7 IMPACTS OF CLIMATE CHANGE ON AUSTRALIA

Key points

This chapter provides a taste 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.

These impacts would be significantly reduced with ambitious global mitigation.

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

This chapter 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 severe. These areas, sectors and subsectors are presented in Table 7.1.

The Review considers both the direct impacts (section 7.3) and indirect impacts (section 7.4) 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, such as those within the Asia–Pacific region, with consequences for Australia. We focus first on the medians of the probability distributions of the impacts identified by the main climate models. For some sectors we supplement the middle-of-the-road assessment with analysis of the higher ends of the probability distribution of impacts. We take the standard IPCC projections and those based on them for cases that correspond most closely to those we expect from no mitigation or from effective global mitigation policies. We do not examine the more serious implications of climatic tipping points, due to the high degree of uncertainty associated with these and the limited time available to the Review to explore the breadth of potential impacts.

Two time periods are discussed. We explore how climate change might affect Australia up to 2030. These impacts can be broadly considered as locked in because of our present level of greenhouse gas emissions. The magnitude of these impacts can only be tempered by our level of adaptation effort. We also explore how Australia might be affected by climate change at the close of the century. The magnitude of impacts in 2100 will be determined by the ambition and effectiveness of international greenhouse gas mitigation as we move forward, and also by Australia's continued adaptation effort.

The chapter offers an illustrative selection and not a complete assessment of the impacts that are likely to be experienced across Australia. It is meant to provide a flavour of the insights contained in a series of papers commissioned by the Review. The papers are available on the Review website. In addition to the sectors and impacts discussed in this chapter, the commissioned papers cover livestock, horticulture, viticulture and forestry; Australia's World Heritage properties; tourism in south-west Western Australia; Ross River virus; ports; and telecommunications. These are an important part of the base from which the modelling of economic impacts on Australia, reported in Chapter 9, has been developed.

The Review encourages readers to examine the accompanying material. We have drawn on Australia's leading experts in 30 fields of inquiry (listed in Table 7.1) to provide a comprehensive collection of impacts stories. We draw on this material at various times through this draft report and it will be further considered in the final report. The availability of these reports on the Review's website provides a valuable public resource to build understanding of the diversity and magnitude of impacts that could be experienced across Australia.

This chapter and the commissioned reports form the foundation of the CGE modelling referred to in chapters 9 and 10. The CGE modelling will illustrate how the impacts flow through the whole of the Australian economy (final report).

The exploration of impacts also enables the Review to demonstrate the importance of both international greenhouse gas mitigation and national adaptation. This chapter makes the case that certain sectors and areas will be severely affected by a business-as-usual treatment of climate change, and that only through globally coordinated greenhouse gas mitigation do we leave open the opportunity to maintain many things that we value.

This chapter further demonstrates that in some cases it will be near impossible to avoid some level of climate change impact. It is possible that we will not avoid large and costly impacts. Where this is the case adaptation to the arising impacts will be required. The necessary response to the climate change impacts discussed in this chapter will be discussed in the adaptation chapters of the final report.

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

Table 7.1 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
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	Yes	Yes
Bacterial gastroenteritis	No	Yes
Health of remote northern Australian Indigenous communities	No	No
Rural mental health	No	No

Table 7.1 Sectors and areas considered in this chapter *(continued)*

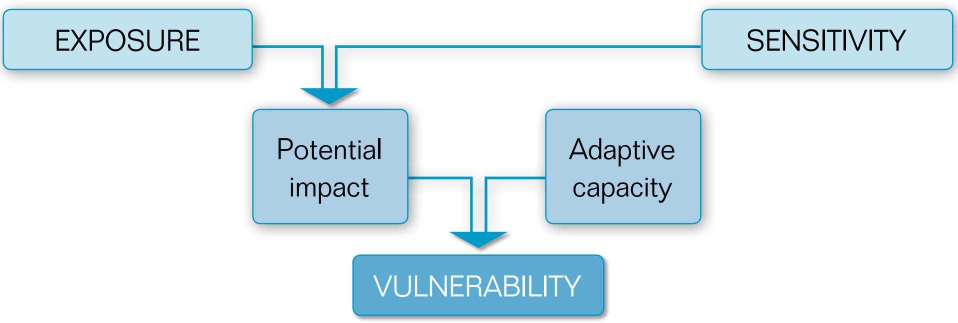
Sector or area	Discussed in this chapter	Modelled by the Review
Ecosystems and biodiversity		
Subsector or area		
Considers a range of ecosystems and impacts on plants and animals	Yes	No
Changes in demand and terms of trade	Yes	Yes
Geopolitical stability		
Subsector or area		
Geopolitical instability 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

