



Climate change impacts in Gippsland

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1 Introduction

This report provides a summary of available knowledge on the potential impacts of climate change in Gippsland. It forms a component of the project “Climate change impacts and adaptations in Gippsland”, which has been undertaken by the Pathfinder Network and CSIRO’s Climate Impacts and Risk group for the West Gippsland Catchment Management Authority. The project is one of three regional pilot studies on climate change impacts and adaptation funded by the Victorian Department of Sustainability and Environment (DSE).

Enhancing the ability of communities to adapt to climate change is a key concern for natural resource management in Victoria. The *Victorian Greenhouse Strategy Action Plan Update* (DSE, 2005) notes that

- Victoria’s climate is already changing;
- Even with action to reduce greenhouse gas emissions, our climate will continue to change;
- The Victorian government continues to support research to improve understanding of the potential impacts of climate change;
- It is also important to develop adaptation strategies that lessen the impacts of climate change on the environment, society and the economy;
- The government will support efforts to reduce vulnerability of water supply, coasts, infrastructure, fire risk, biodiversity, primary industry and health;
- Adaptive capacity will be fostered in communities (e.g. Gippsland) and in government.

The recent DSE consultation paper *Adapting to climate change: Enhancing Victoria’s capacity* notes that strategic action is needed in order to

- Set priorities for integrated research on climate change impacts and adaptation options, based on risk management principles;
- Increase community awareness and understanding of potential climate change impacts and the need to adapt;
- Facilitate planning for adapting to potential climate change impacts and ensuring knowledge is available for investment and strategic decision-making; and
- Identify strategies for minimising the impacts of climate change, while taking advantage of any opportunities it may create.¹

In public responses to the Government’s discussion paper, availability and accessibility of information was identified as a critical issue to the community and their ability to adapt.² CSIRO and DSE have produced a number of information products summarising climate change impacts in the various Victorian catchments, including East and West Gippsland.³ This report expands on these profiles by reviewing research of relevance to climate change impacts in the Gippsland region, and serves as a first step towards effective adaptation.

2 Climate change

2.1 Temperature

Gippsland’s climate has already undergone measurable change over the course of the 20th Century. Victorian maximum temperature has increased by 1.06 °C per century, the minimum by 0.67 °C per century and the

¹ http://www.greenhouse.vic.gov.au/impacts/Consultation_Paper_14_07.pdf

² http://www.greenhouse.vic.gov.au/files/Summary_of_Submissions_Feb_2005.pdf

³ http://www.greenhouse.vic.gov.au/impacts/media/East_Gippsland.pdf
http://www.greenhouse.vic.gov.au/impacts/media/West_Gippsland.pdf

average by 0.86 °C per century (Whetton *et al.* 2002). Average maximum temperatures are increasing faster than the national average and minimum temperatures are increasing at a slower rate.

CSIRO's latest climate change projections for Victoria are based on the results of 12 climate models including the CSIRO Mark 3 model and the high resolution CC50 (Whetton *et al.* 2002; Suppiah *et al.* 2004). Global warming is likely to mean that average temperatures in the North and East of Victoria (including East Gippsland) will be between 0.3 and 1.6°C higher by 2030 and 0.8 to 5.0°C higher by 2070 (relative to 1990). Inland areas are likely to warm more than coastal regions, and warming is likely to be greatest in summer and least in winter. In the South (most of West Gippsland), these warming ranges are between 0.2 and 1.4°C in 2030 and 0.7 to 4.3°C by 2070. Future changes in daily variability appear to be small, and increases in daily maximum and minimum temperatures will be similar to changes in average temperatures.

2.2 Precipitation

Annual average rainfall is likely to decrease in Gippsland. In autumn the direction of change is uncertain in East Gippsland, but tends toward decrease in the West. Summer, winter and spring rainfall has a tendency to decrease. Potential decreases in rainfall are strongest in spring, however there is less of a reduction in East Gippsland. In general, rainfall-bringing processes are not as well simulated by the models in spring and summer as they are in autumn or winter, so there is more confidence in the ranges for autumn and winter. The projected ranges of change are shown in Table 1.

Precipitation is highly dependent on prevailing inter-annual and decadal climate regimes. The El Niño/Southern Oscillation (ENSO) is linked to dry conditions over much of Australia and the link between rainfall, streamflow and ENSO is statistically significant (Chiew *et al.* 1998). Step changes in climate from flood-dominated to drought-dominated regimes are evident in the historical record, with periods of relatively low rainfall in 1890-1940 and the 1990s (Vives and Jones 2003). The period since 1994 has been dry in West Gippsland, and this could be attributed to such natural variability.

| Rainfall change | 2030 | 2070 |
|-----------------|---|--|
| Annual | -9 to +3% | -25 to +9% |
| Summer | -10 to +5% | -40 to +20% |
| Autumn | -10 to +10% (East) -10 to +5% (West) | -25 to +25% (East) -20 to +10% (West) |
| Winter | -10 to +5% | -25 to +10% |
| Spring | -20 to -2% | -60 to -5% |

Table 1 Ranges of projected rainfall change for Gippsland in 2030 and 2070, relative to 1990 (Suppiah *et al.* 2004)

2.3 Potential evaporation, water balance and relative humidity

CSIRO's Victorian climate change scenarios indicate increases in potential evaporation of 2-8% per degree of global warming (Whetton *et al.* 2002). This tendency for increase is stronger in winter and spring than in summer and autumn, with stronger increases in southern Victoria. Increased evaporation and changes in rainfall are likely to lead to decreases in available moisture. The annual average atmospheric moisture balance is the difference between rainfall and potential evaporation. Decreases in moisture balance range

from 40 to 160 mm per degree of global warming, with the largest decreases during spring. The decrease is 20 to 200 mm by 2030, and 45 to 600 mm by 2070.

There is a general tendency for decreased humidity over most of Australia under global warming simulations. Decreases of up to 3% by 2030 and 9% by 2070 occur in summer and autumn, with larger and more widespread decreases occurring in winter and spring (Hennessy *et al.* 2005b).

2.4 Solar radiation

Changes in solar radiation (sunlight) can have implications for plant productivity and agriculture. In water limited environments, a decrease in solar radiation, especially when combined with an increase in diffuse radiation, can act to increase productivity (Stanhill and Cohen 2001). Over the latter half of the 20th century there has been an observed 'global dimming', thought to be due to increases in aerosols and changing optical properties of the atmosphere and clouds (Stanhill and Cohen 2001). However this trend appears to have reversed since the 1990s, allowing greenhouse signals to become more evident (Wild *et al.* 2005).

In an analysis of 17 recent climate model simulations, Watterson and Arblaster (2005) found decreases in cloud cover (implying increases in solar radiation) over Victoria. By 2090, the decreases in cloud cover are 2 to 4% in summer and 4 to 6% in winter.

2.5 Extreme events

Australian extreme temperatures have changed over the 20th century, with the number of extremely hot days increasing and the number of extremely cool days decreasing (Collins *et al.* 2000). This trend is expected to continue due to global warming (Whetton *et al.* 2002). Table 2 shows the possible changes for selected sites in Gippsland.

| Average summer days over 35°C | | | |
|-------------------------------|---------|-------|------|
| Site | present | 2030 | 2070 |
| Omeo | 2 | 2-5 | 3-20 |
| Orbost | 5 | 6-9 | 7-21 |
| Sale | 4 | 5-7 | 6-16 |
| Average winter days below 0°C | | | |
| Site | present | 2030 | 2070 |
| Omeo | 44 | 29-40 | 7-35 |
| Orbost | 3 | 0-2 | 0-1 |
| Sale | 11 | 4-9 | 0-7 |

Table 2 Extreme temperature and rainfall changes, selected Gippsland sites (Whetton *et al.* 2002)

Projecting changes in extreme rainfall events is more difficult because precipitation processes occur on scales often not adequately resolved by models and have random components. However both theory and models predict increases in extreme precipitation events with global warming (Hennessy *et al.* 1997; Trenberth 1999). Increased water vapour in the atmosphere can produce more intense precipitation events even when total precipitation remains constant (Karl and Trenberth 2003). This will have implications in a number of areas, including flood risk, erosion rates and water management.

