CLIMATE CHANGE IMPACTS ON AUSTRALIA

Key points

This chapter provides a sample of conclusions from detailed studies of Australian impacts. These studies are available in full on the Review's website.

Growth in emissions is expected to have a severe and costly impact on agriculture, infrastructure, biodiversity and ecosystems in Australia.

There will also be flow-on effects from the adverse impact of climate change on Australia's neighbours in the Pacific and Asia.

These impacts would be significantly reduced with ambitious global mitigation.

The hot and dry ends of the probability distributions, with a 10 per cent chance of realisation, would be profoundly disruptive.

This chapter focuses on Australia's exposure and sensitivity to climate change and considers the impacts of climate change on Australia in six key sectors and areas, chosen either because they make a large economic contribution to Australia, or because the impacts on market or non-market values are expected to be pronounced. These areas, sectors and subsectors are presented in Table 6.1.

The Review considers both the direct (section 6.3) and indirect (section 6.4) impacts of climate change on Australia. 'Direct' refers to those impacts that are experienced within Australia's land and maritime boundaries. 'Indirect' refers to impacts experienced in other countries with consequences for Australia. The first focus is on the medians of the probability distributions of the impacts identified by the main climate models. For some sectors the middle-of-the-road assessment is supplemented with analysis of the higher ends of the probability distribution of impacts. The standard IPCC projections, and those based on them, provide cases that correspond most closely to those we expect from no mitigation or from effective global mitigation policies (Table 6.2). The more serious implications of

climatic tipping points are not examined, due to the rapidly developing nature of the relevant science and the limited time available to the Review.

Two time periods are discussed. The first is up to 2030. Impacts over the next two decades can be considered to be locked in because of past and present greenhouse gas emissions. The magnitude of these impacts can only be tempered by our adaptation effort. The second is the period from 2030 to the close of the century. The magnitude of impacts on Australia in 2100 will be determined by international greenhouse gas mitigation and also by Australia's continued adaptation effort.

This chapter offers an illustrative selection rather than a complete assessment of the impacts that are likely to be experienced across Australia. It reflects the insights provided in a series of papers commissioned by the Review, which are available on the Review's website. In addition to the sectors and impacts discussed in this chapter, the papers cover livestock, horticulture, viticulture, forestry, Australia's World Heritage properties, tourism in the south-west of Western Australia, the Ross River and dengue viruses, ports, roads and telecommunications. These studies are an important part of the base from which the modelling of economic impacts on Australia has been developed.

The Review encourages readers to examine the commissioned studies. It has drawn on Australian experts in 30 fields of inquiry (listed in Table 6.1) to provide a wide-ranging collection of analyses of impacts.

Further details on potential impacts can be found in various synthesis reports (CSIRO & BoM 2007; IPCC 2007; PMSEIC 2007; Pittock 2003; Preston & Jones 2006).

Table 6.1 Sectors and areas considered in this chapter

Sector or area	Discussed in this chapter	Modelled by the Review
Resource-based industries and communities		
Subsector or area		
Dryland cropping	Yes – wheat	Yes
Irrigated cropping	Yes – in the Murray- Darling Basin	Yes – nationally
Livestock carrying capacity	No	Yes
Fisheries and aquaculture	No	No
Forestry	No	No
Mining	No	No
Horticulture	No	No
Viticulture and the wine industry	No	No
Australia's World Heritage properties	No	No
Alpine zone of south-east Australia	Yes	No
South-west Western Australia	No	No

Table 6.1 Sectors and areas considered in this chapter (continued)

Sector or area	Discussed in this chapter	Modelled by the Review
Great Barrier Reef	Yes	No
Critical infrastructure		
Subsector or area		
Buildings in coastal settlements	Yes	Yes
Urban water supply	Yes	Yes
Electricity transmission and distribution network	No	Yes
Port operations	No	Yes
Roads and bridges	No	No
Telecommunications	No	No
Cyclone impacts on dwellings	No	Yes
Human health		
Subsector or area		
Temperature-related death and serious illness	Yes – death	Yes
Ross River virus	No	No
Dengue virus	No	Yes
Bacterial gastroenteritis	No	Yes
Health of remote northern Australian Indigenous communities	No	No
Rural mental health	No	No
Ecosystems and biodiversity		
Subsector or area		
A range of ecosystems and impacts on plants and animals	Yes	No
Changes in demand and terms of trade		
	Yes	Yes
Geopolitical stability		
Subsector or area		
Geopolitical instability in the Asia–Pacific region and the subsequent aid and national security response from Australia	Yes	No
Catastrophic events as affect Australia		
	Yes	No
Severe weather events in Australia		
	Yes	No

To illustrate the impacts of climate change out to 2100, the Review considered a set of physically plausible climate outcomes for Australia, as shown in Table 6.2.

Table 6.2 Climate cases considered by the Review

Case	Emissions	Climate sensitivity	Rainfall and relative humidity (surface)	Temperature (surface)	Mean global warming in 2100
Unmitigated 1 Hot, dry	A1FI path	3°C	10th percentile	90th percentile	~4.5°C
Unmitigated 2 Best estimate (median)			50th percentile	50th percentile	
Unmitigated 3 Warm, wet			90th percentile		
550 mitigation Dry	CO ₂ -e stabilised at 550 ppm by		10th percentile	90th percentile	~2°C
550 mitigation 2 Best estimate (median)	2100 (CO ₂ 500 ppm)		50th percentile	50th percentile	
550 mitigation 3 Wet			90th percentile		
450 mitigation Best estimate (median)	CO ₂ -e stabilised at 450 ppm by 2100 (CO ₂ 420 ppm)		50th percentile		~1.5°C

Note: For each of the above cases global mean temperature is presented from a 1990 baseline. To convert to a pre-industrial baseline add 0.5° C.

6.1 Understanding Australia's vulnerability to climate change

The effect of climate change on the Australian population and natural assets will depend on *exposure* to changes in the climate system, *sensitivity* to those exposures and the *capacity to adapt* to the changes to which we are sensitive. These components of *vulnerability* to climate change are illustrated in Figure 6.1.

Australia's level of exposure and sensitivity to the impacts of climate change is high. The extent to which these impacts are realised will depend on the success and timing of global greenhouse gas mitigation and on national adaptation efforts.

As a nation, Australia has a high level of capacity to plan for and respond to the impacts of climate change—that is, its adaptation potential is high.

The consideration of impacts in this chapter assumes some adaptation at the level of an individual or firm.

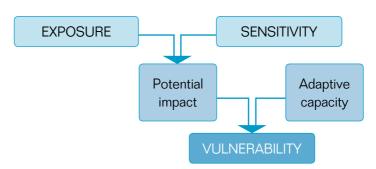


Figure 6.1 Vulnerability and its components

Australia without global mitigation 6.2

If global development continues without effective mitigation, the mainstream science tells us that the impacts of climate change on Australia are likely to be severe.

For the next two decades or so, the major impacts of climate change are likely to include stressed urban water supply and the effects of changes in temperature and water availability on agriculture. All major cities and many regional centres are already feeling the strain of declining rainfall and runoff into streams. Most major cities are beginning to develop high-cost infrastructure for new water sources. In the absence of effective global mitigation, continued investment in expensive new sources of water is likely to be a necessity.

By mid-century, there would be major declines in agricultural production across much of the country. Irrigated agriculture in the Murray-Darling Basin would be likely to lose half of its annual output. This would lead to changes in our capacity to export food and a growing reliance on food imports, with associated shifts from export parity to import parity pricing.

