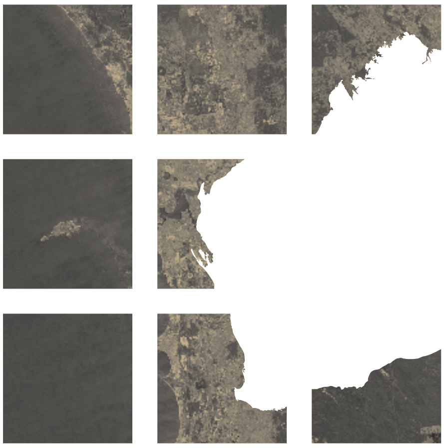
STATE OF THE ENVIRONMENT REPORT 2007
Western Australia

Theme 1

FUNDAMENTAL PRESSURES



INTRODUCTION

Fundamental pressures are the broad factors that cause environmental change; namely population growth, consumption of natural resources and climate change. These pressures are driven by collective and individual attitudes, values and behaviours that in turn shape characteristics of human societies and the way people interact with the environment. They are the underlying causes of most environmental issues outlined in the 2007 State of the Environment Report.

Human activities are now so extensive that all ecosystems on the planet have been modified to some extent. In the rapid cultural evolution of humans, most societies have become physically and psychologically detached from the natural environment. Humans have established institutions (such as financial markets, government structures and social networks) and developed technologies to further social and economic wellbeing. This has led to an over use of natural resources (e.g. wood production, water supplies, fisheries, land for agriculture) and resulted in the dramatic modification of many of the Earth's ecosystems (Costanza & Farber, 2002). Large-scale changes in natural systems, including the global climate system, are occurring as a result. Population growth and consumption of natural resources are central to the nature and scale of these impacts.

How we respond, as a society, in managing these fundamental pressures will affect the health of the natural environment on which humanity depends.

Cafe strip, Fremantle (Tourism Western Australia)

1.1 POPULATION AND CONSUMPTION

INDICATIVE EXTENT OF ISSUE

PRIORITY RATING: 1

KEY FINDINGS

- WA's population has grown by 1.7% per year over the past decade – approximately 30% faster than the national average.
- There is growing demand for WA's natural resources domestically and overseas due to economic development, population growth and increasing personal levels of consumption.
- Western Australians have amongst the largest ecological footprints (a measure of consumption) in the world.

Description

Population growth and consumption are fundamental drivers of human environmental impacts. Humans have changed the Earth's ecosystems more rapidly and extensively in the past 50 years than in any other period of human history. This is mostly due to the ever growing human demand for natural resources such as energy, food, water and wood. These changes have degraded almost two-thirds of the ecosystems on which humanity depends and have resulted in a largely irreversible loss in the diversity of life on Earth (Millennium Ecosystem Assessment, 2005). Humans are increasingly reducing the capacity of the Earth to maintain the ecosystem services that are essential to life such as water filtration and purification, photosynthesis, climate regulation, and waste absorption and breakdown.

The world's population doubled between 1960 and 2000 to 6 billion people and continues to grow, currently at around 1.2% per annum. Despite a continuing decline in fertility levels, the global population is expected (under a medium-growth scenario) to reach 9 billion by 2050. In the same period (1960–2000) the global economy increased six-fold, resulting in a doubling or more of water use, food production and wood harvests (Millennium Ecosystem Assessment, 2005).

While most developed nations have low and declining population growth, their personal consumption rates continue to increase, placing growing demands on the world's natural resources. Nations in transition to more industrialised economies are creating a new and rapidly increasing consumer class, comprising 1.7 billion people and it is projected this will lead to greatly increased global demand for natural resources (United Nations Population Fund, 2004). In contrast, nations in sub-Saharan Africa have the fastest rates of population growth but suffer some of the world's worst poverty, a combination which can lead to the degradation of their local environments (United Nations Population Fund, 2004). The disparate consumption between rich and poor nations remains a key environmental concern. Around 86% of global private consumption expenditure is accounted for by 20% of the world's population who live in the highest income countries (United Nations Population Fund, 2001).

In WA, population growth and distribution, and patterns of consumption, are drivers of many environmental pressures in the State, including loss of biodiversity, air pollution, impacts on water quality and waste generation. Reducing, or at least stabilising, global population growth and consumption is a key requirement for sustainability and reducing environmental degradation from human activities.

Objectives

- Assess, monitor and manage the impact of population growth and distribution on WA's environment.
- Decouple economic growth from growth in the use of natural resources.
- Reduce consumption levels of Western Australia's population.

WA is a large exporter of natural resources (Department of Agriculture and Food).

Condition

Indicator FP1: Population growth in Western Australia.

Western Australia's population has grown steadily since the 1940s, reaching two million in January 2005 (Figure FP1.1). The average population growth rate in WA over the past decade was 1.7% and in 2005–06 it peaked at 2%. Over this period the growth rate was consistently higher than the national average and represents a doubling time for WA's population of approximately 41 years compared to 54 years for Australia as a whole. The population growth rate for WA is also higher than most developed and some developing nations.

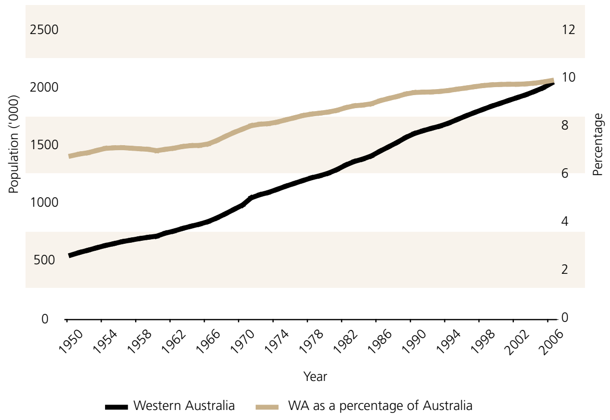


Figure FP1.1: Population growth in Western Australia, by total and percentage of Australia's growth,1950–2006.

Data source: Australian Bureau of Statistics (2006).

There are three major sources of growth of WA's population: natural increase (births minus deaths), net overseas migration and net interstate migration. Net migration is the difference between immigration (arriving) and emigration (leaving). In the past decade, net overseas migration has overtaken natural increase as the largest contributor to population growth in the State. Historically, WA's high rates of population growth have been associated with periods of high economic growth and development. During these periods, including the current resource development boom, both overseas and interstate migration tend to increase in response to an increased demand for labour.

Western Australia's population is projected to grow by 41%, or approximately 800 000, by 2031. If present policy settings are maintained, most of this growth will occur in the Perth, Peel and South West regions, with population in the Peel region projected to double by 2031. Perth's population is projected to reach over two million by this date. The growth in population will increase demand for land, energy and water, and will lead to more waste generation and pollution.

Indicator FP2: Ecological footprint of the Australian population (based on 'global hectares').

A nation's well being is broadly equivalent to its per capita rate of consumption. Australia has a relatively high standard of living according to the United Nations Human Development Index, when compared to other countries (United Nations Development Programme, 2005). The index is based on three dimensions of human development: standard of living, life expectancy and education. The ecological footprint is a tool used to measure the land area required to support consumption levels of natural resources by the average citizen. There is a fairly close correlation between a nation's well being and its ecological footprint; the higher the standard of living, the greater the ecological footprint (Figure FP1.2).

The average Australian currently requires about seven 'global hectares' per person to support their consumption, less than US and Canadian citizens, but more than those of the United Kingdom, Russia, China and Japan. In comparison, the biologically productive land available per person globally is less than two global hectares (Global Footprint Network, 2006). Global hectares do not represent actual land areas but rather standardised values that are adjusted to reflect the differing productivities of different nations, which enable comparison between nations.

The global ecological footprint is currently estimated to exceed the Earth's carrying capacity by 20%. This means that we are living beyond our planet's means and that some renewable natural resources are being harvested at rates higher than they can be replenished.

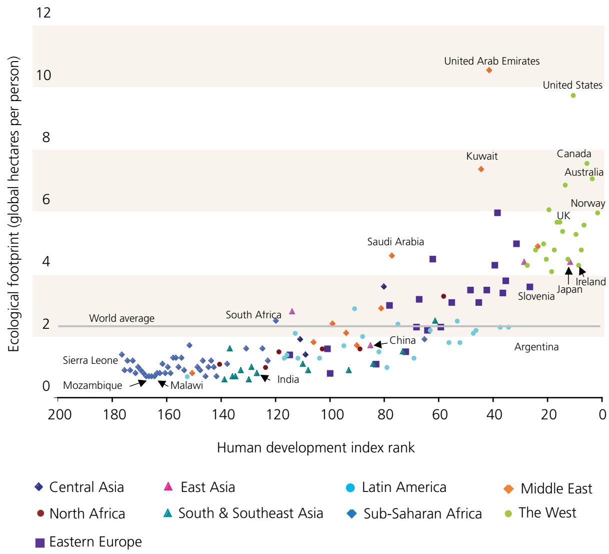


Figure FP1.2: Human welfare and ecological footprint of nations.

Data source: Global Footprint Network (2006); United Nations Development Programme (2006).

Indicator FP3: Ecological footprint of the Western Australian population (based on actual land area).

Consumption in WA is contributing significantly to global environmental pressure. Western Australia's consumption patterns have changed in recent decades and it now has one of the highest per capita rates of consumption in the world. There are several reasons for this. Most importantly, the State's economy is heavily based on the use of natural resources – namely mining and agriculture – requiring large inputs of water and energy. In addition, Western Australians have high standards of living and associated high personal consumption rates.

In 2001 the ecological footprint of the average WA citizen was 14.5 hectares. This estimate is much larger than the estimated seven global hectares required by the average Australian because it is based on actual land area rather than standardised global hectares. It includes land used overseas and interstate to produce goods exported to WA as well as land used within the State to produce goods for local consumption. Approximately 80% of the WA ecological footprint is land that is used to produce consumed resources. The remainder is classified as 'emissions land', which is the amount of land required to sequester carbon dioxide emissions from burning fossil fuels. When divided into broad consumption types, land use associated with food makes up 46% of the State's ecological footprint (Figure FP1.3). The food component represents a large proportion of the ecological footprint because of the agricultural inputs to the food production. Agriculture uses large amounts of land, particularly in the production of crops and livestock. In WA, this input to the ecological footprint is very high because large areas of land are used for grazing livestock at very low densities. The food footprint also includes land required for processing, transport and disposal. Approximately one-third of WA's ecological footprint is land used to produce goods imported from interstate and overseas.