When mean rainfall decreases, analyses show that prolonged and more intense periods of drought are likely under enhanced greenhouse conditions (Kothavala 1999). Rainfall is not the sole determinant of drought conditions - higher temperatures and increased evaporation can also contribute to drought severity (Nicholls

2004). In Victoria, most climate models show increases in drought in the spring-summer period and in some simulations drought frequency more than doubles (Whetton *et al.* 2002).

2.6 Fire

Global warming may lead to an increase in Australian fire danger (Williams *et al.* 2001; Cary 2002). Higher litter loads could make fires more intense and difficult to control (Noble 1999). A recent study by Hennessy *et al.* (2005a) investigated changes in the forest and grassland danger indices for 17 sites in the South-east, including Sale in Gippsland. Many sites show a doubling or greater of the number of days classified as extreme by 2050 under the high scenario. The average number of days when the forest fire danger index (FFDI) is very high or extreme at Sale could change from 8.7 at present to between 9.3 and 10.7 by 2030 and 10.1 to 14 by 2070. Similarly, the grassland fire danger index (GFDI), could increase from a present value of 95.4 days (very high or extreme) to a maximum of 124.2 days in 2050 (Hennessy *et al.* 2005a).

In Gippsland the greatest fire danger is in summer, or in spring and summer in the far East.⁴ Changes in the FFDI may require prescribed burning to take place earlier in spring and later in autumn, prolonging the effective fire season (Hennessy *et al.* 2005a). Typical fire frequencies vary from once every 2-3 years in woodlands and savannas to only once per century or longer in some cool temperate forests. More frequent and intense fires could also change hydrological characteristics of catchments, and lead to erosion, reduced water quality, and more opportunities for weeds and pests (Noble 1999).

Throughout Australia, fire regimes have changed significantly since European settlement (Jurskis *et al.* 2003), and altered fire regimes appear to have already had an impact on biodiversity in Gippsland.⁵ In the East Gippsland bioregion, the Eastern Bristlebird and Smoky Mouse may be declining because the pattern of fire in their limited habitat is not suitable. The optimal habitat for the Ground Parrot is thought to rely on a 10-15 year fire regime. On Wilson's Promontory, changed fire regimes have enabled fire sensitive species such as White Kunzea and Coastal Tea-tree to invade some vegetation communities. In the Gippsland plains, fires are more infrequent but individual fires are more intense, and this affects the vegetation age classes that form the required habitat of species such as the endangered New Holland Mouse. Lunt (1997) compared sites on the Gippsland plain that had been frequently burnt with those that had been irregularly grazed and rarely burnt and found that the two management regimes had resulted in markedly different flora.

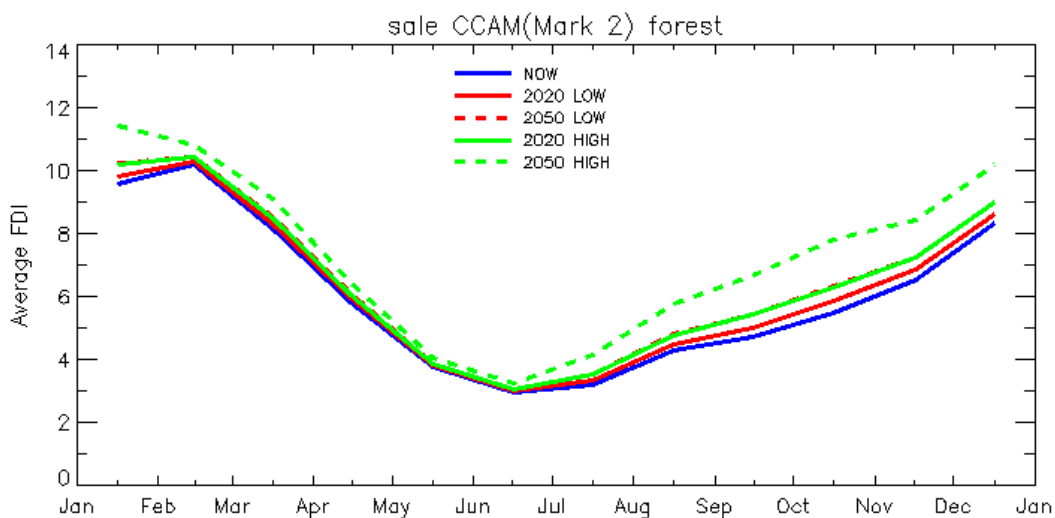


Figure 1 Changes in the Forest Fire Danger Index at Sale (Hennessy *et al.* 2005a, pg.67)

⁴ www.bom.gov.au/climate/c20thc/fire.shtml

⁵ www.nre.vic.gov.au/plntanml/biodiversity/directions/eastgipp.htm

3 Climate change impacts

3.1 Water resources

The consequences of climate change for water resources in Gippsland could include increased irrigation demand, increased stress in the lower reaches of major rivers such as the Mitchell, Tambo and Snowy in summer, deterioration of water quality in the Gippsland Lakes, reduced flows to wetlands, and potential increases in salinity due to reduced flows. Increased temperature and changes in potential evapotranspiration may lead to shifts in optimal growing periods, regional suitability or per hectare irrigation requirements (Doll 2002). Naturally occurring droughts are likely to be exacerbated by enhanced potential evapotranspiration (Trenberth 1998; Dai *et al.* 2004). These impacts could occur in systems that are already severely stressed. The National Water Resources Assessment (2001) found that 26% of surface water management areas and 30% of groundwater management units are either fully or over-allocated. The ecological effects of over-allocated water resources are significant and include loss of wetlands, decline of riparian forests, altered aquatic plant community structure, biodiversity decline, blooms of toxic cyanobacteria, and invasions of exotic species (Arthington and Pusey 2003).

The major river basins in the Gippsland region are the Snowy, Tambo, Mitchell, East Gippsland, Thomson-Macalister, Latrobe, and South Gippsland basins. In a recent report Jones and Durack (2005) used ten climate modes and three scenarios of global warming to provide a preliminary estimate of changes in mean annual runoff for all major Victorian catchments in 2030 and 2070. The results for Gippsland show a tendency for decreased runoff in all of the above basins with the possible exception of East Gippsland. Table 3 summarises the expected runoff changes for the region.

Climate change may result in a number of potentially negative effects on urban water systems. These include reduction in supply or changes in peak streamflow timing; reduced water quality; increased salinity or pollutant loads; increased evaporation; changed catchment hydrology; and increased frequency or severity of extreme rainfall, floods and droughts. The potential impacts on urban water and waste disposal infrastructure are discussed further in section 3.6.

3.2 Agriculture

In Gippsland the primary agricultural activities are horticulture (predominantly vegetables), grazing (dairy, beef, lamb and wool), and timber production. Climate change can have a number of complex effects on these agricultural activities. Increasing carbon dioxide (CO₂) enhances plant water use efficiency, and leads to increased growth, although this CO₂ fertilization effect tends to decrease after extended exposure and varies widely between species (Drake and Gonzalez-Meler 1997; Mooney *et al.* 1999).