7.1 Understanding Australia's vulnerability to climate change

The effect of climate change on the Australian population and our natural assets will depend on our *exposure* to changes in the climate system (as discussed in Chapter 3), our *sensitivity* to those exposures and whether we have the capacity to adapt to the changes to which we are sensitive. This concept, which constitutes our *vulnerability* to climate change, is illustrated in Figure 7.1.

Australia's level of exposure and sensitivity to the impacts of climate change are 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.

Figure 7.1 Vulnerability and its components



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. Australia has a well-developed and flexible economy with high per capita income, advanced scientific and technological knowledge, low population densities, strong emergency management capabilities, and abundant natural resources.

Several chapters in the final report will focus on Australia's adaptation challenge. This chapter focuses on Australia's exposure and sensitivity to climate change.

Unless otherwise stated, the consideration of impacts in this chapter assumes adaptation at the level of an individual or firm (autonomous adaptation), rather than economy-wide. Autonomous adaptation is likely to occur gradually, as impacts are felt but require little policy intervention.

7.2 Implications of the no-mitigation case for Australia

If global development were to continue along a no-mitigation path, 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 impacts of climate change are likely to be dominated by stressed urban water supply and the effects of changes in temperature and water availability on agriculture. Already all major cities and many regional centres are feeling the strain of declining rainfall and runoff into streams. Some cities are commencing the development of high-cost infrastructure for alternative water sources. In a no-mitigation case, the development of this infrastructure is likely to be a necessity.

By mid century the no-mitigation case is likely to lead to major declines in agricultural production across much of the country. Irrigated agriculture in the Murray-Darling Basin is 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 the mid century effective destruction of the Great Barrier Reef. The three-dimensional coral of the reef is likely to disappear. This will have serious ramifications for marine biodiversity and the tourism and associated service industries reliant on the reef.

By the close of the century, the impacts of a no-mitigation case, at the median of the probability distributions of mainstream science's assessment of the range of possible impacts, are profound. 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, and depopulation will be under way.

The increased incidence of heatwaves and hot days is likely to lead to about 4000 more deaths across Queensland annually. The rise in temperatures is likely to have caused the end of snow-based tourism.

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 fragile states in our Asia–Pacific neighbourhood are further weakened by the effects of climate change in a no-mitigation case, we can expect the Australian Defence Force and Australian Federal Police to be more heavily committed in support of peacekeeping operations.

Australians will be substantially wealthier in 2100 in terms of access to goods and services, despite any 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 carbon dioxide equivalent (CO_2-e), then the story of risks of impacts for Australia could be radically different. The differences are summarised in Table 7.2, again in terms of the median of the probability distributions emerging from the assessments of contemporary mainstream science. For some sectors, the difference between the median of the distributions at 550 ppm to 450 ppm CO_2-e is material.

Table 7.2 Differences between probable unmitigated and mitigated futures at 2100

Sector	No mitigation	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 artificial snowmaking.	
Water supply infrastructure	Up to 35% 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.

Table 7.2 Differences between probable unmitigated and mitigated futures at 2100 ***(continued)***

Sector	No mitigation	Mitigated 550 ppm CO_2-e	450 ppm CO_2-e
Dengue virus	5.5 million Australians exposed to Dengue virus.	720 000 Australians exposed to Dengue virus.	
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.	

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.

