Climate change

The challenge for natural resource management

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Minister's foreword

Climate science informs our future

Over the past decade, a group of Queensland Government scientists has turned their attention to the phenomenon of climate change. They are striving to understand it and to measure its effects.

They have worked on a range of projects with their colleagues in the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Bureau of Meteorology, other Australian institutions and through international collaborations. Some of these projects have confirmed locally what other eminent scientists have been saying for decades—that the Earth's climate is changing because of the higher levels of carbon dioxide and other 'greenhouse' gases in the atmosphere, brought about by human activity, principally industrialisation.

Locally, this scientific effort is also producing some groundbreaking results, such as the development of hypotheses, and more recent firmer findings, about the role of stratospheric ozone depletion in influencing the climate of the Southern Hemisphere.

While world leaders draw closer to a resolution on what we need to do collectively about the causes of climate change, there is now a strong consensus that climate change is happening. For example, British Prime Minister Tony Blair has described it as 'the world's greatest environmental challenge', while Britain's chief scientist David King has described climate change as the planet's biggest problem.

International business is also concerned. Shell chairman Lord Oxburgh said that climate change makes him 'very worried for the planet', while chief executive of Rio Tinto's energy group Preston Chiaro has described climate change as a 'deadly' threat to humans.

The debate has moved on from dissecting what changes in our weather patterns mean, to a realisation that we need to get on with developing strategies to deal with it on a daily basis. In Queensland, this means dealing with the implications for the broader economy and in specific areas as diverse as public health and transport planning.

This booklet presents in a straightforward way what the current science tells us about climate change, particularly in Queensland, and what the Queensland Government is doing. While the focus is on the Department of Natural Resources and Mines and the implications for natural resource management, the effort necessarily involves many other agencies and policies.

The debate about what we need to do to adapt to climate change is only just beginning. As we consider our recent efforts and current activities, we hope to set in place signposts for the way forward.

Stephen Robertson

Minister for Natural Resources and Mines

Tackling global warming

Atmospheric levels of greenhouse gases have risen sharply since the industrial revolution. Despite international efforts to reduce them, global emissions of greenhouse gases continue to grow, particularly in rapidly developing economies. In response, the planet's climate is already warming and changing and further changes are inevitable.

The Intergovernmental Panel on Climate Change (IPCC), established by the World Meteorological Organization and the United Nations Environment Programme, is the leading international scientific authority on climate change. According to the IPCC's latest report, Earth's average surface temperature rose by 0.6°C during the 20th century, and the planet's average surface temperature is likely to rise by a further 1.4°C to 5.8°C by the end of this century. Sea levels are likely to rise by between 9cm and 88cm over the same period.

The ranges of temperature and sea-level rises reflect different assumptions about future global emissions of greenhouse gases and, to a lesser extent, uncertainties associated with Earth's climate. However, global emissions of greenhouse gases from human activities are continuing to grow, and concern is mounting that biological feedbacks, such as melting permafrost and emissions from peat bogs, are adding to emissions. It therefore appears that atmospheric carbon dioxide levels are set to more than double over pre-industrial levels by the end of this century.

As a result, future temperatures and sea-level rises are expected to be in the mid to upper end of the ranges quoted and the climate of the past will no longer be a guide to the climate of the future.

While Queensland's climate is naturally highly variable, there is already evidence that our climate is changing. Since 1910, for example, average temperatures have risen across all of Queensland, while rainfall has declined in some coastal areas, notably central Queensland.

The Queensland Government has the benefit of significant in-house expertise in climate science. Agencies such as the Department of Natural Resources and Mines (NR&M), Primary Industries and Fisheries (DPI&F) and the Environmental Protection Agency (EPA) are investigating climate change and its associated impacts as part of broader research into the key drivers of Queensland's climate. Since 1995, NR&M has coordinated a study by CSIRO's Atmospheric Research Division – jointly funded with other agencies – into how Queensland's climate will change in the years ahead. While such information is vital for natural resource managers, it is also of assistance to policy makers and planners across government as well as local governments and the wider community.

According to the latest CSIRO work, Queensland's temperatures are projected to rise significantly in the years ahead, with inland areas warming more rapidly than coastal areas, and the frequency and severity of heatwaves increasing. Average rainfall is also expected to decrease by up to 15 per cent over most of the state. While overall rainfall is expected to decline, the incidence of extreme rainfall events is expected to increase. This has implications for soil erosion and could diminish water quality through increased sediment and nutrient loads in waterways. The combination of reduced rainfall and increasing temperatures is also expected to cause a marked decline in soil moisture, particularly in inland areas, and reduce the availability of water for primary producers, industry and regional and urban communities.

While the recent trend towards fewer cyclones crossing Queensland's east coast is expected to continue, tropical cyclones are expected to become more intense with maximum wind speeds likely to increase by five to 10 per cent by 2050. The amount of rain produced by tropical cyclones is also expected to increase by up to 30 per cent over the same period, with implications for flood levels. Cyclonic storm surges would also be greater due to higher sea levels and increases in cyclone intensity.

Climate change will therefore affect the economy, regional development and urban planning—particularly in rapidly growing regions such as south-east Queensland, Cairns and Wide Bay—as well as major infrastructure, climate related disasters, water availability and quality, primary industries, human health and lifestyle, natural systems and biodiversity. In short, there are major implications for our health, the way we live our daily lives, our economy and the environment.

The Queensland Government recognises the gravity of the threat posed by climate change, with its response based on the Queensland Greenhouse Strategy launched in May 2004.

The strategy has three central objectives:

1. To foster greater knowledge and understanding of greenhouse issues and climate change impacts.
2. To reduce greenhouse gas emissions throughout Queensland, and assist carbon sequestration.
3. To help Queenslanders adjust to the potential environmental, social and economic impacts.

Major greenhouse initiatives being implemented by the Government include the *Queensland Energy Policy—A Cleaner Energy Strategy* and the phase-out of broad scale clearing of remnant vegetation by December 2006.

In partnership with all other Queensland agencies, the Department of Natural Resources and Mines is also leading a process to raise awareness of the expected impacts of climate change and commence the process of developing appropriate adaptation strategies.

As part of this, the department will:

- facilitate ongoing discussions with other agencies to build knowledge and understanding
- coordinate ongoing scientific research across government on climate change and its impacts
- consult with key stakeholders to assess community awareness about the risks posed by climate change and to identify areas of particular concern.

This work is being done collaboratively with a number of agencies, including the Environmental Protection Agency, Treasury, Emergency Services, Primary Industries and Fisheries, Energy, Transport, State Development and Innovation, Health, Local Government and Planning, Public Works, Housing, Tourism, Fair Trading and Wine Industry Development and Police.

While reducing greenhouse gas emissions remains a high priority, with further and significant changes in Queensland's climate now inevitable, climate change poses particular challenges for all levels of government and the wider community.

These challenges are acute for natural resource managers, as climate change is expected to impact significantly on water resources, sustainable land use and management, biodiversity, pests, diseases and exotic organisms, coastal and marine environments and bushfires.

The Queensland Government is working to ensure that Queensland's natural resources are managed sustainably and that climate change considerations are increasingly incorporated into natural resource planning and decision-making.

This publication is designed to assist natural resource managers and others by providing the latest scientific information and expected impacts of climate change on Queensland. By raising awareness, we aim to foster better decisions and help Queensland respond to the challenges posed by climate change.

Contents

Introduction—Global climate change science

Greenhouse gases occur naturally in the atmosphere where they trap part of the Sun's warmth. This results in temperatures capable of supporting life.

Human activities, including the burning of fossil fuels and land clearing, are causing atmospheric levels of greenhouse gases to rise. The level of carbon dioxide, the principal greenhouse gas emitted by human activities, is rising particularly rapidly and is now 379 parts per million (ppm), about one-third higher than it was before the industrial revolution began in the late 18th century. Most of the increase has occurred since the 1970s.

The greenhouse effect

The greenhouse effect is natural, but human activity is enhancing it.

Most of the Sun's energy reaches the Earth and warms its surface (item 1 in Figure 1). About one-third of the Sun's energy is reflected back into space by clouds and particles in the atmosphere (2). Naturally occurring greenhouse gases (water vapour, carbon dioxide and methane) trap some of the heat radiated back from the Earth's surface (3), warming the atmosphere by about 15°C, enough to maintain life. This is called the greenhouse effect.

Burning fossil fuels for energy production and transport and changing patterns of land use (such as land clearing) increase carbon dioxide levels in the atmosphere. Methane levels have also increased as a result of emissions from deforestation, landfills, livestock and agriculture and fossil fuel burning (4). These and other greenhouse gases added by human activities enhance the Earth's natural greenhouse effect and result in additional global warming (5).

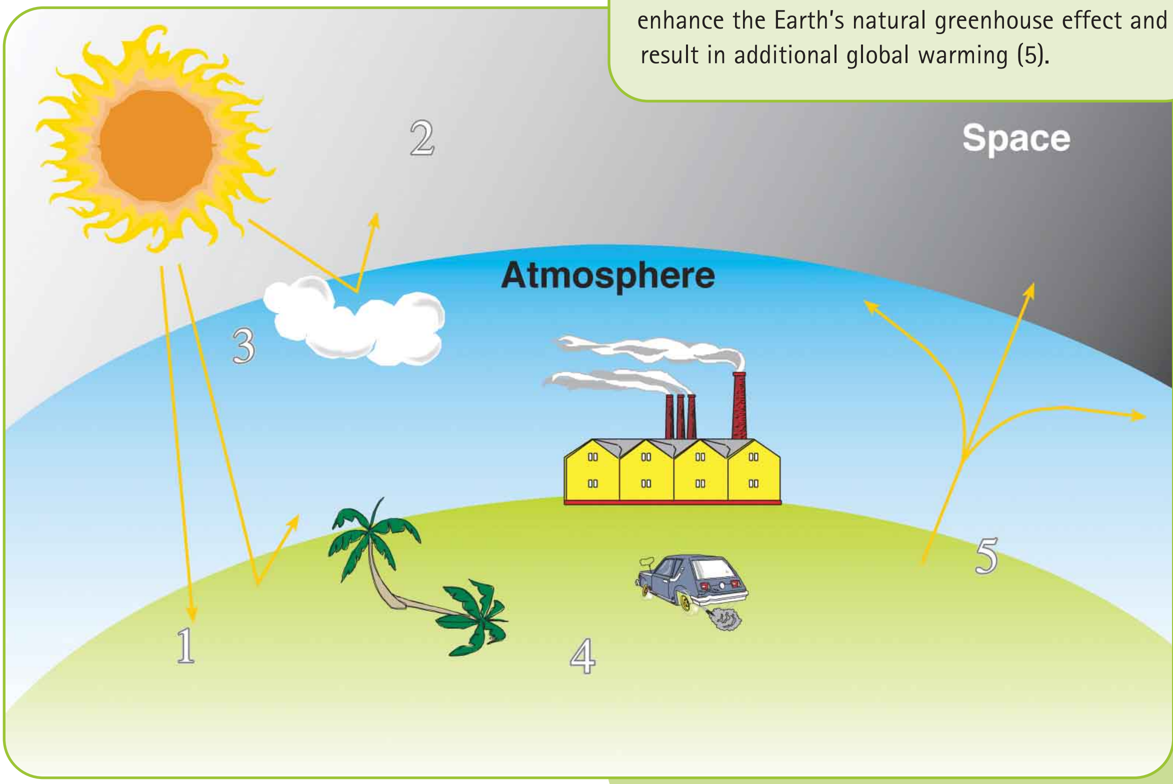


Figure 1. The greenhouse effect

Scientists can measure the historical amount of greenhouse gas in the atmosphere by drilling into the Antarctic ice and measuring the bubbles of air trapped in the layers of ice. These measurements confirm that current atmospheric concentrations of greenhouse gases are unprecedented in the past 420 000 years. More recent research on ice cores suggests that current concentrations are the highest in 750 000 years (see Figure 2).

As atmospheric levels of greenhouse gases rise, more of the Sun's warmth is trapped in the atmosphere. The clear conclusion is that the Earth's climate will warm and change significantly in the years ahead. Mounting historical evidence points to the planet's climate already warming and changing at an unusually rapid rate.

Ice cores reveal climate history

Ice cores are cylinders of ice drilled from glaciers or ice sheets. Over time, snowfalls are buried by successive snowfalls creating layers, which become ice at depths below 80m, due to the weight of the layers above. Small bubbles of air are trapped within these layers providing scientists with information about the composition of the atmosphere at the time the ice was formed. The ice itself provides information about past temperatures, through the ratio of naturally occurring oxygen isotopes (^{18}O to ^{16}O isotopes).

Ice cores drilled at Vostok, Antarctica, have provided information on climate going back 420 000 years (Figure 2). Temperatures (red line) and carbon dioxide levels (green line) follow similar cycles, but in the past have remained within lower and upper bounds, with carbon dioxide levels ranging from 180 to 280 ppm. The troughs are ice ages and the peaks are warmer interglacial periods. The cycles are driven by slight variations in the Earth's orbit and angle of tilt in the Earth's axis towards the sun that cause fluctuations in climate and subsequent changes in greenhouse gases and ice sheets. We are now in a favourable warm period between ice ages.

The increase in greenhouse gas levels is causing further warming and pushing global temperature towards levels not seen for thousands of years.

Source: Melanie Conner, National Science Foundation USA

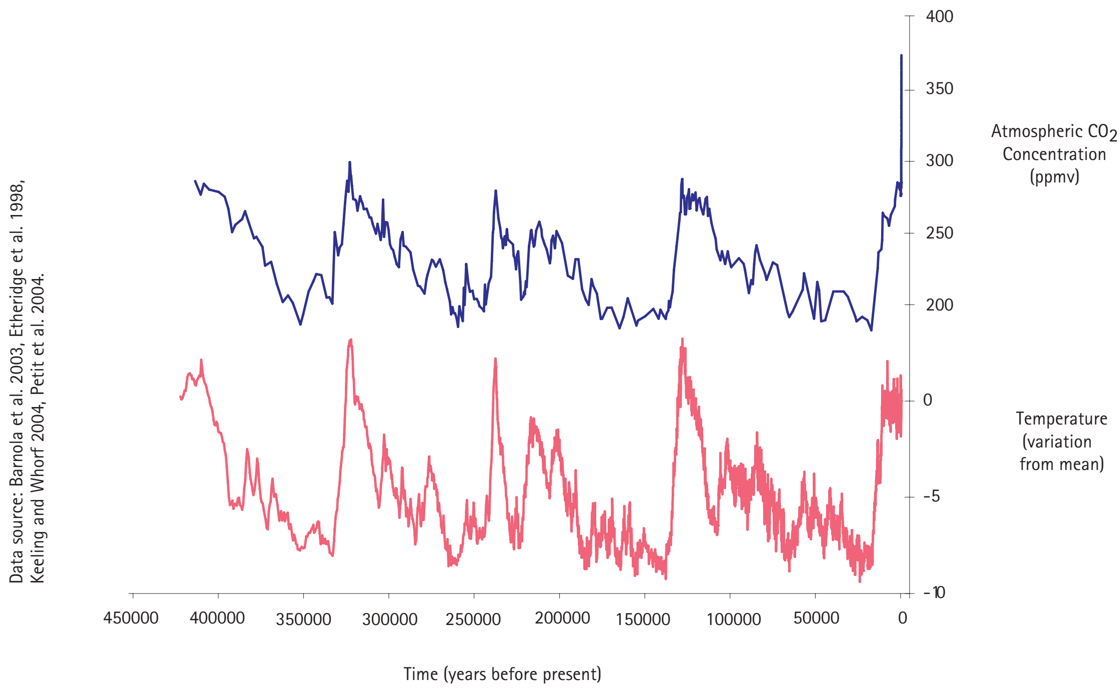


Figure 2. CO_2 concentration and temperature levels for the past 420 000 years from the Vostock ice cores.

The Intergovernmental Panel on Climate Change (IPCC) says the average surface temperatures of the Earth rose by about 0.6ºC over the 20th century, with 17 of the 18 hottest years on record occurring since 1980 (see Figure 3). The increase in temperatures observed since the 1970s is particularly notable because it has been so widespread across the globe (Pittock 2003).

