off over much of southern & eastern Australia and eastern NZ, but, increased flows in major NZ rivers	Reduction in water supply for irrigation, cities, industry and environmental flows in those areas where river flows decline. Improved water supply for irrigation and hydro-electricity in regions and dams fed by major NZ rivers.	Capital cities, Bay of Plenty (NZ), Northland (NZ), Eastern Lowlands (NZ), east Queensland (Aus), MDB (Aus)
Coastal comm.-unities	Sea level rise, more intense tropical cyclones and larger storm surges	Sea-level rise is virtually certain to cause greater coastal inundation, erosion, loss of wetlands and mangroves, and salt-water intrusion into freshwater sources. Regions exposed to cyclones are likely to experience larger inundation due to higher storm surges. Accelerating coastal development is exacerbating the climate risks	Capital cities, coastal towns along Eastern Lowlands (NZ) & much of eastern Australia, Bay of Plenty (NZ), Northland (NZ)

System	Climate scenarios	Impacts	Hot spots
Bio-security	Higher temperatures	Invasion of warm provenance species and disease vectors, affecting human and animal health, agriculture, forestry and natural ecosystems.	Effects likely to be widespread in both countries
Major infrast-ructure and threats to life	Increases in extreme weather events, i.e. heavy rainfall, cyclone intensity, floods, fires and heat waves	Significant impacts on health, insurance, urban infrastructure, peak energy demand and black-out risk in summer. Increased threats to hydro dams and floodplain settlements behind protection levees. Urban drainage is likely to be inadequate. Threat of glacier outburst floods in NZ.	Capital cities, NZ Southern Alps, floodplains of major rivers, north eastern parts of both countries

Table 11.6: *Projected impacts after adaptation in Australia and New Zealand for 2020, 2050, 2080 and for the SRES B1 and A1FI greenhouse gas emission scenarios.*

Time slice	SRES B1 (low emissions scenario)	SRES A1FI (high emissions scenario)
Near-term impacts (about 2020s) Global warming approx. 0.4-0.8^{o}C	• 2 cm sea level rise negligible • localised coral bleaching • 20% decrease in frost days benefits horticulture and viticulture, reduces winter energy demand • 10% increase in hot days (over 35^{o}C in Aus and 30^{o}C in NZ) increases peak electricity demand • 10% less snow area in Aus and 5% less snow accumulation in NZ affects ecosystems, but glacier retreat barely noticeable • 4% more very high & extreme fire danger days in southeast Aus increases loss of property and lives • 0.3 million at risk of dengue in Aus	• coastal property losses due to 13 cm sea level rise • coral bleaching over most reefs • 80% decrease in frost days benefits horticulture and viticulture, reduces winter energy demand • 100% increase in hot days (over 35^{o}C in Aus and 30^{o}C in NZ) increases peak electricity demand • 40% less snow area in Australia and 10% less snow accumulation in NZ significantly affects ecosystems and glacier retreat is noticeable. • 25% more very high & extreme fire danger days in southeast Aus increases loss of property and lives, and challenges emergency services • 0.5 million at risk of dengue in Aus • increases in crop yields for areas where water resources remain adequate
Mid-term impacts (about 2050s) Global warming approx. 0.9-2.2^{o}C	• sea level rise negligible • slightly more inland flood damage • 22% less snow area in Aus significantly affects ecosystems • 15% more very high & extreme fire danger days in southeast Aus increases loss of property and lives, and challenges emergency services • 3300 more heat wave	• sea level rise of 35 cm produces significant loss of property during storm surges at some sites • significant rise in inland flood damage • coral reefs replaced by macro algae and sea weed • 85% less snow area in Aus critically affects ecosystems • 70% more very high & extreme fire danger days in SE Aus significantly increases loss of property and lives, the most-intense fire can't be controlled