7.3 Direct impacts of climate change on Australia

7.3.1 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, mining, horticulture and natural resource–based tourism are actively exploring the implications of climate change on their operations.

In this section the Review presents the impacts of climate change on:

- agriculture (irrigated agriculture in the Murray-Darling Basin and dryland cropping)
- natural resource–based tourism.

Agriculture

Climate change is likely to affect agricultural production through changes that include changes in water availability, water quality and temperatures. Crop production is likely to be affected directly by changes in average rainfall and temperatures, and by changes in distribution of rainfall during the year. The productivity of livestock industries will be influenced by the changes in the quantity and quality of available pasture, as well as by the direct effects of temperature changes, and the increased likelihood of greater extreme temperatures inducing heat stress in livestock (Adams et al. 1999).

Some impacts are potentially positive. Increases in carbon dioxide concentration will have positive carbon fertilisation effects by increasing the rate of photosynthesis in some plants where there is adequate moisture to support it (Steffen & Canadell 2005). There is some trade-off: higher concentrations of carbon dioxide could also reduce crop quality, by lowering the content of protein and trace elements (European Environment Agency 2004). 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 benefit (Howden et al. 1999; Crimp et al. 2002).

Severe weather events such as bushfire and flooding are likely to reduce agricultural production by decreasing crop yields and increasing stock losses (Ecofys BV 2006). Changes in temperatures are also projected to alter the incidence and occurrence of pests and diseases. For example, Queensland fruit fly is expected to spread southwards in response to future higher temperatures, reducing yields and increasing costs to the Australian agriculture sector (ABARE 2007).

Irrigated agriculture in the Murray-Darling Basin

The Murray-Darling Basin covers over one million square kilometres 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 in South Australia.

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

The Review considered the impacts of climate change on several different 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. This is because inflows are a residual variable, consisting of water flows that are not lost to evapo-transpiration, or absorbed by the soil. Jones et al. (2001) indicate that a 10 per cent reduction in precipitation will generate a reduction in inflows of at least 35 per cent. Similarly a 10 per cent increase in evaporation will reduce inflows by around 8 per cent. Thus, quite modest changes in precipitation and evaporation could reduce inflows substantially. For the Review modelling, the reductions in runoff were capped at 84 per cent based on advice from R. Jones (2008, pers. comm.).

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 7.3.

Table 7.3 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	Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100	Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100	Hot, dry extreme case (the 'bad-end story')
Year	**Decline in economic value of production (%)**			
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 7A 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 in the immediate term. 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 ambitious stabilisation of greenhouse gas concentrations to 450 ppm CO_2-e by 2100, it is very likely that producers would be able to adjust their production systems with greater efficiency and technological improvement (not modelled) to adapt with little cost to overall economic output from the Basin under this scenario. 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 due to climate change.

While the differences between economic output in the 450 and 550 ppm 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 ambitious global mitigation.

In the 10th percentile hot, dry case, by 2050 the rivers in the Basin would barely be flowing. This would be well outside of 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 7.1 Is there potential for a positive irrigation story? The possibility of a wetter Murray-Darling Basin

Mainstream contemporary 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 greater flexibility in commodity choices.

Under a warm, wet no-mitigation case the average value of irrigated agriculture in the Murray-Darling Basin would increase from a world with no human-induced climate change by less than 1 per cent over the century.

Dryland cropping: wheat

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 past 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 and can vary by as much as 60 per cent in response to climate variability (Howden & Crimp 2005). Thus the Australian wheat industry is highly sensitive to climatic influences.

The value of wheat is based on both quantity and quality (protein content), which determines market price and end use. 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 protein losses of 4–14 per cent (Howden et al. 2001), which would significantly downgrade prices unless fertiliser application or pasture rotations were incorporated to reduce the effect (Crimp et al. 2008). Increases in heat shock also may reduce grain quality by affecting dough-making 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. The results are presented in Table 7.4.

As Table 7.4 shows, there are markedly different yield impacts between regions and also between the no-mitigation case and the global mitigation cases.

