New South Wales Government

CSIRO

Climate Change in the Hawkesbury-Nepean Catchment

Prepared for the New South Wales Government by the CSIRO

- Border Rivers-Gwydir
- Central West
- **Hawkesbury-Nepean**
- Hunter-Central Rivers
- Lachlan
- Lower Murray-Darling
- Murray
- Murrumbidgee
- Namoi
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- Western

The following brochure has been prepared by the CSIRO to provide information regarding climate change and its consequences for landowners, landusers and the general public within the Hawkesbury-Nepean Catchment. The information presented is based upon recent technical reports produced for the New South Wales Government by the CSIRO as well as data from the Australian Bureau of Meteorology and other peer-reviewed scientific studies. This brief summary provides an entry-point for raising awareness about climate change and for locating additional information.

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Hawkesbury Nepean

1.0 The Problem of Climate Change

The Earth's plants and animals depend on the climate to which they are exposed – they benefit when conditions are favourable, and they suffer when conditions become extreme. Humans are no exception.

The crops and water resources that we use to sustain our communities are linked to the climate, and the economic as well as human losses that we experience from hail, cyclones, floods, droughts and bushfires are a reminder of our ever-present vulnerability to the climate system.

It is increasingly clear that our climate is changing. Whereas in the past humans have learned to cope with climate variability and change that was natural in origin, we are now living in a climate of our own making. The rate at which our climate is being transformed is unprecedented throughout much of human history.

Evidence of a Changing Global Climate

- Temperatures in the northern hemisphere at the end of the 20th century are believed to have been warmer than they have been at any time in the previous 1,000 to 2,000 years.
- The average global temperature in 2005 was the warmest on record, and eight of the ten warmest years have occurred since 1997.
- The Earth's average surface temperature has risen 0.7°C since 1900.
- Heatwaves and extreme rainfall have become more common in many regions.
- The sea level has risen 1.8 mm per year since 1950 and that rate is accelerating.
- There have been fewer frosts and the ice sheets of Antarctica and Greenland are shrinking.
- The timing of physiological processes in plants and animals is changing throughout the world, and populations are shifting their distributions.

Evidence of Australian Climate Change

- Average temperatures in Australia rose 0.9°C from 1910 to 2004. There have been more heatwaves and fewer frosts.
- Since 1950, annual rainfall has declined on the eastern seaboard and the south of the continent, but increased in the northwest.
- Since 1973, droughts have become more intense, and extreme rainfall events have increased in the northeast and southwest.

According to the United Nations' Intergovernmental Panel on Climate Change "most of the warming observed over the last 50 years is attributable to human activities." These activities –mainly the burning of fossil fuels such as coal, oil, and natural gas – have released vast quantities of greenhouse gases into the atmosphere.