As temperatures rise, glaciers are melting at unprecedented rates; snow cover is declining, as is sea-ice cover in the Arctic and around Antarctica, and 'traditional' weather patterns are changing. For example, in 2003 many areas of Europe experienced what was believed to be the hottest summer for at least 500 years. An estimated 34 000 people died as a result of the heatwave conditions (United Nations Environment Programme 2004).

Biological systems in many parts of the world are also responding to the warming with changes in the ranges and populations of plants and animals. There are also documented trends towards earlier flowering of plants, egg laying in birds and the emergence of some species of insects after winter.

Sea levels rose 10-20 cm during the 20th century due to melting glaciers and thermal expansion of the oceans, rising at an average of 1.8 ± 0.3 mm a year from 1950 to 2000. Recent measurements using satellites suggest that the rate of increase has accelerated, with global sea levels now rising by an average of 2.8 mm/year. This compares with an average rate of increase of less than 0.2 mm/year over the previous 1000 years (Church et al. 2004b).

Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 and plays a vital role in providing impartial and robust assessments of climate change research to governments around the world. The IPCC has produced three Assessment Reports, which are based on peer reviewed scientific research from around the world. The growing confidence in the science, as new evidence emerges, is clearly evident in the reports.

The first report, published in 1990, concluded that the increase in greenhouse gas concentrations was changing the energy balance of the Earth/atmosphere. However, it was too early to attribute the observed warming to human activities.

By 1995, when the Second Assessment Report was published, new data and analyses, and more advanced climate models, using atmosphere and ocean interactions, assisted in separating natural variability and human induced changes. The IPCC's conclusion was 'the balance of evidence suggests a discernible human influence on global climate'.

Additional data, better information about past climates and more rigorous evaluation methods continued to provide a better understanding of the change in climate. The Third Assessment Report, released in 2001 concluded: 'There is new and stronger evidence that most of the warming observed over the last 50 years is directly attributable to human activities'.

Subsequently a group of 17 national academies of science issued a statement endorsing the IPCC as the most reliable source of information on climate change.

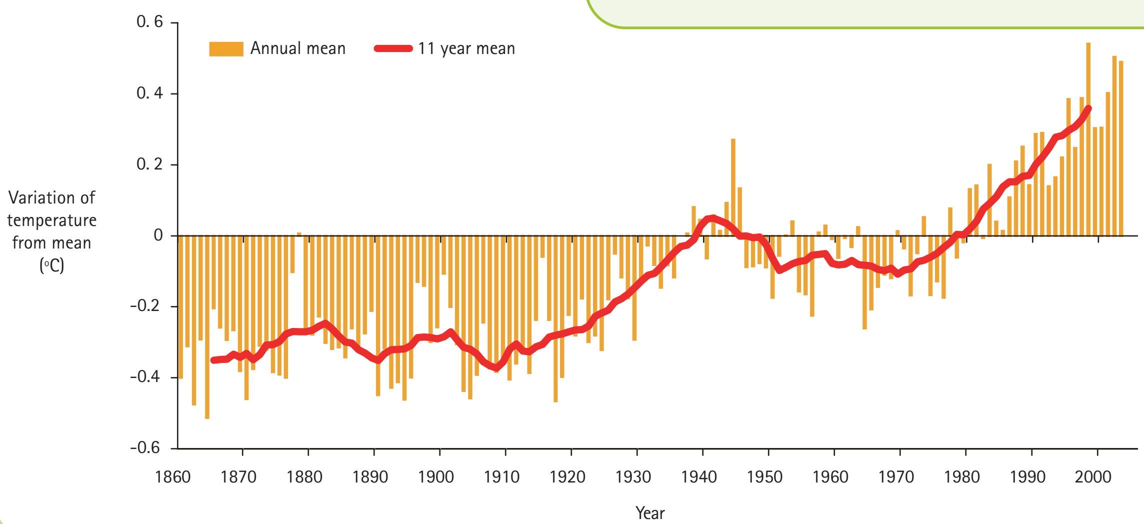


Figure 3. Global average annual temperatures (Bureau of Meteorology)

While the satellites measure sea levels in the open ocean, a range of factors affect sea levels at individual locations, such as whether the land is rising or falling. Ocean currents and variations in sea temperatures also impact on local sea levels (Walsh et al. 2003).

Around Australia, sea levels rose by an average of 1.2 mm/year from 1920 to 2000. In part, this lower rate of increase is due to the land slowly rising in some areas. This accounts for about 0.3 mm of the difference between the rate of increase in global average sea levels and the rate of increase observed around Australia (Church et al. 2004a). El Niño events also affect sea levels. During an El Niño, sea surface temperatures around Australia are lower as the prevailing weather patterns push water towards the eastern half of the Pacific Ocean.

As global temperatures continue to rise, scientists expect the rate of increase in sea levels to accelerate further. Sea levels will continue rising for hundreds of years, long after the planet's climate stops warming because the deep oceans absorb heat relatively slowly.

Evidence is also mounting that the break up of ice shelves such as the Larsen B, which broke up in Antarctica in 2002, causes the glaciers that flow into them to speed up on their journey to the sea, where they break up and melt adding to global sea levels.

The 2001 Intergovernmental Panel on Climate Change report concluded that the observed warming, and other changes in the global climate, could not be explained by natural climate variability alone. In particular, the Hadley Centre, which is part of the UK's Met (meteorology) Office, examined the history of temperature increases observed since the 1860s and ran a series of experiments looking at the influence of various factors. These factors included natural forces, such as changes in the Sun's energy and the influence of volcanos, as well as the influence of greenhouse gases. The experiments were designed to determine what caused the changes in temperatures observed since the 1860s. This process of identifying changes in the climate and determining the likely causes is called detection and attribution. The Hadley Centre's experiments indicated that natural forces alone would not have brought about the higher temperatures, and that much of the warming observed since the 1970s can be attributed to the increase in greenhouse gas levels. (See Figure 4).

Climate change around the world

In Europe's North Sea, there have been changes in plankton and the fish and birds species that rely on them. Species normally associated with warmer waters are appearing, while species that rely on the more typical cold conditions found locally are disappearing. Scientists blame global warming.

In the UK, breeding colonies of the green vegetable bug (*Nezara viridula*), which is normally only found in warmer parts of Europe, the Middle East, Africa and warmer parts of North America, have been found. In the past they have sometimes arrived in shipments of vegetables, but until recently the cold British winter used to kill them off.

The Arctic is warming rapidly with tragic consequences for the Inuit people: hunters have fallen through the rapidly thinning sea ice and drowned, while buildings have collapsed because their permafrost foundations have melted.

In the northern Tien Shan mountains (the 'celestial mountains'), which stretch from Kazakstan and Kyrgyzstan into China, the area's glaciers lost up to two cubic kilometres of ice each year during the later 20th century.

In Nepal, a new lake is forming high above the most densely populated Sherpa Valley in the country. The lake, which is being formed by the rapid melting of the Imja Glacier, is over a kilometre long and 100 metres deep, and held in place by a natural dam of rock and ice, which is itself melting. If this dam bursts (which appears likely) the valley below will be devastated.

In Bolivia, during the 1990s the country's glaciers melted at up to 10 times the rate observed over previous decades.

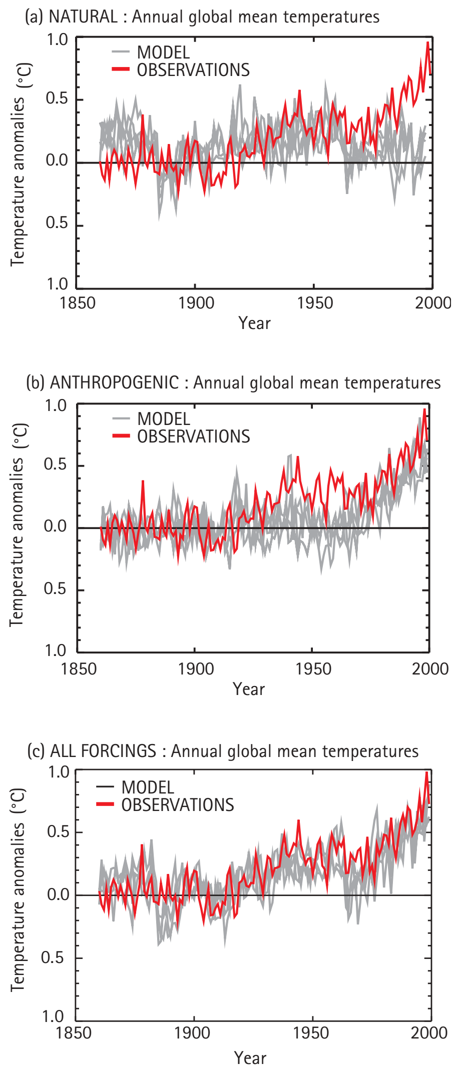
In France, the largest glacier in the Alps, the Mer de Glace is melting faster than at any time in recent history.

Over the 20th century, the areal extent of Africa's Mt Kilimanjaro's ice fields has decreased by about 80 per cent, and if current climatological conditions persist, the remaining ice fields are likely to disappear between 2015 and 2020.

A study of butterflies in Europe showed that the ranges of 22 butterfly species shifted north by 35 km to 240 km during the 20th century, while only two species shifted south.

The Hadley Centre's results contributed to the IPCC's conclusion, contained in their 2001 report, that 'there is new and stronger evidence that much of the warming observed over the past 50 years is attributable to human activities'. The IPCC also believes that the Earth's average surface temperature is likely to rise by a further 1.4°C to 5.8°C in the next 100 years, depending partly on the future rate of greenhouse gas emissions, while sea levels are expected to rise between 9 cm and 88 cm. Among other effects, the intensity of tropical cyclones is also expected to increase, with higher wind speeds and rainfall, as is the intensity of other extreme forms of weather, including storms.

The ranges of projected temperature and sea-level rises reflect different assumptions about future global emissions of greenhouse gases and, to a lesser extent, uncertainties associated with Earth's climate system. However, despite international efforts to reduce them, global emissions continue to grow, particularly in some developing countries.[1] There is also growing concern that biological feedback, such as melting permafrost and emissions from peat bogs, may be adding to emissions from human activities. This raises the possibility of global warming accelerating the release of biologically fixed carbon dioxide. Atmospheric carbon dioxide levels are expected to reach at least two times pre-industrial levels by the end of this century and, as a result, future temperatures and sea-level rises are expected to be in the mid to upper end of the ranges quoted for 2030, and the mid-range for 2070.



(Source: IPCC 2001a)

Figure 4. Observed and simulated historical global temperatures 1860–2000

Detection and attribution experiments by the Hadley Centre

The United Kingdom's Hadley Centre ran a number of simulations to generate global temperatures, to assess natural and human influences on climate. The simulations (grey line in each figure) were then compared against the observed global temperature record (red line).

The first experiment (Figure 4a), only took into account changes in natural influences (solar output and volcanic events), while levels of greenhouse gases were kept constant. The simulation reproduced the warming observed in the early part of the 20th century, but failed to reproduce the rapid warming in the latter part.

In the second experiment (Figure 4b), solar and volcanic influences were kept constant, while the historic increase in greenhouse gases was included. This reproduced the warming observed in the latter part of the 20th century, but was unable to match the middle of the century.

Finally, in the third experiment (Figure 4c), the Global Climate Model (GCM) was run with both the changes in the natural influences and increases in greenhouse gases included. This provided the best match with the temperature record (DEFRA 2004), indicating both natural and human influences have affected the temperature in the 20th century.

[1] On a per capita basis, emissions in developing countries are substantially lower than they are in developed countries, reflecting differences in living standards and lifestyle. However, economic growth and industrialisation in many developing countries is resulting in growing emissions as the living standards in such countries begin to catch up with those enjoyed in developed countries.

Regardless of future emissions, there is general scientific consensus that atmospheric levels of greenhouse gases have already reached the point where significant climate change is inevitable.

There is also potential for climate change to occur more rapidly as critical thresholds are reached and abrupt shifts in the climate remain possible (US National Research Council).

Of particular importance is the IPCC's warning that the lack of full scientific understanding about the global climate system is contributing to the uncertainty of future projections. The IPCC also warns that 'surprises' are likely to occur and that investment in climate science is important to reduce the uncertainty of future projections and support well thought out policy responses (IPCC 2001a).

Responding to the sceptics

A few researchers dispute that humans are responsible for changes in the planet's climate over at least the past 50 years, or that it will further and significantly change in years ahead due to rising atmospheric concentrations of greenhouse gases. These sceptics are few relative to the large number of mainstream climate scientists who are convinced human activities are causing unprecedented climate change.

Some of the arguments put forward by climate change sceptics:

The rise in greenhouse gases is not due to humans

Response—Greenhouse gases emitted by human activities, such as the burning of fossil fuels, have distinct physical and chemical properties that scientists can detect. There is clear physical evidence that the rapid rise in greenhouse gas concentrations is overwhelmingly the result of human activities (IPCC 2001).

Carbon dioxide is good for plants

Response—While carbon dioxide is good for plants, not all species respond to higher carbon dioxide levels in the same way. Impacts on plants will be mixed, causing changes in plant composition in some ecosystems and possibly some weeds becoming more of a problem (see Carbon dioxide fertilisation, page 24).

It's all just natural variability

Response—The planet's climate is variable, with a key driver being wobbles in the Earth's axis, changes in axial tilt and changes in the 'roundness' of orbit—so-called 'orbital variations' occurring at a frequency of 19 000–23 000, 41 000 and 96 000 years respectively. Orbital changes drive ice ages and warmer interglacial periods. Other factors, including changes in the Sun's radiation, also influence climate. However, the warming observed since the late 1970s can only be explained by climate models when the rapid increase in greenhouse gases since the industrial revolution is included.

The warming just reflects the growth of cities

Sceptics argue that cities tend to be warmer than surrounding countryside, because of concrete buildings and bitumen roads (the 'urban heat island' effect), and that the growth of cities has influenced the global climate record, creating a false impression that temperatures are rising. However, scientists measuring global temperature are well aware of this effect and wherever possible only used data from recording stations not affected by it, such as those located in rural areas (see High quality data sets, page 8).

We are due for an ice age

Response—The most recent research indicates that the Earth's orbit has entered a particularly stable phase. So another ice age is not expected for at least 130 000 and potentially 620 000 years.

Satellite data shows much less warming

Response—Until recently (2001), it appeared that while measurements taken at the Earth's surface and from weather balloons showed a clear warming trend, satellite data showed no such warming trend. This led some to say that the temperature record was being influenced by the warming effect of cities—even though analyses of surface measurements take account of this. However, corrections to the satellite data (including for the effect of orbital decay) and longer satellite records now indicate that rather than disagreeing with surface observations, satellite observations support the evidence of an increase in surface temperatures.

Climate change and Queensland

Several Queensland Government agencies have developed significant expertise in climate science. The Department of Natural Resources and Mines focuses on the implications of climate variability and climate change for natural resource management, and works collaboratively with other agencies such as the Department of Primary Industries and Fisheries and the Environmental Protection Agency. Since 1995, the department has also coordinated a study by CSIRO's Atmospheric Research Division into how Queensland's climate will change in the years ahead, with the project funded jointly by a number of agencies.[2] The projections developed by CSIRO form the basis for assessing impacts across sectors and for developing adaptation strategies. Confidence in the climate change projections and associated impacts has increased over the life of the study, particularly over the past two years. This greater assurance is consistent with the growing confidence of respected international atmospheric scientists.

National and Queensland temperature trends

While Australia's climate is one of the most naturally variable in the world, there is already evidence that our climate is changing. Since 1910, for example, average temperatures have risen across almost all of Australia as shown in Figure 5a, from the Bureau of Meteorology—only high-quality data sets are used in analysing these trends.