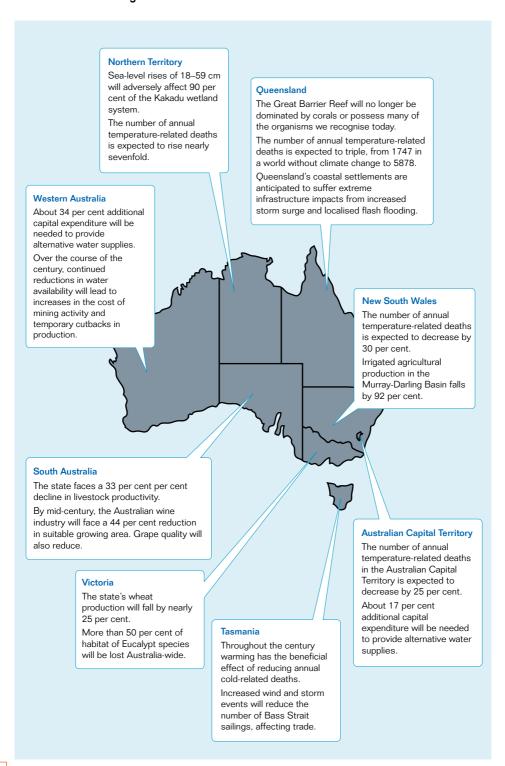
A no-mitigation case is likely also to see, by mid-century, the effective destruction of the Great Barrier Reef and other reef systems such as Ningaloo. The three-dimensional coral of the reefs is likely to disappear. This will have serious ramifications for marine biodiversity and the tourism and associated service industries reliant on the reefs.

By the close of the century, the impacts of a no-mitigation case can be expected to be profound (see Figure 6.2). The increased frequency of drought, combined with decreased median rainfall and a nearly complete absence of runoff in the Murray-Darling Basin, is likely to have ended irrigated agriculture for this region. Depopulation will be under way.

Much coastal infrastructure along the early 21st century lines of settlement is likely to be at high risk of damage from storms and flooding.

Key Australian export markets are projected to have significantly lower economic activity as a result of climate change. This is likely to feed back into significantly lower Australian export prices and terms of trade. As some states

Figure 6.2 State and territory impacts of climate change by 2100 under the no-mitigation case



in our Asia-Pacific neighbourhood are further weakened by the effects of climate change, we can expect Australian defence personnel and police to be more heavily committed in support of peacekeeping operations.

Australians will be substantially wealthier in 2100 in terms of goods and services, despite setbacks from climate change. They are likely to be substantially poorer in terms of environmental amenity of various kinds. Australians over a century of change will have demonstrated the capacity to adapt in various ways. In some regions, retreat will have been the only viable strategy.

If the world were to have agreed and implemented global mitigation so that greenhouse gas concentrations were stabilised at 450 ppm or even 550 ppm CO₂-e, the impacts on Australia could be radically different. The differences are summarised in Table 6.3, again in terms of the median of the probability distributions emerging from the assessments of contemporary mainstream science. The difference between the median of the distributions at 550 ppm to 450 ppm CO₂-e is generally of material importance.

Table 6.3 Differences between probable unmitigated and mitigated futures at 2100—median of probability distributions

	A.	Mitiga	
Sector	No mitigation	550 ppm CO ₂ -e	450 ppm CO ₂ -e
Irrigated agriculture in the Murray- Darling Basin	92% decline in irrigated agricultural production in the Basin, affecting dairy, fruit, vegetables, grains.	20% decline in irrigated agricultural production in the Basin.	6% decline in irrigated agricultural production in the Basin.
Natural resource– based tourism (Great Barrier Reef and Alpine areas)	Catastrophic destruction of the Great Barrier Reef. Reef no longer dominated by corals.	Disappearance of reef as we know it, with high impact to reef-based tourism. Three-dimensional structure of the corals largely gone and system dominated by fleshy seaweed and soft corals.	Mass bleaching of the coral reef twice as common as today.
	Snow-based tourism in Australia is likely to have disappeared. Alpine flora and fauna highly vulnerable because of retreat of snowline.	Moderate increase in snowmaking.	artificial

Table 6.3 Differences between probable unmitigated and mitigated futures at 2100—median of probability distributions (continued)

		Mitigation				
Sector	No mitigation	550 ppm CO ₂ -e	450 ppm CO ₂ -e			
Water supply infrastructure	Up to 34% increase in the cost of supplying urban water, due largely to extensive supplementation of urban water systems with alternative water sources.	Up to 5% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources.	Up to 4% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources.			
Buildings in coastal settlements	Significant risk to coastal buildings from storm events and sea-level rise, leading to localised coastal and flash flooding and extreme wind damage.	Significantly less storm energy in the climate system and in turn reduced risk to coastal buildings from storm damage.	Substantially less storm energy in the climate system and in turn greatly reduced risk to coastal buildings from storm damage.			
Temperature- related death	Over 4000 additional heat-related deaths in Queensland each year. A 'bad-end story' (10% chance) would lead to more than 9500 additional heat-related deaths in Queensland each year.	Fewer than 80 additional heat- related deaths in Queensland each year.	Fewer deaths in Queensland than at present because of slight warming leading to decline in cold-related deaths.			
Geopolitical stability in the Asia–Pacific region	Sea-level rise beginning to cause major dislocation in coastal megacities of south Asia, south-east Asia and China and displacement of people in islands adjacent to Australia.	Substantially lower sea-level rise anticipated and in turn greatly reduced risk to low-lying populations Displacement of people in small isla countries of South Pacific.				

Note: The assessment of impacts in this table does not build in centrally coordinated adaptation. The median of the probability distribution is used for the scenarios considered.

6.3 Direct impacts of climate change on Australia

6.3.1 Resource-based industries and communities

Climate variability has long posed a challenge to Australian communities and industries that rely on access to or use of natural resources. This challenge is now compounded by risks of human-induced climate change. Australia's forestry, agriculture, mining, horticulture and natural resource—based tourism sectors are exploring the implications of climate change for their operations.

Agriculture

Climate change is likely to affect agricultural production through changes in water availability, water quality and temperatures. Crop production is likely to be affected directly by changes in average rainfall and temperatures, in distribution of rainfall during the year, and in rainfall variability. The productivity of livestock industries will be influenced by the changes in the quantity and quality of available pasture, as well as by the effects of temperature increases on livestock (Adams et al. 1999).

Some agricultural impacts are positive. Increases in carbon dioxide concentration will increase the rate of photosynthesis in some plants where there is adequate moisture to support it (Steffen & Canadell 2005). The positive impacts of carbon fertilisation are likely to be restricted by higher temperatures and lower rainfall, which are both expected to become more important through the 21st century. A 10 per cent reduction in rainfall would be likely to remove the carbon dioxide fertilisation benefit (Howden et al. 1999; Crimp et al. 2002). Higher concentrations of carbon dioxide could reduce crop quality, however, by lowering the content of protein and trace elements (European Environment Agency 2004).

Severe weather events, including bushfires and flooding, are likely to reduce agricultural production, through effects on crop yields and stock losses (Ecofys BV 2006). Changes in temperatures are also projected to alter the incidence and occurrence of pests and diseases.

Irrigated agriculture in the Murray-Darling Basin

Note: This section draws heavily on a paper commissioned by the Review on the impacts of climate change to irrigated agriculture in the Murray-Darling Basin. See Quiggin et al. (2008), available at <www.garnautreview.org.au>.