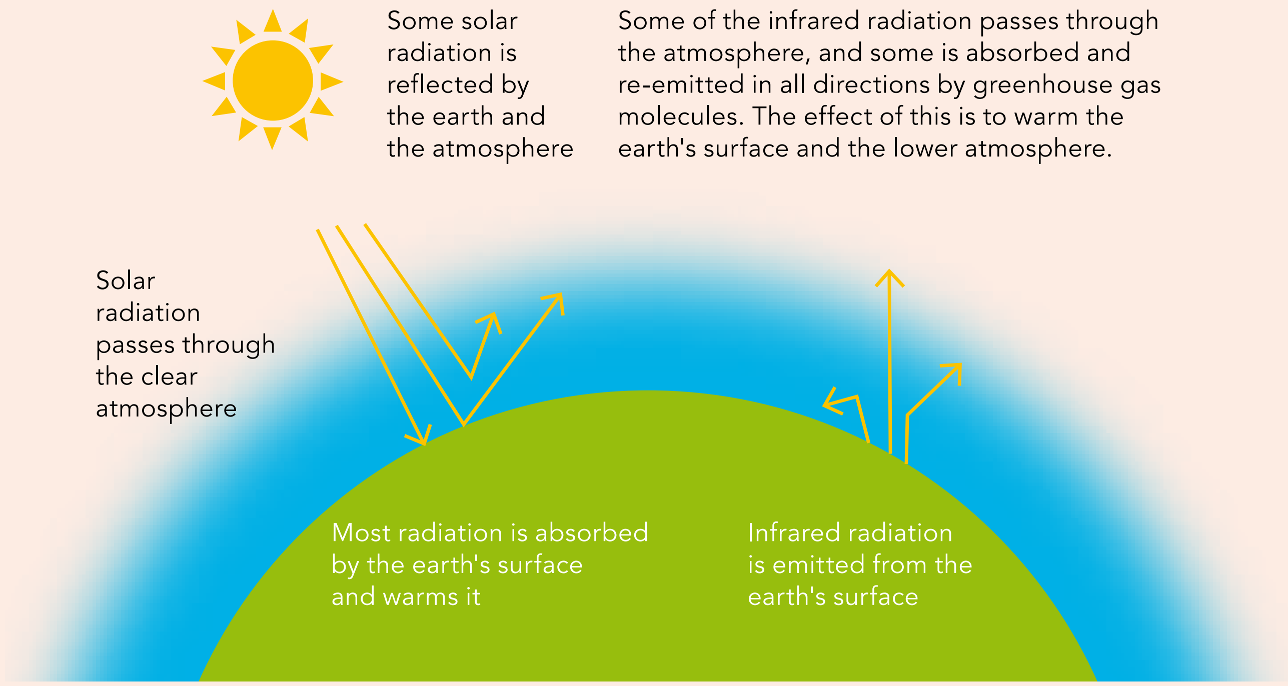
Most greenhouse gases have a long lifetime in the atmosphere.This means that even with reductions in greenhouse gas emissions, there would be a delay of several decades before those reductions have a significant effect on greenhouse gas levels in the atmosphere. Recent studies indicate that no matter how quickly we act, we are already committed to additional global warming during the 21st century of around 0.5°C and the subsequent impacts that are likely to follow.

1.1 What is Causing Climate Change?

Much of the energy that drives the Earth's natural processes comes directly from the Sun. Around half of the Sun's energy that reaches the Earth breaks through the atmosphere, warming the surface of the planet. The land and oceans then radiate that heat, some of which is trapped by greenhouse gases in the atmosphere. The principal greenhouse gases are water vapour, carbon dioxide, methane and nitrous oxide.

This trapping of heat energy is known as the 'greenhouse effect' – keeping temperatures higher than they otherwise would be, just like a glass greenhouse keeps plants warm (Figure 1). Without this process, the global average surface temperature would be closer to minus 18°C, instead of the current 15°C.

Figure 1. The Greenhouse Effect



The problem we now face is that human actions—particularly burning of fossil fuels, agriculture and land clearing—are increasing concentrations of greenhouse gases in the atmosphere. Since 1750, the amount of carbon dioxide in the atmosphere has risen 35%, and the current concentration is higher than any time in at least the past 650,000 years. The level of nitrous oxide has also risen 17% and methane 151%

This has enhanced the greenhouse effect by trapping more heat, leading to global warming.

Scientists assert that there will be continued warming and increases in sea level with significant impacts on natural and human systems. Globally, these impacts include coastal flooding; more heatwaves, storms and droughts; less frost, snow and polar ice; more people at risk of food and water shortage; reduced habitat for many plant and animal species and more people exposed to infectious diseases such as malaria.

In response to this challenge, we need to do two things: start planning adaptation strategies to minimise those consequences, and reduce greenhouse gas emissions to slow the rate of global climate change.

2.0 Climate Change in New South Wales

In 2004, CSIRO and the Bureau of Meteorology released a report on behalf of the NSW Government which looked at past and likely future changes to NSW's climate.

The report found that between 1950–2003, NSW became 0.9°C warmer, with more hot days/nights and fewer cold days/nights. Annual total rainfall declined by an average of 14 mm per decade, with the largest declines in rainfall near the coast due to an increase in El Niño years since the mid-1970s. Extreme daily rainfall intensity and frequency have also decreased throughout much of the state.

The report predicted that by the year 2030:

- NSW is likely to become warmer than it was in around 1990.
- There will be more hot days over 35°C and fewer frost days below 0°C.
- Annual rainfall is likely to decline.
- Rainfall runoff and stream flows will be reduced.
- Droughts are likely to become more severe.
- The risk of bushfires is likely to increase.
- Extreme rainfall may become more intense in central and southeast NSW.