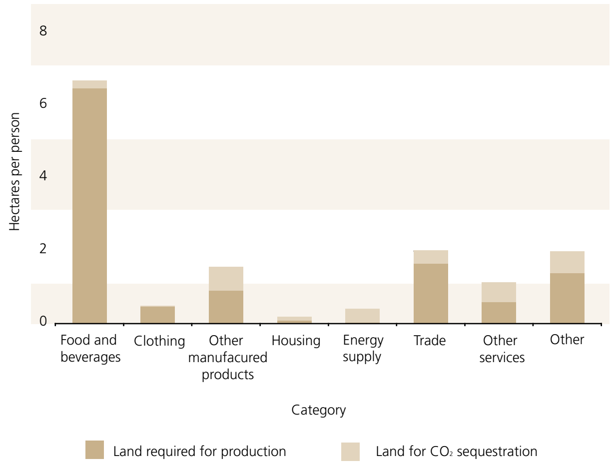


Figure FP1.3: Ecological footprint of the Western Australian population by consumption category.

Indicator FP4: Trends in domestic consumption patterns.

Food, housing and transport are three consumption areas that have the greatest impact on the WA's environment (e.g. through air pollution, land clearing/loss of biodiversity, greenhouse gas emissions and waste generation), place pressure on demands for natural resources (e.g. water and energy) and contribute indirectly to other environmental issues in the production of goods and use of services (e.g. land salinisation, eutrophication and erosion). While these consumption areas can be considered fundamental to provision of the basic necessities for life, they are no longer simply at levels of need, but rather have grown increasingly to meet the wants of individuals.

With respect to housing, the typical house size in WA has more than doubled over the past 50 years, from 110 m^2 in the 1950s to 230 m^2 in 2000 (Office of Policy and Planning, 2000). This is due to larger and more bedrooms, bathrooms and additional rooms such as games rooms. Larger dwellings use more natural resources in their construction, such as bricks, wood, metals, water and energy. Household occupancy has also decreased over the same period (Australian Bureau of Statistics, 2005).

Per capita residential energy consumption in WA has risen over the past two decades from 15.5 gigajoules (Gj) per capita in 1984–85, to 17.2 Gj in 2004–05 (see '*Energy use in settlements*'). The increase in household energy use over this period reflects the increasing number and use of labour saving appliances (e.g. computers, power tools, kitchen appliances), lifestyle appliances (e.g. mobile phones, LCD and plasma televisions, compact audio devices), and heating and air-conditioning systems. Total residential energy consumption has increased by 60% over the same period to 34.2 petajoules due to population growth and increasing rates of personal consumption.

Unlike energy consumption, water use per capita is showing signs of stabilising (see '*Water use in settlements*'). Both total and per capita residential water use have declined since 2001. This trend can be attributed to the introduction of a *State Water Strategy* with a targeted water conservation campaign and increased media focus on water shortages.

Food demand is proportional to population. In 2000, each Australian is estimated to have consumed around 695 kg of food and 227 litres of beverages per year (Australian Bureau of Statistics, cited in Australian Food & Grocery Council, 2003). It is likely that the amount of food consumed per capita has changed little in recent times, but calorie intake has increased. Western Australians are consuming more food products from overseas and interstate, and consumer demand is driving year-round production of seasonal produce and exotic local produce. Imported seafood products now provide more than 60% of the market in Australia, while most of WA fisheries production is exported to overseas or interstate markets (CSIRO, 2003; Australian Bureau of Agricultural and Resource Economics, 2004). The trend towards more processed (e.g. confectionery and snack foods) and 'ready-to-eat' (e.g. take-away and packaged meals) foods is also growing. Nutrition surveys show that energy, protein and carbohydrate intakes of WA children and adolescents increased between 1985 and 2003 (Glasson et al., 2004). The trends toward increased consumption of processed foods, imported foods and out-of-season produce has environmental implications from greater inputs of energy, water and materials (e.g. packaging) used in production, manufacturing, transport, consumption and/or disposal. A survey undertaken by the Australian Food and Grocery Council in 2003 found that Australia wastes about 2.2 million tonnes of food annually, or 13% of total food consumed (Australian Food and Grocery Council, 2003). This equates to the annual food consumption of nearly 3.2 million Australians.

Transport patterns have environmental consequences including land clearing for transport infrastructure, consumption of fossil fuels, materials used (metals, plastics, rubber) and exhaust emissions (see '*Transport*'). Vehicle ownership in WA is the highest in Australia. In 2004, the total number of vehicles was 749 per 1000, representing a 10% increase in vehicle ownership since 1996. Passenger vehicles make up the majority of these (568 per 1000). Since 1998, vehicle kilometres travelled has increased by 10% to 7900 kilometres per capita, reflecting continuing urban development of Perth and parts of the South West.

Indicator FP5: Trends in consumption arising from economic activity.

Western Australia is heavily dependent on the use of natural resources to sustain economic growth, with a major emphasis on export-oriented industry: over 70% of land used and carbon dioxide emissions in WA are associated with the production of exports. Measuring trends in resource use arising from economic activity is as important as monitoring personal rates of consumption in understanding the environmental consequences of consumption in WA. Macroeconomic models of resource use, such as materials flow analysis and the CSIRO's 'stocks and flows model' can provide overall measures of resource consumption. They enable understanding of the movement of natural resources through the economy and how they affect the environment. While a scoping report for a WA 'stocks and flows model' has been prepared, a model has not yet been developed. Despite this some trends are apparent.

Resource use arising from economic activity in WA has been steadily increasing in recent years. Total WA water use has grown from around 1800 gigalitres (GL) in 1998 to around 2400 GL in 2005. Mining and irrigated agriculture are responsible for nearly two-thirds of water consumption in WA and are likely to be responsible for much of the growth in water use over this period. The aggregate energy intensity (energy use per dollar of gross state product) of the WA economy decreased between 1998 and 2005, but total primary energy use grew at an average rate of 4.6% per annum over this period, and has been consistently higher than the national average. Much of this growth is due to steady economic activity and a structural shift towards more energy-intensive industries (Tedesco & Thorpe, 2003). The mining and petroleum sector in particular is experiencing rapid growth and projections indicate that sector output is likely to grow by 50–75% over the next decade (Chamber of Minerals and Energy, 2005).

Pressures

Population policy is a complex and contentious topic for any society to address. Some argue that we need a much lower population than we have now and others argue that we need a considerably larger population. The Commonwealth Government is responsible for population policy, with most strategies directed at control of immigration and births. The *State Sustainability Strategy* (Government of Western Australia, 2003) recognises that population growth should be promoted in areas where there is a real social and economic disadvantage (in many rural and regional areas), and that growth should be redefined in areas where further development is a threat to sustainability, such as Perth and many South West coastal towns. However, this approach is yet to be adopted in WA's planning system.

Current consumption levels are influenced by a combination of cultural and social factors, economic drivers and technology. Embedded in conventional economics is the perceived view that human wellbeing is tied to economic growth and consumption (Rees, 2002). Economic growth refers to the expansion of the volume of goods and services produced by a country. It is typically measured by the annual rate of increase of Gross Domestic Product (GDP) – the value of goods and services produced each year. Economic growth has the potential to solve many problems faced by individuals, communities and countries. However, the endless pursuit of continued economic growth is also leading to exacerbation of environmental problems (e.g. growth in greenhouse gas emissions). There are many environmental initiatives that, after years of debate, are yet to be implemented for fear that they will reduce economic growth (e.g. the Kyoto Protocol, carbon trading, true pricing of water, halting land clearing). Strong economic growth remains the current dominant political and economic driver in WA and is likely to continue increasing consumption of the State's natural resources.

Cultural trends have a significant influence on personal levels of consumption. In Australia our standard of living is often defined by material wealth, which drives increased demand for consumer products (e.g. mobile phones, LCD and plasma televisions, air conditioners, computers, home appliances, four wheel drive vehicles). Consumer goods play a symbolic role in our lives, in shaping our personal identities and in communicating group identity (Jackson & Michaelis, 2003). Marketing now plays a major role in defining consumer desires and has contributed significantly to the development of a consumerist society. Other factors influencing personal levels of consumption include the trend towards desire for convenience and keeping up with the pace of technology. Cultural shifts and changes to economic theory are required to solve many of these inherent consumer-related problems.

Current responses

Western Australian State Sustainability Strategy: was released by the State Government in 2003. The strategy outlines a blueprint for sustainable development in WA and contains a number of actions to manage the environmental impacts of WA's population and its use of natural resources. The strategy established two important and relevant targets aimed at reducing consumption in WA:

- reduce the ecological footprint of the WA economy by 50% by 2020; and
- increase eco-efficiency of the WA economy by a factor of four by 2020.

Implications

As WA continues to grow in population and the economy expands, demand for its natural resources (e.g. minerals, water, energy) will also rise: many of these resources are already under pressure from existing human activities (see '*Towards Sustainability*'). The flow-on effects of increased use of natural resources are not easily measured. Aspects of natural resource use have hidden environmental and economic costs: the natural environment supports the economy in providing many ecosystem services which are not readily recognised, and for which no market price has been determined or considered. Few of these ecosystem services have been given an accurate economic value (Prime Minister's Science Engineering and Innovation Council, 2002).

While it is difficult to value intangible or nonmarket assets like ecosystem services, they cannot be discounted or ignored in the long term. For example, if a commercial project of high economic value utilises valuable environmental resources, damages an ecosystem or biodiversity, or has a detrimental impact on the wellbeing of a nearby community (through noise, pollution or infrastructure damage), it clearly has an economic cost. As part of implementing best practice environmental management, such 'hidden costs' should be included as components of the total economic value of commercial projects (Department of the Environment, Sport and Territories, 1996).

Ecological systems usually have a buffering capacity to absorb pressures up to a threshold level, beyond which degradation occurs. However, environmental impacts are often cumulative, difficult to reverse, may only become apparent years or decades after the inducing pressure has occurred, and often extend beyond the natural environment to adversely affect social structures and the wellbeing of human societies. This highlights the fact that the WA society and economy is dependent on the prudent management of the environment and the sustainable use of its natural resources.