The Murray-Darling Basin covers over one million km² of south-eastern Australia. Water flows from inside the Great Dividing Range from Queensland, New South Wales, the Australian Capital Territory and Victoria, eventually draining into the Southern Ocean off South Australia.

The Basin produces more than 40 per cent of Australia's total gross value of agricultural production, uses over 75 per cent of the total irrigated land in Australia, and consumes 70 per cent of Australia's irrigation water (ABS 2007).

The Review considered the impacts of climate change on several irrigated production groups: beef and sheep products, dairy, other livestock, broad-acre (cotton, rice and other grains), and other agriculture (grapes, stone fruit and vegetables).

A crucial feature of the analysis is that inflows to river systems vary much more than precipitation, and particularly rainfall. Inflows are a residual variable, consisting of water flows that are not lost to evapotranspiration or absorbed by the soil. Quite modest changes in precipitation and evaporation reduce inflows substantially. For the Review's modelling, the reductions in runoff were capped at 84 per cent based on advice from R. Jones (2008, pers. comm.), reflecting the likelihood that there

would continue to be occasional opportunities for irrigated cropping in the north of the Basin.

In aggregating our findings across all production groups, the Review found big differences between the implications of a no-mitigation case and one of global mitigation. The differences between runoff levels and consequently economic activity within the Basin have large implications for the viability of many aspects of life in the Murray-Darling. The change in economic value of production in the Murray-Darling Basin from a world with no human-induced climate change through to 2100 is presented in Table 6.4.

Table 6.4 Decline in value of irrigated agricultural production in the Murray-Darling Basin out to 2100 from a world with no human-induced climate change

	No-mitigation case	Global mitigation with CO ₂ -e stabilisation at 550 ppm by 2100	Global mitigation with CO ₂ -e stabilisation at 450 ppm by 2100	Hot, dry extreme case (the 'bad-end story')
Year		Decline in econom	nic value of production	ı (%)
2030	12	3	3	44
2050	49	6	6	72
2100	92	20	6	97

Note: Moving from left to right, the first three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see Table 6.2 for a description of each case). The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

In an unmitigated case, irrigation will continue in the Basin for some time. Later in the century, decreasing runoff and increased variation in runoff are likely to limit the Basin's ability to recharge storages. By 2030, economic production falls by 12 per cent. By 2050 this loss increases to 49 per cent and, by 2100, 92 per cent has been lost due to climate change. Beyond 2050, fundamental restructuring of the irrigated agriculture industry will be required.

If the world were to achieve greenhouse gas concentrations of 450 ppm $\rm CO_2$ -e by 2100, it is likely that producers would be able to adjust their production systems with technological improvement to adapt with little cost to overall economic output from the Basin (such adaptation efforts have not been modelled). By 2030, economic production falls by 3 per cent. By 2050, this loss increases to 6 per cent. By 2100, 20 per cent has been lost.

While the differences between economic output in the 450 and 550 ppm $\rm CO_2$ -e mitigation cases are not substantial until the end of the century, the additional considerations of environmental flows and water quality in the Basin create a presumption that there is greater value in higher degrees of global mitigation.

In the 10th percentile hot, dry case, in the absence of mitigation, by 2050 the rivers in the Basin would be barely flowing. This would be well outside the range of natural variation observed in the historical record. By 2070 all except one

catchment would be operating on the maximum possible reduction on which the model has been allowed to run (84 per cent decline in runoff from baseline). By 2030 economic production falls by 44 per cent. By 2050, 72 per cent of production has been lost. By 2100, 97 per cent has been lost. Only opportunistic upstream production might persist in 2100.

Box 6.1 Is there potential for a positive irrigation story? The possibility of a wetter Murray-Darling Basin

Mainstream science says that there is a 10 per cent chance of Australia becoming wetter under a no-mitigation case. This would be associated with a significant increase in rainfall in the northern part of the Murray-Darling Basin by 2050 (that is, a 20-30 per cent increase). The increased water supply flowing south would support higher levels of economic activity.

Under a warm, wet no-mitigation case, the average value of irrigated agricultural production in the Murray-Darling Basin would be less than 1 per cent greater than with no human-induced climate change.

Dryland cropping: wheat

Note: This section draws heavily on a paper commissioned by the Review on the impacts of climate change to Australia's wheat industry. See Crimp et al. (2008), available at <www.garnautreview.org.au>.

Wheat is the major crop in Australia in terms of value (\$5.2 billion in 2005-06), volume (25 Mt in 2005-06) and area (12.5 Mha in 2005-06) (ABARE 2008). On average, over the 10 years to 2005-06, about 80 per cent of the Australian wheat harvest has been exported, worth on average about \$3.2 billion a year (ABARE 2008). Yields are generally low due to low rainfall, high evaporative demand and low soil fertility. Thus the Australian wheat industry is highly sensitive to climatic influences. Average crop yields can vary by as much as 60 per cent in response to climate variability (Howden & Crimp 2005).

Both quantity and quality (protein content) determine the wheat crop's value. A range of studies indicate that grain protein contents are likely to fall in response to combined climate and carbon dioxide changes. There could be substantial protein losses (Howden et al. 2001), which would lower prices unless increased fertiliser application or more frequent pasture rotations were incorporated to reduce the effect. Increases in heat shock also may reduce grain quality by affecting doughmaking qualities (Crimp et al. 2008).

The Review considered 10 study sites to understand the difference in magnitude of impacts on wheat yield between a no-mitigation case and one of global mitigation. As Table 6.5 shows, there are markedly different yield impacts between regions and also between the no-mitigation case and the 550 and 450 global mitigation cases.

Table 6.5 Percentage cumulative yield change from 1990 for Australian wheat under four climate cases

	No-mitigat	ion case		h ČO ₂ -e sation at	wi stabili	nitigation th CO ₂ -e sation at by 2100	Hot, dry extreme case (the 'bad-end story')		
			Cum	ulative yie	ld change	(%)			
	2030	2100	2030	2100	2030	2100	2030	2100	
Dalby, Qld	8.2	-18.5	4.8	-1.0	1.6	-3.7	-6.6	-100.0	
Emerald, Qld	7.2	-10.1	4.4	0.0	1.8	-2.5	-7.6	-100.0	
Coolamon, NSW	11.6	1.9	9.9	12.3	8.2	7.4	1.2	-100.0	
Dubbo, NSW	8.1	-5.9	6.1	6.7	4.0	2.3	-2.4	-100.0	
Geraldton, WA	12.5	22.4	9.7	5.6	6.9	2.6	9.5	-16.9	
Birchip, Vic.	14.8	-24.1	10.7	1.5	6.8	-0.3	-0.7	-100.0	
Katanning, WA	15.6	16.8	14.8	18.9	13.9	14.6	-15.7	-18.7	
Minnipa, SA	0.8	-23.9	-3.4	-15.3	-7.4	-15.7	-13.8	-82.0	
Moree, NSW	20.6	10.9	17.7	14.1	14.8	10.8	6.4	-79.2	
Wongan Hills, WA	16.1	-21.8	13.0	5.5	10.0	4.4	5.5	-100.0	

Note: Moving from left to right, the first three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see Table 6.2 for a description of each case). The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

Under the no-mitigation case and through adaptive management, much of Australia could experience an increase in wheat production by 2030. This would involve moving planting times in response to warming and selection of optimal production cultivars. Increases would also result from higher carbon dioxide concentrations. Over time, even with adaptive management, a number of regions would experience substantial declines in wheat yield.