More detailed findings of the report are listed in Table 1 (below).

Table 1. Annual and Seasonal Climate Projections for New South Wales

Season	2030	2070
Annual	• Warmer by +0.2 – +2.1°C • Rainfall change of -13 – +7%	• Warmer by +0.7 – +6.4°C • Rainfall change of -40 – +20%
Summer	• Warmer by +0.2 – +2.3°C • Rainfall change of -13 – +13%	• Warmer by +0.7 – +7.1°C • Rainfall change of -40 – +40%
Autumn	• Warmer by +0.2 – +1.9°C • Rainfall change of -13 – +13%	• Warmer by +0.7 – +5.6°C • Rainfall change of -40 – +40%
Winter	• Warmer by +0.2 – +2.3°C • Rainfall change of -13 – +7%	• Warmer by +0.7 – +5.6°C • Rainfall change of -40 – +20%
Spring	• Warmer by +0.2 – +2.1°C • Rainfall change of -20 – +7%	• Warmer by +0.7 – +7.1°C • Rainfall change of -60 – +20%

3.0 The Hawkesbury-Nepean Catchment

The Hawkesbury-Nepean Catchment covers over 22,000 square kilometres. It is one of the most important and varied catchments in Australia, providing a substantial proportion of the drinking water supplied to the 4 million people living in Sydney, the Illawarra and the Blue Mountains. Almost 1 million people live in the catchment, of which 90% live in the suburbs to the west, northwest and southwest of Sydney. Over the next 30 years this population is expected to grow by more than 400,000.

The economy of the catchment is driven by an extensive range of agricultural, extractive, manufacturing and processing industries.

The catchment's natural landscapes are incredibly varied, from rainforests to open woodlands, heathlands to wetlands, and highland freshwater streams to the magnificent Hawkesbury River estuary. The catchment includes most of the Greater Blue Mountains World Heritage Area of over one million hectares of national park and reserves protecting diverse Eucalypt forests and exceptional native plants and animals. These contribute to the catchment's many unique and spectacular recreation and tourism opportunities. The catchment has many major rivers, including the Hawkesbury, Nepean, Wollondilly, Mulwaree, Tarlo, Wingecarribee, Nattai, Nepean, Coxs, Kowmung, Grose, Capertee, Colo and Macdonald.

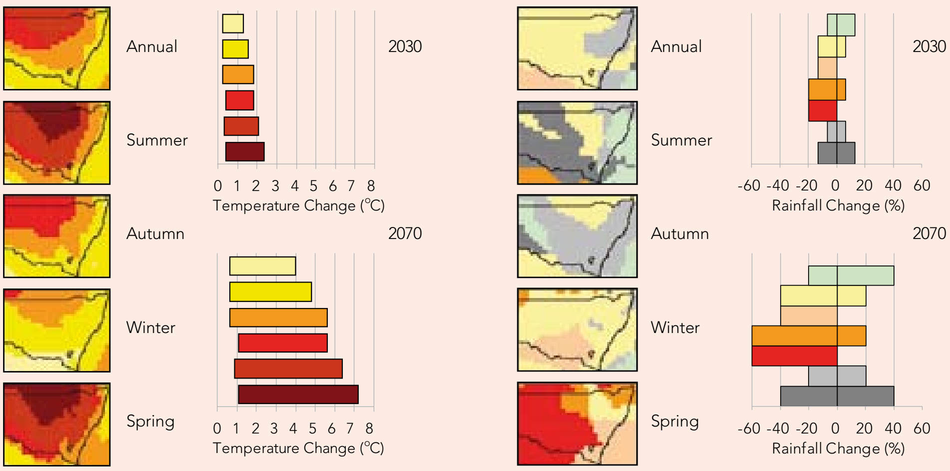
3.1 The Climate of the Hawkesbury-Nepean Catchment

Summers in the Hawkesbury-Nepean region are mild to hot, with average maximum January temperatures approaching 30°C at Richmond (Table 2), although further south at Moss Vale, maximum summer temperatures average only 26°C. Meanwhile, summer highs at Katoomba average only 23°C. Based upon data from neighbouring Sydney, the catchment experiences approximately 3 days above 35°C each year, although more hot days are expected at Richmond and fewer at Katoomba. Winters are cool to mild, with average maximum July temperatures of 17°C at Richmond and 9°C at Katoomba. Temperatures rarely fall below 0°C at sea-level, but frosts are common at higher altitudes. The catchment receives approximately 800–1,400 mm of rainfall each year. Peak precipitation occurs between November and March, and the variability in rainfall from one year to the next is high.