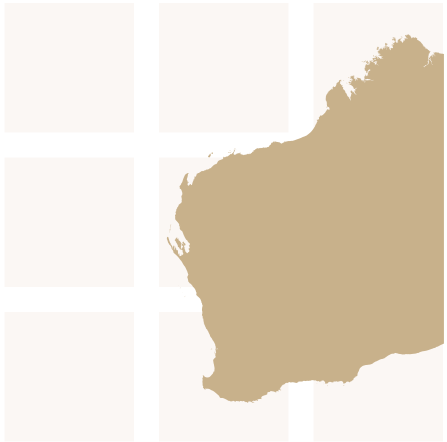
SUGGESTED RESPONSES

1.1 Implement the *State Sustainability Strategy*. Released in 2003, there is yet to be public reporting on its implementation. The State Government needs to remain committed to the strategy's implementation and a five year review of progress is warranted.

1.2 Develop tools to apply total economic value to future development proposals: the value of non-market (including environmental) services should be more rigorously included in future decision making in the pursuit of sustainability. Accounting for total economic value is needed to provide WA with improved environmental outcomes.

1.3 Adopt a plan to stabilise the State's ecological footprint, including measuring and reporting on a regular basis.

1.2 CLIMATE CHANGE



INDICATIVE EXTENT OF ISSUE

PRIORITY RATING: 1

KEY FINDINGS

- Climate change is happening now. Most of the climate changes over the past 100 years can be attributed to human activities.
- Average temperatures across WA have increased 0.8°C over the past 100 years.
- Sea level has risen 15 cm at Fremantle over the past 100 years and will continue to rise.
- Average winter rainfall in the South West has dropped 15% over the past 30 years. In contrast, average annual rainfall in parts of the Pilbara and Kimberley has increased.
- WA's net greenhouse gas emissions increased 17% between 1990 and 2005. If land use concessions are excluded, then emissions have increased 45% over the same period.
- WA's environment is highly vulnerable to climate change and the State's natural resources, biodiversity, industry and human health are at risk, and in some instances are already being affected.

Description

Climate change is one of the most complex and serious challenges facing humanity. Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This definition is in accordance with that outlined by the Intergovernmental Panel on Climate Change (2001). In the *Western Australian Greenhouse Strategy*, climate change is defined more specifically as a change of climate that is attributed directly or indirectly to human activity observed over comparable time periods – in accordance with the United Nations Framework Convention on Climate Change (Government of Western Australia, 2004).

Earth's climate varies naturally due to many factors including fluctuations in the amount of incoming solar radiation, the Earth's orbit, the El Niño Southern Oscillation (and other ocean and atmosphere interactions), and unpredictable events such as volcanic eruptions. Such variations can affect a small region or the entire planet, and drive the evolution and adaptation of species and ecosystems. The greenhouse effect is another natural process that plays a major part in shaping the Earth's climate. Certain gases in the atmosphere (known as greenhouse gases) absorb infrared radiation reflected by the Earth, creating the relatively warm and hospitable environment near the Earth's surface which makes life possible (Bureau of Meteorology, 2003).

Since the start of the Industrial era (about 1780), human activities have been influencing the greenhouse effect. Fossil fuel use, broadscale deforestation and land use changes have caused dramatic increases in atmospheric concentrations of carbon dioxide, methane, nitrous oxides and other greenhouse gases, resulting in the 'enhanced greenhouse effect' (see '*Greenhouse gas emissions*'). This effect has been altering the energy balance of the global climate system. The Earth's climate has demonstrably changed on both global and regional scales over the past century: global average air and ocean temperatures have warmed; global mean sea level has risen and there has been widespread melting of snow and ice (Intergovernmental Panel on Climate Change, 2007b). While the current climate is a consequence of both natural variability and human induced changes, it is now recognised that human activities are responsible for most of changes observed over this period (Intergovernmental Panel on Climate Change, 2007b).

Further changes to climate are expected, including at the Western Australian scale. Although average global temperature is expected to continue to rise, regional temperatures in WA will vary and in some areas are predicted to decrease. Similarly, rainfall patterns are expected to change, increasing in some regions and decreasing in others. Despite the high level of complexity there is broad agreement that under current projected trends the impacts of climate change will be substantial, including accelerated loss of biodiversity, changes to economic productivity and the availability of water supplies, and hence people's lifestyles.

Stirling Range (Tourism Western Australia)

Objectives

- Develop a comprehensive understanding of climate change and its associated impacts in WA.
- Reduce WA's vulnerability to climate change by developing and implementing programs to increase resilience and reduce sensitivity to its impacts.
- Foster greater community awareness in the Western Australian community about climate change and an informed response.
- Reduce WA's greenhouse gas emissions.

Condition

Over the past century, the Earth has been in a period of sustained rapid warming, with the average global surface temperature rising by around 0.6°C (Figure FP2.1). This rate of warming is unequalled in any other century in the past 1000 years. The rate of global warming is projected to accelerate further, with a global average surface temperature increase of 1.1–6.4°C over the period 1980–99 to 2090–2099, with a best estimate of about 0.2°C warming per decade for the next two decades (Intergovernmental Panel on Climate Change, 2007b). This represents roughly a two- to ten-fold increase in the rate observed during the 20th century and could lead to an unprecedented change in the Earth's weather systems.

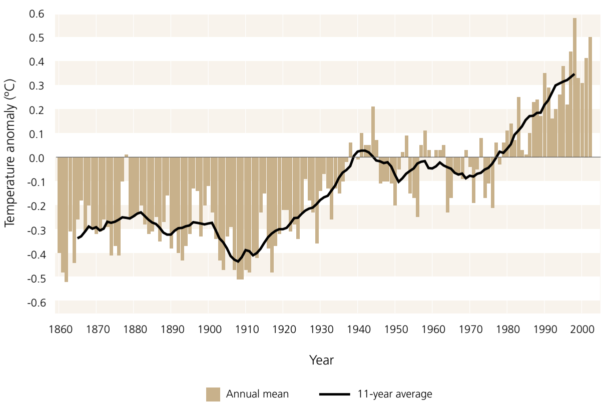


Figure FP2.1: Global average land and sea-surface temperature anomalies, 1860 to present.

Data source: Bureau of Meteorology (2003).

Indicator FP6: Historic trends in temperature for Western Australia.

Since 1910, the annual average temperature throughout WA has increased by just over 0.8°C, mirroring the trend to increasing global average temperatures (Figure FP2.2). Most of this increase has occurred since 1950 and has been greater in winter and spring than in summer and autumn. The warming trend has been greater in western parts of the State and the east Kimberley, although annual average temperatures have declined marginally in the east Kimberley since 1950. The warming trend across WA has been associated with rising minimum and maximum temperatures, although there have been some seasonal decreases, most notably a decline in summer maximum temperatures in the north east and southern coastal parts of the State (Figures FP2.3 and FP2.4).

In terms of temperature extremes, a decrease has been observed in the number of very cold nights across much of the State. There is also evidence that the number of very hot days has decreased over the past 40 years or so (J Cramb, Bureau of Meteorology, pers. com.). It is important to note that while the frequency of extreme temperature events may be decreasing, the average temperature is still rising across much of WA.

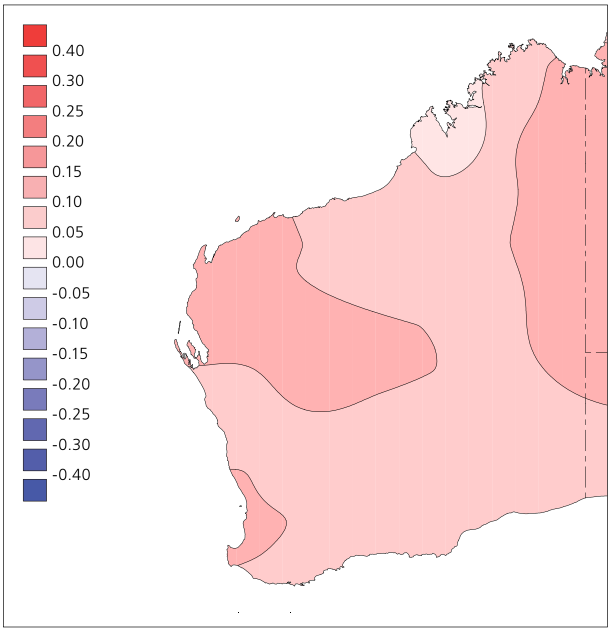


Figure FP2.2: Trend in average annual temperature in Western Australia, 1910–2006 (degrees Celsius per 10 years).

Map courtesy of Bureau of Meteorology.