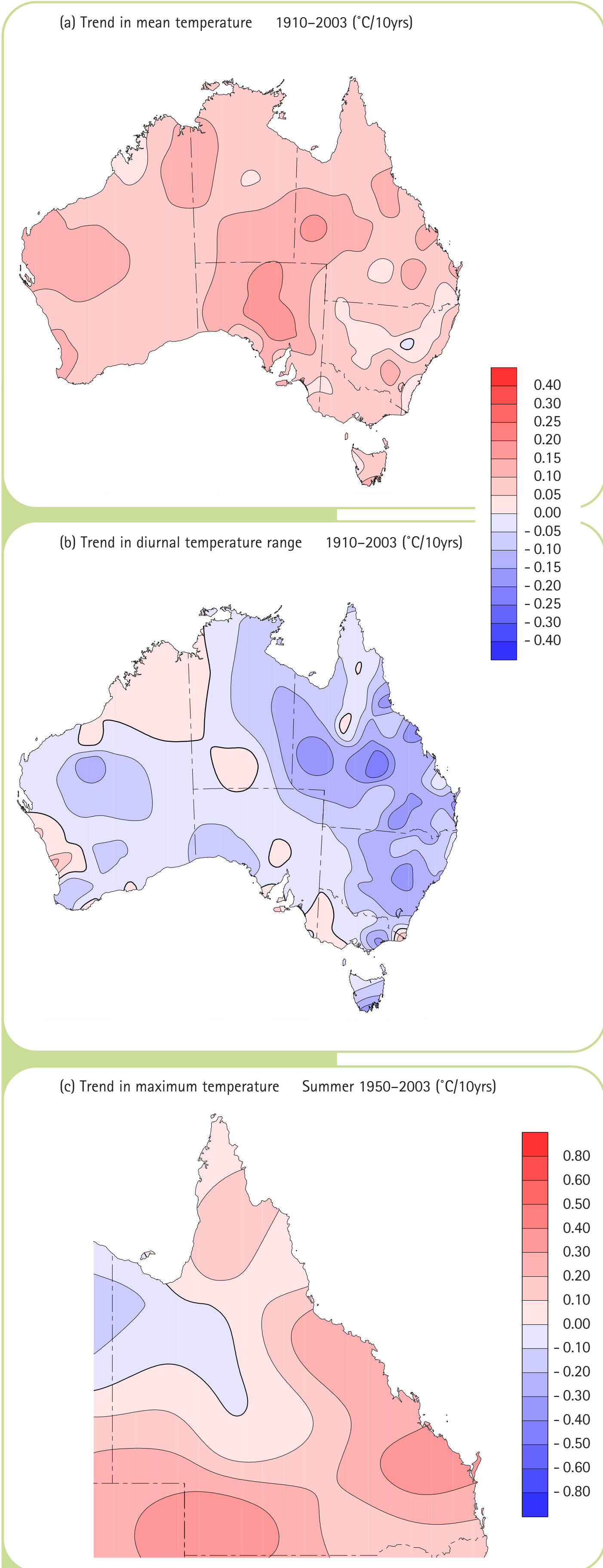


Figure 5 (Source: Bureau of Meteorology)

[2] The project is currently funded by contributions from the departments of Natural Resources and Mines, State Development, Main Roads, Public Works, Primary Industries and Fisheries, Queensland Health, Queensland Transport, Treasury and the Environmental Protection Agency.

The difference between day and night temperatures (diurnal range) has also decreased in most areas since 1910, with the trend particularly evident in Queensland and parts of New South Wales (Figure 5b). So, while average daytime temperatures are increasing, night-time temperatures are increasing more rapidly. This is consistent with what climate models suggest in relation to climate change.

For Queensland, the Bureau of Meteorology reports average annual minimum temperatures have increased by 0.9ºC and average annual maximum temperatures by 0.6ºC since1950. Maximum summer temperatures also rose by up to 0.3ºC per decade in many areas of the state over the same period, including along most of the east coast (Figure 5c). Queensland temperatures are in fact rising more rapidly than the global average. The number of hot days is also increasing in many Queensland centres, while the incidence of cold nights is declining.

According to the work being conducted by CSIRO on behalf of the Queensland Government, the trend towards higher temperatures will accelerate, with projections showing increases in average temperatures of between 0.3ºC and 2ºC by 2030 and between 0.4ºC and 6ºC by 2070, with inland areas tending to warm more rapidly than coastal areas.

As with global temperature increases, future temperature rises in Queensland, including the number of days above 35ºC, can be expected to be in the mid to upper end of the ranges, projected for 2030, and the mid-range for 2070, due to continuing strong growth in global emissions.

High-quality climate data sets

The Bureau of Meteorology has chosen a number of non-urban locations where high-quality data are available over long periods. Any significant irregularities in the data, caused by changes in the location of the observation site or by changes in instrumentation, have been identified and corrected. The resulting 'high-quality' climate records are used to detect climate trends and validate climate models. (Bureau of Meteorology, 2003).

The availability of high-quality climate data is essential to allow scientists to distinguish real trends in temperature and rainfall from changes caused by other factors, such as upgrades to equipment, moving the recording station or the growth in trees. By using statistical techniques, visual checks and station history information, scientists exclude unreliable data from their calculations and correct significant data irregularities.

Another important factor that can influence climate data is the 'urban heat island effect'. Towns and cities tend to be warmer than surrounding rural areas due to factors such as concrete and asphalt absorbing more solar energy, fewer trees for shade and evaporation, reduced wind speeds due to the effects of buildings, and the warming effects of pollution and industrial and domestic activities. As urban areas grow, the urban heat island effect increases.

To prevent the urban heat island effect from influencing climate trend calculations, scientists make sure that they only use high-quality data sets from rural and remote areas that are free from the influence of the urban heat island effect. In cases where urban stations are used, this effect has been accounted for.

Temperature projections for Queensland centres

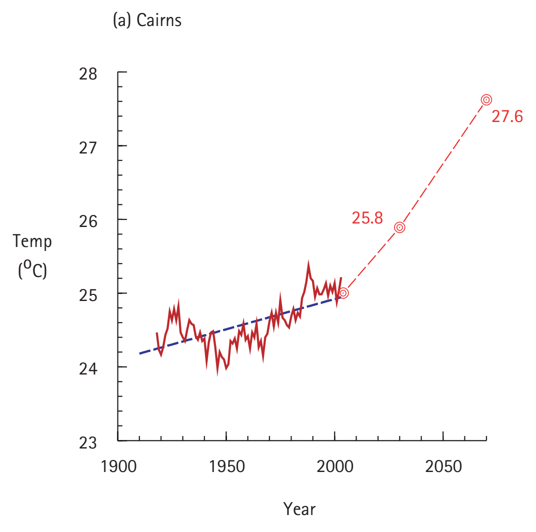
Changes in future average temperature are often presented in a way that makes them difficult to appreciate compared to observations. For this reason projections and observations have been combined for a number of high-quality temperature recording stations in Queensland. Mid-range warming projections for 2030 and 2070 were applied to the observed record, with the results clearly showing the extent to which future average temperatures will be outside those experienced historically.

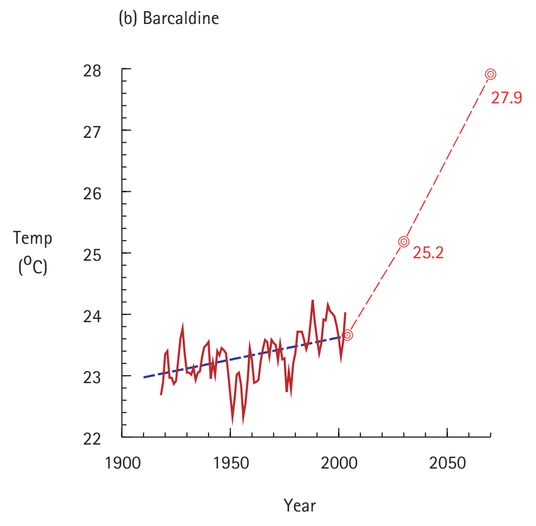
Inland areas are expected to warm more than coastal areas.

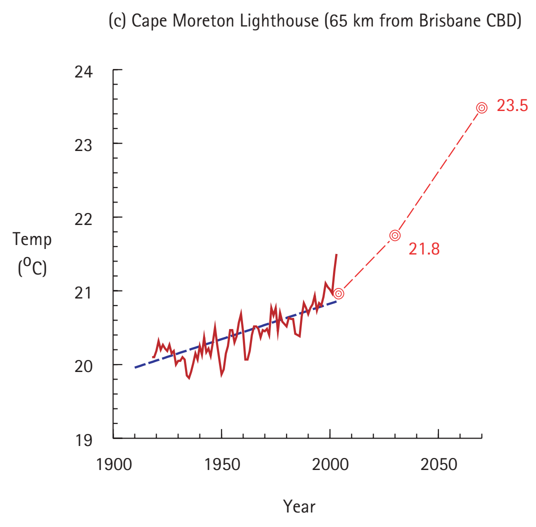
Figure 6. Observed and projected temperatures (1910–2070)

- Observed average temperatures
- Trend in observed average temperatures
- 00.0 Projected average temperatures
- Trend in projected average temperatures

(Data sources: Observed temperature data—Bureau of Meteorology; Temperature projections—CSIRO)







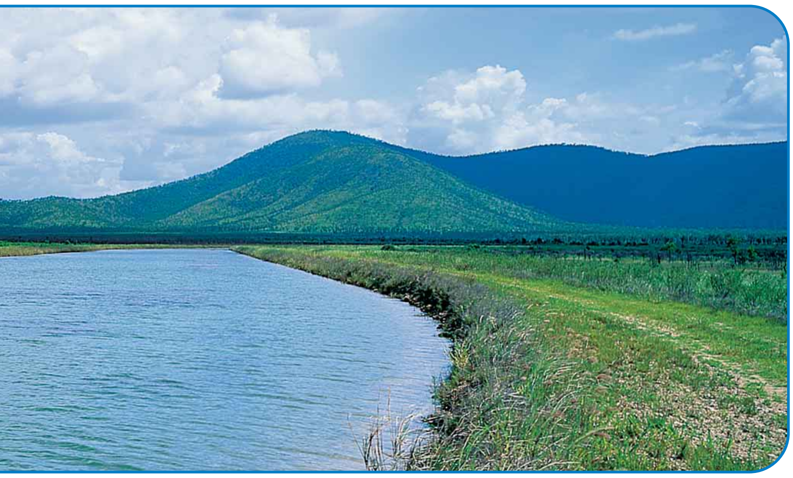


Figure 6. Continued

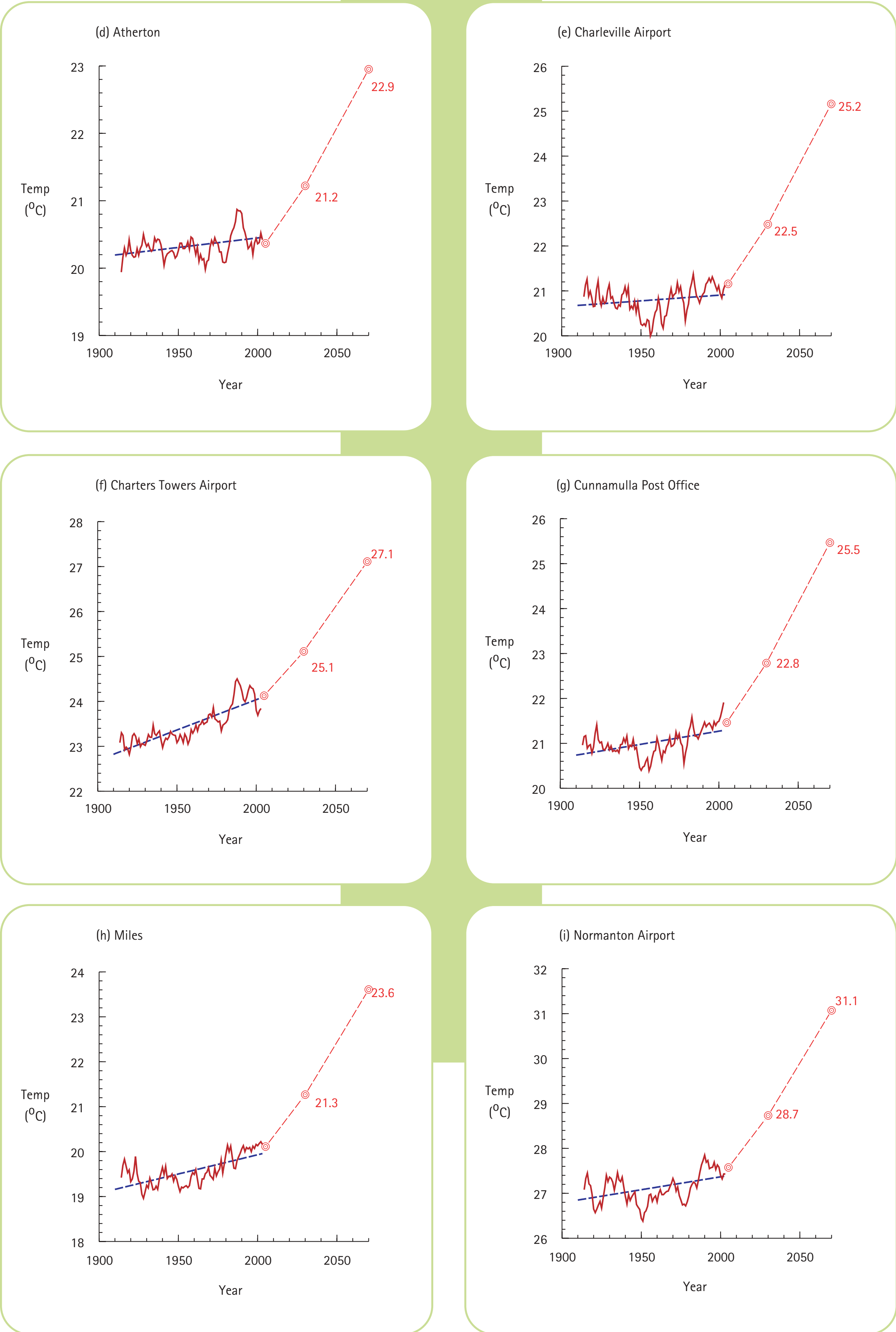
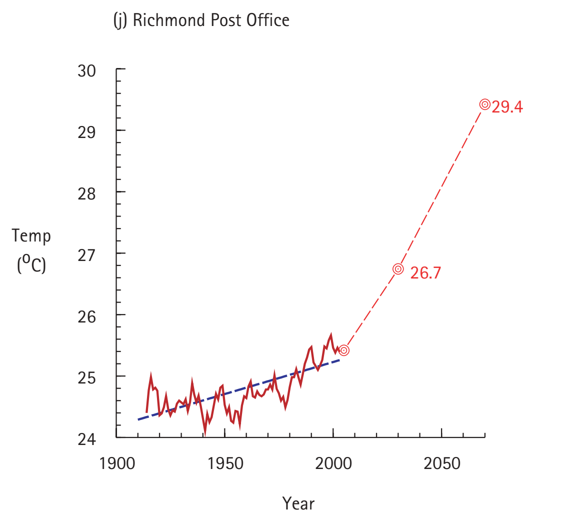
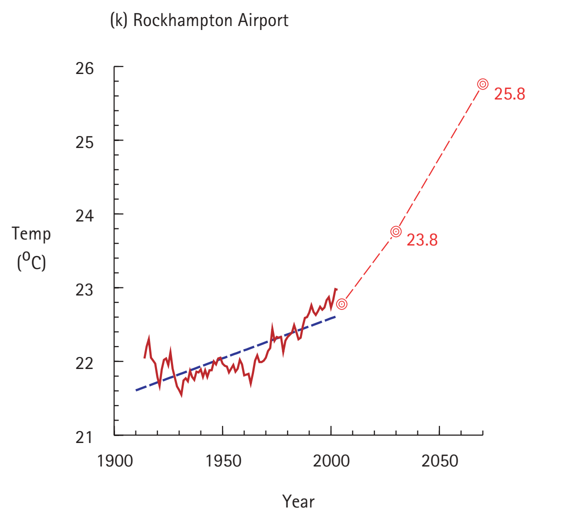
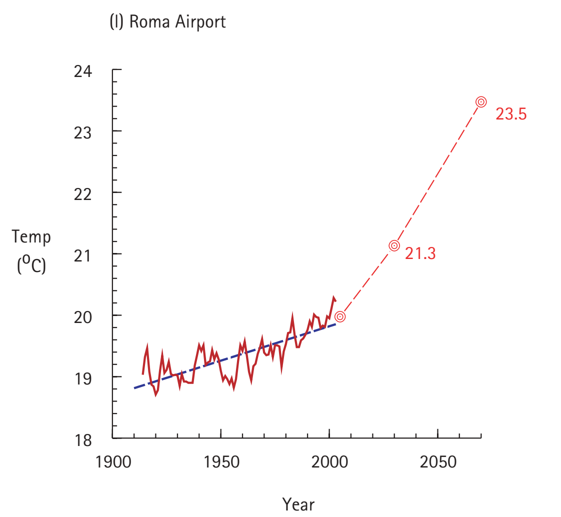
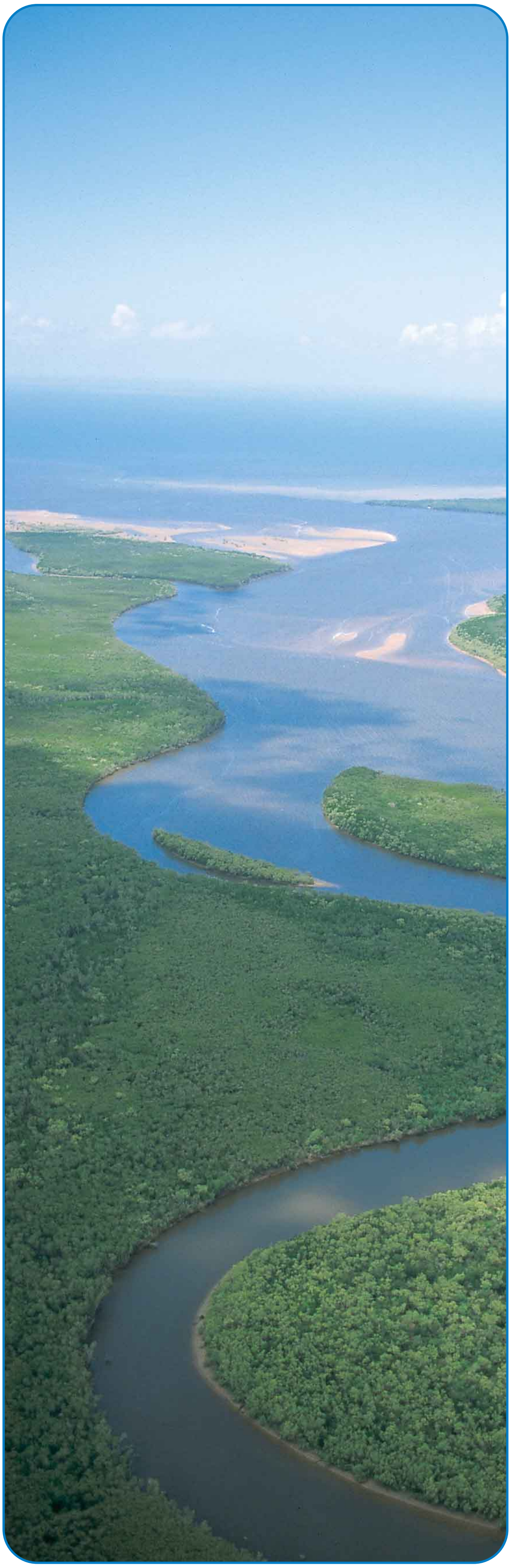