A warming of 1.0°C and no change in rainfall (a moderate scenario for 2030) would make the climate of Richmond similar to the current climate of Cessnock in the Hunter Valley.

Figure 2. Climate Projections for New South Wales

(The coloured bars show the range of projected changes corresponding with the colours in the maps)



Since 1950, the region has experienced warming of around 0.8°C. This is likely to be partly due to human activities. The catchment has also experienced a significant drop in annual rainfall at a rate of approximately 20–50 mm per decade, depending on location. The contribution of human activities to the rainfall decline is hard to distinguish from natural variability.

The future climate of the Hawkesbury-Nepean Catchment is likely to be warmer (Figure 2). Although projected changes in average rainfall are currently not clear, given projected increases in evaporation, the catchment is likely to be drier. Such climate changes would also increase heat waves, extreme winds and fire risk. Nevertheless, despite this trend toward drier conditions, there is also potential for seasonal increases in extreme rainfall events. Further details about these changes are described in the following table (Table 2), which compares average conditions for the present climate with ranges of potential change in 2030 and 2070. These projections account for a broad range of assumptions about future global greenhouse gas emissions, as well as differences in how various climate models represent the climate system.

Table 2. Current and Projected Climate Change in the Hawkesbury-Nepean Catchment			
	Present (1990)[1]	Projected Change	
		2030	2070
Temperature			
Average	Katoomba: 9 – 23°C[2] Moss Vale: 12 – 26°C[2] Richmond: 17 – 29°C[2]	+0.2 – +1.6°C	+0.7 – +4.8°C
No. Days below 0°C	Sydney: 0	Sydney: 0	Sydney: 0
No. Days above 35°C	Sydney: 3	Sydney: 4 – 6	Sydney: 4 – 18
No. Days above 40°C	Sydney: 0	Sydney: 0 – 1	Sydney: 0 – 4
Rainfall			
Annual Average	Katoomba: 1,399 mm Moss Vale: 973 mm Richmond: 801 mm	-7 – +7%	-20 – +20%
Extreme Rainfall[3]		-3 – +12%	-7 – +10%
Evaporation		+1 – +8%	+2 – +24%
No. Droughts per decade[4]	3	2–5	1–9
Extreme Winds		-5 – +8%	-16 – +24%
No. Fire Days[5]	Richmond: 12	Richmond: 12 – 14	Richmond: 10 – 19

1 Present day conditions for temperature and rainfall represent long-term averages from the Bureau of Meteorology. For extreme temperatures, the present average is based on 1964-2003. For fire danger, the present average is based on 1974-2003. For drought, the present average is for a period centred on 1990.
2 Range represents average July and January maximum temperature.
3 Defined as 1 in 40 year 1-day rainfall total. Values represent the range in seasonal projections from a limited set of climate models.
4 The values for drought represent average monthly drought frequencies, based upon the Bureau of Meteorology's criteria for serious rainfall deficiency (see also Burke et al., 2006).
5 Number of days annually with a "very high" or "extreme" fire danger index. Changes are for 2020 and 2050, respectively, as in Hennessy et al. (2005).

3.2 Impacts of Climate Change in the Hawkesbury-Nepean Catchment

Although changes in average temperature, rainfall and evaporation will have long-term consequences for the catchment, the impacts of climate change are more likely to be felt through extreme weather events. Projections suggest there will be more hot days, bushfires, droughts and intense storms. These can all place human life, property and natural ecosystems at increased risk. Additional details regarding climate change impacts on various activities and assets in the catchment are discussed below.