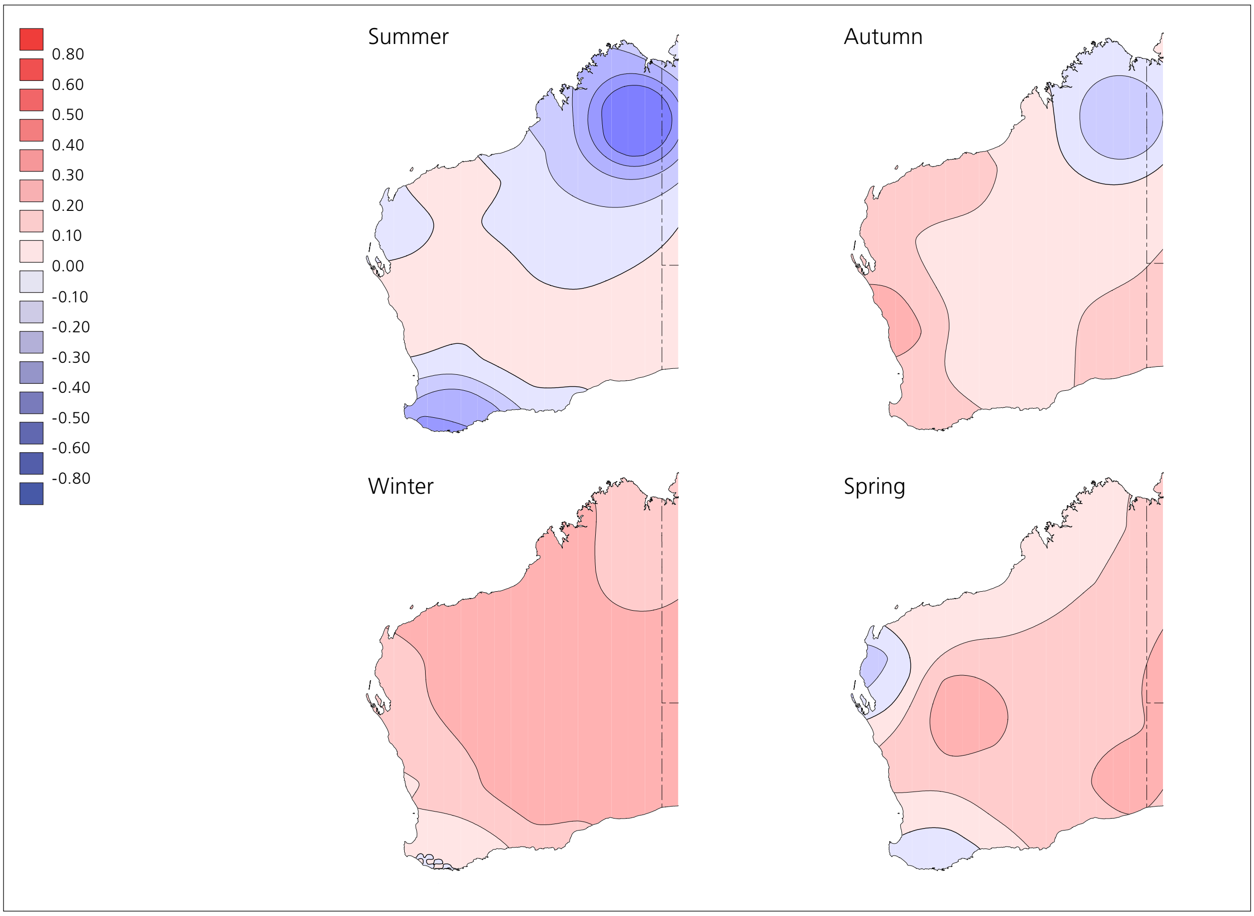


Figure FP2.3: Trend in average daily maximum temperatures in summer, autumn, winter and spring in Western Australia, 1950–2006 (degrees Celsius per 10 years).

Map courtesy of Bureau of Meteorology.

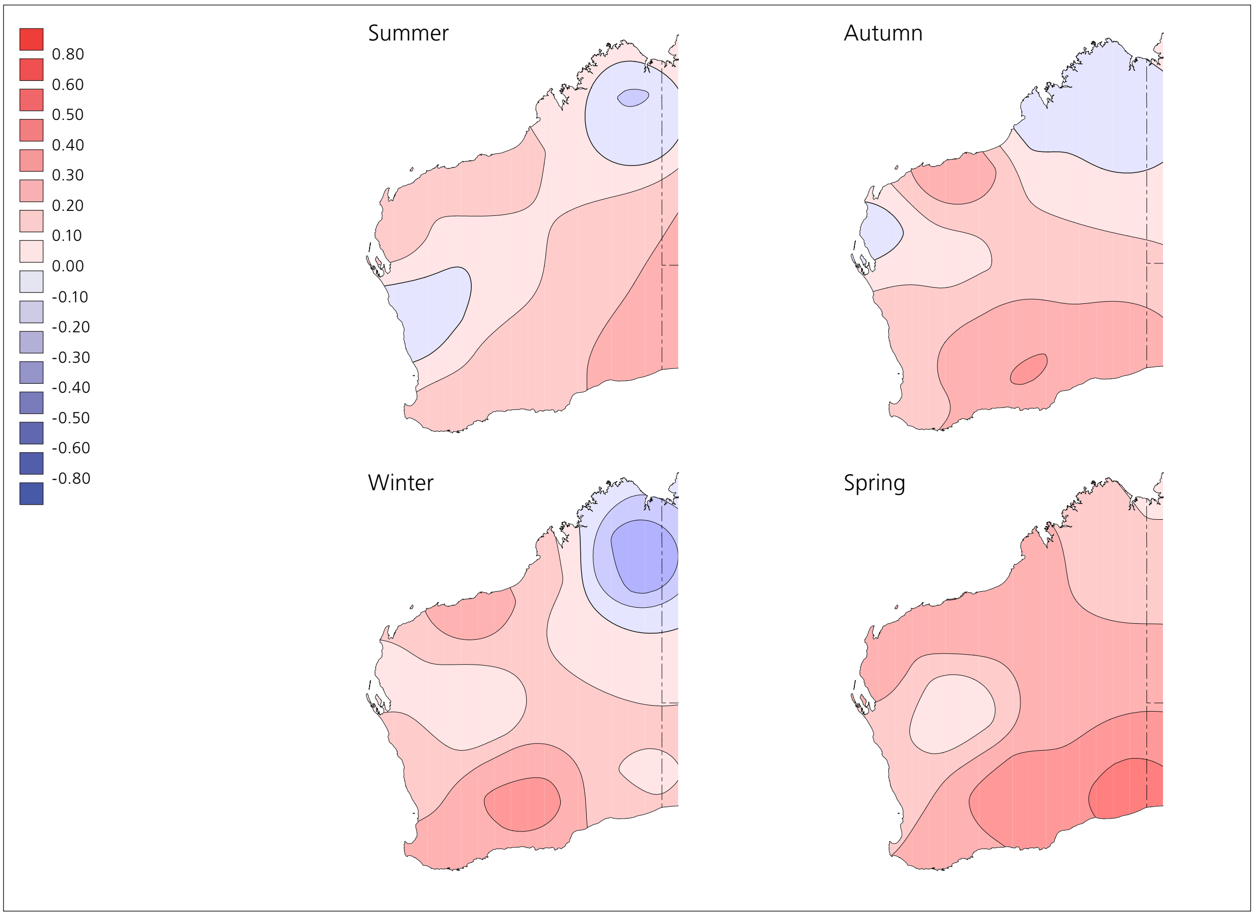


Figure FP2.4: Trend in average daily minimum temperatures in summer, autumn, winter and spring in Western Australia, 1950–2006 (degrees Celsius per 10 years).

Map courtesy of Bureau of Meteorology.

Indicator FP7: Projected trends in temperature for Western Australia.

Climate modelling by the CSIRO (CSIRO, 2001) indicates that a continued trend of warming is likely to occur in WA. Average annual temperatures for the State are projected to increase 0.4–2.0°C by 2030 and 1.0–6.8°C by 2070 (Figure FP2.5). Warming is projected to be greatest in summer and spring, with much of the northern half of the State likely to experience the greatest warming. This contradicts the observed decline in temperature in the east Kimberley since 1950, which may be due to the methodologies and uncertainties in the models used.

More recent climate modelling by the Indian Ocean Climate Initiative also projects a rise in temperature in all seasons in the South West of WA by 2030, based on a range of emission scenarios (Indian Ocean Climate Initiative 2005i).

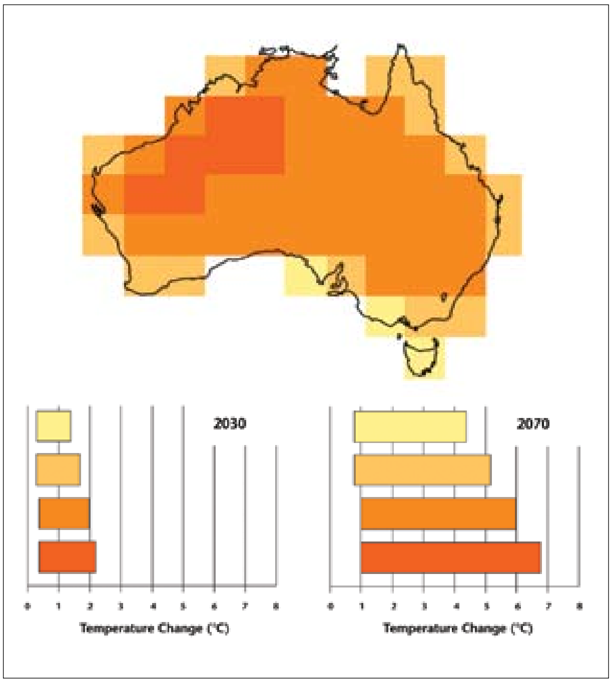


Figure FP2.5: Projected changes to average annual temperature for Australia: 2030 and 2070.

Map courtesy of CSIRO (2001). Note: These projections are based on results from computer models that involve simplifications of real physical processes that are not fully understood. As such, they should be treated with caution.

Indicator FP8: Historic trends in rainfall for Western Australia.

Total annual rainfall for WA has remained fairly consistent over the past century but there have been substantial regional changes, mostly in the past 30 years (Figure 2.6). Total annual rainfall in the South West has declined by 10% since the mid 1970s. Most of the decrease is due to a fall in May to July average rainfall of about 15% (Figure FP2.7; Indian Ocean Climate Initiative, 2005b). This is associated with an increase in summer rainfall, and winter rainfall occurring later in the season. The South West derives much of its winter rain from passing cold fronts and associated storms, and since the 1970s both the number of storms and the amount of rainfall generated by them has decreased (Indian Ocean Climate Initiative, 2005g). The sharp drop in rainfall occurred at the same time as a global change in atmospheric circulation, which has been attributed to both the enhanced greenhouse effect and natural variability (Indian Ocean Climate Initiative, 2005b).

In contrast, total annual rainfall has substantially increased in the Pilbara, the arid interior and the Kimberley since the 1970s. This change is primarily due to increased summer monsoonal rainfall. Recent research suggests that increased monsoonal rainfall in the north of the State is caused by particulate haze in Asia, which is cooling the Asian continent and nearby oceans, and thereby altering the balance of temperature and winds between Asia and Australia.