Later in this century, the benefits of carbon dioxide fertilisation and adaptive management are likely to have been negated by increasing temperatures and declining available water.

In some sites in Western Australia (Geraldton and Katanning), the rainfall changes with no mitigation would improve yields. This unexpected result arises because subsoil constraints to growth, for example salinity, respond to declines in rainfall. This beneficial impact is only associated with modest rainfall declines (that is, less than 30 per cent of the long-term annual mean). Yields are negatively affected with larger declines.

Under the global mitigation cases, the carbon dioxide fertilisation effect is less marked and early yield increases are lower than for the no-mitigation case. However, for those regions that under the no-mitigation case were facing large declines in yield, this impact is reduced substantially with global mitigation by 2100.

The hot, dry extreme case has devastating consequences for the Australian wheat industry, leading to complete abandonment of production for most regions.

The cases above use average change in temperature and rainfall, and therefore available runoff, as the key variables. The approach implicitly assumes that there is no change in either the frequency or intensity of El Niño and La Niña events with climate change. There is concern among mainstream scientists, however, that the frequency of El Niño events may increase, thus changing the proportion of good and bad years. This would cause the net impact on wheat to be different from that of the average change in rainfall (Crimp et al. 2008). A world of climate change would be associated with less predictability and greater variability of rainfall, generating large problems for management of farm systems to make optimal use of available water resources.

Natural resource-based tourism

Note: This section draws heavily on a paper commissioned by the Review on the impacts of climate change to the Great Barrier Reef and associated tourism industries. See Hoegh-Guldberg and Hoegh-Guldberg (2008), available at <www.garnautreview.org.au>.

The Australian tourism industry generated value added of \$37.6 billion per annum or 3.7 per cent of GDP for 2006–07 (ABS 2008a). International tourism generated \$21 billion of export income in 2005-06, or 10.5 per cent of total exports (ABS 2008b).

In 2006-07, 482 000 people were employed in the tourism industry, or 4.7 per cent of total employment (ABS 2008a). Tourism is often the major nonagricultural source of livelihoods in rural and regional areas, and is the major industry in some regions.

Australia's natural landscapes are important to the Australian tourism industry. The Great Barrier Reef and rainforests of tropical north Queensland, Kakadu, the deserts of Central Australia, the Ningaloo Reef and coastal environs of southwest Western Australia, and the alpine regions of New South Wales, Victoria and Tasmania (see Box 6.2) are leading examples of tourist attractions defined by features of the natural environment. Many are World Heritage areas, which Australia has international legal obligations to protect.

Each of these attractions, and many that are less well known, would be significantly affected in a future of unmitigated climate change. Climate change would lead to loss of attractions; loss of quality of attractions; costs of adaptation; increased cost for repair, maintenance and replacement of tourism infrastructure; and increased cost for developing alternative attractions (Sustainable Tourism Cooperative Research Centre 2007).

Some tourist activities may benefit from drier and warmer conditions—beachbased activities, viewing of wildlife, trekking, camping, climbing and fishing outside the hottest times of the year. However, even in these cases, greater risks to tourism are likely from increases in hazards such as flooding, storm surges, heatwaves, cyclones, fires and droughts.

In a study by Hoegh-Guldberg (2008), 77 Australian tourism regions were assessed for prospective risk of climate change. The following three were identified as the most threatened:

- Tropical north Queensland, the hub of Great Barrier Reef tourism, contains the coral reef complex, severely threatened rainforest areas, beaches in danger of inundation and increasing storm damage. There are threats to tourism from increased incidence of bushfires and increased ultraviolet radiation. The threats to the region are exacerbated by a high reliance on international holiday tourism, which could be relatively easily diverted elsewhere.
- South-west Western Australia is the scene of Australia's only internationally recognised biodiversity hotspot, one of 34 in the world. It has high risk ratings based on the greatest diversity of vulnerable native flora, a vulnerable wine industry and, together with the Murray-Darling Basin, the greatest salinity problem in the country. It attracts a large number of holiday tourists, but few are international visitors.
- In the Top End of the Northern Territory, national parks and wetlands are at risk, and tourism is threatened by increased ultraviolet radiation and increased exposure to disease.

Australia is likely to be greatly diminished as an international tourist destination by climate change.

Domestically, the loss of tourism income from one region, such as the Great Barrier Reef, does not necessarily equate with overall loss of tourism income for Australia. Some of the tourism expenditure will be diverted to other Australian regions.

Box 6.2 Alpine tourism in south-east Australia

The alpine resorts in Australia are located in areas of great environmental sensitivity and are at severe risk from climate change. The total alpine environment in Australia is small: approximately 0.2 per cent of the total land mass, with alpine areas restricted to New South Wales, Victoria and Tasmania.

The alpine resorts generate 2 per cent of total Australian tourist activity (National Institute of Economic and Industry Research 2006). The industry is characterised by many small businesses, a large proportion of which only operate during the snow sports season, a period of around four months.

In the alpine regions of south-east Australia, natural snow conditions over the past 35 years have been in slow but steady decline, with increased maximum and minimum temperatures across many locations (Hennessy et al. 2003). This has created greater reliance by the ski industry on the production of artificial snow to service tourism demand (for snow depths and season length). There have also been implications for sensitive alpine flora and fauna due to changing snow conditions.

Box 6.2 Alpine tourism in south-east Australia (continued)

The no-mitigation case would see the average snow season contract by between 85 to 96 per cent by 2050 (Hennessy et al. 2003) and disappear before the end of the century. Conversely, if the international community were to limit concentrations to 450 ppm CO₂-e by 2100, snow depths and coverage would fall only marginally. In this latter case, it is likely that alpine resorts could continue their current operations with minimal technological adaptation. Stabilisation at 550 ppm CO₂-e by 2100 would be likely to result in maintenance of snow depth and coverage at higher elevations. However, the alpine areas located at lower elevations would experience a loss of snow coverage as the snowline moved to higher ground.

As many as a third of all visitors to the alpine region visit outside the traditional snow season, to enjoy the unique flora and fauna, as well as recreational activities such as hiking, camping and fishing. However, summer recreational activities are also at increasing risk from bushfires and storm and wind events.

6.3.2 Critical infrastructure

Climate change will have wide-ranging and significant impacts on the infrastructure critical to the operation of settlements and industry across Australia. This will occur through changes in the average climate and changes in the frequency and intensity of severe weather events.

Buildings and infrastructure being constructed will have functional lives of many decades. An understanding of the anticipated impacts from climate change over the course of the century is helpful to inform construction decisions being made now, and to avoid increased operation and maintenance costs in future, or the early retirement of infrastructure.

This section presents the impacts of climate change on two key forms of infrastructure:

- water supply infrastructure in major cities
- buildings in coastal settlements.

The Review offers a broad commentary on the magnitude of impacts in a no-mitigation case compared to a future with global mitigation.

Water supply infrastructure in major cities

Note: This section draws heavily on a paper commissioned by the Review on the impacts of climate change on urban water supply in major cities. See Maunsell (2008), available at <www.garnautreview.org.au>.

Nearly all major Australian cities are already experiencing the effects of reductions in rainfall on water supplies. All capital cities except Darwin and Hobart are now relying on severe restrictions on water use. Some regional cities are facing sharply diminished supply and extreme restrictions (Marsden Jacob Associates 2006).