Water

Changes in rainfall and higher evaporation rates are likely to lead to less water for streams and rivers in the Hawkesbury-Nepean Catchment, which will have downstream consequences for storages and place strains on the catchment's water resources. For example, due to recent trends toward reduced rainfall, as of August 2006, catchment storages such as the Avon, Cataract, Cordeau, and Warragamba were at only 30–45% of capacity. However, other storages such as Wingecarribee and Nepean were 75–80% full. [1]

1 Data obtained from the Water Observation Network: http://wron.net.au/DemosII/DamData/DamMap.aspx

Various studies of stream flows in NSW indicate that climate change is likely to reduce flows in the future (Hassall and Associates, 1998; Jones and Page, 2001; Beare and Heaney, 2002; Bates et al., 2003; Warner, 2003). This has implications not only for water users within the catchment, but also for neighbouring Sydney, which derives the majority of its drinking water from the Hawkesbury-Nepean Catchment. Under the National Water Initiative, the Commonwealth, State and Territory Governments have agreed that water users should bear the risk of such reductions in water availability. In addition, changes in flows of the Hawkesbury River may affect navigation along the waterway.

Lower flows and higher temperatures may also reduce water quality within the catchment. For example, low flows, higher temperatures and elevated nutrients create a more favourable environment for potentially harmful algal blooms. Greater fire activity could contaminate water catchments with sediment and ash. Salinity problems in the catchment may be exacerbated by changes in rainfall, temperature and stream flows (Beare and Heaney, 2002). In addition to effects on surface water, the quality of coastal groundwater aquifers may be adversely affected by rising sea levels and salt-water infiltration. Decreases in runoff due to climate change may reduce the extent and function of freshwater wetlands, such as Wingecarribee Swamp, the Thirlmere Lakes and Longneck Lagoon, as well as the Hawkesbury Estuary, that provide habitat for birds and other wildlife.

Farms

The farmers of NSW have developed useful adaptation skills that stand them in good stead for climate change, but they will need to plan for new climatic challenges and opportunities.

Climate change will have both positive and negative impacts on the types of crops that can be grown and on agricultural productivity. For example, higher levels of carbon dioxide in the atmosphere are likely to increase plant growth, but the protein content of those plants is expected to be lower. Low to moderate warming will also help plant growth and extend growing seasons, but a rise in the number of very hot days or droughts could damage crops. Dry land grazing (sheep and beef cattle) and broad acre cropping are also likely to benefit from higher carbon dioxide levels, but this may be offset by the effect of higher temperatures (Hassall and Associates, 1998). For example, warmer temperatures will increase heat stress on livestock (Howden et al., 1999a; Jones and Hennessy, 2000), which may affect growth and productivity and, subsequently, livestock management.

Irrigated agriculture is also significant in the region, including dairy and horticulture. These industries are likely to be affected by reductions in water availability meaning that water efficiency will be increasingly important. Warmer temperatures will increase heat stress on dairy cattle, reducing milk production unless management measures such as shade sheds and sprinklers are adopted (Jones and Hennessy, 2000).

Higher temperatures will lead to inadequate winter chilling for some fruit trees, which may reduce fruit yield and quality (Hennessy and Clayton-Greene, 1995). It may become necessary to consider low chill varieties and alternative management options. However, higher temperatures are likely to reduce the risk of damaging winter frosts. In viticulture, higher temperatures are likely to reduce grape quality, but there may be opportunities to shift production to varieties better adapted to warmer conditions (Webb, 2006).

The key consequence of climate change on farming will clearly be rainfall. Any reduction in rainfall will place most farms under stress, particularly when linked to higher temperatures. For dryland cropping, reductions in rainfall and increases in evaporation directly contribute to reductions in soil moisture. Meanwhile, irrigated agriculture is likely to be affected by tighter constraints on water allocations possibly resulting in a more developed and competitive water market. In this sense, the unusually hot droughts of 2002/03 and 2005/06 may be a sign of things to come. Furthermore, heavy rains and winds from storm events also contribute to crop damage and soil erosion. Indirect impacts due to changes in weeds, pests and international markets may also place farms under stress.

