Climate Change: How real is it? The issues and implications

Professor Bob Miles[1] and Associate Professor Ken Purnell[2]

[1]Executive Director, Institute for Sustainable Regional Development, Central Queensland University

[2]Associate Dean (Teaching and Learning) and Head of School of Education and Innovation, Faculty of Education and Creative Arts, Central Queensland University

For many people confusion still exists about climate change, how real is it, what does it mean, what are the impacts and can we ameliorate them, how do we adapt? For more than a decade, scientists and governments throughout the world have been investing resources in a collaborative effort to examine and address emerging issues in the stability of the world's climate. This collaborative effort has largely been driven by concern over the changing climate and the impact that major climatic events have on the global economy. One of the major products to emerge from this effort was the formation of the International Panel on Climate Change (IPCC, 2001a). The IPCC's three major working groups that include internationally-recognised scientists examined the science behind understanding climate change and the cause, the impacts of the change in climate and possible adaptation strategies, and the mitigation of the impacts (IPCC, 2001a).

'The global average surface temperature has increased over the 20th Century by 0.6° C' (IPCC, 2001b) was a key finding. While that is a global average, the local level implications are significant. These include increased energy demands for cooling, and consequent rises in greenhouse gas emissions, more health care infrastructure for the aged, increases in pests and more widespread distributions of diseases (see IPCC, 2001c). The CSIRO noted that temperatures in Australia are likely to rise and predicted that by 2070 the number of days Brisbane experiences temperatures above 35°C will increase tenfold from its present three per annum. Major groups such as the CSIRO and the Bureau of Meteorology (BoM) have made clear the issues about emerging trends in climate (Bureau of Meteorology, 2003; CSIRO, 2003a). Adaptation strategies to climate change are now a priority for governments in Australia with, for example, many local governments seeking to 'drought proof' their areas as we remain in this drier phase of the climate. An authoritative overview of likely Australian impacts and responses to climate change is provided in chapter 4 of 'Climate Activities in Australia 2003' by the Bureau of Meteorology (see www.bom.gov.au/inside/eiab/reports/caa03/chapter4/introduction.shtml):

> *Climate variability and trends impact on Australia's economy, environment and society. Australian research organisations are conducting many research projects to understand the magnitude of climate change (including natural variability and human induced climate change) and the physical drivers that underpin our ability to forecast and manage its impacts.*
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> *Australia's average temperature varies by up to 1 degree Celsius from year to year, and has experienced a warming trend of about 0.8°C since 1910, most of this since 1950. Averaged over Australia, maximum temperatures have risen 0.56°C since 1910 and minimum temperatures have risen 0.96°C, with the largest warming since about 1950. According to CSIRO projections released in mid-2001, which use as their reference point the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), annual average temperatures over most of the continent could be 0.4 to 2°C greater than 1990 by 2030. By 2070, average temperatures are projected to increase by 1 to 6°C. Warmer conditions will produce more extremely hot days and fewer cold days and frosts. Greatest warming is to be expected in spring and winter will warm the least.*

Australia's current rainfall averaged over the whole continent is about 450mm a year, varying between 300–800mm in any year (with the variability much larger in specific regions). Averaged over Australia, annual total rainfall has increased slightly since 1910 and the intensity of heavy rainfall has also risen. According to the CSIRO projections, rainfall decreases are projected for the southwest of Western Australia and for parts of the southeast of the continent and Queensland. Most other locations have an even chance of wetter or drier conditions. Decreases are projected to be most pronounced in winter and spring. Some inland and eastern coastal areas are projected to become wetter in summer, and some inland areas to become wetter in autumn. These projections include the effect of simulated changes in El Niño and La Niña events.

The following data are largely drawn from information available through the IPCC, the Bureau of Meteorology, the Australian Academy of Science, CSIRO and the Australian Greenhouse Office. A detailed review of climate activities in Australia is provided by the Bureau of Meteorology (2003b).

Key drivers and historical trends in Australia's climate

Australia is the driest continent that has a significant population and also has some of the greatest variability in climate in the world. The eastern seaboard of Australia where almost 80per cent of the population live is subject to a high degree of climate variability with a concentration of this around the Tropic of Capricorn and the mid-latitudes and, within that, especially Queensland.

The Walker Circulation (Southern Oscillation) is a key driver of climate in the south Pacific. This is where La Niña events occur as the sea surface temperatures on the eastern coast of Australia rise and there is a concurrent cooling in the eastern equatorial areas and the eastern Pacific causing, generally, above-average rainfall. Conversely, when the western Pacific cools, the eastern coast of Australia experiences El Niño-like conditions and, therefore, generally lower-than-average rainfall.

For a quality animation showing El Niño and La Niña, you may care to look at the animation provided on the Bureau of Meteorology website at <www.bom.gov.au/lam/Students_Teachers/elnanim/elani.shtml>.

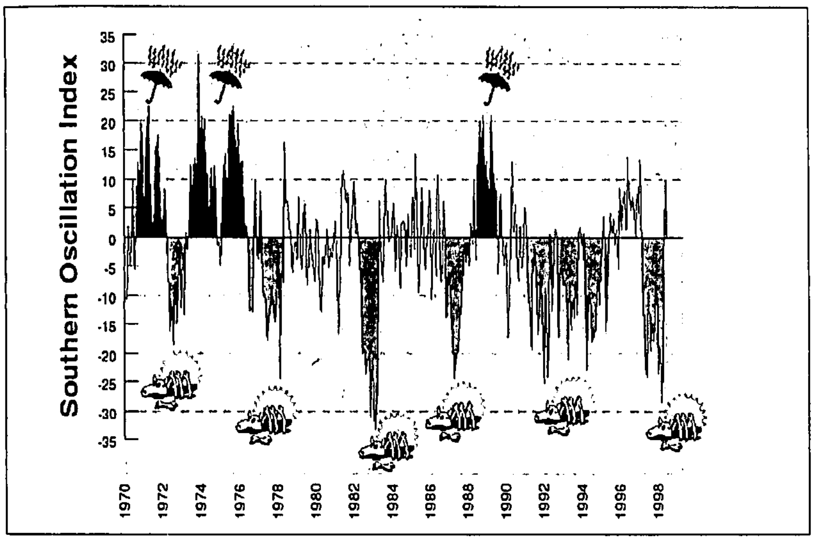
The Southern Oscillation Index (SOI) measures the barometric pressure differential between Tahiti and Darwin. A sustained negative SOI is indicative of El Niño events and positive SOI values of La Niña events (Bureau of Meteorology, 2002). The IPCC reported that El Niño events are dominant over the last three decades and likely to dominate into the foreseeable future (IPPC, 2001a). El Niño has a major impact on Queensland precipitation and consequently river systems that are the major water source for life and economic activity in the state. The IPCC (2001a). has predicted increased dry summers over most continental interiors of the world, decreased crop yield from that drier phase and decreased water resource quantity and quality as well as increased risk of bushfires (wildfires). Figure 1 provides a graphic representation of the SOI changes from 1970 and the resultant drier or wetter periods and their duration in Queensland.