An overview of the effect of climate change on horticulture is provided by Webb *et al.* (2003). Periods of heat stress can reduce uniformity at harvest time, but horticultural crops with extended potential flowering periods are less sensitive to heat stress than those with more tightly determined flowering times. Deciduous fruit needs vernalisation, or accumulated chilling, and so temperature increases of 1°C or more can have negative consequences for growth and development. The impacts of extremes such as high temperatures, frost and persistent drought will depend on when they occur in the crop's developmental cycle. Changes in other climatic factors can be influential depending on the crop in question (e.g. cherries are sensitive to levels of solar radiation). Plants grown under elevated CO₂ conditions can have lower protein and nitrogen contents (Drake and Gonzalez-Meler 1997), so it will be necessary to monitor for quality. Changes in plant nitrogen, weed growth or pest regimes may lead to an increased need for fertilizer, herbicides, or pesticides.

| Basin | Profile | 2030 wettest | 2030 driest | 2070 wettest | 2070 driest |
|---------------------------|--|--------------|-------------|--------------|-------------|
| East Gippsland | Rivers: Genoa, Batka, Wangan, Thurra, Cann, Bemm Mean annual runoff: 655 000 ML Land use: Hardwood timber production, beef cattle, conservation Development status: low | +5% | -30% | +20% | > -50% |
| Snowy | Rivers: Suggan Buggan, Little, Murrindal, Buchan, Deddick, Rodger, Brodribb Land use: Hardwood timber from native forest, horticulture, cattle and sheep grazing, conservation, Snowy Mountains Hydroelectric scheme (in NSW) Mean annual runoff: 863 000 ML (Victorian catchment) Development status: medium | 0% | -30% | 0 | > -50% |
| Tambo | Rivers: Tambo and Nicholson flow into Gippsland lakes, Boggy creek flows into Lake Tyers Mean annual runoff: 329 000 ML Land use: Cattle and sheep farming, horticulture and grain production, fishing Development status: medium | 0% | -30% | 0 | > -50% |
| Mitchell | Rivers: Wongungarra, Dargo, Wentworth Mean annual runoff: 1 100 000 ML Land use: Dairying, grazing and grain production Development status: medium | 0% | -25% | -5% | > -50% |
| Thomson-Macalister | Rivers: Thomson, Avon, Perry and Macalister rivers. Storages: Lake Glenmaggie and the Thomson reservoir Mean annual runoff: 841 600 ML Land use: Dairying, mixed farming of beef cattle and sheep, vegetable growing Development status: high | 0% | -25% | -5% | > -50% |
| Latrobe | Rivers: Toorong, Tanjil, Tyers, Moe and Morwell. Storages: Blue Rock lake, Yallourn, Hazelwood Pondage, Moondarra reservoir Mean annual runoff: 887 000 ML Land uses: Agriculture, timber, coal mining and energy generation (65% of water taken from the Latrobe River is used for thermal power) Development status: medium | 0% | -20% | -5% | > -50% |
| South Gippsland | Rivers: Bass, Powlett, Tarwin, Franklin, Agnes, Tarra. Storages: Candowie and Lance Creek reservoirs Mean annual runoff: 851 000 ML Land uses: Dairying, crops, pigs, cattle, sheep for wool, tourism Development status: low | -5% | -25% | -5% | > -50% |

Table 3 Climate change impacts on runoff, Gippsland basins (Jones and Durack 2005; NLWRA unpublished)

In grassland systems, 90% of the variance in primary production is accounted for by annual precipitation (Campbell *et al.* 1997). Large reductions in rainfall (~20%) could reduce plant productivity and substantially increase the variability of stocking rates compared with the present (Howden *et al.* 1999). The vigour of pasture growth may increase, but forage quality and water supply could decrease, and there is an increased probability of heat stress in dairy cattle (Jones and Hennessy 2000). Climate change could affect a hierarchy of interacting issues, such as changes in landscape hydrology, forage quality and stocking, fire regimes, and vegetation composition (Campbell *et al.* 1997).

The potential impacts of climate change on agriculture in Gippsland were examined in a pilot study by Hood *et al.* (2003), who used a Land Suitability Analysis approach together with CSIRO's climate scenario generator OzClim (Page and Jones 2001) to look at the potential suitability of cool climate grapes, high yield pasture and blue gum plantations under two different climate scenarios for 2020 and 2050. The authors produced a series of maps in consultation with agronomists, growers and soil scientists with expertise in the Gippsland region (Figures 2-4).

In the present climate, the highest suitability areas for cool climate grapes are around the townships of Maffra and Sale, and also to the west near the township of Wonthaggi. Areas of moderate suitability are located to the north of Yarram. In the moderate scenario in 2050 there is a greater occurrence of high suitability areas in the west of Gippsland. In the extreme scenario in 2050 the western half of Gippsland is highly suited for cool-climate grape-growing and there are significant areas of moderate suitability located to the south-west of Bairnsdale (Figure 2).

Pasture in Gippsland is typically Perennial Rye Grass and White Sub-clover pasture. At present the western half of the region is highly suitable for pasture, with its high rainfall and relatively gentle terrain. Climate change under a moderate scenario is likely to have limited impact on the suitability of the Gippsland region for production of high-yielding pastures, because the level of climate change is not sufficient to influence the factors considered critical to its production. However the extreme scenario leads to significant decrease in land suitability by 2050 due to increased mean monthly temperatures during the pasture growing season (Figure 3).

Timber harvesting is a significant economic activity in the region. In East Gippsland, for instance, 34% of public land is available for timber harvesting, and about 6000 hectares of forest are harvested each year.⁶ The climate change scenarios considered had little effect on land suitability for Blue Gum (*Eucalyptus globulus*), with areas of highest suitability located in western Gippsland and significant areas of moderate suitability in central Gippsland (Figure 4). However the local conditions that favour species' suitability or productivity are likely to change. Grand Ridge Plantations currently has 5 trial sites in Gippsland to examine the performance of different types of tree (Phil Whiteman, pers. comm.).

3.3 Biodiversity

The Gippsland region is home to a number of Victorian bioregions and a large proportion of the State's biodiversity. The shires of Baw Baw, Bass Coast, East Gippsland, La Trobe, South Gippsland and Wellington cover a number of Victorian bioregions: the Victorian Alps, Highlands-Southern Fall, Highlands-Northern Fall, Gippsland Plain, Wilson's Promontory, East Gippsland Uplands, and East Gippsland Lowlands. Climate change could have adverse impacts on native vegetation, birds and mammals, and aquatic biodiversity and wetlands. Anecdotal evidence from beekeeping indicates that changes have already occurred in Gippsland; for instance Narrow Leaf Peppermint (*E. radiata*) is yielding in some areas for the first time (Terry O'Kane, pers. comm.). There has been a relative lack of data on the ecological impacts of climate change in Australia; however the Bureau of Meteorology, Macquarie University, and the University of Melbourne are currently developing a National Ecological Meta database.⁷