Figure 6. Continued









Small increases in average temperature might not seem important on their own, but they reflect significant increases in extreme temperatures. Simply, this means a higher incidence and increased severity of heatwaves.

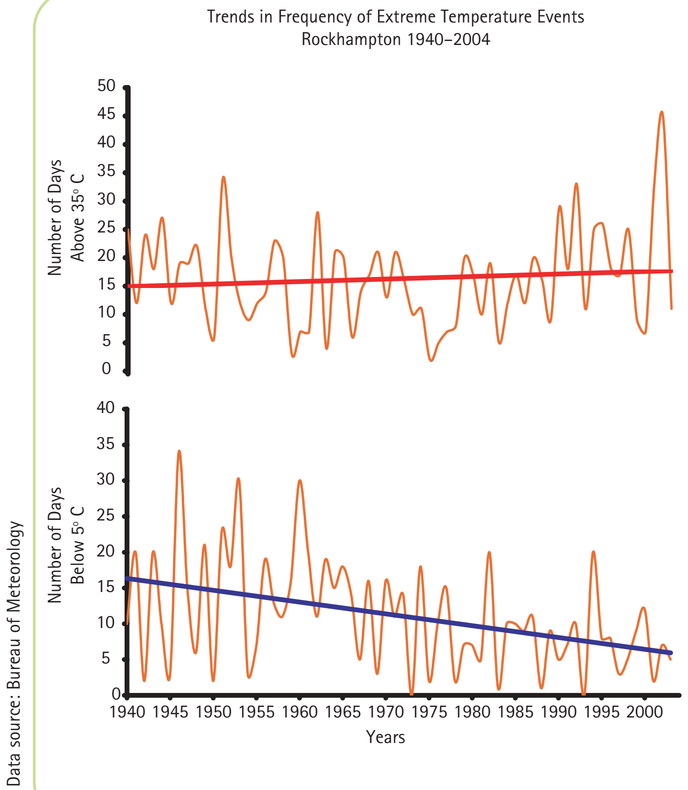
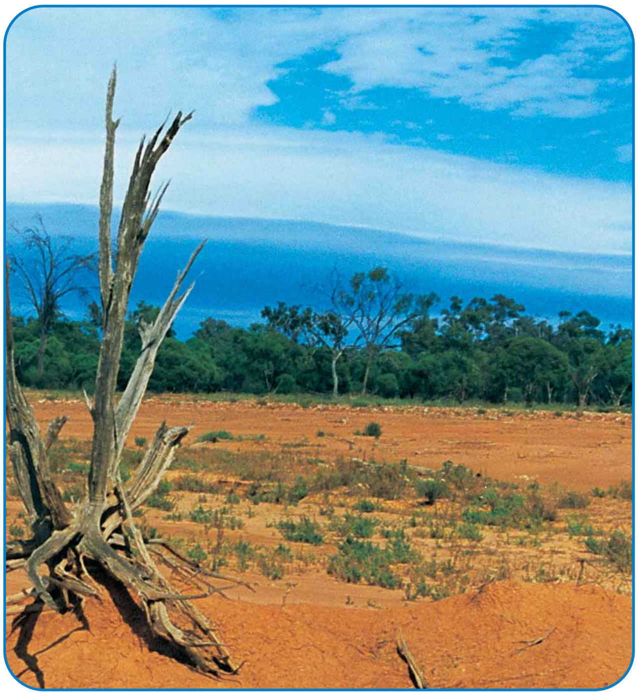


Figure 7. Trends in frequency of extreme temperature events—Rockhampton 1940–2004



Extreme temperatures

Modest increases in average climate conditions will have large impacts on extremes. This is clearly demonstrated in changes in extremes during the 20th century. For example, at Rockhampton, in response to a modest increase in the average temperature (about 1°C since 1910) the average number of hot days per year (maximum above 35°C) has risen by four days since 1940 (Figure 7). Similarly the average number of extremely cold days per year (minimum below 5°C) has declined by 10 days since 1940. Significant changes in extreme hot and cold days are clearly visible in the time series data after 1970 and 1950 in the respective graphs.

The declining trends in extremely cold temperatures and increasing trends in extremely hot temperatures are expected to continue in the future across the state. The projected changes in the number of extremely hot and cold days for a number of centres are shown in tables 1 and 2 (see also Figure 6, Temperature projections for Queensland centres).

In Brisbane the current long-term annual average number of days above 35°C is three. By 2030 Brisbane could experience an average of up to six days above 35°C and by 2070, up to 35 days. Conversely the average number of extremely cold days per year will continue to decline with Dalby experiencing a decline of up to seven days below 0°C by 2030 and a decline of up to 10 days by 2070.

Table 1: Number of days in summer (Dec–Feb) with maximums above 35°C

	Brisbane	Townsville	Cairns	Barcaldine
Present	3	2	3	55
2030	3–6	2–9	3–8	57–69
2070	4–35	4–75	5–76	61–84

Table 2: Number of days in winter (Jun–Aug) with minimums below 0°C

	Dalby	Stanthorpe	Charleville	Tambo
Present	10	37	12	17
2030	3–7	24–33	4–10	7–14
2070	0–6	4–31	0–8	0–11

Source: CSIRO

Rainfall

Since 1900, many areas of Australia have experienced an increase in rainfall. However, parts of central Queensland and south-west Western Australia have seen a pronounced drying trend. At the same time, rainfall has increased markedly in the north-west of Western Australia (Figure 8a).

While national attention has focused on the drying trend in south-west Western Australia, the drying trend along Queensland's coast south from Cairns is arguably even more pronounced, particularly in central Queensland (Crimp and Day 2003). Queensland's dry extends across much of the state, including many inland areas and the south-east where the bulk of the population lives. Preliminary analysis of the drying trend since 1950 (Figure 8b) indicates the effects of both sea surface temperature variations across decades and possible human-induced changes (Crimp and Day 2003). The marked trend towards increasing rainfall in north-west Western Australia is associated with an increase in the number of tropical cyclones crossing the west coast, while the decline in rainfall in central Queensland is associated with a decline in the numbers of tropical cyclones crossing the east coast.

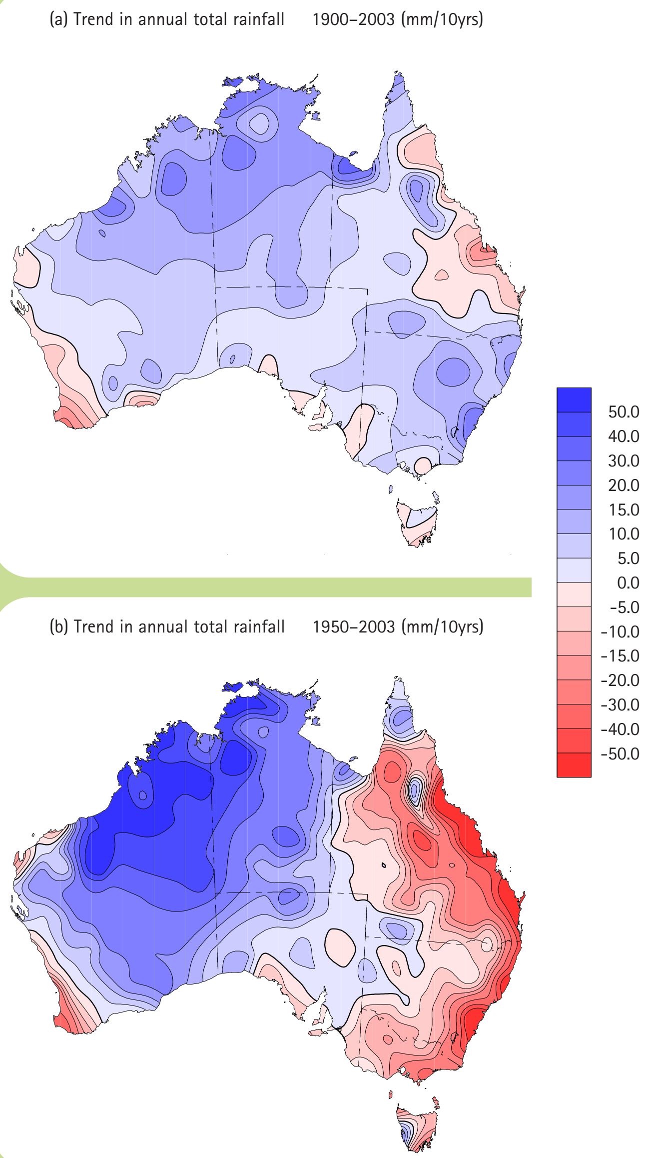


Figure 8. Maps highlighting trends in annual rainfall for the periods (a) 1900–2003 and (b) 1950–2003 (Source: Bureau of Meteorology)

SPOTA-1

Current research by NR&M scientists has established a statistical link between Pacific Ocean sea surface temperatures and summer rainfall in Queensland. Based on this new understanding of factors influencing summer rainfall in Queensland, a prototype climate risk assessment scheme has been developed, known as SPOTA-1 (Seasonal Pacific Ocean Temperature Analysis—Version 1).

SPOTA-1 is a significant achievement as it provides more accurate risk assessment based on the probability of next summer's rainfall and pasture growth. The improved lead-time (up to seven months) and accuracy of SPOTA-1 compared to current systems supports better natural resource management decisions.

This preliminary research has also provided greater insight into Queensland's rainfall trends, particularly how natural variability in Pacific Ocean surface temperatures contributes to the sequence of years of above and below average rainfall since 1950.

Departmental scientists are linking this new understanding of influences on Queensland's rainfall with research using global climate models to better project the impact of climate change.

The projections by CSIRO indicate that the drying trend observed over much of Queensland is expected to continue, with a further decline in rainfall of up to 15 per cent expected in most areas by 2030. The central and southern coastal regions appear to be most affected.

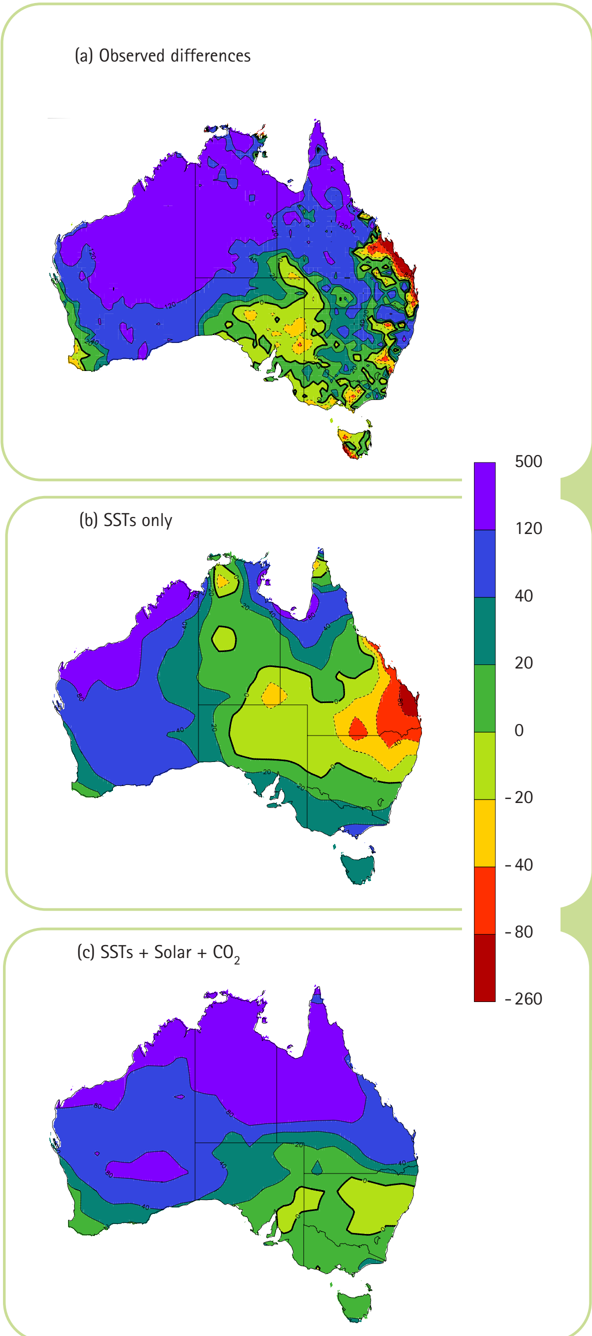
Preliminary research by NR&M scientists also indicates stratospheric ozone depletion combined with increasing atmospheric greenhouse gases is causing changes in Antarctic circulation patterns, which in turn may be intensifying the drying trend observed across much of eastern Australia.

How changes in the atmosphere mean less rain on the coast

NR&M scientists are using the CRAY SV1 supercomputer at the Indooroopilly Science Centre and CSIRO's global climate model to run experiments evaluating the relative contribution of various factors on the climate from 1871 to 2003. These include changes in solar variability, increases in atmospheric concentrations of carbon dioxide and depletion of stratospheric (upper atmospheric) ozone.

Results of these experiments show that the model most accurately recreates climate conditions that match the record of observed climate conditions from1971 to 2003 when the effects of ozone depletion on Antarctic weather patterns are factored in. Specifically, the loss of ozone over Antarctica is causing changes in the Antarctic vortex and an increase in the frequency of 'blocking' highs in the Tasman Sea.