In Figure 2 the 20-year moving average of the SOI is provided. As there are high levels of variability in the data, mathematical smoothing is used that creates a moving average to highlight long term trends. In Figure 2 you can observe that the long term SOI changed in the mid-1970s (1976 to be precise). The question from Figure 2 is—will that long term negative SOI be likely to continue? The IPCC reports clearly indicate that El Niño conditions (negative SOI) are likely to prevail into the foreseeable future as noted previously.

Data in Figure 2 is from 1890—in geological time this is very short for the many millions of years of phenomena such as the SOI. So where this century plus data sits in the longer-term scenario as being 'typical or atypical' of trends or cycles cannot be predicted.

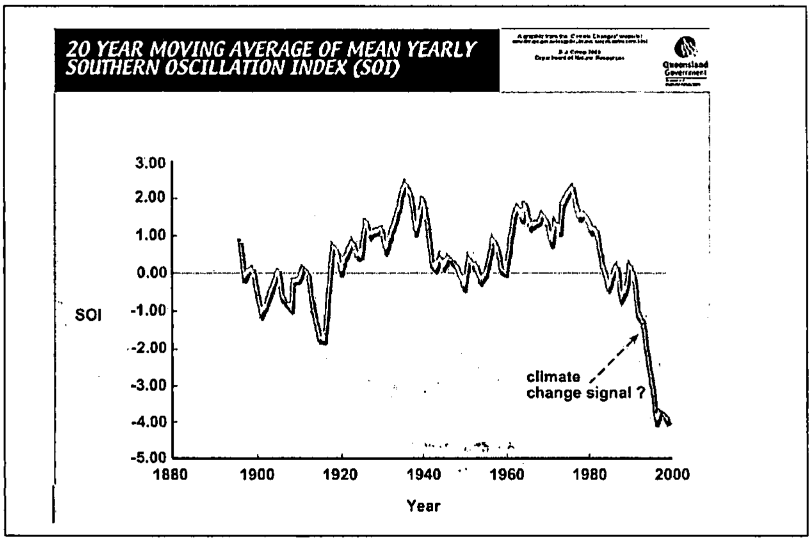
SOI changes align with changes in the activity and movement of cyclones. El Niño conditions cause cyclones that would normally cross the Queensland coast and cause significant rain episodes to track eastwards instead, as can be seen in Figure 3. This may reduce

Figure 1: The relationship between positive and negative Southern Oscillation Index values and wet and drought conditions in Queensland



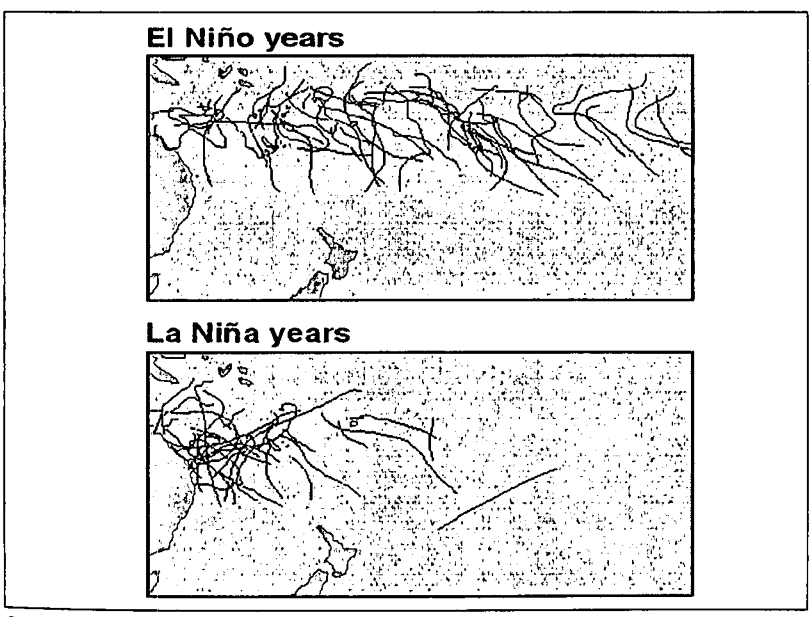
Source: courtesy of Dr Roger Stone, Queensland Centre for Climate Applications.

Figure 2: Twenty year moving average of SOI since 1880



Source: courtesy of Steven Crimp Department of Natural Resources and Mines, Queensland.

Figure 3: Patterns of cyclone movement in El Niño and La Niña years



Source: Peter Hasting, University of Queensland

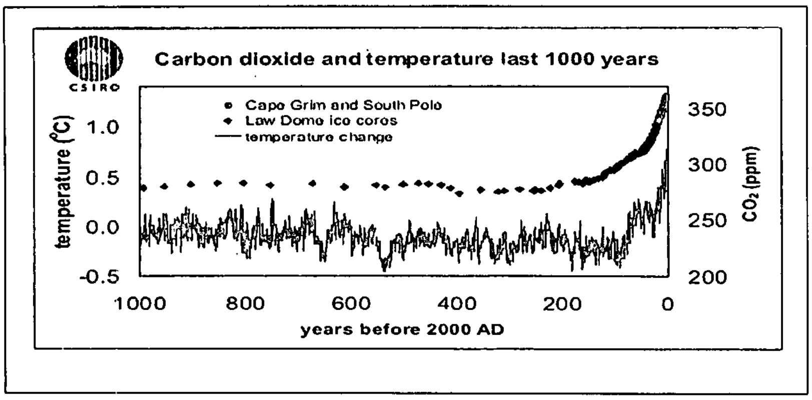
insurance premiums, but results in less precipitation and adversely affects land dependent on cyclonic rainfall events. Conversely, in La Niña episodes, cyclones that form in the equatorial areas track south and west and can bring torrential rain to the eastern seaboard.

However, the reverse is true on the other side of the continent in Western Australia. For example, El Niño events result in the north west coast of Western Australia having significant rainfall events.

The patterns shown in Figure 3 are over about a twenty-year period—miniscule in geological time. We know that world climate over extended periods of time varies between wet phases and dry phases. Scientific evidence indicates the 'normality' of these phases and we can see the extent to which current events correlate to past climate episodes. Such evidence includes carbon dioxide (CO_2) that accumulates in the polar ice caps. Deep core samples from the ice have enabled scientists to look back 400,000 years and measure levels of CO_2. The evidence from the ice core samples clearly shows that CO_2 levels vary considerably over time. Notwithstanding this, more recent monitoring of CO_2 levels over the past century reveals that present levels are well beyond concentrations evidenced in the past 400,000 years. There has been a steep recent rise to unprecedented levels above 370ppm when the average previously has been around 230ppm and once, some 300,000 years ago, reached 300ppm.