⁶ www.nre.vic.gov.au/plntanml/biodiversity/directions/eastgipp.htm

⁷ <http://www.bom.gov.au/bmrc/cfor/cfstaff/lec/NEMD.htm>

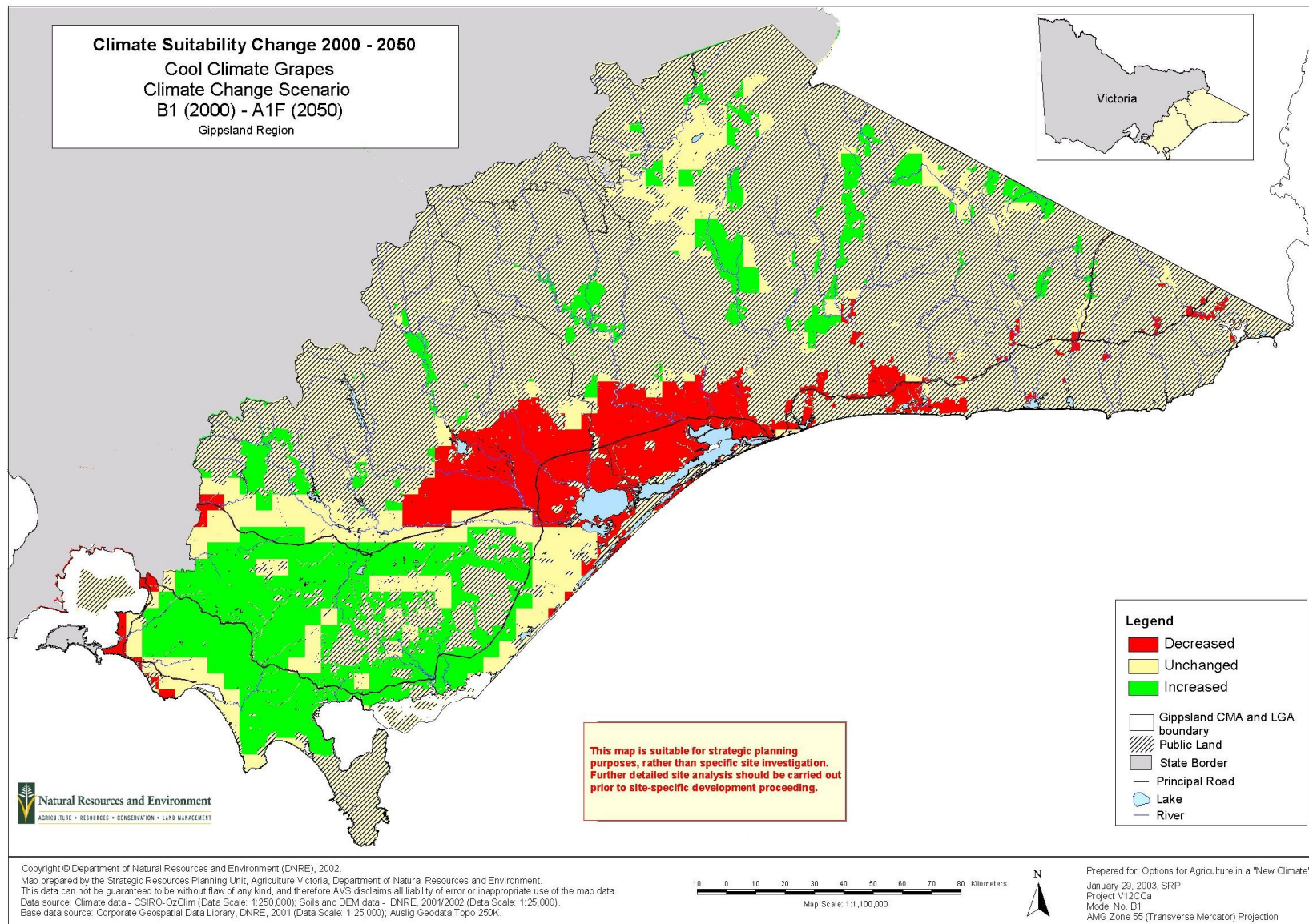


Figure 2 Change in land suitability for cool climate grapes in Gippsland (H. Hossain, pers. comm.)

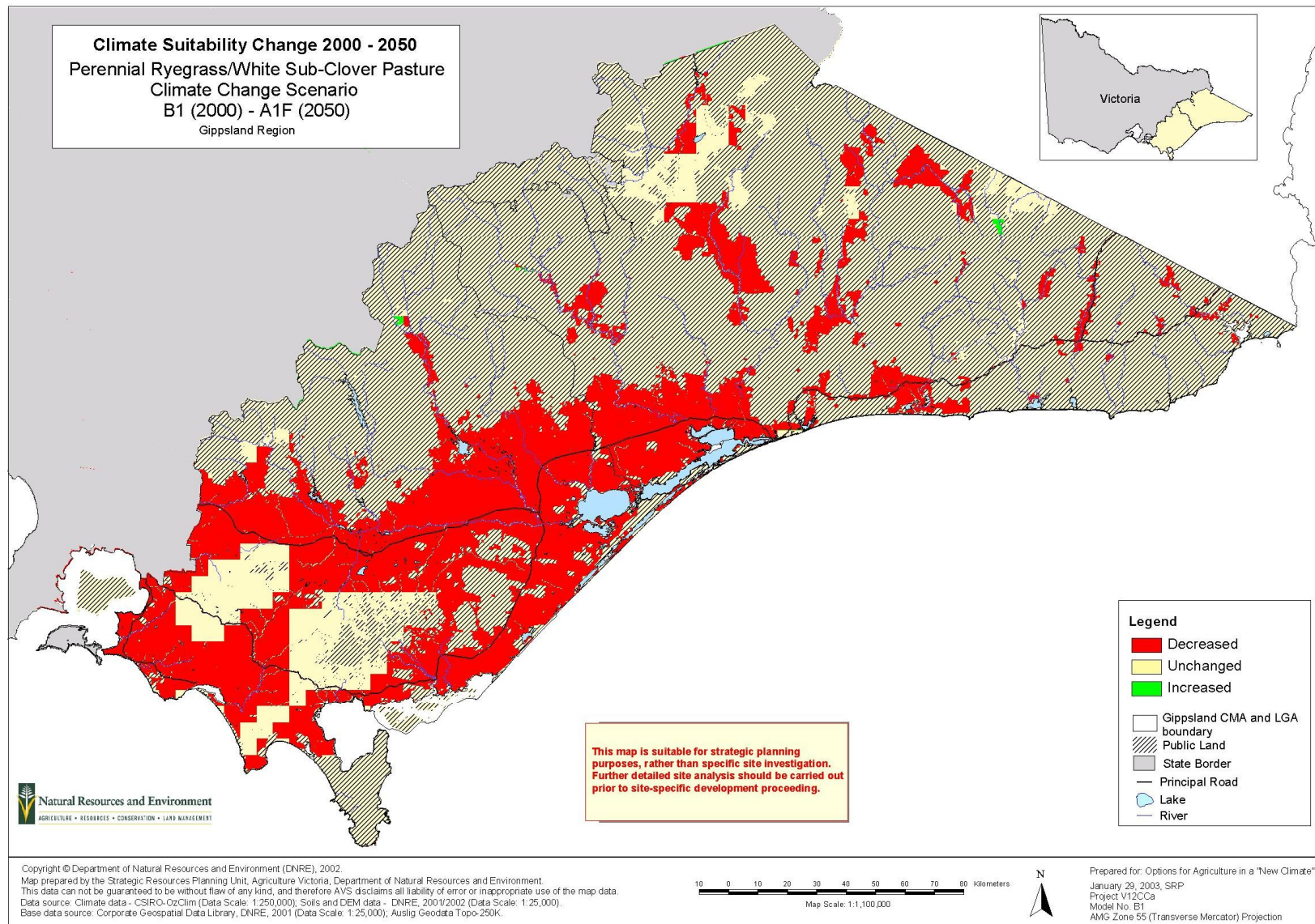


Figure 3 Change in land suitability for high-yield pasture in Gippsland (H. Hossain, pers. comm.)