Under a no-mitigation case, with outcomes near the median of the probability distributions generated by mainstream Australian science, most major population centres across the country will be required to supplement their water supply system with substantial new water sources through the 21st century. As shown in Table 6.6, there will be differing impacts across the states and territories, with Western Australia and South Australia the most severely affected by climate change. The development of new water sources for Perth and Adelaide is required now.

In a case of global mitigation, the reduced level of temperature increase relative to business as usual lessens the changes in rainfall and evaporative demand, and therefore places less stress on water supply. However, a low level of supplementation would still be required across most major centres.

Table 6.6 Magnitude of impacts to water supply infrastructure in major cities under four climate cases

	No-mitigation case		with stabilis	nitigation CO ₂ -e sation at 1 by 2100	with (stabilis	nitigation CO ₂ -e ation at by 2100	Hot, dry extreme case (the 'bad-end story')				
Region	2030	2100	2030	2100	2030	2100	2030	2100			
ACT	М	Е	L	М	L	М	Н	Е			
NSW	Н	Е	L	Н	L	Н	Н	Е			
NT	L	Н	N	L	N	N	L	Е			
Qld	Н	Е	L	Н	L	Н	Н	Е			
SA	Е	Е	М	Е	М	Е	Е	Е			
Tas.	N	М	N	N	N	N	N	Е			
Vic.	Н	Е	М	Н	L	L H	Н	Е			
WA	Е	Е	М	Е	М	Е	Е	Е			
Magnitud	Magnitude of net impact										
N Neu	ıtral	L Low	М	Moderate	Н	High	E Ex	treme			

Note: Moving from left to right, the first three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see Table 6.2 for description of each case). The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

A description of each level of impact is provided in Box 6.3.

Box 6.3 Infrastructure impacts criteria

The Review's assessment of impacts of climate change on infrastructure is based on determination of net impact to capital expenditure, operational expenditure and productivity. The criteria for this assessment are presented in Table 6.7.

Table 6.7 Infrastructure impacts criteria

	Magnitude of net impact	Description of impact
N	Neutral	No change in capital expenditure, operational expenditure or productivity.
L	Low	Minor increase in capital expenditure and operational costs but no significant change to cost structure of industry. Minor loss in productivity.
		For example, minor loss in port productivity due to increased downtime of port operations.
М	Moderate	Moderate increase in capital and operational expenditure with a minor change to cost structure of industry. Moderate loss in productivity.
		For example, moderate increase in capital and operational expenditure for electricity transmission and distribution due to increased design standards, maintenance regimes and damage from severe weather events.
Н	High	Major increase in capital and operational expenditure with a significant change to cost structure of industry. Major loss of productivity.
		For example, major increase in capital expenditure for increased building design standards for new and existing residential and commercial buildings.
Е	Extreme	Extreme increase and major change to cost structure of industry with an extreme increase in operational and maintenance expenditure. Extreme loss of productivity.
		For example, extreme increase in capital expenditure from significant investment in new water supply infrastructure.

Buildings in coastal settlements

Note: This section draws heavily on a paper commissioned by the Review on the impacts of climate change to buildings in coastal settlements. See Maunsell (2008), available at <www.garnautreview.org.au>.

More than 80 per cent of the Australian population lives within 50 km of the coastline. For most of the past century, coastal regions have experienced significant growth and are projected to continue to show the most rapid population growth (IPCC 2007). Without mitigation, the impacts of climate change on these regions are likely to be substantial (Table 6.8).

The increased magnitude of storm events and sea-level rise under a no-mitigation case is likely to exert significant pressure on coastal infrastructure through storm damage and localised flash flooding. This would cause immediate damage to assets, particularly building contents, and accelerate the degradation of buildings.

Changes in temperature, and extreme rainfall and wind, may also accelerate degradation of materials, structures and foundations of buildings, thereby reducing the life expectancy of buildings and increasing their maintenance costs. Low soil moisture before severe rainfall events would increase the impact and magnitude of flooding. In between flooding episodes, the low levels of soil moisture would lead to increased ground movement and cause building foundations to degrade.

In the medium term (2030 to 2070) the cost of climate change for coastal settlements would mainly arise from repair and increased maintenance, clean-up and emergency response. Later in the century, costs for preventive activity are likely to be higher. There will be large costs associated with altered building design, sea-wall protection and higher capital expenditure for improved drainage.

Table 6.8 Magnitude of impacts on buildings in coastal settlements under four climate cases

		No-mitigation case		5	Global mitigation with CO ₂ -e stabilisation at 550 ppm by 2100		Global mitigation with CO ₂ -e stabilisation at 450 ppm by 2100			Hot, dry extreme case (the 'bad-end story')					
Reg	ion	2030	2	2100	2	030	2100)	2030		210	0	203	0	2100
NS	N	М		Н		М	М		Ν	1	Μ		М		Е
NT		L		М		L	М		L	-	L		L		Н
Qld		М		Е		М	М		Ν	1	Μ		М		Е
SA		L		Н		L	М		L	-	L		L		Н
Tas.		L		М		L	М		L	-	N		L		М
Vic.		М		Н		М	М		٨	1	L		М		Н
WA		L		М		L	М		L	-	L		L		Н
Maç	Magnitude of net impact														
Ν	Neu	ıtral	L	Low		М	Moderate			Н	High		Е	Ex	treme

Note: Moving from left to right, the first three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see Table 6.2 for description of each case). The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

A description of each level of impact is provided in Box 6.3.

Changes to building design are expected to improve the resilience of buildings in the latter part of the century as stock is renewed or replaced. However, even with improved design and use of materials, the magnitude of climate change leading up to 2100 under a no-mitigation case is expected to generate high impacts.

In a future with global mitigation, the reduced level of temperature increase would lessen the magnitude of temperature-driven storm energy in the Australian climate system. This would greatly reduce impacts from storm surge, severe rainfall and flash flooding. As shown in Table 6.8, overall impacts to buildings in coastal settlements would be substantially lower under the global mitigation cases.

Human health 6.3.3

Note: This section draws heavily a paper commissioned by the Review on the impacts of climate change to human health. See Bambrick et al. (2008), available at <www.garnautreview.org.au>.

Climate change is likely to affect the health of Australians over this century in many ways. Some impacts, such as heatwaves, would operate directly. Others would occur indirectly through disturbances of natural ecological systems, such as mosquito population range and activity.

Most health impacts will impinge unevenly across regions, communities and demographic subgroups, reflecting differences in location, socio-economic circumstances, preparedness, infrastructure and institutional resources, and local preventive (or adaptive) strategies. The adverse health impacts of climate change will be greatest among people on lower incomes, the elderly and the sick. People who lack access to good and well-equipped housing will be at a disadvantage.

The main health risks in Australia include:

- impacts of severe weather events (floods, storms, cyclones, bushfires)
- impacts of temperature extremes, including heatwaves
- vector-borne infectious diseases (for example, dengue virus and Ross River virus)
- food-borne infectious diseases (including those due to Salmonella and Campylobacter)
- water-borne infectious diseases and health risks from poor water quality
- diminished food production and higher prices, with nutritional consequences
- increases in air pollution (for example, from bushfire smoke)
- changes in production of aeroallergens (spores, pollens), potentially exacerbating asthma and other allergic respiratory diseases
- mental health consequences and the emotional cost of social, economic and demographic dislocation (for example, in parts of rural Australia, and through disruptions to traditional ways of living in remote Indigenous communities).

Temperature-related death

Exposure to prolonged ambient heat promotes various physiological changes, including cramping, heart attack and stroke. People most likely to be affected are those with chronic disease (such as cardiovascular disease or type 2 diabetes). These tend to be older people.