Table 7.4 Percentage cumulative yield change from 1990 for Australian wheat under four climate cases

	No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end story')	
	Cumulative yield 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 7A 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 is attributable to the farm-scale (autonomous) adaptive management considered (that is, moving planting times in response to warming and selection of optimal production cultivars) and increases in growth and water-use efficiency resulting from higher carbon dioxide concentrations. Over time, even with adaptive management considered, a number of regions may experience substantial declines in wheat yield. This is particularly evident later in this century. At this stage the benefits of carbon dioxide fertilisation and adaptive management are likely to have been negated by increasing temperatures and declining available water.

In some Western Australian sites (that is, Geraldton and Katanning) the rainfall changes associated with the no-mitigation case serve to improve yields. This unexpected result arises as sub-soil constraints to growth e.g. salinity is reduced in response to less annual rainfall. This beneficial impact is only simulated for modest rainfall declines (that is, less than 30 per cent of the long-term annual mean) with yields negatively affected with larger declines.

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

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

In interpreting these findings it should be noted that 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/La Niña events with climate change. There is concern in mainstream science, however, that El Niño frequencies may increase, thus changing the proportion of good and bad years. This may cause the net impact on wheat to be different from the average change in rainfall (Crimp et al. 2008). A world of climate change would be associated with less predictability of rainfall, generating large problems for management of farm systems to make optimal use of available water resources.

Natural resource–based tourism

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 2007a). Tourism is often the major non-agricultural 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 coastal environs of south-west Western Australia and the alpine regions of New South Wales and Victoria are leading examples of tourist attractions defined by features of the natural environment.

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; increased cost of adaptation; increased cost for repair, maintenance and replacement of tourism capital; and increased cost for developing alternative attractions (Sustainable Tourism Cooperative Research Centre 2007).

Some tourist destinations may benefit from drier and warmer conditions—perhaps beach-based activities, viewing of wildlife, trekking, camping, climbing and fishing outside the hottest times of the year. However, 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. Among the 77 tourism regions, the following three were identified as the most threatened:

- **Tropical north Queensland**, the hub of Great Barrier Reef tourism, contains the coral reef, severely threatened rainforest areas, beaches in danger of inundation and increasing storm damage (see also Box 7.4). 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 only 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. This area also attracts many holiday tourists; more than one-fifth of bed nights represent inbound holiday visitors.

The same study offers the following observations on state-by-state threats:

- Queensland is most at risk from climate change in terms of absolute number of tourist nights, especially the tropical north. The Gold and Sunshine coasts may retain some relative advantages despite the risk of sea-level rise, storm surges and rising summer temperatures.
- Western Australia has the largest number of regions at relatively high risk.
- New South Wales is rated at moderate risk (except its northern regions), and the southern states of Victoria, South Australia and Tasmania at least risk overall. This does not mean that these states or individual regions within them are without risk. For example, the Victorian Alpine region (see Box 7.2) would be heavily affected.

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 7.2 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 across New South Wales, Victoria and Tasmania 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 (see discussion in section 7.3.4).

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 to disappear before the end of the century. Conversely, if the international community were to achieve stabilisation of 450 ppm CO_2-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 CO_2-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 snow line moves 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 of bushfires and storm and wind events.

7.3.2 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 extreme events.

Buildings and infrastructure being constructed now have projected functional lives of many decades and longer. Therefore, 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 future operation and maintenance costs 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

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 substantially supplement their water supply system with alternative water sources through the 21st century. As shown in Table 7.5, there will be differing impacts across the states and territories, with Western Australia and South Australia the most severely affected by climate change–induced water scarcity. The development of alternative water sources for Perth and Adelaide will require a significant response in the short term.

In a case of global mitigation, the reduced level of temperature increase relative to the no-mitigation case has the effect of lessening the changes in rainfall and evaporative demand, and therefore creating less stress on water supply. However, a low level of additional supplementation would still be required across most major centres.

Buildings in coastal settlements

More than 80 per cent of the Australian population lives within the coastal zone, that is, within 50 kilometres of the coastline. In recent years coastal regions have experienced significant growth and are projected to continue to show the most rapid population growth (IPCC 2007).