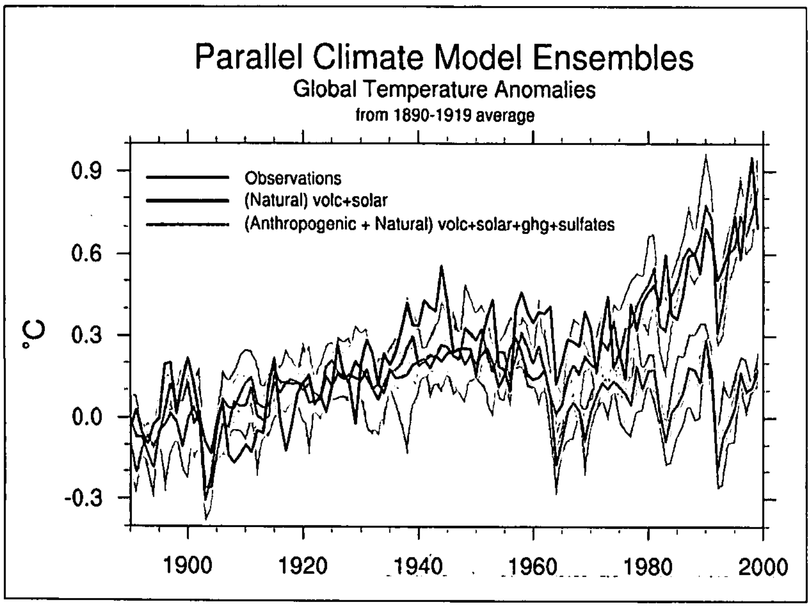
Figure 4 shows graphically the analysis completed by the CSIRO that there is a high correlation between CO_2 levels and atmospheric temperature. There are natural causes of temperature changes from, for example, volcanic and solar activities. In addition there are ones that humans create such as through additional greenhouse gases (see Purnell, 2001). The CSIRO has analysed the relative contributions of these natural and anthropogenic sources and this is presented in Figure 5. It is evident that the trend for the natural contributions has remained fairly constant for thousands of years but more recent human activities, especially in the last fifty years, has added much by way of greenhouse gases and sulphates to the

Figure 4: CO_2 levels and temperature over the last 1000 years



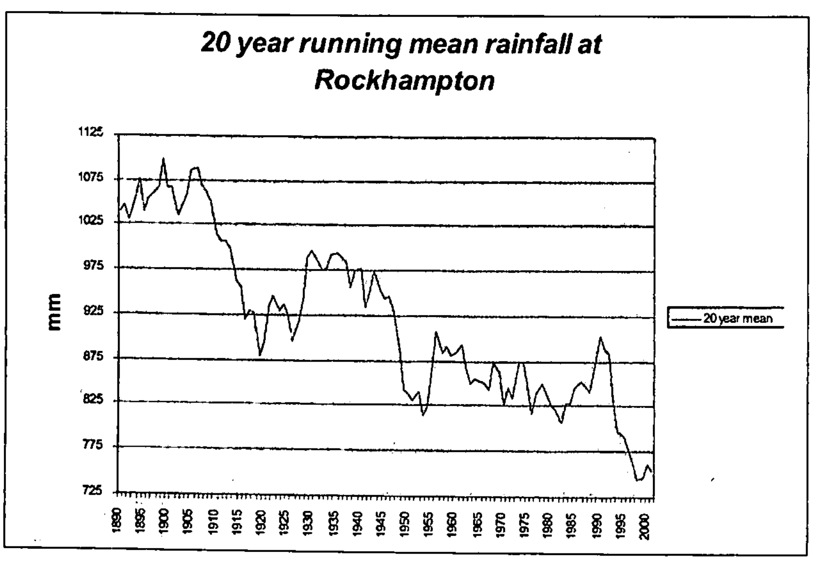
Source: CSIRO, 2003.

Figure 5: Parallel climate model ensembles of global temperature anomalies



Source: CSIRO, 2003.

Figure 6: Twenty-year running mean rainfall for Rockhampton, Queensland 1890–2003



Source: Bureau of Meteorology, 2003

atmosphere and in Figure 5 you can see that this coincides with warmer temperatures.

The IPCC (2001c) has predicted that the average temperature in Australia could rise by as much as 6°C by 2030. This will have a significant impact on pests with, for example, the extent and spread of the mosquito borne diseases such as Malaria and Ross River Fever, and the general well being of our ageing population (IPCC, 2001c). Naturally, energy demands for cooling are likely to increase thus adding further to greenhouse gas emissions.

Case study of Queensland's drier climate phase

Increasing temperatures will affect water balance and much of Queensland is expected to experience an increased deficit in the water balance of the order of 40 to 130mm per annum caused by evapotranspiration (CSIRO, 2003). This will result in less water availability in water storages and adversely affect plant and crop growth (IPCC, 2001c).

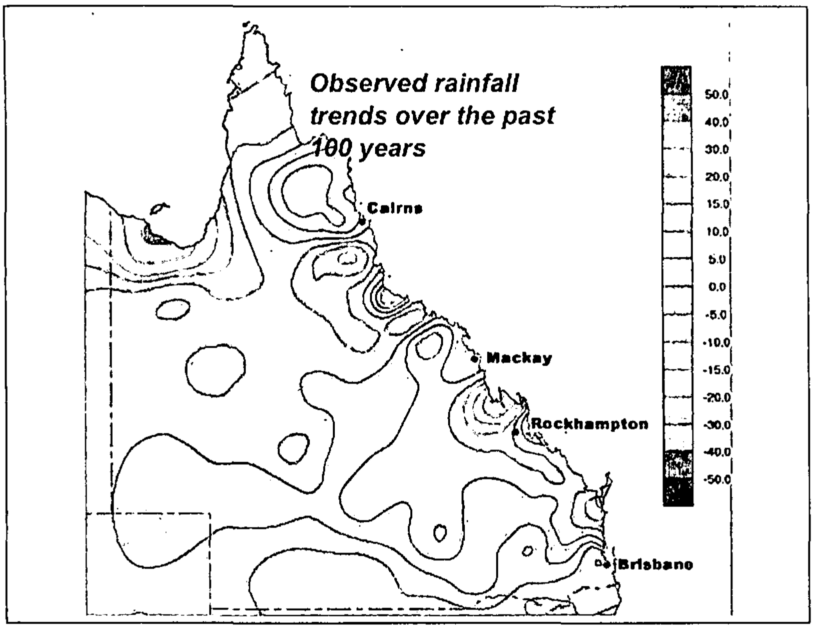
Queensland has already experienced a significant reduction in rainfall over the past hundred years. One example is in Central Queensland, where the coastal city of Rockhampton, located on the Tropic of Capricorn, receives about two-thirds of the rainfall it did a hundred years ago (see Figure 6). As shown in Figure 7, this trend is symptomatic of many towns and cities where the Bureau undertakes official measuring of rainfall.