In the maps below, the observed rainfall during the La Niña of 1998-2001—when coastal Queensland was unexpectedly dry—is compared with the average rainfall for 1961-2003 in Figure 9a. The results from three experiments are also shown. Figure 9b incorporates only sea surface temperatures (SSTs) influences on climate, Figure 9c show the influences of SSTs, solar variability and observed increases in carbon dioxide, and Figure 9d shows SSTs, solar variability, increased carbon dioxide and stratospheric ozone depletion. Figure 9d shows the best agreement with the observed pattern of rainfall in 9a and indicates that the effect of ozone depletion appears to be a key driver in contributing to the coastal drying observed during those years.



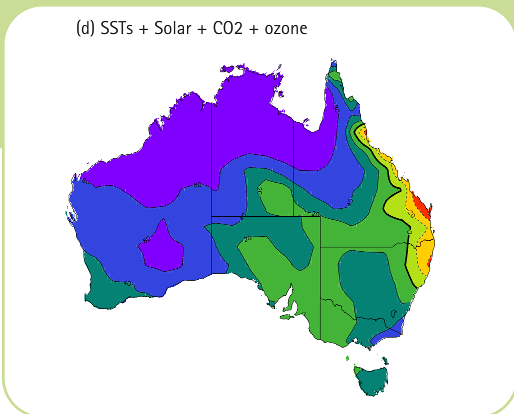


Figure 9. Summer rainfall difference comparing 1961–2003 and 1998/89–2000/01 (a) and the results of model runs with various influences (b, c and d)

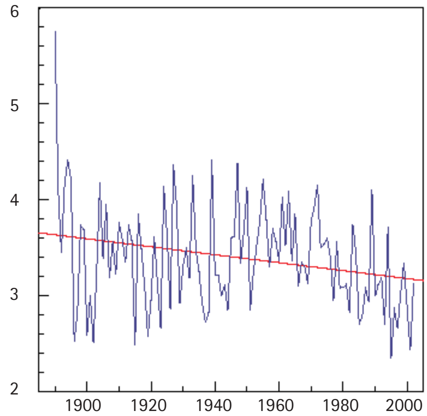
Trends in extreme rainfall events

Over the 20th century, coastal Queensland (Figure 10a) had fewer rainy days (Figure 10b), while there was a trend toward more intense rainfall on days when it occurred (mainly in summer, Figure 10c) or, less rain, but of greater intensity. The number of cyclones in the Australian region has declined, but the number of cyclones with central pressures below 970hPa has risen (Figure 10d).

The CSIRO consultancy research indicates that climate change impacts on extreme rainfall events are likely to be most pronounced in north Queensland, as a result of related 25 per cent increases in cyclone peak rainfall intensity. The rainfall figures show that in northern Queensland, by 2050, a one-in-12-year extreme rainfall event may be of similar magnitude to a present day one-in-40-year event. In recent years, population growth has meant people have settled in regions that are more prone to extreme rainfall events. So societies are becoming more vulnerable to extreme weather (Pittock, 2003).

(a) Analysis region highlighted in darker green

(b) Coastal rainfall persistence (days)



(c) Daily average coastal rainfall intensity (mm) per rain day

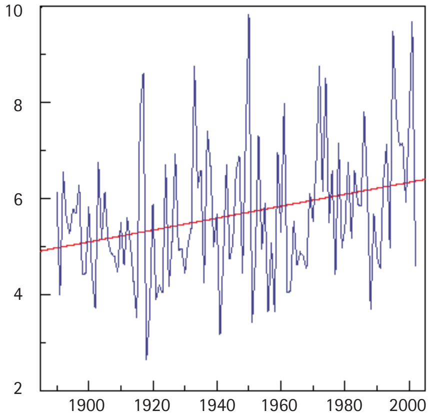
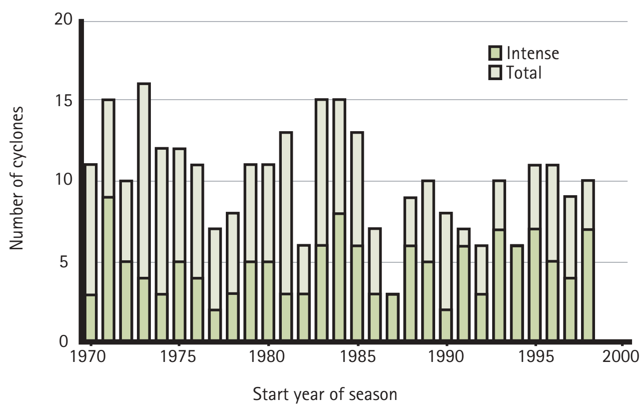


Figure 10. Trends in extreme rainfall

(d) Tropical cyclones in the Australian region

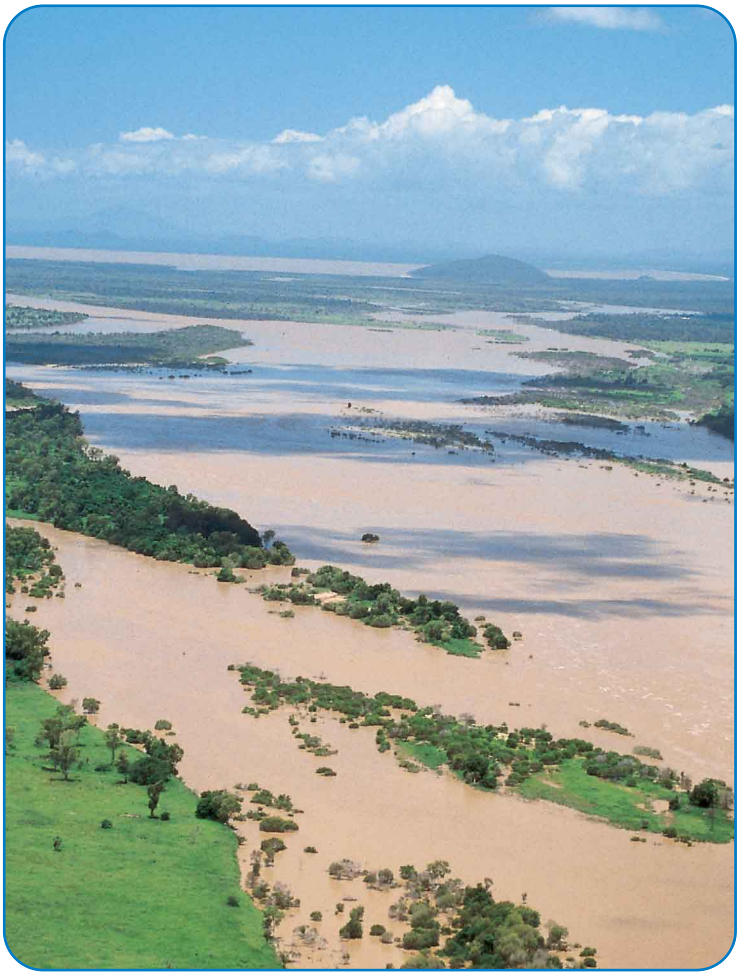


Source: Bureau of Meteorology

Even in areas more prone to drought, expectations are that there will be an increase in the amounts of rain that fall during extreme rainfall events with implications for soil erosion, nutrient run-off and flash flooding.

According to the Bureau of Meteorology, the number of stronger tropical cyclones in the Australian region appears to have increased slightly. Tropical cyclones are expected to become more intense as the climate warms. Projections suggest peak wind speeds five to 10 per cent faster and increases in maximum rainfall of 20 to 30 per cent by about 2050. Other severe weather events including storms are also expected to become more intense.

In summary, while Queensland's climate is naturally quite variable and will continue to be so, temperatures are expected to rise significantly. Rainfall, water availability and water quality will decline in most areas and droughts will become more severe. Other extreme weather events, including tropical cyclones, are expected to become more intense. Confidence in the projections has reached the point where significant changes in Queensland's climate in the years ahead appear inevitable. Climate change will therefore eventually result in patterns of temperature and variability not experienced at least since European settlement—and possibly for eons before that.



Queensland's climate projected to change

Climate change projections have been made and are compared with the climate of the 1990s—which already experienced some warming and lower rainfall than the previous 30 to 40 years—as the base, or average.

Annual mean temperatures are projected to rise by from 0.3°C to 2.0°C above 1990 values by 2030 and by from 0.8°C to 6.0°C by 2070, with the greatest warming occurring in inland areas.

Brisbane's annual mean temperature is projected to rise from 20°C to between 20.3°C and 22°C by 2030 and between 20.8°C and 26°C by 2070.

The number of Brisbane summer days with temperatures above 35°C is projected to rise from its present annual average of three days to between three and six days by 2030 and to between four and 35 days by 2070.

Annual rainfall across Queensland is projected to decline by up to 15 per cent over most of the state.

Soil moisture is expected to decrease over most of Queensland, with the greatest reduction in inland areas, due to the combined effects of increased temperatures and reductions in annual rainfall.

Maximum tropical cyclone wind speeds are likely to increase by five to 10 per cent by 2050. This will be accompanied by increases of 20 to 30 per cent in rainfall.

Current expectations are that with global emissions growing strongly, the warming will be towards the upper end of the temperature ranges quoted for 2030 and the mid range for 2070.

Impacts of climate change

Climate change impacts are expected to range broadly across the economy, regional development, major infrastructure, cities and towns, human health and lifestyle and the environment.

Impacts are expected to include:

Health and lifestyle

- Higher average temperatures and an increase in the incidence and severity of heatwaves.
- Potential for spread of insect-borne diseases (like dengue fever) during warmer, wetter episodes.
- Increased risk of injury and death from extreme weather events.

Water

- Less water run-off, more sediment and higher nutrient loads in rivers and creeks.
- Increased risk of algal blooms due to higher nutrient loads.
- Decline in water security and quality.
- Increasing competition for water among primary producers, industry and regional and urban communities.

Rural industries

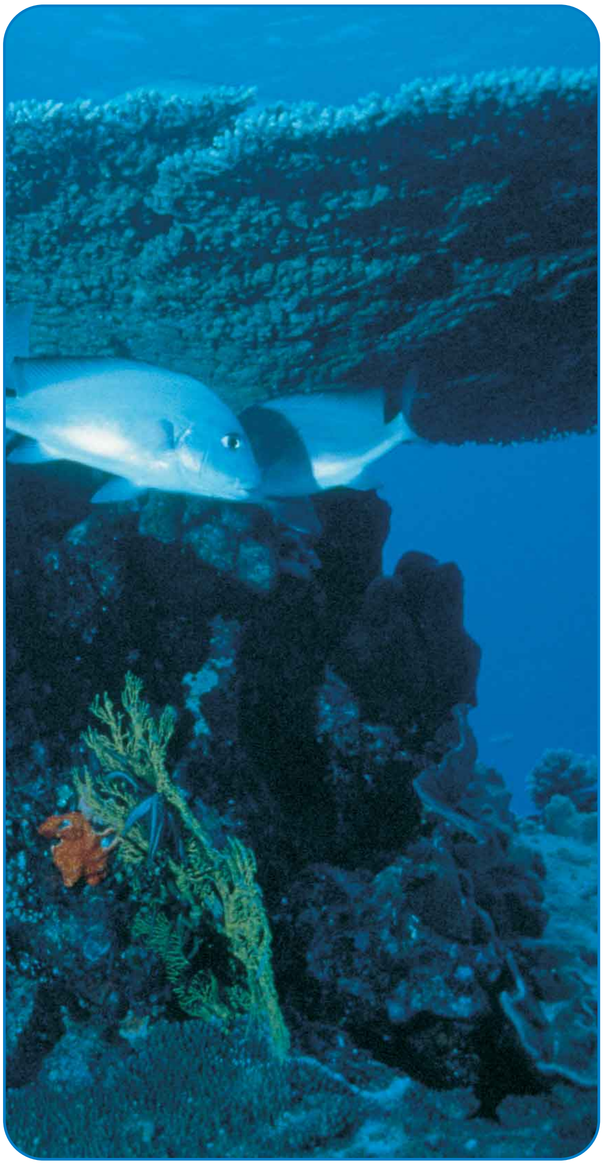
- Changes to cropping and grazing industries from rising temperatures and more variable and declining rainfall.
- Potential for spread of tropical pests and diseases and changes in the composition and range of woody weeds.
- Changes to the suitability of some areas for agriculture and change to the productivity in others.

Severe storms

- Increased damage from tropical cyclones, thunderstorms and other severe weather events due to expected higher wind speeds.
- Changes to flood risk and frequency, with potentially higher flood levels and greater risk to infrastructure.
- Higher storm surge levels due to more intense tropical cyclones combined with rising sea levels.
- Increased risk of flash flooding associated with extreme rainfall events.

Marine ecosystems and coastal communities

- Increased incidence of coral bleaching.
- Potential for loss of wetlands and mangrove habitat over the long term as sea levels rise.
- Changes in species diversity in near coastal regions due to temperature changes.
- Increased risk of flooding in developed areas from king tides and storm surges and, in the longer term, inundation of some developed areas.



Land ecosystems

- Changes to many ecosystems with potential for loss of some species.
- Substantial loss of areas capable of supporting mountain and tropical rainforests in north Queensland, with a number of species at risk of extinction.

Tourism

- Degradation and potential loss of iconic ecosystems such as the Great Barrier Reef would impact adversely on tourism.
- Reduction in water availability to some tourist facilities.
- Potential decline in attractiveness of Queensland as a tourist destination caused by higher temperatures and potential increase in extreme events and risk of tropical diseases.
- Greater seasonal range of crocodiles and other dangerous species such as poisonous jellyfish.

Bushfire risk

- Potential for more days with a high bushfire risk.

The economic costs of climate change are expected to be significant. Already, the costs of extreme climatic events such as flooding, severe storms, cyclones and bushfires (excluding droughts) are substantial, with floods causing the greatest financial damage in Queensland. With extreme events expected to intensify as a result of climate change, the costs to the Queensland Government, the economy—including the insurance industry—and the wider community from such events will increase.

Costs in other sectors, such as energy, will rise. Climate change will add to the demand for air-conditioning and the subsequent cost to the electricity network of meeting peak summer demand. Water resources will come under even greater pressure due to declining rainfall and growing demand from an expanding economy and population, particularly in south-east Queensland.

While reducing global greenhouse gas emissions remains a high priority, governments around the world are increasingly recognising the need to incorporate climate change into their planning and decision-making and are developing prudent adaptation strategies.

Climate change and natural resources

Queensland has one of the most variable climates in the world. Since European settlement, episodes of droughts and floods, extremes of temperature and the savagery of tropical cyclones have been documented and are accepted as an essential part of Queensland's environment. The state's unique flora and fauna has evolved to cope with this variability. Aboriginal and Torres Strait Islander peoples were familiar with these fluctuations in climate and had strategies to survive. They used landscape patch mosaic burning to manage the tree/grass balance across the savanna woodlands covering much of the state.

Major advances in the understanding of global meteorological cycles have been made at international and national levels. Weather forecasting has become vastly more accurate in the past 20 years.

Science also has revealed how longer scale ocean-atmosphere circulations such as the El Niño-Southern Oscillation and Interdecadal Pacific Ocean phenomenon affect seasonal and decadal conditions. Only in the past decade have climate applications scientists shown how to make use of these forecasts in agricultural and pastoral management systems using climate risk decision-support systems. Land managers will now need to make long-term structural decisions about their enterprises, using improving knowledge about the impending threat of global climate change.

In November 2003, The Department of Natural Resources and Mines hosted a national conference on Queensland's Gold Coast entitled *Climate impacts on Australia's natural resources: current and future challenges*. The conference brought together climate and natural resource scientists, natural resource users, resource managers, community stakeholders and policy-makers from across Australia and overseas. The participants were concerned with the challenges facing Australia's natural resource base in response to global, national and regional climate variability and climate change.

Climate impacts on Australia's natural resources: current and future challenges

This conference, organised by NR&M on behalf of the national Standing Committee of the Natural Resource Management Ministerial Council, provided an opportunity for key stakeholders and natural resource managers to obtain up-to-date scientific knowledge on climate change and climate variability impacts on natural and managed systems. The conference also was a chance to identify practical steps towards more adaptive natural resource management to enhance current levels of resilience to climate change and variability.