The effects of climate change on temperature-related mortality and morbidity are highly variable over place and time. Temperature-related deaths and hospitalisations may fall at some places and times (due to fewer cold-related deaths) in some parts of Australia, but increase in others. Table 6.9 illustrates the change in the number of temperature-related deaths in Australia over time under four different climate change cases. In Australia as a whole and across all cases, small declines in total annual temperature-related deaths are expected in the first half of the century due to decreased cold-related sickness and death. The winter peak in deaths is likely to be overtaken by heat-related deaths in nearly all cities by mid-century (McMichael et al. 2003).

Table 6.9 Change in likely temperature-related deaths due to climate change

	Baseline – a world with no human-induced climate change		world with no human-induced			iigation ise	Glo mitiga with C stabilis at 550 p 210	ation CO ₂ -e sation opm by	Glol mitiga with C stabilis at 450 by 21	otion O ₂ -e cation ppm	Hot, extrem (the 'ba	e case ad-end
				Number	of temper	ature-rela	ated death	s				
Region	2030	2100	2030	2100	2030	2100	2030	2100	2030	2100		
ACT	300	333	280	250	278	285	276	295	275	262		
NSW	2 552	2 754	2 3 1 6	1 906	2 290	2 224	2 268	2 334	2 255	2 040		
NT	63	61	63	407	63	93	64	76	64	768		
Qld	1 399	1 747	1 276	5 878	1 274	1 825	1 278	1 664	1 286	11 322		
SA	806	811	770	704	766	735	762	750	758	740		
Tas.	390	375	360	240	357	313	354	327	352	211		
Vic.	1 788	1 966	1 632	1 164	1 614	1 586	1 599	1 673	1 589	1 012		
WA	419	515	418	685	419	529	419	519	420	835		
Australia	7 717	8 562	7 155	11 234	7 061	7 590	7 020	7 638	6 999	17 190		

Note: Moving from left to right, in the baseline case any increase in number of deaths shown is due to the expanding and ageing of the population. The next three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see Table 6.2 for a description of each case). The final case (right-hand side) is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme).

For the no-mitigation case there is a large national increase in temperaturerelated deaths in the second half of the century. Much of the increase is attributable to expected deaths in Queensland and the Northern Territory. The large increases in deaths between 2030 and 2100 are avoided under the global mitigation cases.

The hot, dry extreme case would lead to twice as many temperature-related deaths annually when compared with no climate change. In Victoria, Tasmania and New South Wales, even under the hot, dry extreme case, temperature-related deaths are reduced relative to no climate change because those populations are more susceptible to cold than to heat (K. Dear 2008, pers. comm.).

6.3.4 Ecosystems and biodiversity

Note: This section draws heavily on a paper commissioned by the Review on the impacts of climate change to ecosystems and biodiversity. See Australian Centre for Biodiversity (2008), available at <www.garnautreview.org.au>.

Natural biological systems in Australia have been dramatically altered by human actions. The added stressors from climate change would exacerbate existing environmental problems, such as widespread loss of native vegetation, overharvesting of water and reduction of water quality, isolation of habitats and ecosystems, and the influence of introduced plant and animal pests.

Some species can tolerate the changes where they are or adapt to change. Other species will move to more suitable habitat if possible. Some species may dwindle in numbers in situ, threatening their viability as a species and ultimately leading to extinction.

For biological systems, climate change will affect:

- physiology (individual organisms)
- timing of life cycles (phenology)
- population processes, such as birth and death rates
- shifts and changes in distribution (dispersal and shifts in geographic range)
- potential for adaptation (rapid evolutionary change).

These effects on individual organisms and populations cascade into changes in interactions among species. Changes in interactions further heighten extinction rates and shifts in geographic range. The ultimate outcomes are expected to be declines in biodiversity favouring weed and pest species (a few native, most introduced) at the expense of the rich variety that has developed naturally across Australia.

Many plant and animal species depend on the wide dispersal of individuals for both demographic processes and interchange of genes to avoid inbreeding effects. Over large areas and long periods, many species will respond (and have already responded) to climate change by moving, resulting in geographic range shifts. However, some species will not be able to migrate or adapt to climate change because they lack a suitable habitat into which to move, have limited or impeded mobility or do not possess sufficient and necessary genetic diversity to adapt. For these species, their geographic ranges would contract, heightening the risk of extinction.

Australia's high-altitude species are at risk. These species are already at their range limits due to the low relief of Australia's mountains, and lack suitable habitat to which to migrate. For example, a 1°C temperature rise, anticipated in about 2030 for south-eastern Australia under all cases, will eliminate 100 per cent of the habitat of the mountain pygmy possum (*Burramys parvus*). This species cannot move to higher mountains because there are no such mountains, and will not be able to stay where it is because it does not have the capacity to adapt to warmer temperatures. The potential for extinction is high.

The wet tropics of far north Queensland are also likely to face high levels of extinction. It is estimated that a 1°C rise in temperature, anticipated before 2030 under all four cases, could result in a 50 per cent decrease in the area of highland rainforests (Hilbert et al. 2001). A 2°C rise in average temperatures (anticipated by about 2050 for the no-mitigation case, 2070 for 550 ppm $\rm CO_2$ -e, and after 2100 for 450 ppm $\rm CO_2$ -e) would force all endemic Australian tropical rainforest vertebrates to extinction (Australian Centre for Biodiversity 2008).

Sea-level rise would have implications for coastal freshwater wetlands that may become inundated and saline. A well-documented example is the World Heritage and Ramsar Convention–recognised wetlands of Kakadu National Park in the Northern Territory. The wetland system at Kakadu depends on a finely balanced interaction between freshwater and marine environments. In places, the natural levees that act as a barrier between Kakadu's freshwater and saltwater systems are only 20 cm high. Sea-level rises of another 59 cm (see Chapter 4) by 2100 would adversely affect 90 per cent of the Kakadu wetland system. The area supports more than 60 species of water birds, which congregate around freshwater pools in the wetlands. The coastal wetlands are important nursery areas for barramundi, prawns and mud crabs, and are important breeding habitats for crocodiles, turtles, crayfish, water snakes and frogs. Fundamental changes in the ecological function of the national park will place severe pressure on many species of plants and animals.

Increased warming of Australia's oceans has pushed coral reefs above their thermal tolerance. This has resulted in episodes of mass coral bleaching (see Box 6.4).

Box 6.4 **Climate change and the Great Barrier Reef**

The Great Barrier Reef is the world's most spectacular coral reef ecosystem. Lining almost 2100 kilometres of the Australian coastline, the Reef is the largest continuous coral reef ecosystem in the world. It is home to a wide variety of marine organisms including six species of marine turtles, 24 species of seabirds, more than 30 species of marine mammals, 350 coral species, 4000 species of molluscs and 1500 fish species. The total number of species is in the hundreds of thousands. New species are described each year, and some estimates suggest that we may be familiar with less than 50 per cent of the total number of species that live within this ecosystem.

In addition to housing a significant part of the ocean's biodiversity, coral reefs provide a barrier that protects mangrove and sea grass ecosystems, which in turn provide habitat for a large number of fish species. This protection is also important to the human infrastructure that lines the coast.

The Great Barrier Reef is threatened by increased nutrients and sediments from land-based agriculture, coastal degradation, pollution and fishing pressure. Climate change is an additional and significant stressor.