In Figure 8, which presents data on rainfall changes in Australia over the 50 years to 1999, you can see an increase in average rainfall throughout much of the western half of the country and a drying in the eastern half. As stated previously, this is as a consequence of the changes to the effects of cyclonic activity in El Niño years that mean increased rainfall in the west and reduced rainfall in the east of Australia.

A case study of rainfall changes in Western Australia

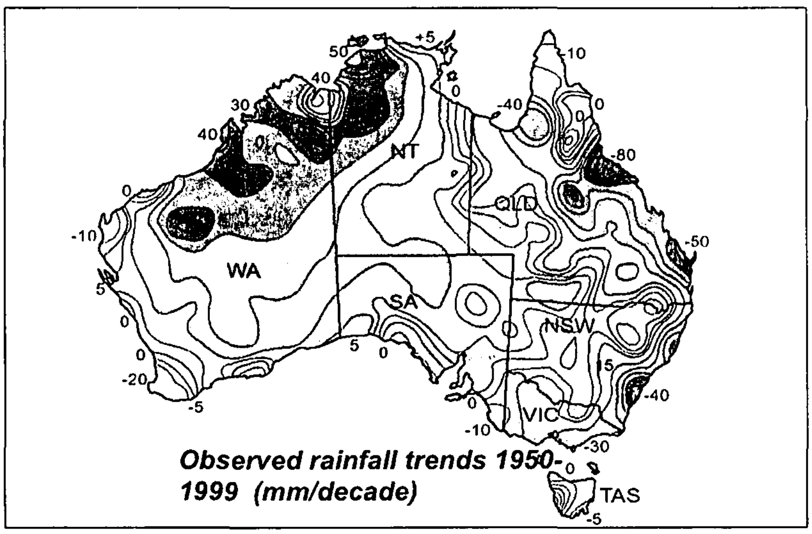
In the lower portion of Western Australia there has been considerable change in rainfall reliability in an area that was always previously described as having a reliable Mediterranean style of rainfall has also shown considerable

Figure 7: Changes in rainfall trends for Queensland over the past 100 years



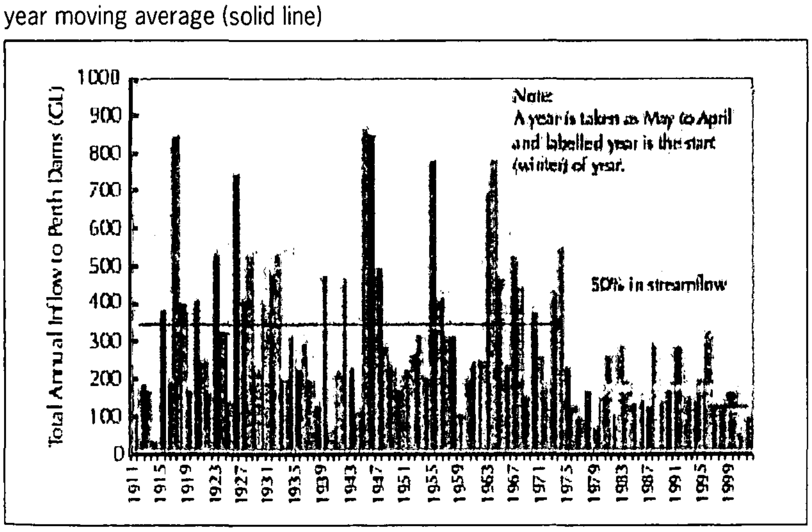
Note: isohyets are in millimetres per decade
Source: Bureau of Meteorology, 2003.

Figure 8: Rainfall trends for Australia 1950–1999



Note: isohyets are in millimetres per decade
Source: Bureau of Meteorology, 2003.

Figure 9: Yearly inflow into Perth's water supply (columns) also showing the ten-year moving average (solid line)



Source: Bureau of Meteorology, 2003b.

change. As this area had displayed high levels of reliability, the Western Australian government in collaboration with the BMRC and CSIRO set up a major initiative called the Indian Ocean Climate Initiative (IOCI) to investigate this. The IOCI looked at climate change and the impact on water resources experienced in southwest Western Australia since the 1970s (see Figure 9). Key findings from the IOCI (2002) study were:

- winter rainfall has decreased sharply and suddenly in the region since the mid 1970s
- the decline was more of a switching to an alternative rainfall regime
- the rainfall decrease was apparently associated with a change in large-scale atmospheric circulation at the time.

Implications for policy-makers and planners

The current shifts in climate and the projected changes are of significant interest to policy makers, community and business and industry sectors. The data collected on climate change and measures of the impact are increasingly being applied to and tested against a diverse range of industry sectors by scientists, the government, and by members of the of the general public concerned over future impacts. Implications of climate change include planning of infrastructure, structural design, risk management, business investment and the formulation of government policy. The next section deals with a range of industry sectors and areas that climate change will impact on and the potential implications.

Agriculture and natural resource management

There are numerous studies on the problems faced by our natural resources under current land use practices. Climate change will significantly add to this pressure as there is a complex inter-relationship between climate and environment—with changes in each impacting on the other, often interactively.

A significant amount of research is underway to better understand these relationships and the risks climate change poses. Many agencies, such as Commonwealth and state government departments, universities, the CSIRO and private sector organisations, are engaged in assessing the risk and management associated with climate variability and climate change implications in agriculture and natural resource management. This research has identified a number of serious points of concern (Bureau of Meteorology, 2003b).

For example, pasture growth rates (kg dry matter/ha/yr) and the subsequent growth rates of animals (live-weight gain) and wool production are dependent on rainfall. Minor changes in rainfall in terms of seasonality, intensity and duration all have a major impact on the plant species mix within pastures and thus the productivity of the grazing landscape. In sheep production systems, the tensile strength and fineness of the fibre can be adversely affected by changes in pasture quality and quantity.

Researchers at Queensland Department of Natural Resources and Mines (Crimp, Flood, Carter, Conroy & McKeon, 2002) used a pasture production model to explore the impact of climate change on native grasses. Their modelling showed that with even small increase in temperature and a decrease in rainfall, such as those projected for 2030 by CSIRO, pasture growth would decline by 10 to 50per cent in the state.

Water use by plants is affected by increases in temperature, and grain yield and quality are affected by the quality and timeliness of precipitation. Changes in frost incidence and number of frosts also have implications for fruiting of horticultural and grain crops. Examples of this include olives in Victoria, grapes in South Australia and citrus in Queensland. Climate change modelling is needed to determine the future suitability of areas for various land use practices in terms of sustainability, as changes in rainfall and temperature will affect economic viability and production risk. Outcomes of climate change will likely affect producer viability, the cost of some commodities, and require national disaster relief, assistance and restructuring programs.

Climate change is already affecting Australian cropping systems and the way they are managed, according to scientists from the Queensland Department of Primary Industries (Menke, 2005, personal communication).