Conclusions and associated recommendations were:

- Climate change will have profound impacts on Australia's natural resources and will result in significant changes in both natural and managed systems. There is an urgent need to understand and mitigate these impacts.
- Mitigation of greenhouse gas emissions is fundamental to the long-term future of Australia's natural resources but adaptation to the inevitable impacts of climate change is equally important.
- The notion that the climate will not change in the future is no longer tenable. Lack of certainty about the timing and magnitude of climate changes and their impacts must not be used as an excuse for inaction.
- Climate change research in Australia requires greater levels of resourcing and more effective conversion of climate change science into policy and strategic management.
- The issue of climate change needs to be in-built as a matter of course in all facets of natural resource management and land use planning and policy development.
- Policies and actions to cope with climate change should be targeted at reducing ecosystem fragmentation and other stresses, as well as enhancing buffers between systems.
- Climate change will combine with and intensify other threats to biodiversity such as salinity, pollution, invasive species and habitat loss.
- Communication between researchers, policy-makers, managers and landholders about the threats of climate change for biodiversity must be improved.

The conference highlighted key issues facing Australia's natural resource managers in:

- sustainable water use and management
- sustainable land use and management
- biodiversity
- pests, diseases and exotic organisms
- coastal and marine environments
- bushfires
- climate change research

A brief outline of how these issues are likely to affect Queensland follows, along with information on recent and current actions by NR&M, working in collaboration with other agencies and key stakeholders.

Sustainable water use and management

Threats

Higher temperatures, increased evaporation and lower rainfall are expected to adversely affect water run-off and water storage facilities, with the amount of water available in many areas likely to decline. Water quality may also decline in some areas and there will be increased risk of algal blooms. These impacts will extend to rural and other industries, regional and urban communities and the environment.

In south-east Queensland, rapid population growth combined with further projected reductions in rainfall will make ensuring the long-term adequacy of water supplies especially challenging. Alternative supplies will need to be considered earlier than might otherwise be the case. Improving water efficiency and diversifying sources, such as water recycling and the use of grey water, are integral to longer-term water supply strategies.

While average annual rainfall is expected to decline, rainfall intensity is expected to increase, with higher risks of flash flooding and soil erosion, and increased sediment and nutrient loads in waterways. The impact of extreme rainfall events on urban communities and associated infrastructure is also a major concern. The risk is heightened by expectations that the intensity of rain during storms will increase and, by 2050, cyclones may produce 20 to 30 per cent more rain than they do now. For this reason, climate change could result in increased rainfall intensities and flood levels not seen since European settlement, along with periods of more intense drought.

Climate change poses significant challenges for water resource planners and managers as well as those involved in urban planning and flood preparedness.

Key issues include:

- reconciling human and environmental demands as the climate changes
- improving rural and urban water use efficiency
- developing non-traditional water sources
- ensuring long-term water security through diversity of water sources, particularly in south-east Queensland
- improving management of surface storages and reducing losses from evaporation
- maintaining water quality through minimising nutrient and sediment loads by preserving vegetation and retaining ground cover
- understanding the implications of climate change for floods
- ensuring that infrastructure can withstand extreme weather
- assessing the potential of rising sea levels to cause saltwater intrusion into coastal freshwater aquifers.

Responses

Water planning and management

Climate variability and issues of risk and uncertainty are integral to water resource planning. The *Water Act 2000* allows for regular review and, if required, changes in the management of water resources. The detailed hydrologic assessments that are used in water resource planning allow for uncertain future climate change by calculating water allocation security contingency provisions for urban water storages and environmental flows.

For example, the South East Queensland Regional Water Supply Strategy considers the issue of contingency plans for water storages and options for managing droughts worse than those that appear in the historical record. Resource operations plans also include critical water supply sharing rules to ensure water is used in the best way during times of critical supply. The strategy is an example of the Queensland Government's commitment to developing collaborative water supply planning solutions.

Water supply planning has traditionally been based on historical records, though consideration must now be given to the possibility of droughts worse than those recorded. Communities need to plan and apply supply arrangements so they do not run out of water.

These supply arrangements would serve as contingency plans and may include:

- Diversification of supply—including integrated urban water management, which adopts a holistic approach to providing urban water services. For example, the use of rainwater and dual water reticulation may help to reduce drinkable water demand, deferring the need for additional water sources while reducing the impact on receiving waters.
- Managed yields–the average annual volume of water supplied from a dam or catchment is based on a given period of historical flow record. This is measured or derived and adjusted downwards for contingency allowances and upwards for the effect of restriction policies. Managed yields allow:
  - for a contingency storage or buffer to provide for risks associated with yield calculations and the prospect of a drought worse than historically recorded
  - the potential to maximise overall water availability by introducing restrictions during drought
  - provisions to be made for climate change and the amount of water available from storages.
- Carting—where water is carted to small communities as an emergency provision. Only done in severe and prolonged droughts, as this is not a routinely practical or cost-effective contingency plan.

The Queensland Government has approved the development of legislation for water service providers to develop drought management strategies. Service providers and their communities will then have a clear strategy to deal with the restricted availability of water supplies during drought.

NR&M, SunWater (a Queensland Government-owned company which manages large scale water storages and irrigation schemes) and its customers have been working closely to develop and implement drought management strategies. These strategies will safeguard the volume of water reserved for urban and industrial water supplies by restricting usage and identifying alternative supplies in the event of failure of normal sources.

In the medium term, these strategies may be adopted in resource operations plans and resource operations licences being developed throughout the state.

Improving water use efficiencies

The Rural Water Use Efficiency Initiative provides funding to help farmers adopt better water management practices, including industry guidelines, training and grants to install the latest water-saving irrigation technology and services.

The Government has also commissioned the National Centre for Engineering in Agriculture at Toowoomba to conduct evaporation mitigation trials to assess the effectiveness and economic viability of dam cover technologies. The outcome of the trials will apply to farm dams and possibly town water supply storages. Results will be available so storage owners can determine the most suitable option for them to reduce water loss through evaporation.

The department is investigating alternative urban water supplies and increased rural water use efficiency at a systems level, to identify key knowledge gaps and impediments to the adoption of innovative solutions. Research includes measuring and understanding the causes of deep drainage in flood irrigated cotton paddocks and documenting the water, energy and waste levels of alternative environmentally sustainable housing such as the Healthy Home at the Gold Coast.

The ultimate goal of these activities is to predict the effect of these initiatives on water demand, and the likely success of alternative urban water supplies for rapidly growing areas such as south-east Queensland. A key issue will be identifying any energy trade-offs that may be required to achieve diversity in water supplies.

Another project, the Queensland Water Recycling Strategy, seeks to encourage and support the use of water recycling that is environmentally safe and cost effective. The Environmental Protection Agency (EPA) is leading implementation of this strategy, covering legislation, guidance, training, community engagement, research and demonstration. The strategy, together with the urban Water Wise Project, is influencing thinking and actions about urban water efficiency and recycling in Queensland.

NR&M is setting up a state-wide water metering project to help achieve water reform. When the metering project is completed in a number of years, all significant water entitlements in the state will be metered. The meters will help water entitlement holders to monitor their own water use practices and to avoid taking more than their allowed volume of water.

The Healthy Home

The Healthy Home is a privately owned, water and energy efficient home at the Gold Coast built to promote human wellbeing in a high-density environment. It has a rainwater tank, grey water treatment system, solar hot water system and a photovoltaic electricity generating system. A University of Queensland architect designed the home to maximise natural cooling using louvres for cross ventilation and wide eaves for solar exclusion in summer. It was built using materials with low embodied energy.

NR&M has monitored the home's water and energy savings and analysed the results. From 2000 to 2003, a 22 000 litre rainwater tank supplied more than 40 per cent of total household water use. Grey water from the laundry and bathroom could increase water self-sufficiency to almost 90 per cent. The Healthy Home used about half of the mains electricity needed to run an average Gold Coast home.

A larger urban metabolism study is underway in an eco-sensitive subdivision of 22 homes at Payne Road, Brisbane, which will be extensively monitored for its water, waste water, energy and waste behaviour.

The Government has approved the development of legislation that will require water service providers to assess, and where possible cost-effectively reduce, losses from their distribution systems. The Government's Drought Water Supply Taskforce is working with communities and rural industries to improve water use efficiency and recycling.

Specific actions include:

- setting water recycling targets for water service providers
- removing policy impediments to the use of dual reticulation systems to distribute recycled water in urban areas
- resolving policy impediments to the widespread use of rainwater tanks in urban areas with reticulated water supplies
- investigating and promoting innovative water treatment technologies such as desalination.

Dam safety

The Bureau of Meteorology has recently revised the size and likelihood of the very rare rainfall events that cause the floods water supply dams are designed to handle. The extent to which climate change will affect these rainfall predictions is not clear. NR&M will continue to monitor research in this area.

Wetlands

As part of the joint implementation by the Australian and Queensland Governments of the Natural Heritage Trust Wetlands Program in Queensland, NR&M is undertaking one of three projects aimed at improving our knowledge of the state's wetlands.

The project is an analysis of what is known about Queensland's wetlands and will include:

- reviewing and documenting knowledge on understanding of wetland functions and values (ecological, economic, social and cultural); and restoration and management of wetlands (natural and built on public and private land in Queensland)
- developing a meta-database of relevant information and data
- undertaking a gap analysis of the ability of wetland science to inform decision makers and managers on appropriate strategies and practices for effective wetland protection and restoration
- making recommendations on priority knowledge gaps and approaches to fill gaps.

The other two projects being led by the Environmental Protection Agency are to map the extent of wetlands across Queensland and to classify them by type. These projects are being jointly run by the Australian and State Governments and will, among other things, contribute to a better understanding of those wetlands that may be at risk from pressures such as climate change.

Floodplain management

NR&M is developing a State Flood Risk Management Policy. Along with recent initiatives such as the *State Planning Policy 1/03—Mitigating the Adverse Impacts of Flood Bushfire and Landslide*, this policy will help reduce the state's exposure to the damaging effects of floods by encouraging better floodplain development. Climate change consideration will be incorporated into the risk assessments.

Sustainable land use and management

Threats

Australia's highly variable climate already poses particular challenges for ensuring land use practices are sustainable. Long-term trends towards higher temperatures and reductions in average rainfall will bring further significant challenges for land use managers in Queensland.

While crops grown in some areas may at first benefit from small increases in temperature, in most areas these benefits will be lost as temperatures continue to rise and evaporation increases, while rainfall and soil moisture decline. Rising carbon dioxide levels are expected to have some positive impacts on plants and water use efficiency although the extent and duration of the long-term benefits is uncertain.

Over time, these and other changes will affect the composition and distribution of plants in urban and rural landscapes, the number of livestock a property can carry and the suitability of land areas for cropping and other activities including intensive irrigation, urban parklands and open spaces.

Increasing evaporation rates and declining rainfall will also reduce ground cover and increase the risk of soil erosion. This risk will increase with expected rises in rainfall intensity. This scenario increases the risk of land degradation and may speed up the next major degradation episode in Queensland's grazing lands (see Pasture degradation and recovery in Australia's rangelands, page 25).

Vegetation clearing contributes to greenhouse gas emissions as cleared vegetation decays and soil carbon gradually runs down following clearing. These processes slowly release carbon dioxide into the atmosphere, adding to global emissions. When cleared vegetation is burnt, carbon dioxide is emitted far more quickly.

Carbon dioxide fertilisation

Through photosynthesis, plants absorb carbon dioxide (CO_2) from the atmosphere and energy from sunlight to produce carbohydrates—the building blocks and energy for plants to grow.

The pores (stomata) through which CO_2 enters the plants also allow water vapour to be lost to the atmosphere. The ratio of CO_2 fixed to water lost, the water use efficiency (WUE), is an important measure of how well plants can grow in dry conditions. In Queensland, and in much of the arid and semi-arid regions of Australia, plant growth is often limited by water and/or nutrients, especially nitrogen and phosphorous.

Plants have evolved with different pathways of photosynthesis—the main ones are the C3 and C4 pathways, named for the number of carbon atoms in the first products incorporating CO_2 from the atmosphere. Most tropical grasses, including sugarcane and many important pasture species in Queensland, have the C4 pathway. Such plants are characterised by higher rates of photosynthesis and growth, higher temperature and light optima for photosynthesis, a higher WUE and lower CO_2 requirement for maximum rate of photosynthesis. The C3 pathway is found in most woody trees and shrubs, herbaceous plants and temperate grasses.

Under conditions of increased CO_2 with adequate water and nitrogen, growth rates are higher in C3 plants, (this is called the CO_2 fertilisation effect). However, C4 species respond less to increased CO_2 levels. As CO_2 levels continue to rise there is some potential for woody weeds to become an increased problem in areas where water and nitrogen are in adequate supply. However, over the next 30 to 50 years, the impact of the CO_2 fertilisation effect is expected to be relatively minor compared to the impact of other global changes such as temperature increase or changes in rainfall.

The challenge of maintaining land productivity will increase as the climate changes.

Major issues include:

- integrating assessments of the impacts of climate change with other factors that influence landscapes
- identifying appropriate land use, including stocking rates
- developing improved regional climate change projections
- improved seasonal climate risk assessment
- incorporating climate change considerations into soil conservation strategies
- understanding changes in plant, animal and insect species composition and distribution, and fire, flood and drought regimes
- raising awareness of the implications of climate change for sustainable land management
- developing adaptation strategies and improved climate risk management options.

Responses

Vegetation management

Queensland has more than 80 million ha of woody vegetation. The land is used mostly for grazing. NR&M is ensuring appropriate vegetation management in Queensland through the use of satellite technologies. The latest State-wide Land-cover and Tree Study (SLATS report) released in January 2003, reported on land cover changes in Queensland for 1999-2001. The report found the state-wide average annual clearing rate of woody vegetation for the 1999-2000 period was 758 000 ha/year. This rate was 78 per cent higher than the 1997-1999 average rate of 420 000 ha/year. During the 2000-2001 period the clearing rate reduced by half to 378 000 ha/year.

Pasture degradation and recovery in Australia's rangelands

Over the past 100 years, Australia's rangelands have suffered degradation episodes that are driven largely by patterns of climate variability at a five-to-10-year timescale. Sequences of years of above average rainfall led to a build-up of domestic livestock, as well as native and feral herbivores and, in some cases, biased expectations of the overall climate. Subsequent rapid declines in rainfall, including periods of extended drought, exposed and exacerbated rangeland degradation. Sometimes resource recovery was delayed until sequences of above average rainfall years occurred again, often decades after the original drought period.

The recent report, *Pasture Degradation and Recovery in Australia's Rangelands: Learning from History*, describes eight major degradation episodes in the history of Australia's rangelands. The report examined the forces of climate and economics that led to these degradation episodes and the extent to which recovery occurred after the major drought periods.

The history of these episodes suggests that the management of rangelands for future climate variability will be a major challenge for resource managers. Climate change scenarios will greatly aid planning to prevent future degradation episodes and help conserve the natural resource base.

The report is available through <http://www.longpaddock.qld.gov.au> and was funded by Australian Greenhouse Office and Climate Variability in Agriculture Program.

From 1999 to 2001, 94 per cent of woody vegetation change was due to clearing for pasture, 2.3 per cent for cropping, and the remaining 3.7 per cent for forestry, mining, infrastructure and settlement. Some 78 per cent of the 1999-2001 state-wide clearing occurred in three major river catchments: the Queensland Murray–Darling catchment (46 per cent), the Fitzroy and the Burdekin (16 per cent in each). There will now be annual reporting on land cover change in Queensland. The next period for reporting covers 2001–02 to 2002–03.

The decline in clearing observed during 2000-2001 was attributable largely to the proclamation of the *Vegetation Management Act 1999* in September 2000.

Historically, vegetation clearing has been a major source of greenhouse gas emissions in Queensland: the Queensland Greenhouse Gas Inventory reports that in 1999, emissions from land use change were estimated at 37 megatonnes of carbon dioxide equivalent.

The Queensland Government has moved to phase out broadscale clearing of remnant vegetation by December 2006. This will help protect Queensland's rich biodiversity, address economic and environmental problems and give landholders greater confidence to manage vegetation on their properties. It has been estimated that phasing out remnant vegetation clearing in Queensland will result in a greenhouse gas abatement of 20 to 25 megatonnes of carbon dioxide per year in the Kyoto Protocol target period of 2008-2012.