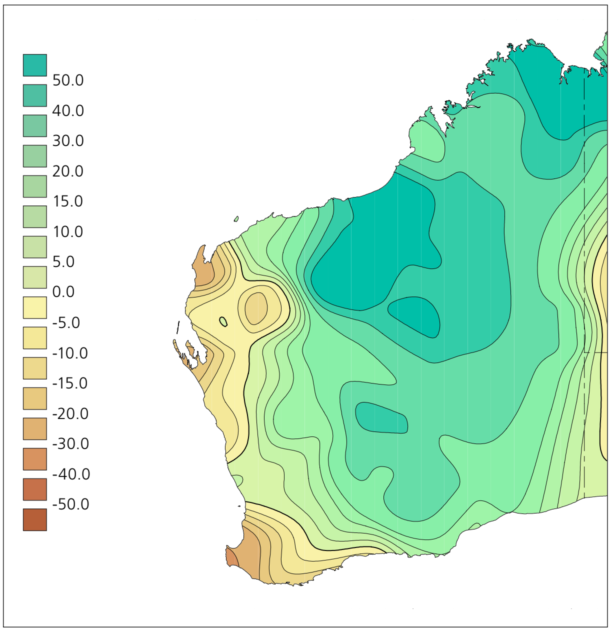


Figure FP2.6: Trend in annual total rainfall for Western Australia, 1970–2006 (mm rainfall per 10 years)

Map courtesy of Bureau of Meteorology.

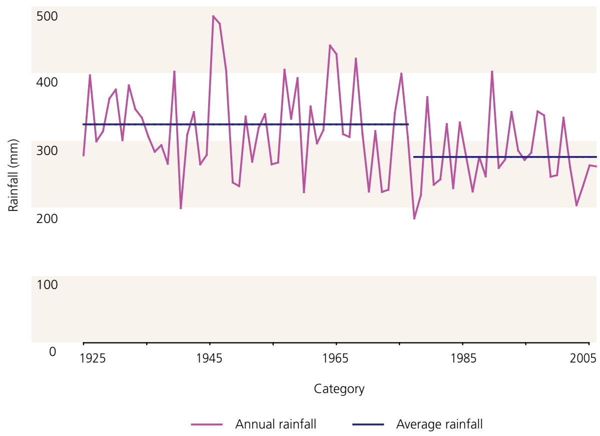


Figure FP2.7: May–July rainfall totals and average rainfall for the periods 1925–75 and 1976–2004, averaged over the South West of Western Australia.

Data source: Indian Ocean Climate Initiative (2005b).

Indicator FP9: Projected trends in rainfall for Western Australia.

Climate modelling by the CSIRO (CSIRO, 2001) indicates that under increasing greenhouse conditions there is a good chance of reduced rainfall in the South West. Average annual rainfall in the South West may vary by -20% to +2% by 2030, and from -60% to +10% by 2070, relative to 1990 levels (Figure FP2.8). In other parts of the State, modelled rainfall projections vary significantly, within the ranges of -20% to +20% by 2030, and -60% to +60% by 2070. The effect of particulate haze in Asia on rainfall in WA has not been included in the CSIRO's climate change models which may explain why the models have not reproduced the observed increase in rainfall for northern WA (Rotstayn et al., in press).

Further climate modelling by the Indian Ocean Climate Initiative supports the CSIRO projections for rainfall decline in the South West. The modelling consistently indicates that 'wet season' (May to October) rainfall will decrease in the South West, in a number of climate models and under a range of emissions scenarios (Figure FP2.9). The results suggest winter rainfall may fall by as much as 20% relative to the 1960–1990 baseline level with the number of winter rain days decreasing by up to 17% (Indian Ocean Climate Initiative, 2005i). Rainfall projections for the 'dry season' (November to April) are less certain as some models project a rainfall increase during the November to April period.

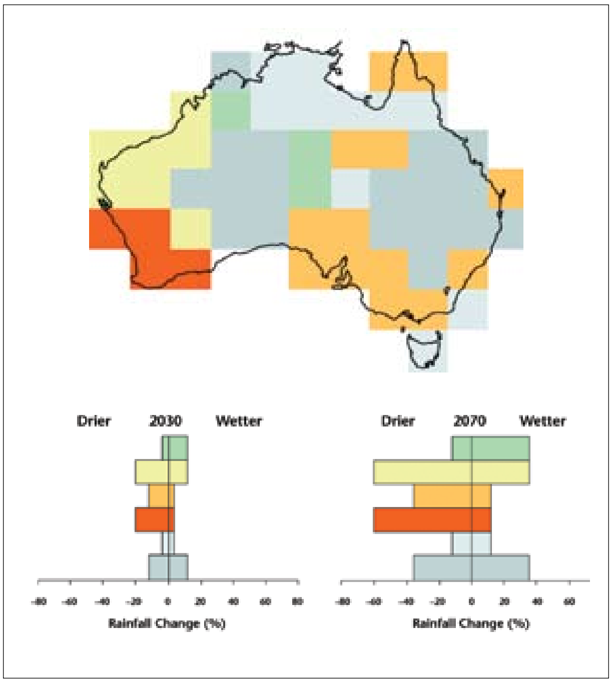


Figure FP2.8: Projected changes to average annual rainfall for Australia: 2030 and 2070

Map courtesy of CSIRO (2001). Note: These projections are based on results from computer models that involve simplifications of real physical processes that are not fully understood. As such, they should be treated with caution.

Indicator FP10: Historic trends in sea level rise for Western Australia.

Global sea level rose 10–20 cm between 1897 and 2005, which is much greater than over the past 1000 years (Indian Ocean Climate Initiative, 2005c). Tide records show that the sea level off Fremantle has increased roughly 15 cm in this period, or an average rise of about 1.5 mm per year (Figure FP2.10). This represents 20% of the maximum tidal range at Fremantle. The rate of change varies due to annual variation from the El Niño-Southern Oscillation phenomenon, and explains why the sea level appears constant between 1952 and 1991. Between 10-35% of the sea level rise over the past century can be attributed to increasing seawater temperatures (and consequent water expansion), while the melting of glaciers and ice caps has contributed about 10-25%.

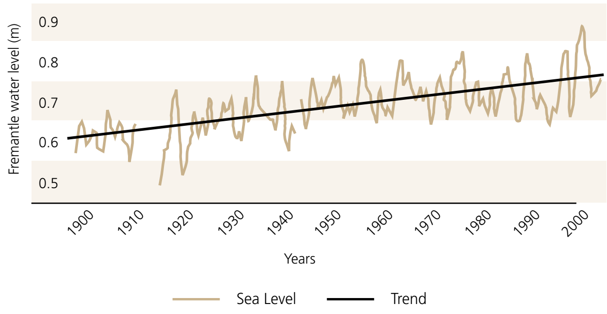


Figure FP2.10: Sea level at Fremantle.

Data source: Indian Ocean Climate Initiative (2005c).

Indicator FP11: Projected trends in sea level rise for Western Australia.

Global mean sea level is projected to rise by 18–59 cm by the end of the 21st century relative to 1980–1999 levels, based on a range of modelled scenarios (Intergovernmental Panel on Climate Change, 2007b).

Pressures

The drivers of recent climate change in WA include both natural climate variability and the enhanced greenhouse effect, but the latter is thought responsible for much of the observed warming in WA since 1950 (Indian Ocean Climate Initiative, 2005f). Other human activities have contributed to the observed warming globally (either positively or negatively) including aerosols released into the atmosphere, tropospheric ozone changes due to emissions from ozone-forming chemicals, and changes in surface reflectivity due to land-cover changes (Intergovernmental Panel on Climate Change, 2007b). However, the enhanced greenhouse effect is having the greatest influence by far on the global climate system. Further to this, the Intergovernmental Panel on Climate Change has concluded that the enhanced greenhouse effect will continue to drive global atmospheric warming and sea level rise for centuries, even if atmospheric greenhouse gas concentrations are stabilised (Intergovernmental Panel on Climate Change, 2007b).

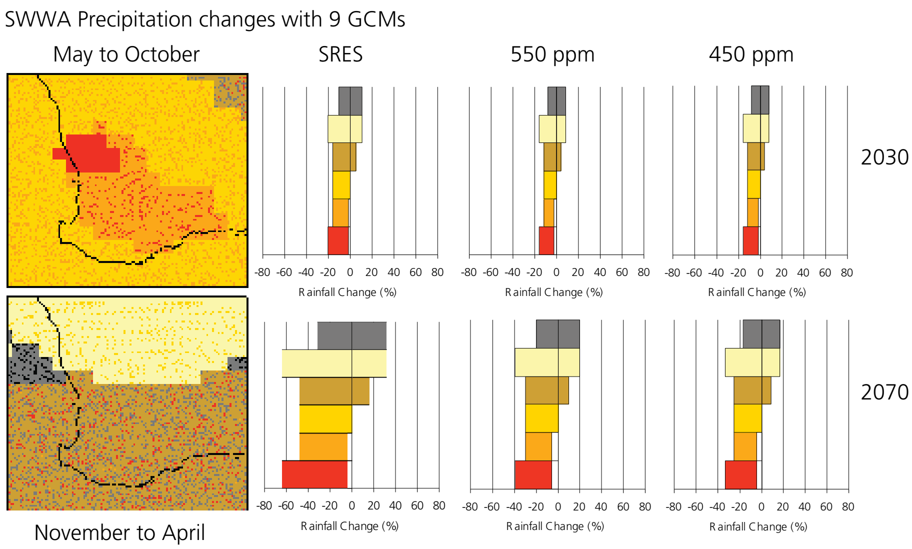


Figure FP2.9: Range of projections for changes to rainfall over the South West of Western Australia from nine international climate models.

Map courtesy of Indian Ocean Climate Initiative (2005i). Note: The graphs on the right are for three different emission scenarios in 2030 and 2070. The bars show the range of model projected rainfall change. The bar colours relate each projection to the corresponding areas on the maps. The emissions scenarios include representative range of future emissions (SRES) and stabilisation of atmospheric carbon dioxide levels at 450ppm (parts per million) and 550ppm.

Indicator FP12: Historic trends in atmospheric greenhouse gases.

Measurements from trapped ice in the Antarctic show there is a close correlation between atmospheric concentrations of carbon dioxide (a major greenhouse gas) and Antarctic temperature over at least the last 400 000 years (Figure FP2.11). Significant natural climate variation has occurred over the Earth's history and global carbon dioxide levels have tended to track glacial cycles (Intergovernmental Panel on Climate Change, 2001).

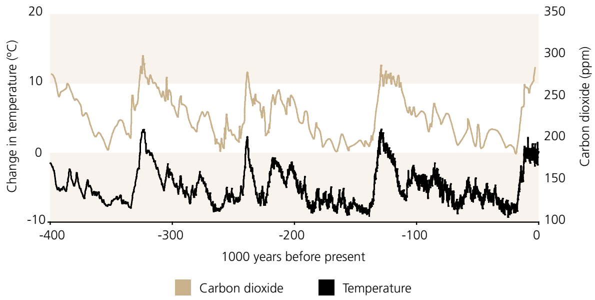


Figure FP2.11: Antarctic temperature and global carbon dioxide in the atmosphere over the last 400 000 years from the Vostok ice core.