Continuing increases in the concentration of atmospheric carbon dioxide will affect growth patterns of crops, trees and pastures while change's in rainfall patterns will influence production. Temperature increases are already leading to changes such as the planting dates for wheat. For example, in Emerald, in Central Queensland, there are around three weeks each year of frost, compared with the ten weeks experienced each year in the 1900s (Stone 2005, personal communication). Further temperature increases will also affect crop rotations and limit the expansion of crops such as canola in Queensland, or supporting the expansion of cotton production further south than it is grown today. Farmers in marginal regions might need to switch from their current grain/grazing mixed operations to grazing or even plantation forestry—evidence of this is already seen in the marginal areas of the Western Downs in Queensland around Miles and Roma. Management changes recommended to farmers may now need to include changes in varieties and planting dates, changes in crop species, erosion and salinity management, pest and disease management, and greater use of seasonal forecast information (Crimp, 2005, personal communication).

CSIRO researchers have shown that under climate change many of Australian viticultural regions, particularly in the north, are projected to experience warmer and drier conditions, especially in winter and spring. It is expected that this will result in earlier ripening and a possible reduction in grape quality. However, in the cooler, southern regions higher temperatures may allow for new varieties. Higher carbon dioxide concentrations may lead to more canopy growth and shading, leading to decreased fruitfulness. Water supplies available and the reliability of supply for irrigation may decrease.

The sugar cane industry is another example of an industry susceptible to climate change. Already under financial stress through global competition, the industry involves an integrated value chain in which climate influences many factors, including:

- determining the amount of sugar produced by sugar cane

- controlling the development and spread of fungal diseases insects, pests and weeds
- influencing runoff and deep drainage, with possible environmental impact associated with nutrients and pesticides, and also
- affecting the harvesting, transport, milling, marketing and shipping of the product.

Long-term crops such as forestry are also likely to be affected and susceptible to changes in climate. For example, pine species planted along the coast on the expectation of rainfall above 1000mm may not grow or mature in a climate that yields less than 800mm. This will make some coastal Queensland areas traditionally considered suitable for forestry no longer suited.

Many wetlands in Australia are under threat from agriculture, dams, irrigation, coastal urban development, and the pollution of the waterways. As an example, the Murray-Darling Basin Commission reported that the quality of wetlands has been significantly reduced in the Murray-Darling Basin, particularly between the Hume Dam and Mildura. Climate change will add to the vulnerability of these sensitive wetlands. Furthermore in northern Australia, if the projected sea level rises occur, the vast freshwater floodplains of the north will be subject to significant saltwater inundation (CSIRO, 2002).

Fisheries (commercial and recreational) are another industry likely to be affected by climate change. Recruitment and survival of coastal and riverine breeding species are likely to be affected by changes in rainfall and temperatures. Sediment transport and deposition following heavy rainfall can smother extensive areas of estuarine habitat, killing trees and resulting in loss of breeding habitat essential to many coastal fish species, dugong and turtles. Any increase in extreme rainfall events and sedimentation would be likely to have major impacts on river, lake, estuarine and coastal waters and lead to reduced ecosystem health and reduced recreational and tourist use. There may be impacts on commercially important fisheries, such as prawns and barramundi, but the economic impacts are unclear (CSIRO, 2002).

Mangroves occur on low-energy, sedimentary shorelines and are the nursery areas for many commercially important fish, prawns and mud crabs. They are highly vulnerable but could be adaptable to climate change, migrating shorewards in response to gradual sea level rise. However, in many locations this adaptation will now be inhibited by human infrastructure such as causeways, flood protection levees and urban and tourist developments, leading to a reduction in the area of wetland or mangrove (CSIRO, 2002).

While it is easy to focus on the negative, it should also be remembered that opportunities emerge out of change. For example, a collaborative project between CSIRO Marine Research and CSIRO Sustainable Ecosystems investigated connections between ocean temperatures and farm management. Using sea surface temperature measurements to estimate atmospheric changes for up to six months ahead, researchers found that production increases in northern Australia of 16per cent are possible, as well as a 12per cent reduction in soil loss (CSIRO, 2002).

Insects, pests and weeds

Australia's crops, horticulture and forestry are vulnerable to introduced pests that have no local biological controls. Climate change may increase the chance that such pests will become established. Researchers at the CRC for Australian Weed Management Systems have found that the moths, weevils and beetles that play a vital role in bio-control of weeds are suffering severely in the current drought.

Researchers at the University of Queensland and CSIRO (White, Sutherst, Hall & Wish-Wilson, in press) investigated the vulnerability of the Australian beef industry to the cattle tick *Boophilus microplus* under climate change. Compared to current estimated losses of 6000 tonnes per year, they found potential losses in live weight gain from 7800 tonnes per year by 2030 to 21,600 tonnes per year by 2100. These figures are in the absence of adaptation measures such as changing to tick-resistant breeds or increasing tick control treatment.

Many insect populations will be affected by climate change. As an example Macquarie University researchers reported on the current distribution of 77 species of Australian native butterflies, and the potential changes in distribution of 24 species in response to climate change. They found that even species with currently wide climatic ranges are vulnerable to climate change. Under a very conservative climate change scenario, the distribution of about 90per cent of species of Australian native butterflies would decrease, and around half of species distributions would decrease by at least 20per cent. The potential changes for insects may be hidden or well removed from the temperature and rainfall distribution impacts (CSIRO, 2002).

Water management and use

Efficient management of water will become increasingly important as we enter times of increasing water use and shrinking sources of supply. Climate variability is the main factor impacting on the availability and reliability of water resources. Improved understanding of the processes linking rainfall, evaporation, soil moisture, groundwater and surface water rely heavily on long time series of hydrological or climate-related data.

Management of Australia's water resources is the responsibility of the state and territory governments. National co-ordination of resource management policy is through the Natural Resource Management Ministerial Council and its underpinning structure of committees. It is of interest to note that the bulk of Australia's surface water resources occur in the eastern portion of Australia which is also the area currently recording the highest rate of reduction in rainfall. It is also the area of highest population density.

Low rainfall conditions during the year resulted in 2002 being one of the driest years on record for Australia as a whole. Much of eastern Australia and southwestern Australia also experienced a dry year in 2001. In parts of southeastern Australia these two dry years came on top of below average rainfall over the proceeding 6 years. The successive dry years have had a serious impact on water resources in eastern Australia with increasingly severe water restrictions being placed on the irrigation supplies and urban water use. By November 2002, almost 62per cent of Australia had serious or severe 9-month rainfall deficiencies, making it the most widespread 9-month drought on record. In Victoria during February 2003, many streams had dried up and irrigation and/or water diversion bans were in place in 23 of the 28 river basins.