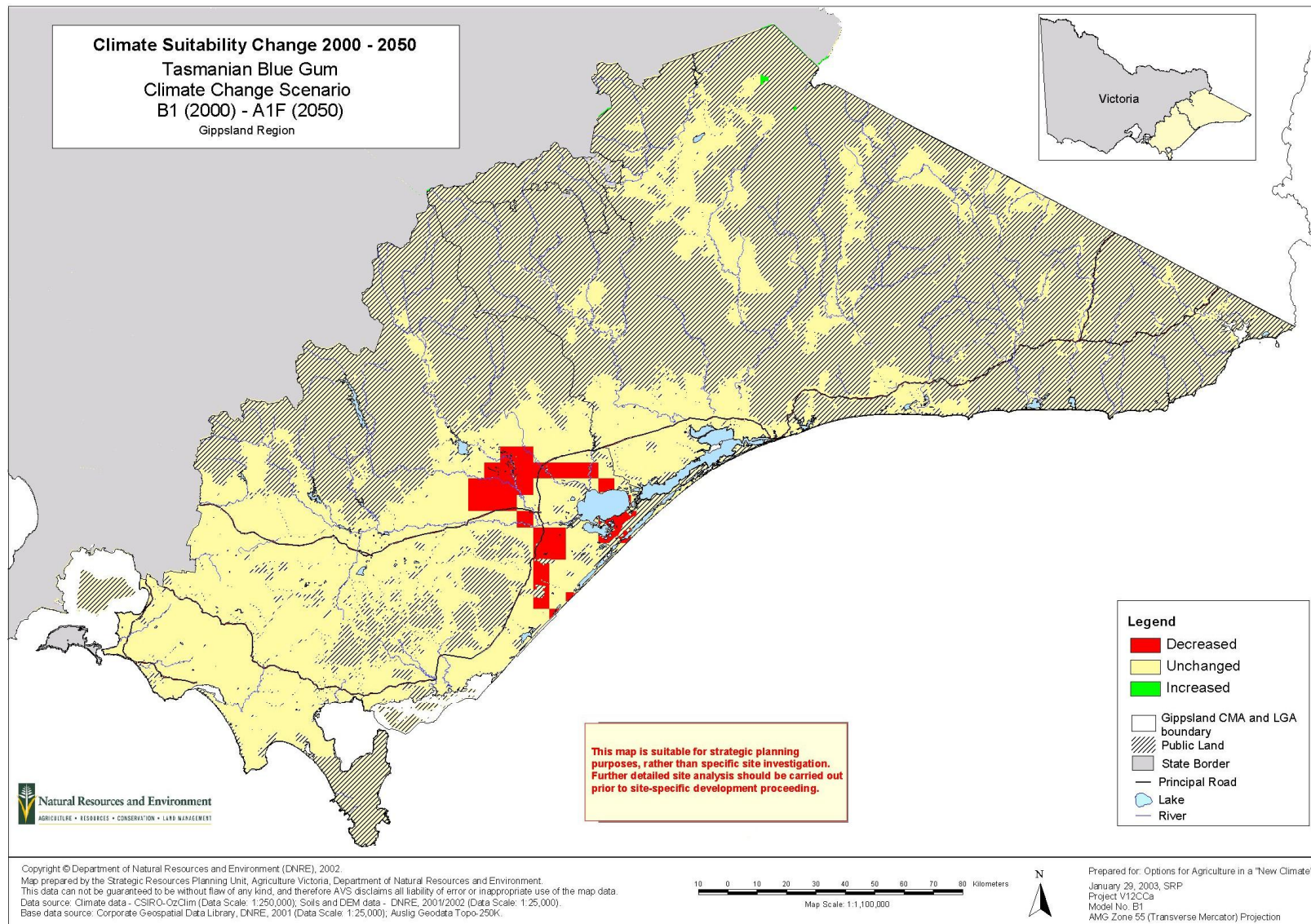


Figure 4 Change in land suitability for Blue Gum plantations in Gippsland (H. Hossain, pers. comm.)

Native forests are a major asset of Gippsland, both from a conservation perspective and for the timber industry. Temperate forests may increase in productivity with higher temperatures and carbon dioxide fertilisation, but the strength of this effect is uncertain as most of Australia's vegetation is subject to nutrient and/or water deficiency (McMurtie and NGAC Project Team 1999). Species with a small distribution range appear to be susceptible to even minor temperature increases, so refuges and centres of diversity are highly vulnerable (Pouliquen-Young and Newman 2000). Such areas exist in Gippsland in the Alps and the far East. Modelling studies suggest range contractions are possible for many native tree species. For instance of the 819 eucalypt species studied by Hughes *et al.* (1996), 53% had climatic ranges of less than 3°C, 41% less than 2°C and 25% less than 1°C. Soil and other constraints mean that species will not track moving climate zones across landscapes (Pouliquen-Young and Newman 2000). The Arthur Rylah Institute has done preliminary modelling of the bioclimatic profiles of 12 Victorian plant species using ANUCLIM software and CSIRO regional climate projections. However this capacity to advance research on climate change and biodiversity in Victoria has not been exploited due to lack of funding (Graeme Newell, pers. comm.).

Birds and mammals could be affected by relatively small changes in climate. Brereton *et al.* (1995) modelled the bioclimates of 42 selected fauna species from Victoria. With a 1°C temperature rise, 79% of the bioclimates were seen to contract. In the case of the Heath Mouse, this reduction was 90-100% of its range. The mountain Pygmy Possum, *Barramys parvus* may lose its bioclimate entirely with a 1°C rise in temperature. Overall, 57% of the species studied were predicted to lose 90-100% of their extant bioclimatic range with a 3°C rise in temperature. Expected impacts on birds include changes in distribution, changed movement patterns, changes in abundance (including some local extinctions), changes in phenology, community composition, physiology, morphology and behaviour (Chambers *et al.* 2005). Indirect effects will occur in response to changed habitat or food supply.

Climate change has been noted as a possible causal agent in the decline of the Baw Baw frog (*Philoria frosti*) from elevations above 1400m by Hollis (2004). The frog has a climate-driven pattern of distribution and population density, and narrow moisture and temperature tolerances related to sheltering, movement and breeding at sub-alpine and montane elevations. Monitoring between 1993-2002 indicates that it currently uses a smaller subset of breeding habitats in topographically protected cool moist environments and breeds 4 weeks earlier. In addition to global warming, regional-scale climatic changes may have occurred as a result of the filling of the Thomson reservoir in 1989.

Gippsland contains some important Ramsar sites such as the Gippsland Lakes and Corner Inlet. Existing threats to wetlands include inappropriate flow regimes, increased brackishness from rising water tables, increased nutrient inputs, algal blooms and infestations of European carp. In the Gippsland Lakes, pressure from human disturbance requires active management to ensure the continued breeding success of threatened species such as the Little Tern.⁸ Documented problems include dieback of fringing vegetation, increasing salinity, declines in population sizes of bird and fish species, and invasion by the weed *Spartina*. Sedimentation in streams and alteration of flow regimes is seen as a threat to biodiversity in many of Gippsland's bioregions.⁹ Reductions in runoff are expected under climate change (see above) and this could exacerbate existing problems and impact environmental flows. There is currently very little recognition of the potential impact of climate change and variability on environmental flow allocations (Schofield and Burt 2003).

Climate change could alter the occurrence of pests, diseases and invasive species. In south and south west Gippsland, fragmentation has already increased the vulnerability of stands of Swamp Paperbark to defoliation from infestations of Paperbark Sawfly.¹⁰ In the Victorian Alps, warming has led to increased penetration of feral mammals into alpine and high subalpine areas (Green 2003).

⁸ www.nre.vic.gov.au/plntanml/biodiversity/directions/plains.htm

⁹ www.nre.vic.gov.au/plntanml/biodiversity/directions/plains.htm

¹⁰ www.nre.vic.gov.au/plntanml/biodiversity/directions/plains.htm

3.4 Coasts and marine

The impacts of climate change in the coastal zone could include sea level rise, coastal erosion, inundation, increased storm surges, and changes to fisheries and marine biodiversity. The Victorian Coastal Strategy (Victorian Coastal Council 2002) includes consideration of climate change. The Coastal Action Plan for Gippsland Estuaries discussion paper (October 2005) lists climate change as a priority emerging issue.¹¹

Around the Gippsland Lakes, climate change could lead to a number of impacts detailed by Bird (2002). These include salt water intrusion; changes to sediment flows; erosion and the possible breaching of the outer sand barrier behind Ninety Mile Beach; and risks to shoreline infrastructure. The lakes were less saline prior to construction of the permanent artificial entrance in 1889; increasing salinity as a result of climate change could lead to further losses of freshwater communities. The effects of erosion and inundation are expected to be most dramatic in low lying-areas along the western and southern shores of Lakes Wellington; Tambo and Latrobe River deltas; McLennan Strait area; western end of Lake Victoria/Blond Bay; sandy spits associated with the outer and inner barriers; northern end of Raymond Island; Point Fullarton; northern shore of Jones Bay; Mitchell River silt jetties; Tambo Bay; Point Jones; Shaving Point; Purran Corner, Baines swamp; islands in Reeve and Hopetoun Channels; parts of Boole Boole Peninsula; and Lakes Entrance foreshore.

A recent study for the Gippsland Coastal Board by McInnes *et al.* (2005) investigated the effect of climate change on storm surges along the Gippsland coast. The results suggest an annual average change of $1 \pm 2\%$ in mean winds by 2030 and approximately $3 \pm 7\%$ by 2070, with a larger uncertainty in the case of extreme winds. Seasonally, the greatest changes occur in winter, with mean wind speeds changing $2 \pm 3\%$ by 2030 and $5 \pm 9\%$ by 2070. The models show consistent future decreases in mean and extreme winds in autumn. Since mid-latitude storms are currently the major cause of extreme wind conditions from late autumn through to spring, the possibility exists of a shift in seasonality of storms under future climate conditions, resulting in a delayed onset of storms until the period between winter and early summer. Under the worst case scenario storm surge height increases by approximately 6% and 19% respectively in 2030 and 2070. Sea level rise, which is projected to lie in the range 3 to 17cm by 2030 and 7 to 49cm by 2070, provides the greatest contribution to flood risk. A complicating factor is the possibility of subsidence along the Gippsland coast east of Wilson's Promontory due to declining groundwater levels in the Latrobe group aquifer. CSIRO is currently commencing high resolution storm surge modelling work for Corner Inlet and Lakes Entrance (Kathy McInnes, pers. comm.).