Data source: Petit et al. (1999). Note: Carbon dioxide levels in parts per million (ppm) are shown alongside temperature change in degrees Celsius (°C).

Although atmospheric concentrations of major greenhouse gases have been relatively steady for much of the last 1000 years, they have increased exponentially over the past 200 years (Figure FP2.12). Some of the principal causes of this dramatic increase globally are fossil fuel burning, deforestation, biomass burning, and some agricultural and industrial practices (Bureau of Meteorology, 2003).

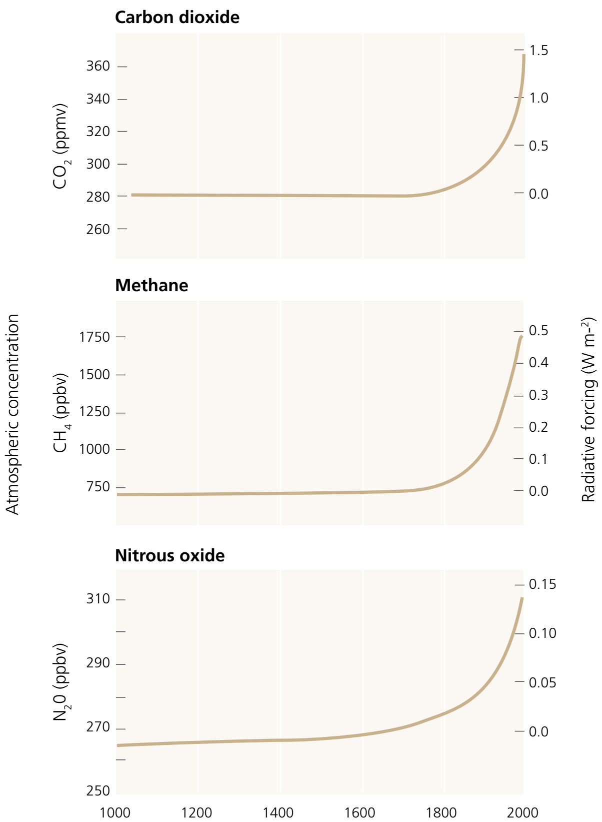


Figure FP2.12: Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 1000 years.

Data source: Bureau of Meteorology (2003). Note: Based on measurements from Antarctic ice cores and, since the 1970s, analyses conducted at Cape Grim Baseline Air Pollution Station. Radiative forcing is a measure of the influence the gas has in altering the balance of incoming and outgoing radiation, and is measured in watts per square metre. Positive forcing tends to warm the surface while negative forcing tends to cool it.

Indicator FP13: Current trends in greenhouse gas emissions for Western Australia.

Western Australia is contributing to the enhanced greenhouse effect through emissions of greenhouse gases. Australia contributes around 1.5% of global greenhouse gas emissions, but it is the greatest emitter in the industrial world on a per capita basis (The Australia Institute, 2004). In 2005, Western Australia generated about 12% of Australia's emissions. Using greenhouse accounting methods, WA's net annual greenhouse gas emissions increased by 17% between 1990 and 2005, to 66.6 million tonnes (Mt) of carbon dioxide equivalent ((CO_2-e); Figure FP2.13; see '*Greenhouse gas emissions*').

Most of the State's emissions (74% in 2004) came from the energy sector, due to its heavy reliance on fossil fuels for energy supply and transport (see '*Energy*'). Emissions from the energy sector alone increased by 58% between 1990 and 2005. The State also has a large number of energy-intensive industries, including oil and gas, minerals, bauxite refining, and iron and steel production. Rapid growth in several of these industries over the past decade has contributed significantly to growth in greenhouse gas emissions. Unless significant changes are made, greenhouse gas emissions from the energy sector will continue to grow rapidly.

The rapid increase in WA's greenhouse gas emissions has been masked to some extent by the decrease in emissions from the land use, land use change and forestry sectors. Greenhouse gas emissions from these sectors decreased significantly between 1990 and 2005, from 9.8 Mt CO_2-e to -1.6 Mt. This was due to a decrease in vegetation clearing for agriculture and an increase in plantations. If the greenhouse gas emissions from these sectors are excluded from the accounting methods, the State's greenhouse gas emissions effectively increased 45%.

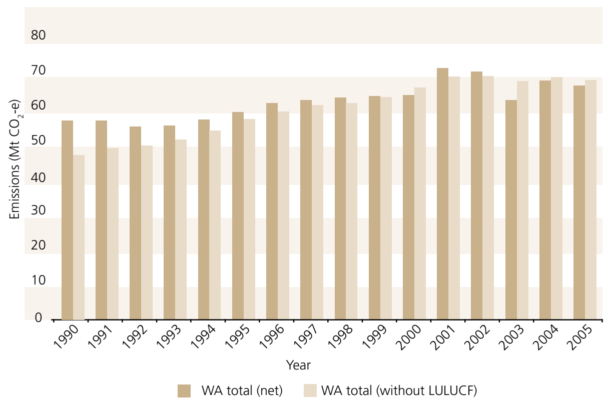


Figure FP2.13: Western Australia's greenhouse gas emissions, 1990–2005.

Data source: Australian Greenhouse Office (2007). Note: This figure depicts greenhouse gas emissions in carbon dioxide equivalents (CO_2-e). LULUCF refers to the land use, land use change and forestry sector.

Indicator FP14: Projected trends in greenhouse gases emissions for Western Australia.

The main pressures driving increasing greenhouse gas emissions in WA are population growth and economic growth with associated increasing rates of production and consumption. Projected trends in greenhouse gas emissions unavoidably have a level of uncertainty associated with them and should therefore be treated with caution. Estimates from the Australian Bureau of Agricultural and Resource Economics (Riwoe et al., 2006, cited in Government of Western Australia, 2006) for the stationary energy sector are that greenhouse gas emissions will increase from 40 Mt CO_2-e in 2004–05 to 71 Mt CO_2-e in 2029–30. This estimate includes uncertainty assumptions of +/- 15% at 2030.

Fugitive emissions (gas which leaks or is vented without combustion) are projected to increase from 1.5 Mt CO_2-e in 2003–04 to 6.6-13.5 Mt CO_2-e by 2030, due to growth in gas production from existing facilities, development of planned new liquefied natural gas developments and growth in supply to the domestic market (Government of Western Australia, 2006). There is a large degree of uncertainty in projected fugitive emissions due to the uncertainty associated with using geosequestration to manage them.

Projected trends in greenhouse gas emissions from other sources are not available.

Current responses

Most responses to climate change in WA focus on addressing greenhouse gas emissions, although there have been some responses from particular sectors to the impacts of the State's changing climate. Key initiatives at global and national levels will also have a significant bearing on outcomes for WA.

Intergovernmental Panel on Climate Change: is an international body established by the United Nations and the World Meteorological Organisation in 1988 to assess, compile and communicate scientific consensus on the state of human-induced climate change, its potential impacts and options for adaptation and mitigation.

The Kyoto Protocol: imposes binding and quantifiable emission reduction commitments on developed signatory nations that have ratified the document. The protocol is acknowledged as a valuable first step in coordinating the global effort to reduce greenhouse gas emissions. Australia has not ratified the Kyoto Protocol, but has committed to meeting Australia's target under it. Current analysis projects Australia's greenhouse gas emissions at 109% of the 1990 level over the period 2008–2012, which is slightly above the 108% target (Commonwealth of Australia, 2006). Currently, Australia's energy-related emissions are more than 30% above the 1990 Kyoto baseline and are increasing rapidly. Discussions are underway for the 'post Kyoto' period.

International climate change partnerships: Australia has arrangements in place with several countries for bilateral and multilateral cooperation on practical actions that contribute to the global effort to respond to climate change.

Asia–Pacific Partnership on Clean Development and Climate: Australia is party to the partnership with nations in the Asia–Pacific region as well as the United States. The partnership, launched in 2006, aims to create a voluntary framework for development, transfer and uptake of cleaner technologies.

The *Western Australian Greenhouse Strategy:* was released in 2004 and aims to guide State efforts to reduce greenhouse gas emissions, and guide responses to opportunities and challenges generated by climate change (Government of Western Australia, 2004). Initiatives include forming a Greenhouse Unit to coordinate a whole of government response to climate change, developing a climate change impact and assessment strategy for the South West, establishing a greenhouse gas emissions reporting framework and developing a renewable energy strategy for the South West Interconnected System.

Greenhouse and Energy Task Force: was established by the State Government in 2005 to provide advice on managing greenhouse gas emissions from the stationary energy sector. It has published a report entitled *A Cleaner Energy Future* (Government of Western Australia, 2006) that outlines recommendations to reduce greenhouse gas emissions by 50% in the longer term, and emissions trading, energy conservation initiatives and on-ground rules for greenhouse offsets.

The Indian Ocean Climate Initiative: is a climate research program started in 1998 focusing on providing a greater understanding of climate variability in the South West. To date, this initiative has produced a range of publications on climate change in the South West.

The *State Coastal Planning Policy*: aims to protect coastal developments from sea level rise by establishing a development setback. The policy guides the Western Australian Planning Commission, local government and other agencies in planning decisions affecting coastal protection (Western Australian Planning Commission, 2003).

Climate change will impact forests in the South West due to shifts in temperature and rainfall patterns (Tourism WA).

Implications

Western Australia is already experiencing changes in average climate conditions, climate variability and the frequency of extreme weather events. Climate scientists warn that dangerous climate change is likely to occur with a total increase in global average temperature of 2.0°C, which under current trends is projected to occur. Reductions in greenhouse gas emission levels to at least 50-60% of 1990 levels will need to be achieved by 2050 to reduce the likelihood of dangerous climate change occurring before the end of the century. Governments of some developed nations, including the United Kingdom, have committed to goals to meet this level of emissions reduction. Western Australia must also work to achieve major reductions in greenhouse gas emissions.