Grazing land management

More than 80 per cent of Queensland is used for grazing livestock. Managing natural grazing lands is important for their economic value of $2 billion annually and to reduce the environmental risk of degradation and downstream impacts on areas such as the Great Barrier Reef.

The Department of Natural Resources and Mines has developed the Australian Grassland and Rangeland Assessment by Spatial Simulation (AussieGRASS) framework. Information such as daily rainfall, temperature and other climate records going back over 100 years, soil and vegetation density, and domestic and feral animal numbers are put into the AussieGRASS model. High-resolution, remote-sensed tree cover data for SLATS are routinely incorporated into AussieGRASS, as are state cadastral data and agricultural datasets from the Australia Bureau of Statistics. The system produces maps and data relating to pasture growth, pasture biomass, run-off to streams and fire risk, which is used for drought assessment and land condition reporting.

Development of AussieGRASS was funded by Land & Water Australia through the Climate Variability Program and is now supported by agencies in Western Australia, Northern Territory, South Australia and New South Wales. The system has been linked to a farm financial performance model to simulate national economic outlooks for agriculture (by the Australian Bureau of Agricultural and Resource Economics). It has also been used in many environmental analyses including tree establishment modelling, greenhouse gas accounting and spread of pest species.

AussieGRASS can be used for simulating how seasonal forecast or climate change scenarios can be run into the future for different landscapes. It can simulate the impacts of climate change scenarios and determine the probability of these scenarios.

Property level planning

One of the most practical ways landholders can prepare for climate change is by planning for possible changes that may affect the productive capacity of their land and degradation risk. Issues include those which are directly or indirectly affected by climate change such as pasture growth, ground cover, drought and woody weed invasion. Property level planning enables landholders to assess the likely changes in land condition, water availability and plant growth to identify issues and develop strategies and plans to address them.

NR&M, the Environmental Protection Agency and the Department of Primary Industries and Fisheries together support property level planning by providing guidelines and access to information and imagery for property mapping. NR&M also encourages and works with industry bodies to help their members address natural resource management issues and meet their environmental responsibilities.

Biodiversity

Threats

Biodiversity could be threatened as higher temperatures and changes in rainfall affect a wide range of land ecosystems. While further work is required, initial studies indicate some ecosystems will struggle to survive, while a few may collapse and their species become at risk of extinction. Others will change in structure and composition over time as new species move in. Ecosystems that are already stressed will be particularly vulnerable, as will ecosystems and species that are physically limited in their ability to migrate. Tropical forests are particularly sensitive to changes in temperature and rainfall, with the plant and animal species of rainforests in mountain areas of north Queensland thought to be most at risk.

Biodiversity threats—Wet Tropics

Recent research has found that the tropical forests of north Queensland are highly sensitive to the projected changes in climate (Hilbert et al 2001). Many Wet Tropics species live only in cooler regions on the mountain-tops and higher tablelands, where the average temperature is less than 22°C. These areas are separated by areas of warmer climate. Figure 11 shows the decline in climatically suitable areas in the Wet Tropics (current area on the left) after a 2°C warming (on the right). Actual habitat area within the suitable climate regions is smaller due to other factors such as fragmentation or unsuitable soils.

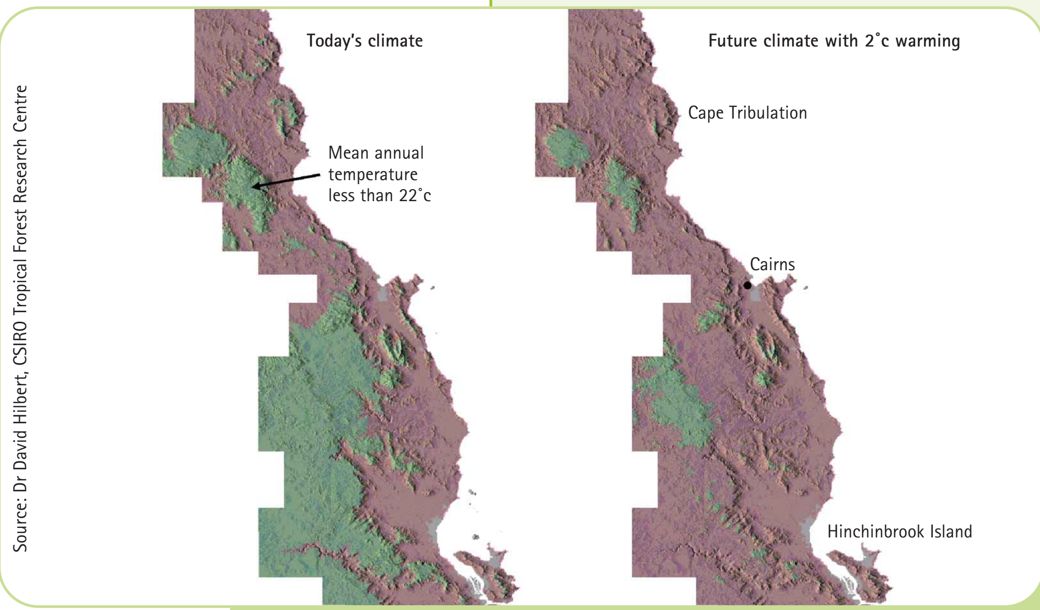


Figure 11. The distribution (Green) of areas with temperatures less than 22˚C (left) and expected areas after a 2˚C warming (right).

With Queensland expected to get warmer, invasive plants can be expected to demonstrate a southward range shift, with tropical and sub-tropical species moving into the border regions, and temperate species being displaced out of these areas. Species currently restricted to the lowlands can be expected to move into higher altitude areas such as the Atherton Tableland and the Border Ranges. For temperature sensitive plants such as lantana this shift may be significant and there is some evidence that lantana is already invading higher altitude areas of the Border Ranges. Frost-intolerant species such as rubbervine and chromolaena can also be expected to shift their ranges significantly further south. (Also see Carbon dioxide fertilisation, page 24.)

The impact of changed rainfall on invasive weeds is difficult to predict. Reduced rainfall will limit the distribution of many weeds such as lantana and the vine species growing in riparian areas. However, reduced rainfall will restrict pasture and crop growth, increasing bare ground and diminishing canopy cover, which favours weed invasion. Increased extremes, with long dry or drought periods interspersed with occasional very wet years, can be expected to exacerbate weed invasion. Established vegetation, whether native or crop, will cope poorly with extremes, leaving areas for invasion. In the past, mass germination and spread of prickly acacia has been associated with very wet years. More severe cyclones will assist in dispersing weeds and open areas of pristine native vegetation for weed invasion, especially in the Wet Tropics.

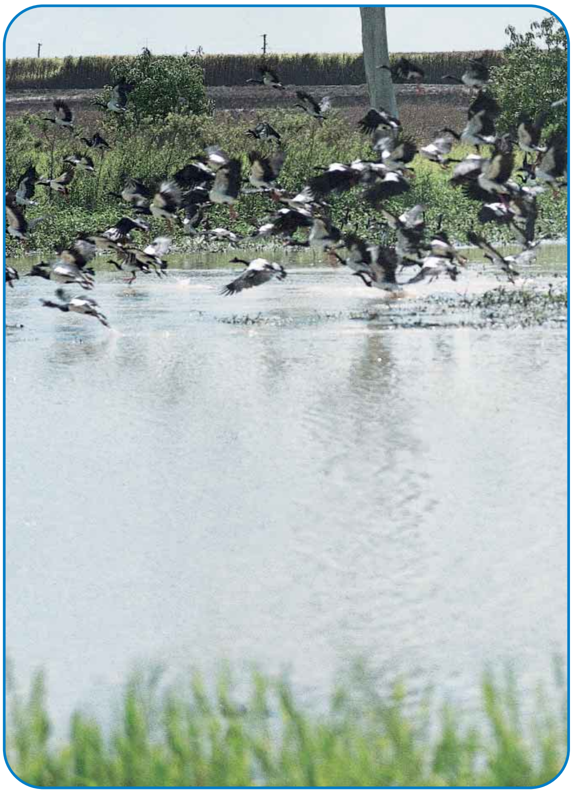
Climatic changes also affect native vegetation ranges. Species with efficient dispersal mechanisms—so that seed arrives into the new zone, whether bird, wind or water dispersed—will cope better than species with poor seed dispersal. Invasive plants generally have excellent seed transport mechanisms, often by human activity or by birds, and can therefore be expected to spread rapidly into new areas. Climate change can therefore be expected to favour invasive plants over established native vegetation, especially if accompanied by an increase in extreme conditions such as droughts alternating with very wet years.

As the climate changes, the geographic ranges of other diseases and exotic organisms may also change. In many cases, this will have a negative effect on natural ecosystems, agriculture, horticulture, grazing and forestry. Some species, either native or exotic, could become pests in the future.

Climate change represents a significant challenge for the management and protection of biodiversity and the control of pests, diseases and exotic organisms. This has implications for managing our national parks and reserves.

Key issues include:

- identifying and reducing other environmental stresses to improve ecosystem resilience
- identifying most vulnerable species and ecosystems
- improving understanding of the impact of climate change on pests, diseases and exotic organisms
- improving the connectivity of ecosystems to facilitate species migration
- improving understanding of the potential impacts of elevated carbon dioxide on plant metabolism and function, and the implications for plant species mix within ecosystems
- improving communication between researchers, policy-makers, managers and landholders about the implications of climate change for biodiversity
- incorporating climate change considerations into regional and local planning and management.



Responses

Regional biodiversity

The Environmental Protection Agency has lead responsibility for addressing biodiversity issues, with the Department of Natural Resources and Mines playing a key supporting role. The Queensland Herbarium prepares regional ecosystem maps that the department uses to show regional biodiversity and develop and implement vegetation management policies. It is recognised that changes to the location, extent and description of regional ecosystems may accelerate due to climate change, depending on an ecosystem's capacity to respond. Changes to woody vegetation will be detected by the State-wide Landcover and Trees Study (SLATS), and these changes will be reflected in the Herbarium's mapping. Potential changes may include rising sea level inundating lowland ecosystems, ecosystems expanding or contracting and communities becoming endangered.

NR&M has also contributed to the National Biodiversity and Climate Change Action Plan 2004-07, released by the national Natural Resource Management Ministerial Council. The plan outlines a 'nationwide strategic approach to protect Australia's biodiversity from the impacts of climate change'. The action plan will help coordinate the activities of different jurisdictions to address the impacts of climate change on biodiversity. As well, the strategies and actions outlined in the action plan will be integrated into the development of broader biodiversity policy and programs.

The goal of the action plan is to minimise the impacts of climate change on biodiversity through a series of adaptation strategies and accompanying actions designed to maximise the capacity of species and ecosystems to adapt to future climate change.

Pests

Researchers are using climate change scenarios to model potential distribution of pests across the state. This modelling includes climate and soils data. Changes in climate may increase the pest potential of some species but maintaining or improving quarantine efforts to prevent entry of likely pest species will lessen the risk.

Drought fodder provided in poor seasons has been a vehicle for spreading weed seeds. NR&M has developed protocols and policies to address this serious problem.

The Queensland Exotic Animal Risk Assessment Committee, a multi-agency committee that advises on the importation of animals into zoological gardens and wildlife parks, takes into consideration the risks storms pose. This committee is likely to require higher building standards in 'at-risk' areas and impose conditions to reduce this risk. For example, species that could pose a threat in parts of the state may be prohibited from being kept as breeding colonies.

Coastal and marine environments

Threats

Queensland's Great Barrier Reef is already exhibiting signs of stress, following hot weather that has bleached coral. As temperatures continue to rise, the Great Barrier Reef will be bleached more regularly and such events could occur annually by 2050. As a result, the Great Barrier Reef is unlikely to survive in its present form. Aside from the loss of intrinsic value, the degradation of the reef will have significant adverse consequences on tourism. (See Impacts of climate change on the Great Barrier Reef, page 29).

While increasing sea temperatures threaten the Great Barrier Reef, there is also growing concern that the oceans may become more acidic as the concentration of carbon dioxide in the atmosphere rises. In turn, this would reduce the availability of carbonate ions in the water for corals and other marine organisms that use carbonate to build shells and other hard structures. This is a concern for all marine reefs.

Aside from potential impacts of rising temperatures and rising levels of atmospheric carbon dioxide, Queensland's coastal ecosystems will be affected by a slow but steady increase in sea levels that is expected to continue for hundreds of years. In undeveloped areas, beaches and other coastal ecosystems can potentially migrate inland, subject to topography. However, in heavily developed areas, coastal ecosystems, including beaches, will be more confined. Aside from the adverse impacts on biodiversity, in areas where coastal ecosystems protect built up areas, their eventual loss will expose these areas to the impacts of storms. In addition, increases in sea levels, combined with changes in wave and wind patterns and possible changes in ocean currents, will also affect coastal processes and in many cases increase erosion.

Loss of wetlands and mangrove habitat, in particular, has significant implications for species that rely on them to provide breeding grounds, including some that form the basis of commercially important fisheries.

Rising temperatures, increasing sea levels and other changes thus pose significant challenges for those responsible for managing coastal and marine environments.

Key issues include:

- improved catchment land use practices and management to minimise nutrient and sediment loads in riverine environments
- reducing other pressures on marine and coastal environments to improve resilience
- identification and protection of nursery zones
- integrating climate considerations into management and policy
- improving coastal land use planning.

Impacts of climate change on the Great Barrier Reef

Average sea surface temperatures have risen over the past 100 years and the frequency of bleaching events on the Great Barrier Reef has increased, particularly since 1980. In 1998, the Great Barrier Reef suffered severe and widespread bleaching. An even more extensive bleaching event occurred in 2001-02 with 60 per cent of all reefs affected, and some inner reefs suffering up to 90 per cent coral death.

NR&M funded research, undertaken by the Australian Institute for Marine Science (AIMS), CSIRO and the Reef Cooperative Research Centre, showed that even under conservative projections of future increases in temperature, coastal reefs are exposed to medium to high levels of bleaching by 2050. However, using less conservative projections there is a marked increase in the incidence of bleaching in the coming one to two decades.

While offshore reefs are less exposed, ecological changes are still expected by 2030. The research also highlighted the importance of considering the interaction with other disturbances such as sedimentation and pollution.

The negative impacts of bleaching have far-reaching implications for biodiversity and management of the reef and for industries that rely on reefs for income. Recent collaborative work by NR&M, DPI&F and CSIRO on behalf of the Australian Greenhouse Office found that coral bleaching is a major concern for the eco-tourism industry in particular.

Responses

Reef Water Quality Protection Plan

The Great Barrier Reef World Heritage Area is a nationally and internationally significant area with outstanding natural, social and economic values. Over the past 150 years, land beside the reef has extensively changed for urban infrastructure, grazing and agricultural production, tourism and mining. The balance of evidence is that the sediment and nutrients from land-based sources are affecting the inner reef and sea grass systems.

The majority of sediment, nutrient and chemical pollutants affecting water quality in waterways in the reef catchment are from many sources, such as land use activities in reef catchments. The Reef Water Quality Protection Plan is a joint initiative of the Australian and Queensland Governments released in December 2003.

The major objectives of the reef plan are to decrease pollutants from these sources and rehabilitate and conserve areas of the reef catchment where water-borne pollutants are removed, such as wetlands and riparian zones.

Implementation of the plan will improve the quality of water entering the reef and potentially make it more resilient to climate change. However, little is known about the combined and cumulative effects of these pressures.

NR&M has a key role in implementing the reef plan—it is involved in all but 10 of the plan's 65 actions and leads or jointly leads the delivery of 34 actions. The department is committed to the reef plan and, with its partners, will provide natural resource science, regional services and policy analysis to help achieve its outcomes.

Bushfires

Threats

Bushfires shape many natural and managed ecosystems (notably for grazing), and have significant impacts on other sectors, such as forestry and agriculture, along with rural and urban-fringe communities. Any change in the frequency and intensity of bushfires would have significant implications across many sectors.

Key factors for bushfires (aside from ignition sources) are temperature, humidity, wind speed and fuel load. Various studies have found that bushfire risk will increase across Australia as a result of climate change (Pittock 2003). However, confidence is higher in relation to the impacts of climate change for southern Australia and further work is required to improve understanding of the impacts of climate change on bushfire risk in Queensland. In particular, while projections of higher temperatures and reduced rainfall may result in more days when weather conditions favour fires, reduced rainfall may result in less vegetation and therefore less fuel for fires.