The impact of climate change on Gippsland's marine environments is poorly understood. However one study of selected Victorian marine species (O'Hara 2002) showed that up to 14% of the species confined to the cool temperate waters of South-eastern Australia could become extinct within Victoria with a sea temperature rise of 1-2°C. Climate change is expected to affect the marine environment through greater sea surface temperatures, rises in sea level, increases in ocean acidity and alterations to aspects of the oceanographic regime such as currents.

3.5 Alpine areas

Parts of Gippsland lie in Australia's alpine region, and are key areas for tourism and conservation. These fragile high-altitude environments could be particularly vulnerable to climate change. Over the period 1962 to 2001, alpine warming trends (i.e. at sites over 1300m) were higher than at lower elevations, with an average warming of 0.02°C per year (Hennessy *et al.* 2003). There is some evidence that warming has already led to impacts on ecosystems in the Alps, for instance Wearne and Morgan (2001) document encroachment of *Eucalyptus pauciflora* into subalpine grasslands near Mt Hotham. A reduction in snow cover over the last 45 years has led to an increased penetration of feral mammals into alpine and subalpine areas, and observable changes in the timing of arrival of migratory bird species in the mountains (Green 2003). Rainfall data from 1950 to 2001 shows a slight tendency for decrease over the Southern Alps (Hennessy *et al.* 2003).

¹¹ <http://www.gcb.vic.gov.au/estuaryplan.htm>

The effects of climate change on snow conditions in the Australian Alps was investigated by Hennessy *et al.* (2003). The study included several areas in or close to Gippsland, such as Mt. Baw Baw, the Mt. Wellington High Plains and Mt. Hotham. The implications of climate change include reductions in snow cover, maximum depth and season duration. The total area with an average of at least 30 days of snow cover decreases 14-54% by 2020 and 30-93% by 2050, and the area that currently experiences at least 60 days of cover is expected to decrease 18-60% by 2020 and 38-96% by 2050. The warming scenarios show that maximum snow depth tends to occur earlier in the season, and depth reductions are larger in the late season (Figure 5). Under the low impact scenario for 2050 there is a reduction in peak depths of over 80% at lower elevation sites such as Mt Baw Baw. Under the high scenario maximum depths are less than 10% of their present value. By 2020 season length is reduced by 5 days under a low scenario and 30-40 days under the high scenario. In 2050 the figures are 15-20 and 100 days respectively.

Adaptation to climate change, in the form of increased investment in snow-making, is a possible response in the short-term. Hennessy *et al.* (2003) conclude that, given appropriate responses such as increased investment in snow-making, the ski industry would be able to manage the impacts of projected climate change until at least 2020.

3.6 Settlements and infrastructure

One potentially significant socio-economic impact of climate change is the possibility of demographic shifts between regions. The Monash University Centre for Population and Urban Research has projected that Victorian coastal regions would be expected to gain population as a result of climate change (Harvey *et al.* 2004). This would lead to increased pressure on local infrastructure in Gippsland.

Climate change could have both direct and indirect effects in the areas of transport, energy, and service infrastructure. Higher temperatures can lead to embrittlement of bitumen and potholing of roads, higher water tables reduce the structural strength of pavements, and salt rusts the reinforcement in concrete structures, while demographic shifts can affect transport planning at the strategic level (Harvey *et al.* 2004). Climate change would influence energy demand and peak periods, and could also have an influence on energy costs if mitigation policies are introduced. A study for Melbourne Water identified a number of risks for urban water infrastructure. These include the potential for corrosion and odours from increased sewage concentrations associated with water conservation or increased temperatures; sewer overflows due to increased rainfall intensity during storms; the risk of pipe failure and collapse due to dry soil conditions; increased salinity levels in recycled water due to rising seawater levels; and the risk of damage to stormwater infrastructure and facilities (Howe *et al.* 2005). The study also indicated that average inflow to Melbourne dams may decline 3-11% by 2020, and 7-35% by 2050.

In June 2004, the Victorian Government announced the Eastern Water Recycling Proposal as part of its action plan, *Our Water Our Future*. The proposal recommended that a study be undertaken to determine the feasibility of transferring recycled water from Melbourne's Eastern Treatment Plant to the Latrobe Valley. The feasibility study could lead to a massive infrastructure project that has the potential to use up to 80% of the plant's treated effluent. The study will take about 18 months to complete. If approved, the project would involve building a 135-kilometre pipeline from the plant to the Latrobe Valley. Recycled water could be supplied to the Latrobe Valley's power stations, paper industry and new industries, substituting the use of surface water from the catchment.¹²

3.7 Health and emergency services

Climate change could lead to a number of effects on human health, ranging from direct impacts such as a rise in heat-related mortality, to more subtle impacts such as heightened psychological stress following natural disasters (McMichael *et al.* 2003). A national risk assessment of the impacts of climate change on health found that annual flood related deaths and injuries could increase up to 240%, depending on the region and climate scenario considered (McMichael *et al.* 2003).

¹² see http://www.melbournewater.com.au/content/water_recycling/eastern_region/eastern_region.asp

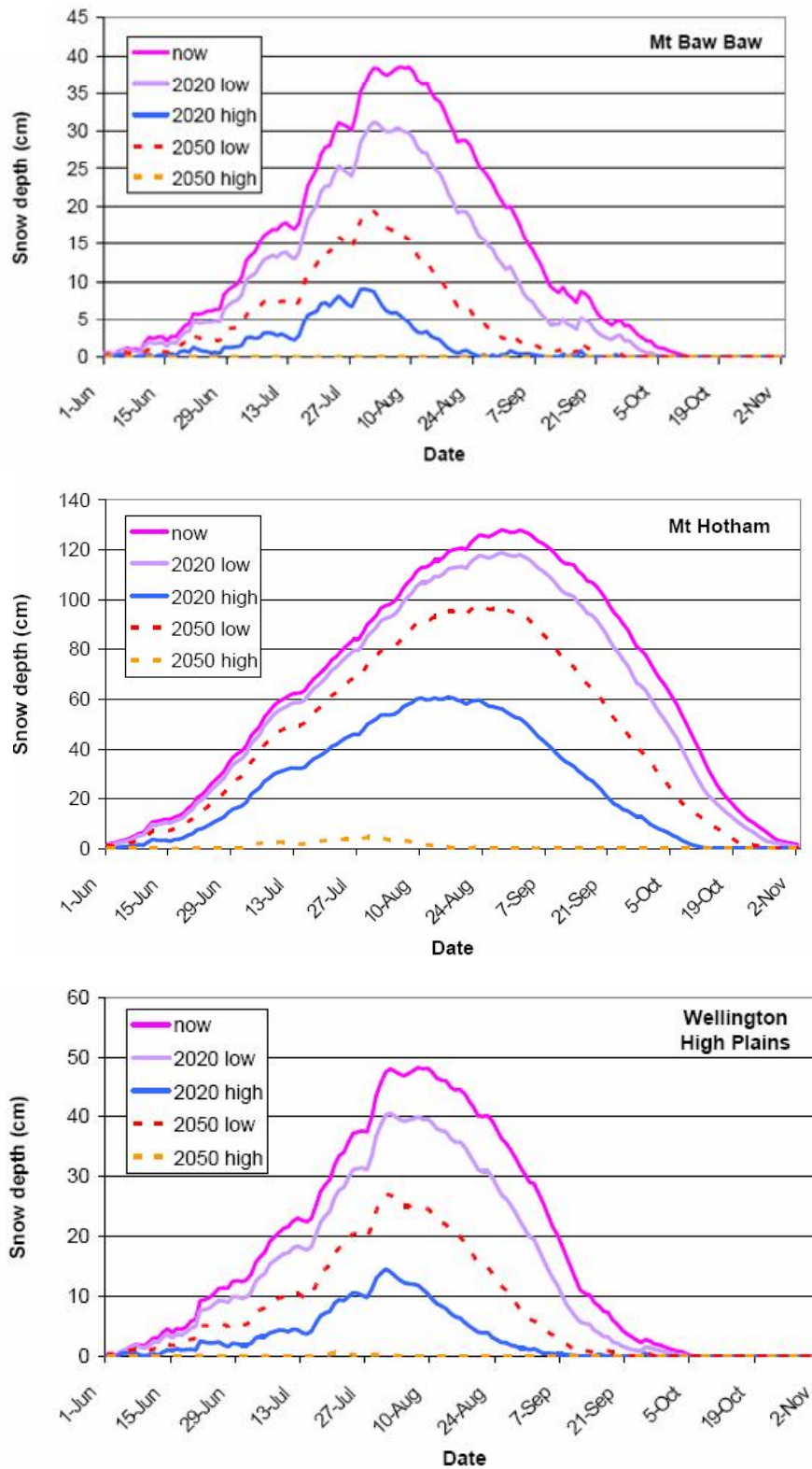


Figure 5 Simulated 20-yr average snow depth profiles at Mt Baw Baw (1560m), Mt Hotham (1882m) and Wellington High Plains (1560m) for present (1979-1998), 2020 and 2050 (Hennessy *et al.* 2003)

The high density of farm animals in some areas where communities rely on surface water sources could increase the risk of contamination following extreme rainfall events. Other impacts include changes to the life cycle of a number of plants and animals that are linked to asthma occurrence, and to the epidemiology of mosquito-borne diseases.