Western Australia's environment, society and economy are vulnerable to the impacts of climate change. The State must continue to protect its natural capital, adapt its economy and adjust societal lifestyles through the pressures of a changing climate. While we need a better understanding of the potential impacts of climate change in order to respond effectively to them, the State's vulnerability can be mitigated by reducing other stresses and increasing resilience, for example by improving ecological linkages, diversifying agricultural practices, and improving water and energy efficiency.

The extent of the impacts from climate change globally and in WA will depend on how rapidly and comprehensively the global community takes steps to abate greenhouse gas emissions. Some recent studies, including the Stern Review of the economic costs of climate change (Stern, 2006) and more locally the CSIRO Energy Futures Forum (CSIRO, 2006), now recognise that the global benefits of taking early action to avoid climate change will far outweigh the global economic costs of not acting. The need to take early action is also the view of the Western Australian Greenhouse and Energy Taskforce (Government of Western Australia, 2006).

The implications of climate change are expected to be significant and far reaching (see following text boxes).

IMPLICATIONS FOR BIODIVERSITY

By the end of the century, climate change and its impacts may be the dominant direct driver of biodiversity loss and changes in ecosystem services globally (Millennium Ecosystem Assessment, 2005). Significant loss of biodiversity is projected to occur in some ecologically-rich parts of Australia by 2020 and the South West of WA is considered to be at considerable risk (Intergovernmental Panel on Climate Change, 2007a). Past climate variability and change has played a key role in shaping ecosystems and the distribution of various species across the State. However, current and future climate change will affect biodiversity directly through changes to temperature, rainfall and extreme events, and through altering the nature and intensity of existing biodiversity pressures (e.g. salinisation, loss of wetlands, density and distribution of weeds). This will bring changes to landscapes and ecosystem services as species adapt, emigrate or immigrate and others become isolated.

Terrestrial ecosystem impacts of climate change are expected to be significant across the State, with modelled temperature increases of several degrees Centigrade in some regions, and significant rainfall changes expected this century. Changes in the frequency or intensity of severe storms and cyclones (particularly in the North West) could affect the ability of some ecosystems to recover from floods, fires, drought and previous storm damage.

Climate change is likely to impact many native fauna species that are already vulnerable to other threats, such as predation (B. Wells).

Climate change models predict small to moderate increases in forest growth where rainfall remains stable or increases, due to increased temperatures and carbon dioxide levels. However, in areas of declining rainfall forest growth may be detrimentally impacted by reduced rainfall, increased fire and disease risks (Allen Consulting Group, 2005). These changes are likely to have the greatest impact on biodiversity for South West forests. There are also likely to be changes in the competitive advantage of grass species and spread of woody shrubs into arid and semi-arid rangelands, which may alter fire regimes and animal habitat. Spread of invasive weeds is likely to accelerate within disturbed ecosystems, particularly for those species that can rapidly adapt to new environments. Rising sea level and resulting tidal incursion into freshwater wetlands is also likely to increase, severely modifying their ecology.

The risk of extinction for already-vulnerable species may increase (Natural Resource Management Ministerial Council, 2004). Loss of species and ecosystems will occur when tolerance thresholds are exceeded. Climate change models predict the current range of species to decline and for habitats to become more isolated across the landscape. Specific local climates required by some plant and vertebrate species may disappear entirely with as little as 0.5–1°C warming (Hughes, 2003). For example, with only 0.5°C warming CSIRO modelling shows that South West habitats for all frog and many mammal species would be significantly reduced and 15 species of endangered or threatened WA mammals would disappear or be restricted to small areas (Pouliquen-Young & Newman, 1999). Leaf-eating herbivores may also be detrimentally affected by a change in plant chemistry following increases in atmospheric carbon dioxide (Cork & Foley, 1991).

Fragmentation of landscapes will inhibit the ability of flora and fauna to adapt to climate change by migrating to more suitable environments. Highly mobile species such as butterflies and birds appear to have already responded to relatively minor climate change and migration responses have been noted within intact vegetation systems (Parmesan et al., 2005). However, many species may not be able to migrate fast enough due to limited distribution or an inability to establish a new location (Hughes et al., 1996; Hughes, Westoby & Cawsey, 1996). In the South West particularly, landscape fragmentation will make it difficult for some species and ecosystems to migrate, especially those with narrow temperature tolerance ranges or those at the upper limits of their ranges. For example, the temperature tolerance range for 41% of Australian eucalyptus species (including many WA species) is less than 2°C in mean annual temperature (Hughes, Westoby & Cawsey, 1996). Similarly, a 2°C rise in temperature would result in the disappearance of 66% of WA Dryandra species and 100% of Acacia species (Pouliquen-Young & Newman, 1999).

The potential impact of climate change on biodiversity is significant and is becoming increasingly well-recognised, but is not well researched or understood. Human intervention, including translocation and breeding programs, may hold the key to the future survival of threatened and endangered species under a dramatic climate change scenario.

IMPLICATIONS FOR LAND

Western Australian land resources are not immune to the projected impacts of climate change. Changes to landscapes and soils will be linked to vegetation changes and the ability of major land uses (such as agriculture, pastoralism and forestry) to adapt. Some plant species may be unable to adapt to a long-term shift in climate, thereby reducing vegetation cover and allowing opportunities for land degradation to occur. However outcomes are by no means certain. For example, further loss of perennial vegetation in the South West could be expected to accelerate dryland salinisation, but if the projected rainfall decline and rising temperatures forecast for this region eventuate, this may actually help alleviate dryland salinity and waterlogging problems.

Loss of vegetation cover will also result in gradual deterioration of soil health as natural biological processes and ecosystem services deteriorate. This is likely to enhance susceptibility of soil to the effects of wind and water erosion. Increased severity of storm events, fires or droughts will enhance the occurrence of soil erosion under these conditions, particularly in the rangelands.

Reduced rainfall in the South West and subsequent lowering of watertables may also cause subsurface soil acidification problems. This process is already apparent on the Gnangara and Jandakot groundwater mounds in Perth, where a sequence of low rainfall years (combined with increasing abstraction of groundwater) has contributed to subsurface soil acidification problems (Appleyard, 2004 & 2005). Under these conditions there is also a significant risk of contamination from the release of toxic metals and chemicals from soil.

Predicting the likely effects of climate change on agriculture, pastoralism and forestry is difficult because changes in climatic factors can work in different ways. For example, increased carbon dioxide boosts plant growth and increases water use efficiency, while the projected increases in temperature and extreme weather events will reduce production. On balance, rainfall patterns are likely to be the major influential factor, with future crop, pasture and tree growth largely dependent on rainfall remaining relatively stable or increasing (Commonwealth of Australia, 2005). The capacity of agricultural industries to adapt to altered climate will significantly influence future management of land issues, such as dryland salinisation, soil erosion, acidification and loss of soil health. Under extreme climate change scenarios, agricultural profitability in some parts of the Wheatbelt may be reduced by up to 80% compared to historical climates (John, Pannell & Kingwell, 2005).

IMPLICATIONS FOR INLAND WATERS

Western Australian inland waters are very susceptible to the predicted effects of climate change. Changes to inland waters will be linked to altered rainfall, temperature and associated impacts on catchment vegetation. There have already been considerable impacts on many aquatic ecosystems across the South West as a consequence of observed climate change. For example, a 10–15% drop in South West rainfall since the 1970s has produced a corresponding 50% reduction in average annual flows in some South West rivers and streams (Indian Ocean Climate Initiative, 2005d). The enormous reduction in flow resulting from a comparatively small decline in rainfall highlights the importance of rainfall in generating stream flows, and the sensitivity of waterways to change. Consequent impacts have already occurred to the structure of some waterways as well as declines in aquatic ecology and fringing vegetation. Further temperature increases and rainfall decreases are projected for this region and will only exacerbate the deterioration of inland waters.

Algal blooms will become more frequent and widespread with increasing temperatures (V. Hosja)

Wetlands are also experiencing the effects of a drying climate. Anecdotal evidence over recent decades suggests that some of Perth's lake systems are being converted to swampy flats. Some wetlands associated with climate-sensitive groundwater systems have also experienced more frequent dry states. Groundwater systems are very sensitive to changes in rainfall. For example, water levels on the Gnangara Mound in Perth have declined by as much as four metres in recent dry decades, also affecting associated wetlands (Indian Ocean Climate Initiative, 2005h).

In South West agricultural areas, groundwater changes due to altered climate are more difficult to establish due to the compounding effects of native vegetation clearing and its replacement with agricultural pasture and crops. In drier parts of the north-eastern Wheatbelt, groundwater levels have declined in upper to mid-slope areas as a result of reduced rainfall. Groundwater levels in the central and eastern Wheatbelt are not rising as quickly as they initially did in response to widespread clearing, and in some areas with shallow water tables (less than 8 m) levels are stable or declining. On the south coast and wetter parts of the Wheatbelt, groundwater levels continue to rise where the landscape is poorly drained (Indian Ocean Climate Initiative, 2005i).

The decrease in waterway flows has dramatically affected refilling of water supply reservoirs that service Perth and nearby country towns (Water Corporation, 2005). This has forced a major review of the sustainability of South West water supplies, including the de-rating of surface water dams and an increased focus on groundwater sources, desalinisation and water conservation initiatives. The decline in streamflow and groundwater recharge has severely impacted the availability of water resources, and affected water quality and water-dependent ecosystems in the South West.

Impacts of climate change on inland waters in other parts of WA are less certain with some uncertainty about future rainfall projections. However, impacts are expected to occur with changes in temperature, light availability, rainfall patterns and altered storm frequency and intensity. For example, instances of eutrophication are likely to increase with global warming, especially given the adaptability of blue-green algae to increased light, temperature and nutrient conditions and potentially reduced flow conditions. These conditions may also benefit subtropical weed species, mosquito breeding and water-borne pathogens (Commonwealth of Australia, 2003; Allen Consulting Group, 2005). More frequent and intense storm events and cyclones in the north are likely to exacerbate soil erosion, bank erosion and sediment loadings in waterways. With rising sea levels and storm surges, many estuaries and coastal freshwater wetlands could also be inundated with salt water and sediment, significantly altering their ecology.

IMPLICATIONS FOR THE MARINE ENVIRONMENT

Climate change is expected to have considerable impacts on WA's marine environment, through rising sea levels and temperatures, and changes in ocean currents. Ocean warming is likely to be caused by the greenhouse effect combined with natural variation in the ocean–atmosphere system. Since 1960 the sea surface temperature in the Indian Ocean has increased by an average of 0.6°C. The North West has experienced some of the highest levels of warming in the Indian Ocean, with Ningaloo Reef experiencing a rise of 0.6°C over the past 15 years (Indian Ocean Climate Initiative, 2005e).