Biodiversity

Changes to the climate will have significant effects on the catchment's plants and animals. Currently, 245 species, ten populations and 32 ecological communities (i.e., collections of species or habitat) in the catchment are classified as threatened or endangered (DEC, 2006). Although current threats to the catchment's biodiversity are largely a product of historical land clearing, climate change is likely to increase the need for conservation efforts.

The geographic distribution of a species is often defined by its 'climate envelope,' reflecting species-specific tolerances to extremes of temperature and moisture. Climate change is likely to drive changes in the distribution of some plant and animal species, driving some species out of the catchment or enabling invaders to move in. Meanwhile, even those species capable of coping with climate change alone may succumb to the cumulative effects of multiple stressors. Despite such impacts, little is actually known regarding how climate change may affect some of the catchment's endangered iconic species such as the Swift Parrot, Gang-gang Cockatoo and the Southern Brown Bandicoot or ecosystems such as the Blue Gum High Forest, or the Castlereagh Swamp Woodlands.

Other risks to biodiversity in the Hawkesbury-Nepean catchment include:

- Reductions in flows of streams within the catchment are likely to have a negative impact on aquatic biodiversity and wetland ecosystems.
- Plants and animals may become 'stranded' in isolated remnants of vegetation due to changing climate and continued development within the catchment.
- More frequent droughts and fires are likely to increase stress on plants and animals.
- Sea-level rise is likely to inundate coastal wetlands and alter the discharge of freshwater into estuaries, with potential adverse effects on coastal wetland habitat (Williams and Thiebaud, 2006).

Forests

The forests, woodlands and natural vegetation of the Hawkesbury-Nepean Catchment are a significant asset that is managed for biodiversity conservation, maintenance of water quality, recreation and other purposes.

Preliminary research suggests that temperate forests in Australia may increase in productivity with higher temperatures and increased concentrations of atmospheric carbon dioxide. However, these benefits may be offset by decreased rainfall, increased bushfires and changes in pests. Also the benefit of higher carbon dioxide concentrations may be limited in the longer term by the availability of nutrients (Howden et al., 1999c).

Climate change is likely to lead to changes in the distributions of tree species, possible increased invasion by pests, and changes to the habitat that these areas provide for local plants and animals. This will raise new challenges in managing forest areas for biodiversity conservation.

Climate change may also create challenges and opportunities for the forest plantation industry. Given appropriate selection of tree species and the availability of suitable land, it may be possible to expand plantation forestry within the catchment. However, increased risk of drought and wildfire may affect the feasibility of establishing successful plantations in some areas.

Communities

Warmer winters are likely to reduce cold-related illnesses, but warmer summers are likely to increase the risk of heat-related health problems, especially in the elderly (McMichael, 2003). Warmer temperatures may also contribute to the spread of infectious diseases, although the spread of tropical diseases such as dengue fever into the Hawkesbury-Nepean Catchment remains unlikely.

The built environment is also vulnerable to climate change. As well as impacting on homes, it will affect infrastructure, commercial buildings and other physical assets. Changes in average climate will affect building design and performance, including structural standards and cooling and heating demand (PIA, 2004). Higher summer temperatures, for example, may induce a rethinking of building design and standards to ensure thermal comfort at minimal cost, while potential increases in extreme winds may necessitate more robust construction. In addition, a study by Austroads (2004) concluded that climate change would contribute to increases in road maintenance costs in NSW of up to 25% by 2100, largely due to assumptions about the effects of climate change and population growth on traffic volumes.

Increases in the intensity of the heaviest rainfall events will increase flash flooding, placing strains on water infrastructure such as sewerage and drainage systems, particularly in urban areas. For example, a study by Minnery and Smith (1996) found that climate change may double flood-related damage in urban areas of NSW, although more recent modelling suggests that extreme rainfall events along the NSW coastline may decline, but increase further inland (Hennessy et al., 2004b). Regardless of changes in such extremes, higher temperatures and lower average rainfall are likely to lead to increased pressure on urban water and energy supplies, unless moderated by demand management measures.