In a no-mitigation case, the impacts of climate change are likely to be substantial. This can be seen in Table 7.6.

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

Table 7.5 Magnitude of impacts to water supply infrastructure in major cities under four climate cases

	No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end story')	
Region	2030	2100	2030	2100	2030	2100	2030	2100
ACT	M	E	M	L	M	L	H	E
NSW	H	E	H	L	H	L	H	E
NT	L	H	L	N	N	N	L	E
Qld	H	E	H	L	H	L	H	E
SA	E	E	E	M	E	M	E	E
Tas.	N	M	N	N	N	N	N	E
Vic.	H	E	H	M	H	L	H	E
WA	E	E	E	M	E	M	E	E

	Magnitude of net impact
N	Neutral
L	Low
M	Moderate
H	High
E	Extreme

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 7A 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 7B.

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 generate degradation in building foundations.

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, higher sea-wall protection and higher capital expenditure for improved drainage.

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 standards, 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 relative to the no-mitigation case would lessen the magnitude of temperature-driven storm energy in the Australian climate system, and impacts from storm surge, extreme rainfall and flash flooding. As shown in Table 7.6, overall impacts to buildings in coastal settlements would be substantially lower under the global mitigation cases.

Table 7.6 Magnitude of impacts on buildings in coastal settlements under four climate cases

	No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end' story)	
Region	2030	2100	2030	2100	2030	2100	2030	2100
NSW	M	H	M	M	M	M	M	E
NT	L	M	L	M	L	L	L	H
Qld	M	E	M	M	M	M	M	E
SA	L	H	L	M	L	L	L	H
Tas.	L	M	L	M	L	N	L	M
Vic.	M	H	M	M	M	L	M	H
WA	L	M	L	M	L	L	L	H

	Magnitude of net impact
N	Neutral
L	Low
M	Moderate
H	High
E	Extreme

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 7A 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). The Australian Capital Territory is not included in this assessment as it does not have any coastline.
A description of each level of impact is provided in 7B.

7.3.3 Human health

Climate change is likely to affect the health of Australians over this century in many ways. Some impacts will become evident before others. Some, 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, socioeconomic 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, and so on)
- 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: yields, costs/affordability, 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 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)
- emotional stresses and mental health problems in children, in response to perceptions/fears of climate change and to family stresses (for example, impaired rural livelihoods).

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 7.7 illustrates the change in the number of temperature-related deaths in Australia over time under four different climate change cases.

As shown in Table 7.7, 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).

For the no-mitigation case there is a large national increase in temperature-related 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 to the baseline. In Victoria, Tasmania and New South Wales, even under the hot, dry extreme case, temperature-related deaths are reduced relative to the baseline because those populations are more susceptible to cold than to heat (K. Dear 2008, pers. comm.).

Dengue virus

The dengue virus is not endemic to Australia. All outbreaks begin from an infected person who has travelled here from another country.

Epidemics of dengue appear to have recently become more regular in north Queensland, where five major epidemics (three affecting the Torres Strait) and many smaller epidemics occurred between 1992 and 2004. In contrast, the five previous epidemics occurred over 90 years (McBride 2005). Increasing international travel to north Queensland and the global amplification in dengue activity have been proposed as the main reasons for this rise.

Table 7.8 shows the estimated change from 2000 in the number and percentage of Australians exposed to dengue virus for a no-mitigation case and for global mitigation cases.

Table 7.7 Change in likely temperature-related deaths due to climate change

Region	Baseline – a world with no human-induced climate change		No-mitigation case		Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100		Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100		Hot, dry extreme case (the 'bad-end story')	
	Number of temperature-related deaths									
	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	2 316	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 7A 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).