Ocean warming has contributed to sea level rises through thermal expansion of sea water. The mean sea level has increased about 20 cm at Fremantle since 1897 (Indian Ocean Climate Initiative, 2005c). Ocean currents, such as the Leeuwin, Capes and Ningaloo currents, play an important role in influencing marine life and local climates. It is projected that the strength of the Leeuwin Current will increase marginally by 2100. This may have implications for tropical species off the western and southern coasts, and influence the life cycle of the western rock lobster, southern blue fin tuna, coastal scallops, fin fish stocks, and the distribution of seagrass, algae, and coral spawning and distribution (Indian Ocean Climate Initiative, 2005c). The effects are also likely to be felt up the food chain, including cuts to fisheries already under stress, and seabird distribution.

With the exception of coral reef environments, very little is known about the likely long-term implications of climate changes on WA's marine environment (Government of Western Australia, 2004). Coral reefs are highly vulnerable to sea temperature rise. During summer months, corals in subtropical and tropical locations exist within 1°C to 2°C of their upper thermal tolerance limit. Temperatures beyond these levels result in coral bleaching and, if severe and prolonged, may result in death (Jones, Berkelmans & Oliver, 1997). Major global coral bleaching events occurred in 1998 and 2001, following abnormally high sea temperature conditions, with several northern reefs seriously affected. A major global coral reef bleaching event in 1998 impacted the Ashmore, Cartier, Scott and Seringapatam reefs and Rowley Shoals (Australian Greenhouse Office, 2003). In early 2005, large reef areas off the Dampier Archipelago were also bleached. Coral recruitment is usually slow and it may take many years for reefs to recover from these events. The most likely outlook is that severe bleaching events could become commonplace in the next 20 years and could eventually result in a shift from coral to algal-dominated ecosystems.

Increased cyclone and storm activity may cause physical damage to reefs and sensitive marine environments, such as seagrass communities. Associated flooding of major rivers may lead to detrimental impacts on sensitive marine environments from low salinity episodes, increased turbidity and pollution of coastal and near-shore marine ecosystems.

In addition, higher carbon dioxide levels will increase acidity in ocean waters leading to reduced coral growth and dissolving of limestone reefs and the shells of many molluscs (LeClerq, Gattuso & Jaubert, 2002). These pressures could result in many tropical near shore communities switching from coral to algal-dominated communities (eds Howden et al., 2003).

Coastal areas are more likely to be impacted by rising sea levels and associated increases in storm surges and wave energy. For example, rising sea levels in the North West are expected to result in mangroves retreating from the coastline. In contrast, a predicted rise of 50 cm in large tidal areas, such as Shark Bay and Exmouth Gulf, would completely inundate existing mangrove ecosystems (Semeniuk, 1994). It is expected that the rise in sea levels will also cause erosion of some coastal beaches by up to 30 m by 2040 (Indian Ocean Climate Initiative, 2005c).

IMPLICATIONS FOR HUMAN SETTLEMENTS

Climate change has already affected some of WA's settlements through increased temperatures and reduced rainfall. Rainfall decline in the South West combined with increased demand for water for settlements has forced the acceleration of water source developments (e.g. desalinisation plants, sourcing from new groundwater aquifers).

Global sea level rise may cause coastal sandy beaches to recede between 5.5–88 m (CSIRO, 2002). Low-lying coastal, waterfront and canal developments will be particularly vulnerable to sea level rise and the likely increase in storm surges and flooding. The impacts on settlements could be substantial, especially if severe weather events affect areas where buildings and infrastructure are not adequately designed to cope with the changes (Allen Consulting Group, 2005). This is a significant concern, as coastal settlements are where the vast majority of people already live in WA and where population growth is currently strong.

Some regional settlements may be vulnerable to climate change, particularly those in areas with climate-dependent industries such as agriculture, pastoralism, wood production and tourism. Impacts on these industries will have flow-on effects to local communities and may exacerbate existing social and financial problems.

Many human health problems, particularly those linked to environmental conditions, are likely to be exacerbated by climate change, and are expected to have greatest impact on vulnerable social groups including remote Aboriginal communities, the elderly and low-income groups (Commonwealth of Australia, 2003; Australian Greenhouse Office, 2005). Prolonged periods of hot, dry spells may lead to elevated incidences of heat stroke and heat-related deaths (Woodruff et al., 2005). The relationship between asthma and temperature may become stronger. There is also a demonstrated relationship between many allergen-producing organisms (including moulds, house dust mites and cockroaches) and climatic factors such as temperature, humidity and rainfall. Higher temperatures will promote proliferation of bacteria in contaminated foods: incidences of food-borne diseases are already known to increase significantly during summer months. Skin cancer rates in WA are already high and preliminary evidence suggests that higher environmental temperatures enhance exposure to ultraviolet radiation (Commonwealth of Australia, 2003).

Climate change is confidently predicted to enhance the transmission of mosquito-borne diseases such as Ross River Virus and Murray Valley encephalitis. Changing patterns of rainfall (particularly more frequent extreme rainfall events), increases in temperature, higher humidity associated with warmer oceans and changes in tidal inundation of coastal areas (associated with higher sea levels) are likely to influence the frequency and level of transmission of mosquito-borne viruses (Lindsay & Mackenzie, 1997). Increased use of rainwater tanks, creation of other water storage infrastructure and recycling of waste and greywater (all responses to climate change) may lead to increased breeding populations of mosquitoes. Climate change may also present opportunities for the re-establishment of exotic mosquito vectors and diseases, such as dengue fever and malaria.

IMPLICATIONS FOR INDUSTRY AND NATURAL RESOURCE SECTORS

Climate change will affect WA industries through shifts in supply and demand for natural resources. The effect of climate change on overseas trading partners and competitors for resource commodities could be just as significant to industry as the local effects of climate change in WA (Foster, 2005).

The impact of extreme climatic events, such as drought, floods, hail storms, cyclones and wildfires, are already very costly. If the severity, frequency or geographic spread of extreme climatic events changes (e.g. tropical cyclones intensify or move further south), impacts on infrastructure may be severe (Australian Greenhouse Office, 2003). This has significant implications for building design, safety and emergency services. The cost of damage from extreme climate-related events in Australia between 1967 and 1999 has been estimated at approximately $33 billion (Bureau of Transport Economics, 2001). Increases in the severity of extreme climatic events may have disproportionately larger impacts on associated damages and repair costs. Some global studies (eds McCarthy et al., 2001) have found the annual number of extreme climate events is increasing, although this may also be a function of better reporting and increased settlement of vulnerable locations, and this trend has not confidently been observed for the Asia-Pacific region.

Business and industry may be affected because rapid climate changes may require the modification or replacement of existing infrastructure before they have reached the end of their intended lifespan. Public infrastructure such as low lying roads, railways, and ports and bridges are also at risk of flooding and storm surges. Adaptive management planning will be needed to minimise the risk of damage from extreme climatic events, and climate change must be integrated into all future planning processes. Many companies in the insurance sector are now including climate risk in their planning and decision-making, and in some cases this is increasing insurance premiums.

Climate change poses a challenge to the energy sector in terms of infrastructure requirements and potential economic impacts. Western Australia's energy supply may come under pressure from higher temperatures which will increase peak electricity demand, and can also affect electricity generation and transmission capacity. Water availability and supplies, particularly in the drying climate expected in the South West, are also likely to come under increased pressure from further climate change, which will further increase competition between users and place upward pressure on costs of supply.

Increased temperatures, changes in evaporation, enhanced carbon dioxide concentrations, increased seasonal variability and changes in rainfall intensity will all directly impact the agricultural (Howden & Meinke, 2001), pastoralism and wood production sectors. While higher temperatures and atmospheric carbon dioxide concentrations may provide some benefits for plant growth through increased productivity in the short term, climate changes in the long term are likely to impact adversely on these sectors. Sustained temperature increases and reduced rainfall are expected to have flow-on effects such as changes to distribution and abundance of native flora, reduced water availability, increased fire risk, reduced soil moisture, increased risk of pests and diseases, decreased nutrient availability, and increased heat stress for crops, forests, plantations and livestock (Australian Greenhouse Office, 2002; Robertson, 2002). There are likely to be rainfall and temperature thresholds beyond which some industries will not be able to adapt. This will have considerable economic and social costs, including the cost of preventative treatments, relocation and reduced productivity.

Western Australia's fisheries industries are also highly climate dependent, with recruitment and migration patterns of some fish species sensitive to climatic conditions. The productivity of many WA fisheries is influenced by the El Niño Southern Oscillation, which influences the Leeuwin Current. These fisheries could be affected if El Niño becomes more prevalent (Australian Greenhouse Office, 2003). Coastal fisheries that are dependent on vulnerable coastal wetlands and estuaries as nursery grounds may be particularly impacted.

SUGGESTED RESPONSES

1.4 Build on the Indian Ocean Climate Initiative to:
- further develop understanding of climate change and its impacts;
- communicate this information;
- coordinate responses; and
- develop adaptive management strategies.

1.5 Develop and implement a risk based policy framework to ensure planning and development decisions fully factor in the likely impacts of climate change.

See also '*Greenhouse gas emissions*':

- Establish a legislative framework to achieve greenhouse gas emission reduction targets.
- Establish a target to reduce emissions by at least 60% below 1990 levels by 2050 and establish interim targets for 2010, 2020, 2030 and 2040.
- Establish a 20% renewable energy target for the State.
- Develop standards for carbon offsets to ensure their integrity and to support a carbon trading market.
- Establish a carbon trading market, with a preference for participating in a national emissions trading scheme.
- Implement all actions of the *Western Australian Greenhouse Strategy*, including a comprehensive review and update by the end of 2008.
- Reduce the greenhouse gas intensity of the State's economy: emission reduction strategies and long term targets need to be developed for each sector of the economy.
- Implement the recommendations of the WA Greenhouse and Energy Taskforce Report: *Strategies to Reduce Greenhouse Gas Emissions from the Western Australian Stationary Energy Sector*.
- Undertake a comprehensive review of energy subsidies and remove subsidies that increase greenhouse gas emissions.

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