Modelling of weather patterns along the NSW coast indicates the potential for increases in the frequency of weather events that contribute to extreme winds and, subsequently, storm surges (Hennessy et al., 2004b). Such an increase in storm surges, in conjunction with future sea-level rise, will increase the risk of coastal inundation, erosion, and damage to infrastructure and property. Modelling of coastal responses to sea-level rise on various locations along the NSW coast indicates the potential for tens of metres of beach erosion over the next century, and the potential for erosion in excess of 100 metres during severe storm events (Hennecke, 2004; Cowell et al., 2006). However, the actual magnitude of beach erosion will vary significantly from one location to another. Given its geographic location, possible impacts from estuarine inundation are likely to be more significant than beach erosion for the Hawkesbury-Nepean Catchment.

The risk of property loss due to bushfire is also likely to increase. For example, Richmond currently experiences approximately 12 days per year with a fire danger index of "very high" or "extreme." This is expected to increase by up to 2 days by 2020 and up to 7 days by 2050 (Hennessy et al., 2005; see Table 2). As a consequence of these and other changes in extremes such as winds and floods, insurance risk assessments and premiums are likely to be affected.

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4.0 Adapting to Climate Change

Adaptation is a risk management strategy involving actions to reduce the negative impacts of climate change and take advantage of new opportunities that may arise. The types of adaptation measures adopted will vary from region-to-region. Because some of the decisions we make today will have lasting implications for future climate vulnerability, we must start planning our adaptive responses now. By doing so, we may help to lessen some of the environmental, economic and social costs of climate change.

Some examples of potential adaptation measures relevant to the Hawkesbury-Nepean Catchment include:

- Linking national parks and remnant vegetation to support migration of species.
- Developing best practice for environmental management.
- Improving water-use efficiency.
- Changing to crops that are more tolerant of heat and drought.
- Changing planting times and practices for crops.
- Providing more shade and cooling for livestock.
- Reviewing flood and fire management arrangements.

Making sure the resources are available for such adaptation measures means continually expanding research, education and communication.

4.1 Adaptation in Action

Throughout much of Australia, users of the land have developed considerable experience in managing the high degree of variability that is characteristic of Australia's climate. However, many individuals and enterprises are recognising that they are contending not just with climate variability, but also climate change – and the past is no longer a reliable indicator of future conditions. In response, a broad range of adaptation actions are being implemented across Australia.

In 1999, the ***Masters of the Climate*** project collected information from more than 80 landholders on how they were using climate tools to better manage their land resources and farm businesses – 23 were selected as case studies. In 2004, those 23 landowners were visited again to see how they fared during the 2002/03 drought and to identify trends in the use of climate tools over the intervening five years.

Some of the observed trends among included:

- Solid understanding of local climate history as a basis for greater understanding of climate variability and change.
- Growing use of weather and climate websites for both long and short-term forecasts.
- The application of sophisticated tools (such as software for tracking sub-soil moisture and wheat yields) for making full use of all available moisture.
- Shifts in the nature of crops and stock run on the properties, with a movement away from riskier varieties and activities.
- Opportunistic decision-making – being ready to act on short notice to take advantage of weather conditions.
- In a few cases, deciding to leave the enterprise altogether.

All of the ***Masters of the Climate*** case studies from 1999 and 2004 are available over the internet at http://www.managingclimate.gov.au/information_resources.asp.

5.0
What is the New South Wales Government Doing?

The NSW Government is taking a leadership role in responding to climate change. In late 2005 the NSW Greenhouse Plan was released, which outlines the NSW Government's response to climate change.

The NSW Greenhouse Plan outlines polices and actions in three main areas:

- Awareness Raising
- Adapting to Climate Change
- Reducing Greenhouse Gas Emissions.

Copies of the Plan can be downloaded from www.greenhouseinfo nsw.gov.au.

6.0
What's happening in the Hawkesbury-Nepean Catchment

The following climate change adaptation activities are currently underway in the Hawkesbury-Nepean Catchment:

• The NSW Government's Climate Change Impacts and Adaptation Research Program is supporting a bushfire risk study focusing on the Hawkesbury-Nepean Catchment. The project aims to measure the impacts of climate change on bushfire risk in the Sydney Basin, and how this will affect biodiversity and risks to human safety and infrastructure in urban areas.