Time slice	SRES B1 (low emissions scenario)	SRES A1FI (high emissions scenario)
	deaths/year • 10-19% decrease in river flow and -6 to +16% change in salinity in the Murray Darling basin (MDB) • 0.8 million at risk of dengue in Aus • increases in crop yields for areas where water supply is adequate	• 5200 more heat wave deaths/year • 14-25% decrease in MDB river flow (for A1 not A1FI) with stress on water supplies, -8 to +19% change in salinity in MDB • 1.6 million at risk of dengue in Aus • drought affects farming over wide areas of Aus and eastern NZ where water supply is limiting
Long-term impacts (about 2080s) **Global warming approx. 1.3-4.5^{o}C**	• sea level rise managed through coastal planning • coral reefs replaced by macro algae communities, species extinctions very likely • 20% less snow in NZ raises snowline 120 m, glacier shrinkage noticeable with serious impacts on tourism and alpine species • drought constrains farming over wide areas of Aus and eastern NZ where water is limiting • 10% more very high & extreme fire danger in Bay of Plenty, central and eastern NZ • Noticeable increase in flood peaks	• sea level rise of 75 cm causes widespread property loss during storm surges • large scale alteration to coral reefs • 55% less snow accumulation in NZ raises snowline 270 m and with loss of lower ski fields and alpine species extinctions • All but the largest glaciers disappear with significant loss of scenic amenity, tourism and summer river flows • frequent and severe drought severely constrains farming practices and limits water supply works over wide areas of Aus and parts of eastern NZ • 50% more very high & extreme fire danger in Bay of Plenty, central and eastern NZ • significant increase in flood peaks and failure of urban drainage and flood protection systems

Notes to Table: In some cases, modelling of impacts is not for the B1 or A1FI scenario, or is for slightly different time slices (eg 2100 rather than 2080); assessments are then based on interpolations. Other likely important impacts at these time slices and scenarios cannot be assessed due to lack of literature. Large sub-regional differences in impacts are likely. No account is taken of impacts on or due to mitigation measures.

11.5 Adaptation constraints and opportunities

As described in 11.2.5, since the TAR, Australia and New Zealand have taken notable steps in the process of adaptation, by increasing support for research and knowledge, expanding assessments of the risks of climate change for decision makers, infusing climate change into policies and plans, promoting awareness and building capacity to deal with the issues. While this has strengthened adaptive capacity, many gaps remain, and there are formidable environmental, economic, informational, social and political barriers or constraints that are very likely to hinder implementation of specific adaptation options in the individual sectors.

For example, impacts on many natural ecosystems and species have limited reversibility and the opportunities for offsetting potentially deleterious impacts are, in many cases, limited due to fixed habitat regions (e.g. the Wet Tropics upland rainforests in Australia and the alpine zone in both Australia and New Zealand). The oft-promoted adaptive strategy of corridors to facilitate migration of species under future warming would require changes in land tenure in many regions with significant economic costs, although schemes to promote such connectivity are already underway in some Australian states (see section 11.2.5). Translocation of species is generally reviewed as a measure of “last resort” due to cost, though it may be considered desirable in the long term for some iconic or charismatic species.

For water, in many instances the demand from rivers has exceeded sustainable levels of supply from both urban and rural activities. The reduced river flows increase salinities. Adaptation opportunities lie in the inclusion of climate risk on both the demand and supply side for urban catchments (Allen Consulting Group 2005). In cities, better use of stormwater and recycled water provide water conservation, although existing institutional arrangements and technical systems for water distribution constrain implementation. For rural activities, more flexible arrangements for allocation are required, via expansion of water markets and trading can increase water use efficiency (Beare; Heaney 2002). Such options would need to overcome significant barriers related to existing attitudes toward water pricing and a lack of political will to change the existing system.