Table 7.8 Estimated change since 2000 in people exposed to dengue virus in Australia

	No-mitigation case	Strong global mitigation with CO_2-e stabilisation at 550 ppm by 2100	Ambitious global mitigation with CO_2-e stabilisation at 450 ppm by 2100	Warm, wet extreme case (the 'bad-end story')
Year	**Number of people exposed**			
2000	310 159	310 159	310 159	310 159
2030	539 819	539 819	539 819	539 819
2100	5 522 133	721 819	721 819	7 930 027

Note: The first three cases (left to right) are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia (see 7A for a description of each case). The final case (right-hand side) is an illustrative 'bad-end story' that uses the 90th percentile rainfall and relative humidity and 50th percentile temperature for Australia (a warm, wet extreme).

Under the no-mitigation case the geographic region suitable for the transmission of dengue is expected to move south along the east coast from its current position in the far north (Cairns region). Under this case the climate becomes suitable for dengue transmission in Mackay by 2050, Brisbane by 2075 and northern New South Wales by 2095. Substantial control measures by public health authorities will be needed to respond to this extended range to avert more frequent and larger epidemics. The global mitigation cases show far less expansion of areas suitable for dengue transmission.

Given the uncertainty in projections for precipitation, the Review explored the 10th percentile wetter case. For the dengue virus this case leads to a far more hospitable environment for mosquito survival. By 2100 under this warm, wet case nearly eight million Australians would be exposed to the dengue virus.

7.3.4 Ecosystems and biodiversity

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 pest plant and animal species.

The impacts of climate change on Australia's biodiversity and ecosystems will be uneven. 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 occurred 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 four 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 about 2050 for the no-mitigation case, 2070 for 550 ppm CO_2-e, and after 2100 for 450 ppm 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 (thermal expansion only) by 2100 would adversely affect 90 per cent of the Kakadu wetland system. Rising sea levels will erode the levees from the seaward side and make the freshwater sections vulnerable to storm surges. 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 key 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 7.3).

Box 7.3 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 fisheries 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 7.3 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 reef-building 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 reef-building 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 and 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. Often the productivity of our natural resource–based industries such as agriculture and tourism depends on them.

The vast majority of ecosystem services are far too complex to implement by 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.

7.4 Indirect impacts of climate change on Australia

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

This section discusses two areas of indirect impact:

- implications of changes in demand for Australian export products and the prices received for Australian goods on the world market
- implications for Australia of geopolitical instability in its Asian and south-west Pacific neighbourhood.

7.4.1 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 and import prices). Australia is projected to be the developed economy whose terms of trade are most adversely affected by climate change (Chapter 9).

The key Australian export markets in China, India, Indonesia and elsewhere in Asia are projected to have significantly lower economic activity as a result of climate change.

A slowdown in global economic activity in other countries would be associated with a decline in international demand for Australia's mineral and energy resources and agricultural products.

The decline in Australia's overall terms of trade as a result of climate change damages will be driven primarily by falls in the prices received for coal, other minerals and agricultural products. These commodities are projected to account for over 60 per cent of the value of Australia's exports in 2100.[1]

7.4.2 Geopolitical stability in Asia and the Pacific region

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 reduced food production, water scarcity and increased disease, while immensely important in themselves, also have the potential for destabilisation of 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 accelerate erosion and desertification and reduce crop and livestock yields (see Box 7.4).
- Rising sea levels could inundate and make unusable fertile coastal land.
- An increase in the intensity or frequency of extreme weather events will disrupt agriculture.

Box 7.4 Asian food security and the south Asian monsoon

Much of Southeast Asia's water supply is dependent on the monsoons. Climate change may affect the nature of the south Asian monsoon (see Chapter 5). Shifts in monsoon-driven rainfall patterns and a reduction in water available for irrigation will have a serious effect on crop yields.

Asia is more dependent on irrigation than any other region of the world for growing rice and other cereals. Although less important than it once was, rice is still a vital food staple, providing 60 per cent of the carbohydrate and second-class protein consumed by Asians (Dupont 2001). If rice paddies and croplands dry out, the carrying capacity of large parts of Asia will diminish and some countries may be unable to sustain their populations without importing large quantities of food, which may be simply unaffordable for poorer nations.

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 potentially large shifts in their production bases. 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, 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 (this issue will be addressed in the adaptation chapters in the final report).