• A NSW and Australian Government sponsored research project conducted in collaboration between, The Cabinet Office (NSW), the NSW Greenhouse Office, CSIRO, Sydney Water Corporation, Sydney Catchment Authority, the Commonwealth Government (through the Australian Greenhouse Office) and the University of New South Wales is examining the impacts of climate change on water supply and demand in the across the greater Sydney area including the Hawkesbury-Nepean catchment.

• The University of Newcastle is undertaking research for the Sydney Catchment Authority on long term rainfall patterns in the Sydney region over the last 1,000 years. This work will inform the nature of past flood and drought sequences experienced in the Hawkesbury-Nepean catchment and in turn increase knowledge regarding the adaptive capacity of the natural environment. Results are expected to be available in 2009.

• The University of New South Wales, in collaboration with the Sydney Catchment Authority is undertaking a study to downscale the global and regional climate models to the scale of Sydney's water supply catchment. The modelled catchment scale rainfall projections will subsequently be translated into runoff projections and will provide an indication of future changes in catchment yields under different greenhouse gas emission levels.

• The Hawkesbury-Nepean Catchment Management Authority (CMA) is a partner in a further study that examines extreme rainfall events across the Sydney region including the Hawkesbury-Nepean Catchment. The study will provide information on rainfall intensity-frequency-duration and depth-area curves for storms with a duration of less than six hours for present day and projected future conditions in 2030 and 2070. The information derived from the study is important in flood design applications.

• The CMA is also is working with the NSW Department of Environment and Conservation to identify biodiversity corridors to link national parks in order to provide a pathway for species migration. These corridors are a priority for funding under the CMA's incentive programs.

• The Biodiversity Conservation Project works with landholders to conserve native vegetation and improve its ongoing sustainability and promote revegetation of cleared areas.

• The CMA, in conjunction with the NSW Department of Primary Industry, is engaging in pasture management activities to increase soil carbon thereby increasing carbon storage in the land and enhancing pasture quality.

Want to know more about Climate Change?

In addition, a number of climate change studies relevant to the Hawkesbury-Nepean Catchment are listed below.

Austroads. 2004. Impact of Climate Change on Road Infrastructure. Austroads Incorporated, Sydney, Australia, 124 pp.

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Beare, S., and A. Heaney 2002. Climate Change and Water Resources in the Murray Darling Basin, Australia: Impacts and Adaptation. ABARE Conference Paper 02.11, 33 pp.

Burke, E.J., Brown, S.J., and Christidis, N. 2006. Modelling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. Journal of Hydrometeorology 7, 1113-1125.

Charles, S.P., B.C. Bates, and N.R. Viney 2002. Linking atmospheric circulation to daily rainfall patterns across the Murrumbidgee River Basin. Proc. 5th International River Symposium, 3-6 September 2002, Brisbane, Qld, Australia.

Cowell, P.J. Thom, B.G., Jones, R.A., Everts, C.H., and Simanovic, D. 2006. Management of uncertainty in predicting climate-change impacts on beaches. Journal of Coastal Research 22, 232-245.

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Hassall and Associates. 1998. Climatic Change Scenarios and Managing the Scarce Water Resources of the Macquarie River. Australian Greenhouse Office. Hassall and Associates, New South Wales Department of Land and Water Conservation, New South Wales National Parks and Wildlife Service, and CSIRO Atmospheric Research, Canberra, Australia, 113 pp.

Hennecke, W.G. 2004. GIS modelling of sea-level rise induced shoreline changes inside coastal re-entrants - Two examples from southeastern Australia. Natural Hazards 31, 253-276.

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For the latest information on climate change, its consequences, and tools for managing risk, visit the following web pages.

The NSW Greenhouse Office website:
www.greenhouse.nsw.gov.au
This site contains more information on what the NSW Government is doing to combat climate change, including downloadable copies of the NSW Greenhouse Plan.

The Hawkesbury-Nepean Catchment Management Authority:
www.hn.cma.nsw.gov.au

This site provides the latest news on catchment management projects and programs, relevant policies, and access to brochures and publications related to management of the catchment.

The Australian Greenhouse Office's National Climate Change Adaptation Program:
www.greenhouse.gov.au/impacts/index.html#programme

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