The IPCC recognises coral reefs globally as highly threatened by rapid human-induced climate change (IPCC 2007). The Great Barrier Reef waters are 0.4°C warmer than they were 30 years ago (Lough 2007). Increasing atmospheric carbon dioxide has also resulted in 0.1 pH decrease (that is, the ocean has become more acidic).

These changes have already had major impacts. Short periods of warm sea temperature have pushed corals and the organisms that support their development above their thermal tolerance. This has resulted in episodes of mass coral bleaching that have increased in frequency and intensity since they were first reported in the scientific literature in 1979 (see Brown 1997; Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2007).

The Great Barrier Reef has been affected by coral bleaching as a result of heat stress six times over the past 25 years. Recent episodes have been the most intense and widespread. In the most severe episode to date, in 2002, more than 60 per cent of the reefs within the Great Barrier Reef Marine Park were affected by coral bleaching, with 5-10 per cent of the affected corals dying.

Consideration has recently been given to how reef systems will change in response to changes in atmospheric greenhouse gas composition. If atmospheric carbon dioxide levels stabilise at 420 ppm and the sea temperatures of the Great Barrier Reef increase by 0.55°C, mass bleaching events will be twice as common as they are at present.

Box 6.4 Climate change and the Great Barrier Reef (continued)

If atmospheric carbon dioxide concentrations increase beyond 450 ppm, together with a global temperature rise of 1°C, a major decline in reefbuilding corals is expected. Under these conditions, reef-building corals would be unable to keep pace with the rate of physical and biological erosion, and coral reefs would slowly shift towards non-carbonate reef ecosystems. Reef ecosystems at this point would resemble a mixed assemblage of fleshy seaweed, soft corals and other non-calcifying organisms, with reefbuilding corals being much less abundant, even rare. As a result, the three-dimensional structure of coral reefs would slowly crumble and disappear.

Depending on the influence of other factors such as the intensity of storms, this process may happen either slowly or rapidly. Significantly, this has happened relatively quickly (over an estimated 30 to 50 years) on some inshore Great Barrier Reef sites.

A carbon dioxide concentration of 500 ppm or beyond, and likely associated temperature change, would be catastrophic for the majority of coral reefs across the planet. Under these conditions the three-dimensional structure of the Great Barrier Reef would be expected to deteriorate and would no longer be dominated by corals or many of the organisms that we recognise today. This would have serious ramifications for marine biodiversity and ecological function, coastal protection and the tourism and associated service industries reliant on the reefs. (Hoegh-Guldberg & Hoegh-Guldberg 2008)

The disruption of ecosystems, species populations and assemblages will also affect ecosystem services—the transformation of a set of natural assets (soil, plants, animals, air and water) into things that we value. These include clean air, clean water and fertile soil, all of which contribute directly to human health and wellbeing. The productivity of some of our natural resource—based industries, including agriculture and tourism, depends on them.

The vast majority of ecosystem services are far too complex to produce through engineering, even with the most advanced technologies. Their benefits are poorly understood but seem to be large. Human-induced environmental change has already disrupted ecosystem processes. Climate change will further degrade the services provided. The complex biotic machinery that provides ecosystem services is being disrupted and degraded. The consequences are impossible to predict accurately.

Indirect impacts of climate change on 6.4 Australia

Australia will be affected indirectly by climate change as experienced by other countries.

6.4.1 International trade impacts for Australia

Climate change is likely to affect economic activity in other countries. It will therefore affect the supply of imports to Australia and demand for Australian exports and consequently Australia's terms of trade (the ratio of Australian export to import prices). The Review's modelling indicates that Australia's terms of trade are affected much more adversely than any other developed country by climate change.

The Review's modelling indicates that China, India, Indonesia and other Asian economies will be by far Australia's major export markets long before the end of the 21st century. These countries are expected to be relatively badly affected by climate change.

Climate change would be associated with a decline in international demand for Australia's mineral and energy resources and agricultural products.

The decline in Australia's terms of trade as a result of unmitigated climate change will be driven primarily by falls in the prices received for coal and other minerals. These and other commodities are projected to account for more than 60 per cent of the value of Australia's exports in 2100 in the absence of climate change impacts.1

Geopolitical stability in Asia and the Pacific 6.4.2 region

Note: This section draws heavily on a paper commissioned by the Review on the impacts of climate change to Australia's security. See Dupont (2008), available at <www.garnautreview.org.au>.

Weather extremes and large fluctuations in rainfall and temperatures have the capacity to refashion Asia's productive landscape and exacerbate food, water and energy scarcities in Asia and the south-west Pacific. Australia's immediate neighbours are vulnerable developing countries with limited capacity to adapt to climate change.

Climate change outcomes such as displacement of human settlements by sealevel rise, reduced food production, water scarcity and increased disease, while immensely important in themselves, also have the potential to destabilise domestic and international political systems in parts of Asia and the south-west Pacific.

Should climate change coincide with other transnational challenges to security, such as terrorism or pandemic diseases, or add to pre-existing ethnic and social tensions, the impact will be magnified.

The problems of its neighbours can quickly become Australia's, as recent history attests. Over the past decade, Australia has intervened at large cost in Bougainville, Solomon Islands and Timor-Leste in response to political and humanitarian crises. Responding to the regional impacts of climate change will require cooperative regional solutions and Australian participation.

Food security

Climate change is likely to affect food production in the Asia–Pacific region for five main reasons:

- Increased temperatures could reduce crop yields by shortening growing seasons and accelerating grain sterility in crops.
- Marine ecosystems could experience major migratory changes in fish stocks and mortality events in response to rising temperatures. Fish is the primary source of protein for more than one billion people in Asia.
- Shifts in rainfall patterns could disrupt flows in rivers used for irrigation, accelerate erosion and desertification and reduce crop and livestock yields.
- Rising sea levels could inundate and make unusable fertile coastal land.
- An increase in the intensity or frequency of severe weather events could disrupt agriculture.

There is particular vulnerability associated with any disruption to the South Asian monsoon, drying of the northern China plain, and disruption to the flows of Asia's great rivers arising out of deglaciation of the Himalayas and the Tibetan plateau (see Box 6.5).

The Consultative Group on International Agricultural Research (2002) has predicted that food production in Asia will decrease by as much as 20 per cent due to climate change. These forecasts are in line with IPCC projections showing significant reductions in crop yield (5–30 per cent compared with 1990) affecting more than one billion people in Asia by 2050 (Parry et al. 2004, cited in IPCC 2007).

Poorer countries with predominantly rural economies and low levels of agricultural diversification will be at most risk. They have little flexibility to buffer shifts in food production. Higher worldwide food prices associated with climate change, its mitigation and other factors will diminish the opportunity to seek food security from international trade—compounding biophysical constraints on production and negatively affecting both rural and urban poor (Consultative Group on International Agricultural Research 2002).

In these circumstances, in the absence of international food trade liberalisation, it is likely that price volatility on world markets will increase, especially at times of pressure on global food supplies. Freer and more deeply integrated international markets for agricultural products would be a helpful adaptive response.

Box 6.5 The security challenge created by the melting of the Himalayan and Tibetan plateau glaciers

The melting of the Himalayan and Tibetan plateau glaciers illustrates the complex nexus of climate change, economic security and geopolitics.

Well over a billion people are dependent on the flow of the area's rivers for much of their food and water needs, as well as transportation and energy from hydroelectricity. Initially, flows may increase, as glacial runoff accelerates, causing extensive flooding. Within a few decades, however, water levels are expected to decline, jeopardising food production and causing widespread water and power shortages.