Water scarcity

Water flows to densely populated parts of Asia could be affected by factors in addition to disruption of the south Asian monsoon. The melting of the Himalayan glaciated regions could destabilise flows in the large rivers of south and south-east Asia and China (see Box 7.5). Water shortages, intensified by human-induced climate change, would aggravate social and political tensions and add to the internal security challenges faced by the Asia–Pacific region's developing states.

Box 7.5 The security challenge created by the melting of the Himalayan and Tibetan glaciers

The melting of the Tibetan and Himalayan glaciers (see section 5.4.2) illustrates the complex nexus of climate change, economic security and geopolitics.

Many hundreds of millions of people are dependent on the flow of these rivers for most of their food and water needs, as well as transportation and energy from hydroelectricity. Initially, flows may increase, as glacial run-off 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 fresh water reserves, China has increased its efforts to redirect the southward flow of rivers from the water-rich Tibetan high plateau to water-deficient areas of northern China. The 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 and people flows and increasing strategic competition in Asia.

(Dupont 2008a)

Infectious disease

There are serious security risks from climate change through infectious disease. Temperature is the key factor in the spread of some infectious diseases, especially where mosquitos are a vector as with Ross River virus, malaria and dengue virus. With warming, mosquitos 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 (World Health Organization 2002).

Health problems can quickly metamorphose into a national security crisis if sufficient numbers of people are affected and there are serious economic and social consequences. However, climate change will not necessarily provide a more favourable environment for the spread of infectious diseases, since transmission rates and lethality are a function of many interrelated social, environmental, demographic and political factors. These include the level of public health, population density, housing conditions, access to clean water and the state of sewage and waste management systems, as well as human behaviour.

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. 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. More recently the Myanmar cyclone has 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 the brunt of any increase in emergency and humanitarian operations in its immediate neighbourhood.

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 fragile 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 every year, 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 exposed to a one-metre 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, Hong Kong, Tokyo, Jakarta, Manila, Bangkok, Singapore, Ningbo, Mumbai, Kolkata and Dhaka. 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; and the Mekong, Chao Phraya and Irrawaddy deltas in Vietnam, Thailand and Myanmar respectively (Handley 1992; Morgan 1993).

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). These small islands are highly vulnerable to sea-level rise because of their topography, high ratio of coast to land area, relatively dense populations and subsistence economies (Barnett & Adger 2003). Ultimately, 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 the forecasts, then the sea will either eventually submerge the coral atolls or groundwater will become so contaminated by salt water 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 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 (the vast wetlands west of Port Moresby to the border, and the densely populated communities in the lower reaches of the Sepik River in the north-east), in coastal and low-lying river areas of Indonesian New Guinea, and in other insular 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 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) writes: '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 km^2 in size and with population densities greater than 100 persons/km^2. It is these people [who are] likely to suffer the most severe consequences of rising sea levels.'

Much of Fiji's productive land and urban areas would also be flooded if the increase is at the upper end of the IPCC forecasts, which would exacerbate ethnic tensions over land (Edwards 1999). Inter-communal strife between Indigenous Kanaks and French settlers in New Caledonia could similarly be inflamed if productive land becomes scarce and the Kanaks cannot sustain their agriculture and lifestyles on their ancestral land (Edwards 1999). 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.

If affected states have the time and resources to anticipate and plan for such exigencies, then the security consequences may be small. Still, climate change is set to stretch the limits of adaptability and resilience in some developing states, overwhelming the carrying capacity of the land, disrupting traditional land management systems and making 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 may experience the ripple effects of climate-induced political disturbances and even violent conflict in the region.

Boundaries and energy

The melting of the Greenland or West Antarctic ice caps and accompanying sea-level rise would throw into question established maritime boundaries and exclusive economic zones, creating tensions at sea that could have an impact on energy supplies and stimulate conflict in Australia's strategic backyard.