For agriculture, opportunities exist for adapting via developing new crop varieties (see Fig. 11.3), developing new farm technology and practices, and extension of cropping to regions with historically higher rainfall, although implementation will require new investment and significant managerial changes (Howden *et al.* 2003c). Farmers in the Eastern Lowlands of New Zealand are engaging in discussion of risks posed by future climate change and how to enhance adaptation options (Kenny 2005). Farming of marginal land at the drier fringe is likely to be increasingly challenging, especially in Australia.

In coastal areas, despite some solid progress in risk assessments and in fashioning policies and plans in New Zealand that take account of climate and sea-level changes at the local and regional level, there remain significant challenges to achieving concrete actions that reduce risks. Consistent implementation of adapation measures (e.g. setback lines, planned retreat, building designs, prohibition of new structures and siting requirements that account for sea level rise) has been difficult due to differences in political commitment, lack of strong and clear guidelines from government, and legal challenges by property owners (NZCCO 2003).

More generally, four broad barriers to adaptation that transcend individual sectors are evident.

1. 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, a good deal of planning and development in New Zealand and Australia focuses on regions and areas like watersheds and coastal zones. In such areas, sectoral concerns like water resources, agriculture and ecosystems are inter-connected regarding climate variability and change and need to be assessed accordingly.
2. lack of well-developed evaluation tools for adaptation options, like benefit-cost analysis, that incorporate climate change and have been adapted for regional and local application.
3. low levels of awareness of the links between climatic extremes and climate change and how they can be used to promote adaptation. Examples of the application of risk-based approaches to adaptation (e.g. for upgrading urban storm-water infrastructure design (Shaw *et al.* 2005) demonstrate how developments can be “climate-proofed” on a project-by-project basis (ADB 2005).
4. weak linkages between the various strata of government, from national to local, as regards adaptation policy, plans and requirements. A recurrent theme expressed by local and regional government authorities is that stronger guidance and support is required from state (in Australia) and central government (in New Zealand) to underpin efforts to promote adaptation locally. For example, while the New Zealand Coastal Policy Statement states that regional councils should take account of future sea-level rise, there is lack of clear guidance on how this should be accomplished and little support for building capacity to undertake the necessary actions. As a consequence, the regional and local responses have been variable and inconsistent.

Some major constraints to adaptation could therefore be lifted if cross-sectoral integrated assessment and evaluation methods were refined, risk-based approaches to incorporating adaptation into development projects and infrastructural designs were expanded, and stronger connections were made between the layers of government as regards their efforts in strengthening guidance and adaptive capacity. Otherwise, some substantial vulnerabilities from future climate change will remain, as discussed in 11.7.

In conclusion, from the broad perspective of the adaptation process it is apparent that:

- both Australia and New Zealand are fairly well advanced in developing the capacity to adapt and are relatively well-positioned to implement adaptation practices, although substantial barriers to implementation remain;
- the provision of technical and scientific knowledge and tools necessary to promote adaptation is well underway in the region, although many gaps remain adaptation is developed most strongly for technical and scientific components of the process, especially at the national scale;
- major constraints exist, especially for capacity building, awareness, monitoring and mainstreaming of climate change into policies and plans at regional and local scales;
- additional efforts are needed to link, in an integrated manner, the national, regional and local levels so as to promote adaptation;
- risk-based approaches for including adaptation in individual development projects and infrastructure show considerable promise for achieving large aggregate benefits.

11.6 Case studies

The following case studies illustrate regions where climate change has already occurred, impacts are evident and adaptation is being considered or implemented.

Adaptation of water supplies in cities

The winter-rainfall-dominated region of south-west of Western Australia has experienced a substantial decline in the May-July rainfall since the mid-20th century. Effects on runoff are potentially serious as evidenced by a 50% drop in annual inflows to reservoirs supplying the city of Perth (Fig. 11.4). 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% per year (IOCI 2002).