High temperatures were also a feature of this drought, with Australian-average maximum temperatures the highest on record. On an annual basis, maximum temperature and rainfall are negatively correlated, i.e. droughts tend to have anomalously high temperatures. However, since about 1973, temperatures have tended to be higher for a given rainfall amount, i.e. droughts have become hotter, Australian researchers concluded that the drought of 2002 and the associated impacts on agriculture, water resources and fire were made more severe than past droughts due to the high temperatures and evaporation which may be partly due to human-induced global warming (Karoly, Risbey & Reynolds, 2003; Nicholls, 2003).

One of the greatest challenges facing Australia is how to stop using more water and to use what we have more efficiently. Water supplies per capita have fallen dramatically since 1970 and are set to continue declining according to a United Nations report (United Nations, 2003). In Australia, consumption of freshwater resources rose from 14,600GL in 1983/1984 to 23,300GL in 1996/1997. Irrigation increased by 30per cent between 1990 and 2000 (CSIRO, 2003). Many solutions have been canvassed, including water trading and more efficient irrigation methods.

In many Australian communities, much of their limited water supply is used to provide evaporative air-conditioning during hot weather. For example during a three-week period during early 2003 in Cobar, the maximum daily temperature did not drop below 40 degrees Celsius. Even with water restrictions, the town used a million litres of water a day on air-conditioning (Bureau of Meteorology, 2003b). At this rate of usage the town's water supply was predicted to run out by June 2003. In 2002 the Queensland Government formed a special cabinet committee to address the emerging water crisis with over 80per cent of towns in Queensland facing severe water shortages. In February 2002, most of these communities had less than 6 months water supply left (CSIRO, 2003).

Australia's highly variable climate creates uncertainty in hydrologic systems that must be taken into account in the design and operation of water resource projects. Perth's water supply reduced by 50per cent following a 25per cent reduction in rainfall (CSIRO, 2003).

Community health and wellbeing

Environmental health is the interaction between the environment and the health of populations of people and has been defined as 'those aspects of human health determined by physical, biological, and social factors in the environment'. Climate is one of those factors and the number of studies examining the influence of climate is growing. A recent investigation by the Bureau of Meteorology's Northern Territory Regional Office and the Australian National University on the influence of climate on outbreaks of meningitis among indigenous people of central Australia provides an example (Bureau of Meteorology, 2003b).

Arboviruses

In Australia, there are more than 70 viruses that are spread by insects, which can breed rapidly during unusually rainy periods. Murray Valley Encephalitis (MVE), Kunjin (KUN) Disease, Barmah Forest Disease, Dengue Fever and Ross River Fever are examples of diseases observed in Australia, which are carried by mosquitoes. An outbreak of Barmah Forest virus disease in Victoria in early 2002, and many cases of dengue fever in Cairns in early 2003, has highlighted the public health threat from arboviruses (diseases carried by arthropods).

MVE is carried from northern Australia by migratory water birds (hosts), which move far into the southern parts of Australia during very wet years. Mosquitoes (vectors) can carry the virus from infected water birds to humans. Monitoring of weather conditions and vector surveillance determines whether there is a potential for MVE activity to occur.

Government (federal, state and local) based programs in most Australian states undertake mosquito monitoring and virus surveillance from mosquitoes. They also aim to provide increasing understanding of interrelationships between arboviruses, vectors and climatic conditions. Organisations involved include state health departments, the Department of Medical Entomology at Westmead Hospital and the Queensland Institute for Medical Research's Mosquito Control Laboratory. The Bureau of Meteorology's Seasonal Climate Outlook is used to predict likely arbovirus risk for the coming summer.

The National Centre for Environmental Public Health has carried out studies of how climatic variations influence the occurrence of several infectious diseases, especially Ross River virus disease and bacterial food poisoning. For example, Ross River Virus in the north of Australia has been shown to be directly linked to the El Niño-Southern Oscillation phenomenon, as La Niña (higher rainfall) years provide ideal conditions for the breeding of the virus' hosts and vectors. Health authorities are concerned that climate change could be bringing Ross River virus further south, threatening Australia's southern cities (CSIRO, 2003).

Between 1991 and 2002 in Australia there were 51,761 notifications of the disease of Ross River virus (CSIRO, 2003). It is well recognised that weather directly affects the breeding, abundance, and survival of mosquitoes, the principal vector of many arboviruses such Ross River Fever. Hence, researchers from the Australian National University believe that an increase in incidence of this disease is highly likely under the projected climate changes.

Malaria is not endemic in Australia. However modelled results in a health risk assessment report (McMichael et al., 2002) indicate that under climate change there is a hypothetical risk of the zone where Australia's only malaria vector could exist, expanding as far south as Bundaberg, a three-hour drive north of Brisbane.

Food poisoning outbreaks may be linked to unusually hot weather, which can enhance bacterial replication. Reports of food poisoning outbreaks are higher during unusually hot summers in Australia. Assuming that a sustained temperature rise has a similar effect to monthly temperature variations, then the incidence of salmonellosis may rise in future decades.

Higher global temperatures could increase human exposure to toxins produced by cyanobacteria (blue–green algae) in water supplies and recreational water bodies, which can cause gastrointestinal and dermatological symptoms.

Natural hazards

The increased incidence of extreme weather events as predicted by the IPCC (2001a) is significant in terms of the social, economic and environmental impacts. The degree of concern over this is reflected in the investment in research into such impacts. For example, the Natural Hazards Research Centre at Macquarie University now record and model the impacts and fatalities caused by tropical cyclones. Data recorded include the effect on areas such as health, the built environment, agriculture, the physical environment, economics and the bio-system as well as the characteristics of the tropical cyclones. Such databases will prove invaluable in determining risk and exposure into the future.

Mood and violence

The Australian Institute of Suicide Research and Prevention has found suicide rates are higher during the hottest times of the year—changes in temperature appear to be a major contributing factor for people who are vulnerable to suicide. It is reasonably well established that violent crime also increases with increasing temperature. Researchers at James Cook University's Psychology Department have linked the unusually hot 2002–03 summer in North Queensland with mood problems among people in the region.

Heat stress

Evaluation of the impact of high temperatures and heat stress is important in areas such as air-conditioning design, industrial relations and sports medicine. Heat is an issue of fundamental concern to those who play sport because it is potentially fatal. Sporting organisations such as Soccer Australia have guidelines for event planning and cancellation, based on thermal conditions (temperature and humidity).

Skin cancer

Skin cancer in humans is linked with sunlight exposure. It is the most common and the most costly cancer in Australia, where light coloured skin and high levels of solar radiation predominate. Australia is recognised as a leader in the field of skin cancer research; one in four adults is likely to contract some form of skin cancer during their life. Skin cancer is directly linked to exposure to the sun and climate change will have a significant negative impact. The World Health Organization has begun work in estimating the global burden of disease attributable to UV exposure—with particular attention to skin cancers, impacts on the eye, and effects due to alterations of immune activity and vitamin D synthesis.