One aspect of the inter-relationship between climate change and energy security that has received scant attention is the impact the submergence of small atolls, rocks and low-lying islands due to sea-level rise could have on the exclusive economic zones of maritime states and disputed seabed resources, including oil and gas. This is a critically important issue since small rocks and islets are commonly used to delineate maritime boundaries and to claim vast tracts of ocean which would otherwise fall outside the exclusive economic zones of contiguous states or be designated as high seas. International law currently provides no answer to the question of what would happen to sovereignty and exclusive economic zones if an island, or even country, is submerged. In the event of significant sea level rise, the low water marks from which exclusive economic zones are measured would shift, raising the real possibility of serious new maritime disputes as states argued about the criteria for resetting baselines and redesignating these zones as high seas (Dupont 2008).

Rising sea level could complicate the resolution of disputed sovereignty claims in the Spratly Islands, a group of low-lying atolls in the South China Sea, which sit astride potentially rich deposits of oil and have already been the source of military tension between China, Vietnam and the Philippines. Some of these islands are already partially submerged and the highest, Southwest Cay, is only four metres above sea level (Central Intelligence Agency 2006). Heightened tensions in the South China Sea could precipitate a crisis between Japan and China, the Association of South East Asian Nations (ASEAN) and China, or between rival ASEAN states. This could complicate attempts to reduce and eventually eliminate longstanding territorial and resource disputes at sea.

7.5 Conclusion

The probable impacts of climate change on Australia will be varied and extensive, and will be unevenly spread across the country. For the next two decades or so, the impacts of climate change are likely to be dominated by stressed urban water supply and the effects of changes in temperature and water availability on agriculture.

By mid century a no-mitigation case will likely lead to major declines in agricultural production across much of the country. This will affect our capacity to export food and create a growing reliance on food imports. An unmitigated future is likely to also see the mid century destruction of the Great Barrier Reef.

By the close of the century, the impacts of a no-mitigation case and associated increased incidence of heatwaves will likely lead to about 4000 more deaths across Queensland annually. The rise in temperatures is likely to have caused the end of snow-based tourism. Much coastal infrastructure along the early 21st century lines of settlement is likely to be at high risk of damage from storms and flooding.

Over the course of the century climate change impacts elsewhere in the world will affect Australians, including through diminished opportunities for trade and investment, and demands in peacekeeping and humanitarian aid.

While this chapter's focus has been on the 'average' of possible outcomes, warming will increase the chance of abrupt and large-scale changes, with potential for much greater impacts.

If the world were to have agreed and implemented global mitigation goals so that greenhouse gas concentrations were stabilised at 450 ppm or even 550 ppm carbon dioxide equivalent, and combined with national adaptation, then the story of impacts for Australia could be radically different.

Note

1. From GIAM modelling for the Garnaut Review (see Chapter 9).

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7A Climate cases considered by the Garnaut Review

For the purpose of illustrating how the impacts of climate change might arise out to 2100 the Review considered a sample of climate cases, which present a set that are physically plausible for Australia. The diversity of choice is intended to inform opinions and decisions about the type of future that is acceptable to us as a nation and as part of the international community.

Case	Emissions	Climate sensitivity	Rainfall and relative humidity (surface)	Temperature (surface)	Mean global warming in 2100
Unmitigated 1 (U1) Hot, dry	A1FI path	3°C	10th percentile	90th percentile	~4.5°C
Unmitigated 2 (U2) Best estimate (median)			50th percentile	50th percentile	
Unmitigated 3 (U3) Warm, wet			90th percentile		
Strong mitigation 1 (M1) Dry	CO_2-e stabilised at 550 ppm by 2100 (CO_2 500 ppm)		10th percentile	90th percentile	~2°C
Strong mitigation 2 (M2) Best estimate (median)			50th percentile	50th percentile	
Strong mitigation 3 (M3) Wet			90th percentile		
Ambitious mitigation 4 (M4) 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 scenarios global mean temperature is presented from a 1990 baseline. To convert to a pre-industrial baseline add 0.5°C.

7B Infrastructure impacts criteria

The 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 below.

	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.
M	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.
H	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.
E	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.