To ensure water security, a US$350 million program of investment in water source development was undertaken by the WA Water Corporation (WA 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. While climate simulations indicate that at least some of the observed drying is due to the enhanced greenhouse effect, work is continuing to better understand the causes. In cities such as Sydney and Melbourne, concern about population pressures and the impact of climate change is leading water planners to consider a range of adaptation options including further reductions in water demand, increasing inter-basin transfers, and the use of groundwater, seawater desalination and water recycling (Howe *et al.* 2005:NSW Government 2004).

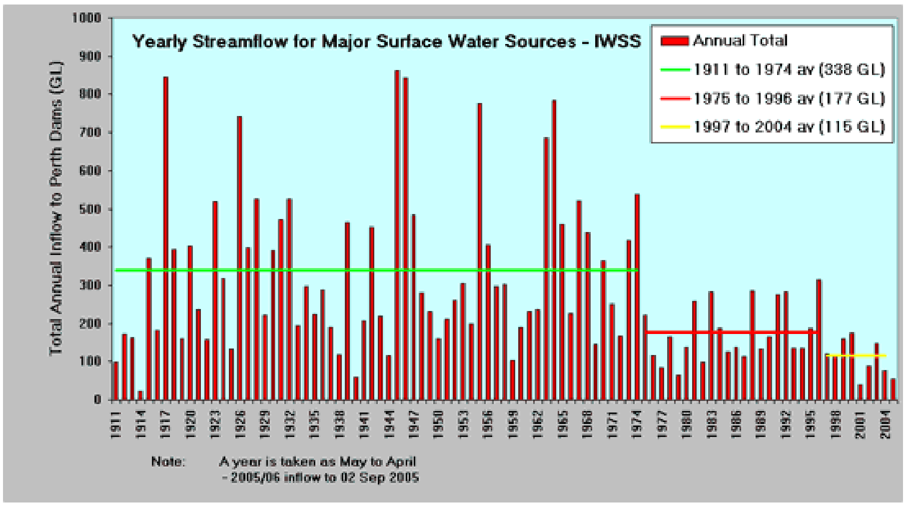

Fig. 11.4 Annual inflow to Perth Water Supply System from 1911-2005. Horizontal lines show averages.

Climate change adaptation in coastal areas

Both Australia and New Zealand have very long coastlines with large and rapidly growing populations living 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 achieve sustainable development and to adapt to changes in climate that could exacerbate vulnerability. Two examples illustrate this challenge.

Bay of Plenty, North Island, New Zealand. This bay is characterised by a narrow coastal zone containing the cities of Tauranga and Whakatane and two of the fastest growing districts of New Zealand, with a combined population growth of 13.4% over the period 1996-2001. By 2050 the population is projected to increase 2-3 times. Beach-front locations demand the highest premiums on the property market and also 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 explicitly included IPCC projections of sea level rise in its Regional Coastal Environment Plan and has identified Areas Sensitive to Coastal Hazards within the next 100 years. Nonetheless, the implementation of policy and plans by local government authorities has been repeatedly challenged by property developers, commercial interests and individual home-owners with different interpretations of the risks.

Sunshine Coast-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 2003a). Sandy beaches and dunes are key biophysical characteristics of the coastline. Fraser Island, the largest sand island in the world, is a major geographic feature and World Heritage Area. These natural features and the human populations they attract are vulnerable to extreme storm events and tropical cyclones. Some estuaries and adjacent lowlands have been developed as high-value canal estates which are especially at risk from flooding. Awareness of climate change risks is slowly taking root. For example, the Sea-Change Taskforce, made up of over 60 coastal councils throughout Australia, has recently added climate change to its agenda. At the regional planning level, climate change was recently imbedded at a policy level into the strategic planning processes for the Wide Bay-Burnett region.

Climate change and the Great Barrier Reef

The Great Barrier Reef (GBR) is the world's largest continuous reef system (2,100 km) and is a critical storehouse of Australian marine biodiversity and as a breeding ground for seabirds and other marine vertebrates such as the humpback whale. Tourism associated with the GBR generated over US$4.4 8 billion in the 12-month period 2004-5 and provided employment for ~63,000 full-time equivalent persons (Access Economics 2005).