Human health

Climate change can affect human health directly through, for example, heat stress or the consequence of natural disasters, and indirectly through, for example, disrupted agriculture. Several of the health impacts of climate change identified by the IPCC are relevant to Australia, including an increase in vector, food and water-borne infectious diseases; a decrease in winter deaths but an increase in heat-related deaths and illness.

In Australia more than 1100 people aged over 65 die from temperature-related causes each year. The projected rise in temperature for the next 50 years is predicted to result in a total of three to five thousand additional heat-related deaths a year (McMichael et al., 2002). Under climate change modelling, temperate cities show higher rates of deaths due to greater temperature extremes than tropical cities.

The built environment

Climate information is essential in most aspects of building siting and design. Energy efficiency, structural integrity, even protection of verandas and loading zones from wind-driven rain are among the climate sensitive aspects of building design.

Low-energy building design

Many architecture schools now place considerable emphasis on the use of climate data for design of climate-responsive buildings. This includes the design of low-energy (hence, climate-sensitive) buildings. It is of note that the construction and operation of homes, and industry and urban infrastructure is one of the most significant human activities contributing to global warming (Bureau of Meteorology, 2003b).

Solar energy

The continued use of fossil fuel energy is likely to affect the global climate. Australian organisations are among world leaders in research and development of renewable energy technology. Renewable energy, mainly hydro, now accounts for about 10.5 per cent of all power generated in Australia. The government's Mandatory Renewable Energy Target requires that 2 per cent of the forecast market in 1997 must come from renewable energy by 2010. The photovoltaic industry (solar electricity) is currently growing at around 30per cent a year worldwide. Australia is already a key player in photovoltaics as the largest manufacturer per capita and a research leader (Prasad & Snow, 2003).

Wind energy

Australia has one of the world's best wind resources, particularly along the southeastern coast. Approximately 40 proposals for installation of wind power systems are awaiting evaluation in South Australia. It is anticipated that South Australia will be the largest producer of wind power in the southeast Pacific area within 10 years. Analyses from the Bureau of Meteorology's regional prediction model and CSIRO's Air Pollution Model are being used to model the potential for wind power generation throughout eastern Australia's mountainous regions.

Industry viability

Climate variability has huge economic impacts, most clearly shown by the financial impact of drought on the Australian economy, but also evident in many industry sectors, such as retailing and tourism.

Dealing with drought is a difficult but essential part of farming in Australia. Climate statistics confirm the 2002 drought ranks as one of the worst. The drought has had a significant impact on economic growth in Australia through the direct and indirect linkages between agriculture and other industries. In March 2003, the drought was estimated to have reduced the rate of economic growth in Australia in 2002–03 by around 0.7 percentage points, or around A$5.4 billion (Bureau of Meteorology 2003b).

The insurance sector is particularly vulnerable to natural hazards such as droughts, storms and floods. The trend toward higher insured losses continues in view of the risk factors: higher population densities and higher concentrations of insured values, especially in endangered areas such as coastal zones. The effects of this trend are illustrated by the experience of Christmas Island and Cocos Island, where the sole insurer withdrew all forms of insurance from the islands due to climatic risk.

Marine ecosystems

Evidence of a global rise in sea level over the past 100 years of between 10 and 20cm comes from measurements around the world, corrected for land movements. The rise is primarily a result of increasing water temperatures and consequent expansion, with some contribution from melting land ice. Additional evidence of sea level rise in Australia has come to light following the discovery of 160-year-old records of observations taken at Port Arthur, Tasmania. The observations, compared with data from a modern tide gauge, indicate an average sea level rise of about 1mm a year, consistent with other Australian observations and the lower end of estimates from the IPCC (2001b).

Another consequence of rising water temperatures is coral bleaching. Coral reefs around the world are becoming stressed by a number of factors: bleaching due to warmer oceans, occasional reductions in salinity due to extreme river outflows, increased cloudiness of water, chemical pollutants, local fishing practices and damage from tropical cyclones. The frequency of occurrence of mass coral bleaching (when reef-building corals lose their symbiotic algae and associated pigments) has increased globally since the late 1970s. During 1997–98 coral bleaching was reported on many of the world's coral reefs and also affected coral reefs in parts of Australia's Great Barrier Reef and Northwest Shelf. Mass coral bleaching was again observed on the Great Barrier Reef in early 2002 (Bureau of Meteorology, 2003a).

Australian Institute of Marine Science (AIMS) researchers are investigating whether the Great Barrier Reef will survive global warming. A rise of 1°C, predicted to occur within 50 years, could cause mass bleaching of coral reefs when combined with seasonal fluctuations. AIMS researchers heated to various temperatures tanks containing different corals. They found some corals bleached or even died, while others coped under the same conditions. They conclude global warming will not destroy the Great Barrier Reef, but there may be a reduction in species of coral, leaving only those species with a special protein that protects them from prolonged temperature rises. However, CSIRO research has shown an increase of 2°C is likely to change the tropical near-shore marine life from coral to algal dominated communities (CSIRO, 2003).

Coastal communities and infrastructure

While there has been a decrease in tropical cyclone numbers affecting the Eastern Australian region between 1969 and 2004, there has been an increase in the number of intense tropical cyclones with pressures of less than 970hPa. Recent decades have also seen a reduction in the number of mid-latitude storms to the south of Australia, but the intensity of these storms has on average increased. Climate models suggest a future decrease in the number of storm centres over southern Australia but an increase in their intensity (CSIRO, 2002).

By 2050, sea levels may rise 0.1 to 0.4 metres and tropical cyclone intensity (not frequency) around Cairns in northern Queensland could increase by up to 20 per cent (CSIRO, 2002). This would increase the flood level associated with a 1-in-100 year flood in Cairns and cover an area about twice that historically affected by floods.

More than 80 per cent of Australia's population live within 50km of the coast. This population is growing rapidly and this growth adds to the exposure of the community to extreme events such as tropical cyclones, storm surges and river flooding. CSIRO (2002) reports that coastal communities and urban infrastructure will be affected by changes in sea level and extreme weather. Torrential rainfall over cities and surrounding catchments can produce severe runoff and flooding and more frequent high-intensity rain in some areas could also be expected to increase the risks of landslides and erosion, particularly in the urbanised catchments on Australia's east coast.

As sea level rises, sediment from sandy shorelines is eroded from the beach and the shoreline recedes. It is generally accepted that the coastline will retreat horizontally 50 to 100 times the vertical sea level rise. Hence global sea level rise of between 9 and 88 cm as projected to occur by 2100 under the IPCC range of emission scenarios would cause a coastal recession of sandy beaches by 5.5 to 88 metres. The Bureau of Meteorology now recommends allowance should be made for the estimated rise in sea level due to the enhanced greenhouse effect and a 10 to 20per cent increase in the maximum intensity of tropical cyclones.