Gippsland has been subject to outbreaks of Ross River Virus and Barmah Forest Virus. Higher temperatures on their own are unlikely to lead to increased disease risk, but greater summer rainfall may increase the availability of mosquito habitat (Kelly-Hope *et al.* 2004). Kelly-Hope *et al.* (2004) found that rainfall was the single most important environmental determinant for Ross River Virus. In south-east temperate regions disease occurrence is also associated with warmer than average minimum temperatures, and in coastal localities outbreaks occur after higher than average sea levels and tides. The outbreak of Barmah Forest Virus in Gippsland in 2002 followed a wetter than average spring to autumn, resulting in an increase in the population of saltmarsh mosquito (Passmore *et al.* 2002).

Climate scenarios show the possibility of increased bushfire and flood risk. Natural disasters already represent a significant cost to the community; the Bureau of Transport Economics estimates the average annual cost of Australia's natural disasters between 1967 and 1999 was \$1.14 billion, with floods, storms, fires and cyclones making up almost 87% of this cost (Bureau of Transport Economics 2001).

3.8 Social vulnerability and equity

Vulnerability is a prior condition, bound up with the social and economic situation of households and communities. Although external physical factors play a role in raising vulnerability, they are not preconditions or sole causes (Adger 1996). Vulnerability can be defined as a *complex and multi-dimensional social space defined by the determinate political, economic and institutional capabilities of people in specific places at specific times* (Downing *et al.* 1996, pg. 186).

Vulnerability and poverty are inextricably linked and so economic development is closely related to the risk of impacts from hazards, and may either amplify or alleviate them. The local institutional context determines both attitudes to hazards and the severity of their impacts. Climate change could have significant social impacts if it leads to changes in regional economic activities. In Gippsland a number of socio-economic changes have occurred in the past as a result of privatisation of the electricity industry and deregulation of the dairy industry. Climate change has the power to interact with regional development pathways in both positive and negative ways.

4 Conclusion and Recommendations

The sectoral and ad-hoc nature of climate impact research means many questions that are important from a regional perspective remain unanswered. For instance, the landscape-level implications of the interaction between climate change and activities such as forestry, water management, or revegetation are unknown. Similarly, critical thresholds beyond which biophysical or social sustainability might be threatened are geographically specific and remain largely unassessed for Gippsland. Our understanding of socio-economic impacts remains generic and very little research has been specific to the region.

A number of regional forums were conducted in Gippsland between September and December 2005 as part of the project *Climate Change Impacts and Adaptation in Gippsland*. Participants discussed existing adaptations, resilience, management structures and information needs, with the aim of providing a platform for ongoing research and adaptive management in Gippsland. A discussion of these workshops is included in a separate project report.

On the basis of the available information on climate change impacts in Gippsland, together with feedback from the workshops, CSIRO has a number of recommendations for further research:

Climate and land use change implications for water resources

One area that requires further research is that of forestry impacts on water yield/quality in the Gippsland catchments and their interactions with climate change. The preliminary work that has been done by CSIRO on runoff in Victorian catchments does not take land use and land use change into account. Understanding the likely feedbacks and thresholds is vitally important to a number of key activities.

Revegetation, landscape interactions, and climate change

There are a number of landscape-level interactions surrounding revegetation in Gippsland that need to be understood in the context of climate change. These are:

- the changing need for revegetation (for biodiversity, or on marginal land);
- species selection and the success of plantings (including evaluation of past efforts);
- implications of carbon sequestration initiatives;
- the feedback effects on water resources; and
- the coordination of and capacity for revegetation across the region.

Risk assessment for extreme events

Extreme events, especially fire and flood, have the capacity to impact a number of natural and built assets in the region. Thorough risk assessments are needed for extreme events, including detailed projections, probabilities and mapping. A related issue is coordination of emergency services, and their capacity for scenario planning.

Fire forum

Fire emerged as a crucial variable for many activities in Gippsland, but fire management is potentially an area with a number of institutional barriers to adaptation. A regional forum on climate change and fire could use climate change as a catalyst for knowledge-sharing on fire regimes for different ecological communities.

Critical thresholds for biodiversity

Basic knowledge is needed on the effects of climate variables on biota at the ecological vegetation class (EVC) level. What are the safe ranges and critical thresholds that might cause the EVC to become a different type?

Integrated regional impact assessments

Most impact studies have considered sector-specific impacts, e.g. water, fire, or snow. Few have attempted to integrate impacts across sectors for a given region, including interactions and feedbacks. Given the amount of information available for various sectors in some parts of Gippsland, it may be possible to do an integrated assessment.

Socio-economic risk assessments

Few impact studies have gone beyond assessment of biophysical impacts. Socio-economic risk assessments are more complex but carry greater influence amongst decision-makers. Methods exist for undertaking socio-economic assessments. Greatest scope for such work exists in the water, infrastructure, coastal and agricultural sectors, with limited scope for biodiversity.

5 References

- Adger, W. N. (1996). "Approaches to vulnerability to climate change." Working paper no. GEC 96-05, Centre for Social and Economic Research on the Global Environment, University College, London.
- Arthington, A. H., and Pusey, B. (2003). "Flow restoration and protection in Australian rivers." *River Research and Applications*, 19(5-6), 377-395.
- Bird, E. (2002). "The effects of a rising sea level on the Gippsland Lakes." Gippsland Lakes Shore Erosion & Revegetation Strategy, E. Sjerp, B. Martin, P. Riedel, and E. Bird, eds., Gippsland Coastal Board, Bairnsdale.
- Brereton, R., Bennet, S., and Mansergh, I. (1995). "Enhanced greenhouse climate change and its potential effect on selected fauna of south-eastern Australia: A trend analysis." *Biological Conservation*, 72(3), 339-354.
- Bureau of Transport Economics. (2001). "Economic costs of natural disasters in Australia." Bureau of Transport Economics Report no. 103, Canberra.
- Campbell, B. D., Stafford Smith, D. M., and McKeon, G. M. (1997). "Elevated CO₂ and water supply interactions in grasslands: a pastures and rangelands management perspective." *Global Change Biology*, 3(3), 177-197.
- Cary, G. J. (2002). "Importance of a changing climate for fire regimes in Australia." *Flammable Australia: The fire regimes and biodiversity of a continent*, R. Bradstock, J. E. Williams, and M. A. Gill, eds., Cambridge University Press, Cambridge, 26-46.
- Chambers, L. E., Hughes, L., and Weston, M. A. (2005). "Climate change and its impact on Australia's avifauna." *Emu*, 105(1), 1-20.
- Chiew, F. H. S., Piechota, T. C., Dracup, J. A., and McMahon, T. A. (1998). "El Nino/Southern Oscillation and Australian rainfall, streamflow and drought: Links and potential for forecasting." *Journal of Hydrology*, 204(1-4), 138-149.
- Collins, D. A., Della-Marta, P. M., Plummer, N., and Trewin, B. C. (2000). "Trends in annual frequencies of extreme temperature events in Australia." *Australian Meteorological Magazine*, 49(4), 277-292.
- Dai, A., Trenberth, K. E., and Qian, T. (2004). "A global dataset of Palmer drought severity index for 1870-2002: Relationship with soil moisture and effects of surface warming." *Journal of Hydrometeorology*, 5(6), 1117-1130.
- Doll, P. (2002). "Impact of climate change and variability on irrigation requirements: A global perspective." *Climatic Change*, 54(3), 269-293.
- Downing, T. E., Watts, M. J., and Bohle, H. G. (1996). "Climate change and food insecurity: Towards a sociology and geography of vulnerability." *Climate change and world food security*, T. E. Downing, ed., Springer Verlag, Berlin, 183-206.
- Drake, B. G., and Gonzalez-Meler, M. A. (1997). "More efficient plants: A consequence of rising CO₂?" *Annual review of plant physiology and plant molecular biology*, 48(1), 609-639.
- DSE (2005). *Vitcorian Greenhouse Strategy Action Plan Update 2005*. Victorian Department of Sustainability and Environment, Melbourne.
- Green, K. (2003). "Impacts of global warming on the Snowy Mountains." *Climate change impacts on biodiversity in Australia. Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October, 2002.*, M. Howden, L. Hughes, M. Dunlop, I. Zethoven, D. W. Hilbert, and C. Chilcott, eds., CSIRO Sustainable Ecosystems, Canberra.
- Harvey, M., Whetton, P., McInnes, K. L., Cechet, B., McGregor, J. L., Nguyen, K., Houghton, N., Lester, C., Styles, E., Michael, N., Martin, T., Heaney, A., Beare, S., and Norwell, G. (2004). "Impact of climate change on road infrastructure. Austroads, Report no. AP-R243/04." Austroads and the Bureau of Transport and Regional Economics, Sydney.
- Hennessy, K., Lucas, C., Nicholls, N., Bathols, J., Suppiah, R., and Ricketts, J. (2005a). "Climate change impacts on fire-weather in south-east Australia." *Climate Impacts Group, CSIRO Atmospheric Research and the Australian Government Bureau of Meteorology, Aspendale.*
- Hennessy, K., McInnes, K. L., Bathols, J. A., Ricketts, J., and Macadam, I. (2005b). "Climate change scenarios for assessing potential impacts on buildings." *Climate Impact Group, CSIRO Atmospheric Research, Aspendale.*
- Hennessy, K., Whetton, P., Smith, I., Barthols, J., Hutchinson, M., and Sharples, J. (2003). "The impact of climate change on snow conditions in mainland Australia." *CSIRO Atmospheric Research, Aspendale.*