The two greatest threats from climate change to the GBR are rising sea temperatures which are increasing the frequency of mass coral bleaching events, and ocean acidification which is reducing the calcifying ability of key organisms such as corals. Sea temperatures on the GBR have warmed by ~0.4^{o}C over the past century (Lough 2000). Temperatures currently typical of the northern tip of the GBR will exist at its southern end by 2040-2050 (SRES scenarios A1, A2) and 2070-2090 (B1, B2; (Done *et al.* 2003a). Temperatures only 0.8^{o}C above the long-term summer maxima cause mass coral bleaching (loss of symbiotic algae). Corals may recover but will die under high temperatures (2-3^{o}C above long-term maxima). The GBR has experienced 8 mass bleaching events since 1979 (1980, 1982, 1987, 1992, 1994, 1998, 2002 and 2006); no events are known prior to 1979 (Hoegh-Guldberg 1999). The most widespread and intense events occurred in the summers of 1998 and 2002, with ~42% and ~ 54% of reefs affected respectively (Berkelmans *et al.* 2004:Done *et al.* 2003a). Mortality was distributed patchily, with greatest effects seen on near-shore reefs, possibly exacerbated by osmotic stress caused by floodwaters (Berkelmans; Oliver 1999). The 2002 event was followed by outbreaks of coral disease, with the incidence of some disease-like syndromes increasing by as much as 500% over the past decade (Willis 2003). The latter is of concern as coral diseases have caused significant impacts in other parts of the world.

Effects from thermal stress are likely to be exacerbated under future scenarios by the gradual acidification of the world's oceans (Orr *et al.* 2005:Raven *et al.* 2005). Recent studies have confirmed that calcification declines with decreasing carbonate ion concentrations, becoming zero at carbonate ion concentrations of approximately 200 μmol kg^{-1} (Langdon 2001:Langdon *et al.* 2000) which occur at atmospheric CO_2 concentrations of about 500 ppm. Reduced growth due to acidic conditions will hinder reef recovery after bleaching events.

Even under a relatively optimistic warming scenario (A1T, 2^{o}C by 2100), corals on the GBR would soon be exposed to regular summer temperatures that exceed the thermal thresholds observed over the past 20 years (Done *et al.* 2003a). Annual bleaching is projected under the A1F1 scenario by 2030, and under A1T by 2050 (Done *et al.* 2003a:Wooldridge *et al.* 2005). Given that the recovery time from a severe bleaching event is at least 10 years (50 years for full recovery), these models suggest that reefs may be dominated by non-coral organisms such as macroalgae by 2050 (Done *et al.* 2003a:Hoegh-Guldberg 1999). Substantial impacts on biodiversity, fishing and tourism are expected. Maintenance of hard coral cover on the GBR will require corals to increase their upper thermal tolerance limits by ~0.1^{o}C per decade. There is currently little evidence that corals have the capacity for this rapid genetic change. Most evidence is to the contrary (Hoegh-Guldberg 1999:Hoegh-Guldberg 2004), but recent initiatives will enhance resilience, e.g. the Reef Water Quality Protection Plan, the Representative Areas Program and the declaration of 33% No-Take Areas within the GBR World Heritage Area.

11.7 Conclusions

An assessment of aggregate vulnerability for key sectors of the region is given in Fig. 11.5 which synthesizes relevant information in sections 11.4 and 11.5 about coping range, adaptive capacity and vulnerability as climate change progresses. It follows the methodology illustrated in Fig 11.1, is based on similar diagrams and concepts elsewhere (Jones *et al.* in press), and emulates the Reasons for Concern diagram of the IPCC TAR. Sectors with a broad coping range and/or adaptive capacity tend to have low vulnerability, e.g. major infrastructure. Sectors with a narrow coping range and/or adaptive capacity tend to have a high vulnerability, e.g. natural ecosystems. Also shown are the three key vulnerability factors identified in Article 2 of the UNFCCC - natural ecosystems, sustainable development and food security.