Warmer temperatures favour pathogen survival and extreme rainfall events may increase nutrient levels. As Australian coastal waters are sometimes contaminated with untreated sewage, it is possible these combined effects may favour the production of harmful algal toxins, resulting in fish and shellfish food poisoning.

Severe storms and tropical cyclones have cost about A$9 billion each over the past 30 years, while the cost of bushfires has been about A$2 billion over the same period (CSIRO, 2002). The annual number of events shows an increasing trend in Australia as it has globally, but this is partly due to better reporting, increasing population and investment in vulnerable areas.

A study of flood damage along the Hawkesbury–Nepean corridor of New South Wales has shown that, by about 2070, average annual direct damage could increase significantly. At present, the 1-in-100 year flood would cause failure of about 70 dwellings and for 2070 this rises to 1200 dwellings. Other intangible losses would include illness and death, and indirect losses such as alternative accommodation in the residential sector or loss of trading profit in the commercial sector (CSIRO, 2002).

Conclusions

The evidence of climate change or at least a downward trend in long-term rainfall patterns and enhanced variability is considerable and there is little doubt that the climate of the eastern Australian seaboard is at present becoming drier and hotter. Given this evidence it is appropriate to consider how the hotter and drier conditions can be factored into the decision-making framework of the local, state and federal government.

Concern over the risk of reliability in water supply and availability

The research and data presented to date highlight the vulnerability of the Australia's economy and community wellbeing to water shortages. Extending this to include potential changes to future international investment in Australia is demonstrated in the recent water shortage in the Awonga Dam in Central Queensland. This dam supplies the large industrial hub of Gladstone (also the fastest growing industrial site in Australia). At this site the Queensland and federal governments have invested considerable resources in attracting offshore investors in the heavy industrial estate. The significant water shortages experienced in the Awonga Dam in 2002 placed at risk the future investment in Australia by large scale multi-nationals.

In addition, in 2002/03 the plight of a large number of rural and urban communities faced by extreme water shortages as the drought gripped the entire eastern seaboard of Australia highlights the need for sound water risk management to include supply and distribution needs to be considered along with water use efficiency, reuse and alternatives such as desalinisation.

The pressure for downstream use of water and the need for environmental flows as well as equity of access are leading to considerable concern by some sectors of the agricultural industry. Supply risk management and the development of water use efficiency strategies are seen as key imperatives for policy makers and industry groups.

Community health and wellbeing

There is now a near constant flow of reports and media articles throughout the world on the effects of higher temperatures, floods and droughts. In 2003, Britain recorded the highest temperatures on record (37°C); on the same day in mid-winter in Australia, Urandangie recorded 35°C. The effect of high temperatures is known to impact on the personal comfort of all people and has considerable impact on the mortality rate of the aged. As reported earlier in August 2003 France recorded over 15,000 deaths related to the European heat wave conditions. Huge rainfall events in California were reported in February 2005 and on the same day history was created with snow falling in Paris. Clear policies are needed on how community health and wellbeing are to be managed into the future under a scenario of climate change.

Shifts in tourism

Many of the people who live on the coastline of Queensland have some reliance or connection with the tourist industry. With current coral bleaching recorded by the Great Barrier Reef Marine Park Authority and a drier and hotter environment with the subsequent impact on the vegetation and aesthetics of the area, many tourists may not see the Queensland coast as a desirable tourist destination in the decades to come. The impact of this potential change in tourism on the economy and land values is significant concern for policy makers involved in the Queensland's development and growth.

Industry rationalisation and investment changes

The financial viability of Australia's cropping and grazing industries are declining due to lower commodity prices and the extended droughts. Grazing representatives feel that the government needs to enhance drought assistance measures, others feel that the government's policy should move toward self reliance in a deregulated environment. If the productivity of the landscape is reduced due to reduced rainfall and higher temperatures then the industry will need to consider what areas are suitable for continued cropping and what ones are not. If the productivity of the grazing lands declines then there is a need to reduce stocking rates to avoid land degradation. This has significant industry restructuring and industry viability implications.

Producers from the cropping industry realise that after ten years of failed crops there is a need to look for alternatives. Examples of the need for industry restructuring included the eight years in ten that the grazing sector in Paroo River was drought declared. A further example of industry-directed change is provided in the cropping industry in the central highlands of Queensland. This industry has shifted to pulse crops such as mung beans and chickpeas after years of failed summer and winter crops. The impact of the changes on land values as other areas in Australia receive increased rainfall.

Use and management of groundwater

Many rural communities and industries are dependent on groundwater reserves from local aquifers. Examples in Queensland where concern is evident include the Yarwun-Targinni fruit growers around Gladstone, the Lucerne growers in the Callide Valley and the dairy farmers in the lower Fitzroy region of Central Queensland. All these industry groups/ communities have experienced a significant and progressive decline in their under ground water reserves over the past 10 to 20 years. In the Callide valley irrigators have been working with the Department of Natural Resources to reassess water usage and reallocation. However locally the problem is seen as over allocation as opposed to over use of a diminishing reserve.

Throughout much of Australia there is a high dependence on groundwater reserves. As rainfall patterns change the recharge of these areas will be dependent on the intensity, frequency and duration of rainfall in the intake areas. Aquifers in the wet tropics of the Cairns area have failed. This is an important area requiring more detailed research, risk management and contingency planning by government at all levels.

Water quality and health

Over the past two decades there has been considerable interest in blooms of blue green algae in many of our major waterways. The cause identified is a combination of increased inflow of nutrients, higher temperatures and fewer flows flushing the river systems. Direct costs included stock losses and water treatment for human consumption. Loss of the recreational resource was also regarded as a significant issue. People from local government reported that many local government water supplies had to be treated extensively due to algae blooms. The Rockhampton City Council is given as an example.

Planning for infrastructure

There is considerable need to consider the adequacy of existing infrastructure to meet the future needs of communities, especially water storages. Examples of this are seen in the discussion on the limits of the existing Sydney water supply to meets the future demand. Much of our existing infrastructure was built around a dataset that was based on a higher rainfall period and may not adequately reflect the current and emerging risks margins.

It is clearly evident that the climate in Australia is changing. The climate on the eastern seaboard of Australia has become drier and hotter over the past 100 years, while the northwestern Australian coast and hinterland is becoming wetter. It is also clear that there is considerable regional variation and that the trend is accelerating and most evident in the past 50 years. While this paper draws no conclusion as to the permanency of these changes, from the data available there is no evidence that the trend is likely to change in the immediate future.

The research undertaken by the IPCC (2001a) and others suggest that the trend is likely to increase. The implications for risk management in water supply, changes in land use, health, energy and infrastructure, etc. are significant. Water affects every part of our life and our lifestyles. Policy makers and planners should now factor the data and trends presented here into their planning horizons. The planning needs to consider how to accommodate or ameliorate these changes and avoid the crisis management that invariably follows major climatic events. There is more than enough evidence to suggest that the time for action is now.

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