As water availability in China has decreased because of rising demand and diminishing freshwater reserves, China has increased its efforts to redirect waters from the Yangtze to water-deficient areas of northern China. Questions are now arising about the reliability of the Yangtze flows for these purposes. A wider problem is that rivers like the Mekong, Ganges, Brahmaputra and Salween flow through several states. China's efforts to rectify its own emerging water and energy problems indirectly threaten the livelihoods of millions of people in downstream, riparian states. Chinese dams on the Mekong are already reducing flows to Myanmar, Thailand, Laos, Cambodia and Vietnam. India is concerned about Chinese plans to channel the waters of the Brahmaputra to the over-used Yellow River. Should China go ahead with this ambitious plan, tensions with India and Bangladesh would almost certainly increase (Chellaney 2007).

Any disruption of flows in the Indus would be highly disruptive to Punjabi agriculture on both sides of the India-Pakistan border. It would raise difficult issues in India-Pakistan relations.

Any consequent conflicts between China and India, or India and Pakistan, or between other water-deficient regional states, could have serious implications for Australia, disrupting trade, displacing people and increasing strategic competition in Asia. (Dupont 2008)

Infectious disease

Climate change can generate security risks through infectious disease. Temperature is the key factor in the spread of some infectious diseases, especially where mosquitoes are a vector as with Ross River virus, malaria and dengue virus. With warming, mosquitoes will move into previously inhospitable areas and higher altitudes, and disease transmission seasons may last longer. A study by the World Health Organization (2002) estimated that 154 000 deaths annually were already attributable to the ancillary effects of climate change due mainly to malaria and malnutrition. The study suggests that this number could nearly double by 2020.

Severe weather events

Severe weather events such as cyclones, intense storms and storm surges pose a significant security challenge for the Asia-Pacific region, because of the death and destruction that results and the political, economic and social stresses these events place on even the most developed states. The densely populated river deltas of south and Southeast Asia and south China are particularly vulnerable. Severe events may call into question the legitimacy or competence of a national government and feed into existing ethnic or inter-communal conflicts.

As an example, the 1998 monsoon season brought with it the worst flood in living memory to Bangladesh, inundating some 65 per cent of the country, devastating its infrastructure and agricultural base and raising fears about Bangladesh's long-term future in a world of higher sea levels and more intense cyclones. The 2008 Myanmar cyclone severely affected an estimated 2.4 million people (OCHA 2008).

Severe weather events have the potential to generate an increasing number of humanitarian disasters requiring national and international relief. Because it has the resources and skilled personnel to respond quickly and effectively, Australia will be called upon to shoulder a substantial part of any increase in emergency and humanitarian operations in its immediate neighbourhood, and the major part in the south-west Pacific, Timor-Leste and eastern Indonesia.

Australian defence personnel and police may also be more heavily committed in support of peacekeeping and peace enforcement operations, particularly in the south-west Pacific, should already unstable states be further weakened by the effects of climate change. This will have significant cost and human resource implications. Since 1999, Australian Defence Force regional interventions have cost the federal budget on average over half a billion dollars per annum, a figure that could rise significantly in the longer term with climate change (M. Thomson 2008, pers. comm.).

Sea-level rise

In Asia and the Pacific, millions of people are exposed to relatively high levels of risk from flooding because of the density of urban populations and industrial economic activity and the prevalence of high-value agriculture in coastal regions. The vulnerability of coasts varies dramatically for a given amount of sea-level rise. Small rises in mean sea level, when associated with storm surges and major coastal populations, can be devastating.

It is estimated that 105 million people in Asia would be at risk of their homes becoming inundated by a 1 m rise in sea level (Anthoff et al. 2006). Most of Asia's densest aggregations of people and productive lands are on coastal deltas, including the cities of Shanghai, Tianjin, Guanzhou, Tokyo, Jakarta, Manila, Bangkok, Ningbo, Mumbai, Kolkata and Dhaka. Much of Hong Kong and Singapore are on low-lying land, much of it recently reclaimed from the sea. The areas under greatest threat are the Yellow and Yangtze river deltas in China; Manila Bay in the Philippines; the low-lying coastal fringes of Sumatra, Kalimantan and Java in Indonesia; the Mekong (Vietnam), Chao Phraya (Thailand) and Irrawaddy (Myanmar) deltas (Handley 1992; Morgan 1993); and the delta cities of south Asia.

Sea-level rise would have proportionately the most severe consequences for low-lying atoll countries in the Pacific such as Kiribati (population 78 000), the Marshall Islands (population 58 000), Tokelau (population 2000) and Tuvalu (population 9000). Human habitation may not be possible on these islands even with moderate climate change. If temperature and sea-level rises are at the high end of expectations, then either the sea will eventually submerge the coral atolls or groundwater will become so contaminated by saltwater intrusion that agricultural activities will cease (IPCC 2007). Their small populations make them relatively easy to absorb into larger countries, and the international community and the islanders themselves would expect Australia and New Zealand to be the main countries of resettlement.

The numbers of people exposed to small increases in sea level are much larger in Papua New Guinea, in coastal and low-lying river areas of West Papua, and in other island areas of eastern Indonesia.

Elementary mapping of the vulnerability of people in these areas to sea-level rise has hardly begun. The tendency for settlement to proceed to the high-tide levels in coastal and river delta areas has meant that small rises in sea level have already been associated with saline intrusion into gardens and household water supplies. Village communities have been displaced by destruction of food and water supplies by unexpectedly high king tides. In addition, as Bourke (2008: 53) notes: 'There are about 100 000 people in PNG living on what have been defined as "Small Islands in Peril." These are about 140 islands smaller than 100 km² in size and with population densities greater than 100 persons/km². It is these people Iwho are likely to suffer the most severe consequences of rising sea levels'.

For these reasons, climate change has risen to the top of the political agenda in the Pacific and will require an Australian response.

Climate refugees

Ecological stress in the form of naturally occurring droughts, floods and pestilence has been a significant factor in forcing people to migrate since the beginning of recorded history. So has war-related environmental destruction. In the future, however, climate refugees could constitute the fastest-growing proportion of refugees globally, with serious consequences for international security (Dupont 2008).

Climate-induced migration is set to play out in three distinct ways. First, people will move in response to a deteriorating environment, creating new or repetitive patterns of migration, especially in developing states. Second, there will be increasing short-term population dislocations due to particular climate stimuli such as severe cyclones or major flooding. Third, larger-scale population movements are possible. These may build more slowly but will gain momentum as adverse shifts in climate interact with other migration drivers such as political disturbances, military conflict, ecological stress and socio-economic change.

Australia will not be immune from the consequences of climate-induced migration in Asia and the Pacific. Although abrupt climate change that triggers a massive exodus of environmental refugees is unlikely, significant population displacement caused by sea-level rise, declining agricultural production, flooding, severe weather and step changes in the climate system are all distinct possibilities.

In developing countries with effective governments, early adaptive action can reduce the eventual impact of climate change. In these cases the security consequences may be small. Even in these countries, climate change is set to stretch the limits of adaptability and resilience. Elsewhere, climate change may overwhelm the carrying capacity of the land, disrupt traditional land management systems and make migration an attractive option to preserve quality of life (Edwards 1999). Poorer states could well be overwhelmed by the task confronting them, in which case Australia is likely to experience the ripple effects of climate-induced political disturbances and even violent conflict in the region.

Note

1. From GIAM modelling for the Garnaut Review (see Chapter 11).

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