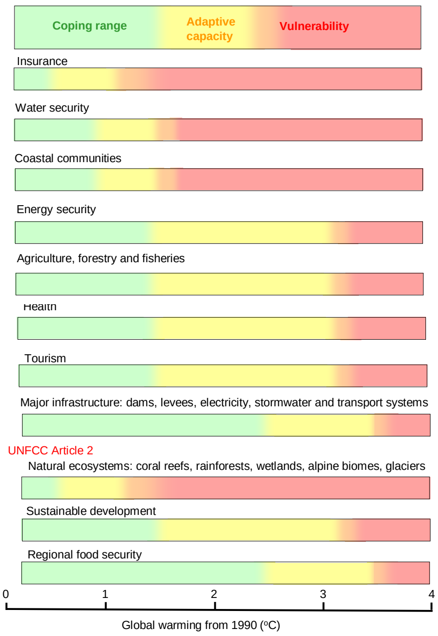

Fig. 11.5: *Schematic diagram assessing the coping range, adaptive capacity and vulnerability of key sectors in Australia and New Zealand expressed in terms of global warming values relative to 1990 (see Tables 11.5 and 11.6)*

Ongoing climate change for Australia and New Zealand is very likely to threaten iconic ecosystems and adaptation options are limited. On the other hand, human systems of the region have considerable adaptive capacity, but this is likely to be limited if warming exceeds 2^{o}C this century. Climate changes are likely to increase vulnerability and threaten economic development and its sustainability in key sectors due to:

- Declining water security
- Increased risks to coastal communities
- Substantial risks to major infrastructure for high-end warmings
- Losses from more extreme events, such heat waves, fire, drought, cyclones and floods
- Loss of ecosystem services, including those for tourism, water supply and fisheries
- New risks to biosecurity (health, pests, disease)

Present growth rates of water use and of coastal development are unlikely to be sustainable. Growing insurance losses are very likely. Additional loss of life from natural hazards (due to increasing climate extremes) is estimated, but because of well-established early warning and rescue services these numbers may not be fully realised. A substantial public health and community response is likely to be needed to avoid the estimated increase of several thousand deaths per year. Substantial shifts in the geographical distribution of food production are very likely. Threats to sustainability are likely to arise from social disruption, new biosecurity hazards and environmental degradation associated with more intensive land use, but there is large capacity for adaptation. Food security of the region is very likely to remain robust with both countries able to produce many times the food they require for internal consumption.

Fig. 11.6 assesses key hotspots for the region, where vulnerability to climate change is likely to be highest. Their selection is based on the following criteria: large impacts, but low adaptive capacity; economically important, with substantial exposed infrastructure and population; subject to other major stresses (e.g. continued rapid population growth, ongoing development, ongoing land degradation, ongoing habitat loss, threats from rising sea level).

Differences in impacts due to emission scenarios are unlikely to emerge until around mid-century. Until then, investment to enhance adaptive capacity can reduce vulnerability. By the end of the century, climate change vulnerability is likely to be substantially greater under higher emission scenarios. Hence, adaptation and mitigation (net greenhouse gas emission reductions) are both necessary to reduce regional vulnerability.