Key issues include:

- improved management and forecasting of bushfire events
- understanding the implications of climate change for fuel vegetation growth and subsequent potential fuel loads
- development of a clearer understanding of potential changes in fire-conducive weather conditions.

Responses

The primary responsibility for managing bushfires in Queensland resides with the Department of Emergency Services. NR&M currently produces simulated estimates of fuel loads and a curing index as part of the operational AussieGRASS framework, which indicate the risk of bushfire in terms of vegetation. This information is made available each month on the Long Paddock website for use by rural landholders.

The department has the capability in the future to:

- assess the probability of fire three months ahead
- develop real time fire danger indices using AussieGRASS and Bureau of Meteorology weather forecasts
- investigate fuel load and stocking rate effects on fire probability
- map fire scars on the landscape through SLATS
- incorporate climate change scenarios into AussieGRASS to investigate possible changes in fire risk over the next 30 years, as a basis for developing adaptation options, such as bushfire preparedness.

The Long Paddock web site

The Long Paddock web site <http://www.longpaddock.qld.gov.au/> was launched in 1995 to make information on climate and resource conditions readily available to natural resource managers, primary producers and other clients across rural areas. The site contains more than 63 000 maps of drought, pastures, satellite imagery and rainfall analyses on a monthly basis back to 1890. In particular, the Long Paddock web site provides maps of rainfall probabilities associated with each Southern Oscillation Index (SOI) phase, allowing changes in conditional rainfall probability to be accessed operationally in the first week of each month. Information for assessing bush fire risk such as fuel loads and curing index are also available.

Climate change research

Participants at the *Climate Impacts on Australia's Natural Resources: Current and Future Challenges* conference in November 2003 identified a number of important knowledge gaps that need to be addressed in developing accurate cost/benefit analyses of potential climate change impacts as well as viable adaptation and/or mitigation actions.

The knowledge gaps were very similar to those identified in both the IPCC Third Assessment Report (2001) and in Pittock, 2003.

Better knowledge of climate and ecosystem interactions was identified as an important step towards managing natural resources sustainably under changing climate conditions. It was conceded that while some long-term monitoring programs were in place to measure climate variables (such as temperature and rainfall) limited long-term monitoring of animals, plants and ecosystems and their interaction with climate has been made (Pittock, 2003).

The conference also recommended research focus on more fundamental climate change scenario development to fill this knowledge gap. More comprehensive assessment of climate change impacts on Australia's natural resources will require more climate change scenarios where the level of uncertainty is reduced and the uncertainty that remains is quantified. The development of probabilistic scenarios of change was seen as an important next step in the assessment of likely impacts on natural resources.

In addition, the production of scenarios at a higher resolution in terms of space (from regional down to sub-catchment level) and time (from seasonal down to daily time step) was also seen as highly desirable for the development of appropriate regional response strategies.

In addition the Department of Natural Resources and Mines, on behalf of the State Government, is also managing ongoing research with CSIRO to provide up-to-date consensus climate change projections from a range of global climate models. This work will be central to the development of probabilistic climate change scenarios in the near future.

A large-scale study into the detection and attribution of recent climate trends has also been run using a complex climate model on the department's Cray supercomputer. The experiments involved the assessment of individual forcing factors such as ozone depletion, greenhouse gases, solar output and sea surface temperatures in recently observed coastal drying trends. These experiments will allow an assessment for determining how climate will change in the next five to 15 years. The interaction of stratospheric ozone depletion with tropospheric greenhouse gases in changing Southern Hemisphere rainfall patterns is an exciting new area of applied meteorological research and will deliver a better understanding of links between natural climate variability and human induced climate change.

Some actions to address this issue have been undertaken by this department in collaboration with CSIRO Land and Water to develop a robust method for producing high-resolution (point scale) climate change projections. This involved the application of a statistical modelling approach to 30 sites in Queensland to produce daily rainfall data from coarse resolution climate model data.

Better quantitative sectoral knowledge about the influence of climate change and variability on a variety of regional issues such as water supply, salinisation, nutrification and sediment loads was identified as a major knowledge gap. Because various sectors such as agriculture, ecosystems, infrastructure and hydrology interact at a variety of scales, a fully integrated approach to climate change adaptation was seen as necessary.

Inherent in this approach is the need for improved knowledge regarding the vulnerability of different ecosystems to climate change, including better knowledge of adaptive capacity and barriers to adaptation. 'The need for greater integration also includes closer collaboration with stakeholders, on adaptation options and their acceptability, costs, co-benefits, side effects, and limits' (Pittock 2003).

'Adaptation should be regarded as a means to maximise gains and minimise losses, with a greater exploration of opportunities' (Pittock 2003).

In addition, the NR&M, the Department of Primary Industries and Fisheries and CSIRO scientists on behalf of the Australian Greenhouse Office have developed a fully integrated approach to climate change impact studies for the Cairns/Great Barrier Reef region. This blueprint represents the first Australian attempt to fully consider the range of potential climate change impacts on a single region.

In order for climate change to be incorporated into strategic decision-making, a clear understanding of the projections, uncertainties and interactions with a variety of ecosystems must be in place. A risk-assessment approach tailored to the requirement of the particular stakeholder group has been identified as an appropriate means of communication (Pittock, 2003).

Working with several other agencies over the past four years, NR&M also supported the assessment of the potential impacts of climate change on:

- the frequency of coral bleaching on the Great Barrier Reef
- water quality (toxic blue-green algal blooms) for a number of Queensland water storages
- storm surge risk along the entire east coast associated with tropical cyclones
- structural damage caused by tropical cyclone winds on the coastal centres of Cairns, Townsville and Mackay.

Bibliography

Barnola, JM, Raymond, D, Lorius C & Barkov, NI 2003, 'Historical CO_2 record from the Vostok ice core', in *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

BBC News 2004, 'PM gives dire warning on climate', published 15 Sept. 2004, <http://news.bbc.co.uk/2/hi/uk_news/politics/3656812.stm>

BBC News, 2004, 'Blair shocked by climate change', published 14 Sept. 2004, <http://news.bbc.co.uk/2/hi/uk_news/politics/3654042.stm>

Burrows, WH, Henry, BK, Back, PV, Hoffman, MB, Tait, LJ, Anderson, ER, Menke, N, Danaher, T, Carter, JO & McKeon, GM 2002, 'Growth and carbon stock change in eucalypt woodlands in north-east Australia: ecological and greenhouse sink implications', *Global Change Biology*, vol. 8, pp. 769–84.

Cai, W, McInnes, K, Hunt, B, Suppiah, R, Collier, M, Elliott, T, Hennessy, K, Jones, R, Page, C, & Whetton, P 2003, *Climate change in Queensland under enhanced greenhouse conditions, Annual Report*, CSIRO Atmospheric Research, Melbourne.

Campbell, BD, Stafford Smith, DM & McKeon, GM 1997, 'Elevated CO_2 and water supply interactions in grasslands: a pastures and rangelands management perspective', *Global Change Biology*, vol. 3, pp. 177–87.

Church, JA, Hunter, J, McInnes, K, & White, NJ 2004a, 'Sea-level rise and the frequency of extreme events around the Australian coastline', *Proceedings from Coast to Coast: Australia's National Coastal Conference*, 19–23 Apr. Hobart.

Church, JA, White, NJ, Coleman, R, Lambeck, K & Mitrovica JX 2004b, 'Estimates of the regional distribution of sea-level rise over the 1950 to 2000 period', *Proceedings of the 1st International CLIVAR Science Conference*, 21–25 June, Baltimore USA.

Commonwealth Bureau of Meteorology 2003, *The Greenhouse Effect and Climate Change*, Commonwealth Bureau of Meteorology, Canberra.

Commonwealth Bureau of Meteorology 2004, *Australian climate change and variability*, <http://www.bom.gov.au/silo/products/cli_chg/>

Crimp, S & Day, K 2003, 'Evaluation of multi-decadal variability in rainfall for Queensland and other Australian rangeland regions using indices of El Niño-Southern Oscillation and inter-decadal variability', *Proceedings of the National Drought Forum: Science for Drought* 15–16 Apr. Brisbane, pp. 106–15.

Crimp, S, Balston, J & Ash, A 2004, *Climate change in the Cairns and Great Barrier Reef region: scope and focus for an integrated assessment*, Australian Greenhouse Office, Canberra.

Department of Environment, Food and Rural Affairs (DEFRA) 2004, *Scientific and technical aspects of climate change, including impacts and adaptation and associated costs*, London.

EPICA community members 2004, 'Eight glacial cycles from an Antarctic ice core', *Nature*, vol. 429, pp. 623–8.

Etheridge, DM Steele, LP, Langenfelds, RL, Francey, RJ, Barnola, J-M, & Morgan VI 1998, 'Historical CO_2 records from the Law Dome DE08, DE08-2, and DSS ice cores', in *Trends: A Compendium of Data on Global Change,* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A

Guardian Unlimited 2004, 'I'm really very worried for the planet' published 17 June 2004, <http://www.guardian.co.uk/life/interview/story/0,12982,1240021,00.html>

Hall, WB, McKeon, GM, Carter, JO, Day, KA, Howden, SM, Scanlan, JC, Johnston, PW & Burrows, WH 1998, 'Climate Change and Queensland's grazing lands: II. An assessment of the impact on animal production from native pastures', *The Rangeland Journal*, vol. 20, pp. 177–205.

Hilbert, DW, Ostendorf, B & Hopkins, M 2001, 'Sensitivity of tropical forests to climate change in the humid tropics of north Queensland', Austral Ecology, vol. 26, pp.590–603.

Howden, SM, McKeon, GM, Meinke, H, Entel, M & Flood, N 2001, 'Impacts of climate change and climate variability on the competitiveness of wheat and beef cattle production in Emerald, north-east Australia', *Environmental International*, vol 27, pp. 155–60.

Hughes, L 2003, 'Climate change and biodiversity in Australia', *Proceedings of Climate Impacts on Australia's Natural Resources: Current and Future Challenges*, 25–27 Nov. 2003, Surfers Paradise, pp. 28–9.

IPCC 1990, *Climate Change, The IPCC Scientific Assessment*, eds Houghton, JT, Jenkins, GJ, & Ephraums, JJ, Cambridge University Press, Cambridge.

IPCC 1995, *Climate change 1995: The Science of Climate Change. Contribution of the Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds Houghton, JT, Meira Filho, LG, Callander, BA, Harris, N, Kattenberg, A & Maskell K, Cambridge University Press, Cambridge.

IPCC 2001a, *Climate change 2001: The Scientific Basis. Contribution of the Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, eds Houghton, JT, Meira Filho, LG, Callander, BA, Harris, N, Kattenberg, A & Maskell K, Cambridge University Press, Cambridge.

IPCC 2001b, *Climate change 2001: Impact, Adaptation and Vulnerability. Contribution of the Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, eds McCarthy, JJ, Canziani, OF, Leary, NA, Dokken, DJ, & White, KS, Cambridge University Press, Cambridge.

Keeling, CD & Whorf, TP 2004. 'Atmospheric CO_2 records from sites in the SIO air sampling network', *In Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Koppe, C, Kovats, S, Jendritzky, G & Menne, B 2004, *Heat-waves: risks and responses*, World Health Organisation, Copenhagen.

McKeon, GM, Howden, SM, Silburn, DM, Carter, JO, Clewett, JF, Hammer, GL, Johnston, PW, Lloyd, PL, Mott, JJ, Walker, B, Weston, EJ & Willcocks, JR 1988, 'The effect of Climate Change on Crop and Pastoral Production in Queensland', in *Greenhouse, Planning for Climate Change*, ed Pearman, GI, CSIRO Division of Atmospheric Research, Melbourne, pp. 546–63.

McKeon, GM, Hall, WB, Crimp, SJ Howden, SM, Stone, RC & Jones, DA 1998, 'Climate Change and Queensland's grazing lands: I. Approaches and Climatic Trends', *The Rangeland Journal*, vol. 20, pp 151–76.

McKeon , GM, Henry, BK, Quirk, M, Howden, SM & Crimp, S · 2003, 'Climate Impacts on Queensland's grazed landscapes', *Proceedings from Climate Impacts on Australia's Natural Resources: Current and Future Challenges*, 25–27 Nov. 2003, Surfers Paradise, pp. 59–62.

McKeon, GM, Hall WB, Henry BK, Stone, GS & Watson IW 2004, *Pasture Degradation and Recovery in Australia's Rangelands: Learning from History*, Queensland Department of Natural Resources, Mines and Energy, Brisbane.

NASA, 2003, 'As sea level rises, beaches shrink', NASA Jet Propulsion Lab, published 4 Sept. 2003, <http://www1.nasa.gov/vision/earth/lookingatearth/Sea_level_rises.html>

NASA, 2003, 'Double vision', NASA Earth Observatory, published 3 Sept. 2003, <http://earthobservatory.nasa.gov/Study/jason/>

National Research Council, 2002, *Abrupt Climate Change: Inevitable Surprises*, National Academy Press, Washington, D.C.

Natural Resource Management Ministerial Council 2004, *National Biodiversity and Climate Change Action Plan 2004–2007*, Department of Environment and Heritage, Canberra.

Nicholls, N 2004, 'The changing nature of Australian droughts', *Climatic Change,* vol. 63, pp. 323–36.

Petit, JR, Jouzel, J, Raynaud, D, Barkov, NI, Barnola, JM, Basile, I, Bender, M, Chappellaz, J, Davis, M, Delaygue, G, Delmotte, M, Kotlaykov, VM, Legrand, M, Lipenkov, VY, Lorius, C, Pepin, L, Ritz, C, Saltzman, E., Steivenard, M 1999, 'Climate and atmospheric history of the past 420 000 years from the Vostok ice core, Antarctica', *Nature*, vol. 399, pp. 429–36.

Petit, JR, Raynaud, D, Lorius, C, Jouzel, J, Delaygue, G, Barkov, NI & Kotlyakov VM 2000, 'Historical isotopic temperature record from the Vostok ice core', in *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Pittock, B & Wratt D 2001, 'Australia and New Zealand', in *Climate Change 2001: Impacts, Adaptation, and Vulnerability, Working Group II, Third Assessment Report of Intergovernmental Panel on Climate Change*, eds McCarthy, JJ, Canziani, OF, Leary, NA, Dokken DJ & White KS Cambridge University Press, Cambridge. Ch 12.

Pittock, AB 2003, *Climate Change: An Australian Guide to the Science and Potential Impacts*, Australian Greenhouse Office, Canberra.

Planning Institute of Australia 2004, *Sustainable regional and urban communities adapting to climate change: issues paper*, June 2004.

Plummer, N, Salinger, MJ, Nicholls, N, Suppiah, R, Hennessy, KJ, Leighton, RM, Trewin B, Page, CM, & Lough, JM 1999, 'Changes in climate extremes over the Australian region and New Zealand during the twentieth century', *Climatic Change,* vol. 42, pp. 183–202.

Statewide Landcover and Trees Study (SLATS) 2003, *Land cover change in Queensland*, Department of Natural Resources and Mines, Brisbane.

Sydney Morning Herald 2004, 'Climate change a deadly threat, Rio Tinto executive admits', published 8 Sept. 2004.

Syktus, J, McKeon, GM & Carter, J 2004, 'What is causing the decline in coastal rainfall in eastern Australia?' Poster paper at the *Fenner Conference on the Environment*, 24–25 May, Canberra, 2004.

Thomson, S 2003, *The impacts of climate change: implications for DEFRA*. Department for Environment, Food and Rural Affairs, London.

UNEP 2004, *Impacts of summer 2003 heat wave in Europe*, United Nations Environment Programme, Geneva.

Walsh, K, Cai, W, Hennessy, K, Jones, R, McInnes, K, Nguyen, K, Page, C, Whetton, P 2002, *Climate change in Queensland under enhanced greenhouse conditions, Final Report 1997–2002,* CSIRO Atmospheric Research, Melbourne.

Walsh, KJE, Betts, H, Church, J, Pittock AB, McInnes KL, Jackett, DR & McDougall, TJ 2004, 'Using sea level rise projections for urban planning in Australia', *Journal of Coastal Research*, vol. 20, pp. 586–98.