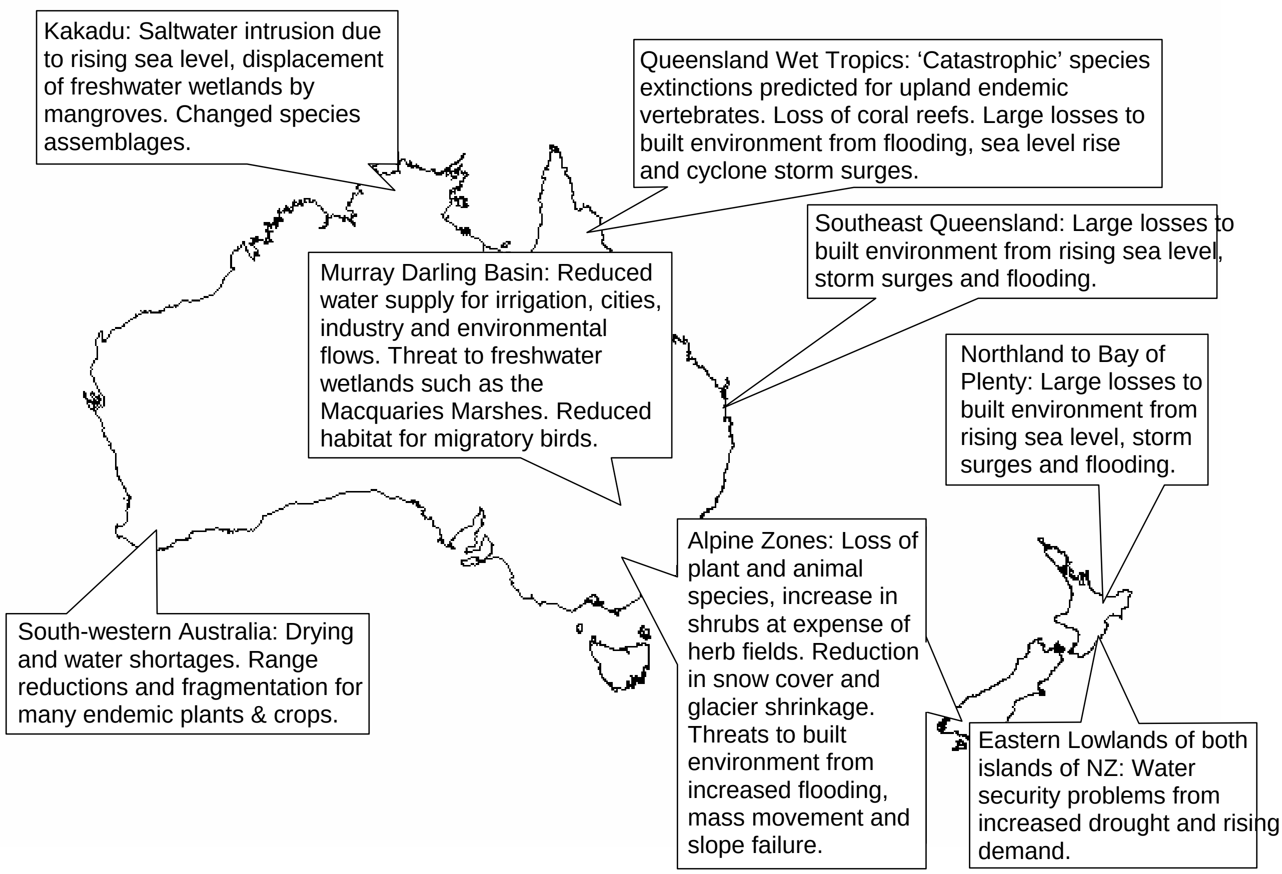

***Fig. 11.6**: Key hotspots for Australia and New Zealand*

11.8 Key uncertainties and research priorities

Uncertainty in potential impacts is partly due to lack of precision in local climate change projections, e.g. in rainfall, rate of sea level rise and extreme weather events. Other uncertainties stem from an incomplete knowledge of natural and human system dynamics, limited resources for undertaking climate impact assessments, and limited knowledge of adaptive capacity, constraints and options (Allen Consulting Group 2005). Research priorities for climate change projections are described in the IPCC Working Group 1 Report. Uncertainties related to vulnerability need to be identified and handled within a risk assessment framework. The main research priorities can be grouped into four categories:

11.8.1 Impacts and vulnerability for critical systems

Based on earlier text in this chapter, research into the following is identified as critical:

- *Natural ecosystems*: Identification of climatic thresholds for natural ecosystems including rates at which autonomous adaptation is possible; long term monitoring and modeling of potential impacts on structure and function of key ecosystems, especially in national parks, the wider conservation estate, and areas important to indigenous peoples; interactions with other stresses such as invasive species; and the potential for human intervention to reduce and manage vulnerability including locations of climatic refugia and landscape linkages.
- *Water*: Impacts and optimum adaptation strategies for projected changes in drought frequency and intensity, and implications for water security within an integrated catchment framework. This includes impacts on long term groundwater levels, water quality, environmental flows and hydro-electricity generation requirements taking into account all other water users and environmental needs.
- *Oceans and fisheries:* Potential climate change impacts, together with changes in ENSO and IPO, on the physical nature of oceans that surround Australia and New Zealand. This includes sea currents, bottom-water formation, upwelling, nutrient supply and impacts of changing oceanography on fish stocks and other marine life.
- *Coastal communities*: Comprehensive vulnerability assessments and adaptation options to provide improved guidance for coastal planning and hazard management. This includes local and regional costs of projected changes in extreme weather events and adaptation planning for very long-term scenarios of sea-level rise beyond 2100.
- *Climate extremes and infrastructure*: Risks to insurance, building, transport, water, mining and communication infrastructure from an increase in extreme weather events. This includes a re-evaluation of probable maximum precipitation and design floods for dams, river protection works and major urban infrastructure.
- *Climate surprises*: Impacts on both natural and managed systems of abrupt climate change, faster than expected sea level rise and changes in ocean circulation. Little is known about potential impacts and vulnerability beyond 2100.

11.8.2 The process of adaptation

There are few integrated sub-regional assessments of impacts and adaptation within the wider context of other multiple stresses, including the roles of national, state and local government. Partnerships between regional/sectoral stakeholders, consultants, government agencies, industries, universities are required to undertake integrated impact assessments and socio-economic risk assessments (Allen Consulting Group 2005). More research is required on the fundamental importance of communities in shaping adaptation from the bottom up (Kenny 2005) and of adaptation options for Maori and indigenous Australian communities, especially for those on traditional lands. Other priorities include reducing vulnerability of low-lying coastal towns, centres dependent on agriculture and ecotourism, tropical and subtropical cities, alpine zones and urban areas facing water shortages (Allen Consulting Group 2005). Research is needed in "hotspot" areas for:

- Regional and local governance mechanisms for increasing adaptive capacity.
- Societal preparedness, including all stakeholders, for adaptation to climate change. Limitations and barriers to adaptation need to be better understood.
- Costs and benefits for the range of adaptation options to reduce vulnerability, including benefits of impacts avoided, co-benefits, side effects, limits and better modeling. Analysis needs to consider implications 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 for different scenarios

Impact scenarios underpin decisions about adaptation options and emission reduction targets. There is only medium confidence in differentiating impacts and vulnerabilities for the different SRES scenarios, largely because of insufficient research and modeling studies. Uncertainties need to be identified and handled within a risk assessment framework. The following analyses are required for the plausible range of SRES and CO_2 stabilisation options:

- Calculation of the probabilities of exceeding critical biophysical and socio-economic thresholds and resultant vulnerability and opportunities.
- Net costs and benefits of climate change, including regional and sectoral differences.
- Impacts on sustainability for vulnerable sectors and sub-regions.
- Better modeling of land use change as climatic boundaries shift, and assessment of the implications for regional development and social change.

11.8.4 Global interactions – trade and immigration

Impacts of climate change and adaptation elsewhere in the world are very likely to affect global trade in commodities, and hence the export-based economies of Australia and New Zealand. However, there is low confidence in potential outcomes. Further studies are needed to assess the impacts of climate change on the region's competitiveness and export mix. Inundation of Pacific and Torres Strait islands is likely to worsen, but the implications for immigration in Australia and New Zealand are unknown.

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