- Hennessy, K. J., Gregory, J. M., and Mitchell, J. F. B. (1997). "Changes in daily precipitation under enhanced greenhouse conditions." *Climate Dynamics*, 13(9), 667-680.
- Hollis, G. J. (2004). "Ecology and conservation biology of the Baw Baw Frog *Philoria frosti* (Anura: Myobatrachidae): Distribution, abundance, autoecology and demography." Unpublished Ph.D thesis, Department of Zoology, University of Melbourne.
- Hood, A., Cechet, B., Hossain, H., and Sheffield, K. "Options for Victorian agriculture in a "New" climate: Pilot study linking climate change and land suitability modelling." *Proceedings, MODSIM 2003: International congress on modelling and simulation*, Townsville, 41-46.
- Howden, S. M., McKeon, G. M., and Reyenga, P. J. (1999). "Global change impacts on rangelands." Working paper series 99/09, CSIRO Wildlife and Ecology, Canberra.
- Howe, C., Jones, R. N., Maheepala, S., and Rhodes, B. (2005). "Implications of potential climate change for Melbourne's water resources." CSIRO Urban Water and CSIRO Climate Impacts Group.
- Hughes, L., Cawsey, E. M., and Westoby, M. (1996). "Climatic range sizes of Eucalyptus species in relation to future climate change." *Global Ecology and Biogeography Letters*, 5(1), 23-29.
- Jones, R. N., and Hennessy, K. J. (2000). "Climate change impacts in the Hunter Valley: A risk assessment of heat stress affecting dairy cattle." CSIRO Atmospheric Research, Aspendale.
- Jones, R. N. and Durack, P.J. (2005). "Estimating the impacts of climate change on Victoria's runoff using a hydrological sensitivity model." CSIRO Atmospheric Research, Aspendale.
- Jurskis, V., Bridges, B., and de Mar, P. (2003). "Fire management in Australia: The lessons of 200 years." Joint Australia and New Zealand Institute of Forestry Conference Proceedings, 27 April- 1 May 2003, Queenstown, Ministry of Agriculture and Forestry, Wellington.
- Karl, T. R., and Trenberth, K. E. (2003). "Modern global climate change." *Science*, 302(5651), 1719-1723.
- Kelly-Hope, L. A., Purdie, D. M., and Ky, B. H. (2004). "Ross River virus disease in Australia, 1886-1998, with analysis of risk factors associated with outbreaks." *Journal of Medical Entomology*, 41(2), 133-150.
- Kothavala, Z. (1999). "The duration and severity of drought over eastern Australia simulated by a coupled ocean-atmosphere GCM with a transient increase in CO₂." *Environmental Modelling and Software*, 14(4), 243-252.
- Lunt, I. D. (1997). "Effects of long-term vegetation management on remnant grassy forests and anthropogenic native grasslands in South-eastern Australia." *Biological Conservation*, 81(3), 287-297.
- McInnes, K. L., Macadam, I., Hubbert, G. D., Abbs, D. J., and Bathols, J. (2005). "Climate change in Eastern Victoria, stage II report: The effect of climate change on storm surges." CSIRO Atmospheric Research, Aspendale.
- McMichael, A., Woodruff, R., Whetton, P., Hennessy, K., Nicholls, N., Hales, S., Woodward, A., and Kjellstrom, T. (2003). "Human health and climate change in Oceania: A risk assessment 2002." Commonwealth Department of Health and Ageing, Canberra.
- McMurtie, R., and NGAC Project Team. (1999). "What are the likely implications of climate change for future forest production?" Impacts of global change on Australian temperate forests, S. M. Howden and J. T. Gorman, eds., Working paper series 99/08, CSIRO Wildlife and Ecology, Canberra.
- Mooney, H. A., Canadell, J., Chapin, F. S., Ehleringer, J. R., Körner, C., McMurtie, R. E., Perton, W. J., Pitelka, L. F., and Schultze, E. D. (1999). "Ecosystem physiology responses to global change." *The terrestrial biosphere and global change: Implications for natural and managed ecosystems.*, B. Walker, W. Steffen, J. Canadell, and J. Ingram, eds., Cambridge University Press, Cambridge, 141-189.
- National Land and Water Resources Audit. (2001). "Australian Water Resources Assessment 2000." Land and Water Australia, Canberra.
- Nicholls, N. (2004). "The changing nature of Australian droughts." *Climatic Change*, 63(3), 323-336.
- NLWRA. (unpublished). "Australian Natural Resources Atlas v 2.0." National Land and Water Resources Audit, http://audit.ea.gov.au/ANRA/atlas_home.cfm.
- Noble, I. R. (1999). "Impacts of global change on Australian forests: fire." Impacts of global change on Australian temperate forests, S. M. Howden and J. T. Gorman, eds., Working paper series 99/08, CSIRO Wildlife and Ecology, Canberra.
- O'Hara, T. D. (2002). "Endemism, rarity and vulnerability of marine species along a temperate coastline." *Invertebrate Systematics*, 16(4), 671-684.
- Page, C. M., and Jones, R. N. "OzClim: the development of a climate scenario generator for Australia." *MODSIM 2001: International Congress on Modelling and Simulation: proceedings*, Australian National University, Canberra, 667-671.
- Passmore, J., O'Grady, K. A., Moran, R. J., and Wishart, E. (2002). "An outbreak of Barmah Forest virus disease in Victoria." *Communicable Diseases Intelligence*, 26(4), 600-604.

- Pouliquen-Young, O., and Newman, P. (2000). "The implications of climate change for land-based nature conservation strategies." Final Report 96/1306, Australian Greenhouse Office, Canberra; Institute for Sustainability and Technology Policy, Perth.
- Schofield, N., and Burt, A. (2003). "Issues in environmental water allocation- an Australian perspective." *Water Science and Technology*, 48(7), 83-88.
- Stanhill, G., and Cohen, S. (2001). "Global dimming: A review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences." *Agricultural and Forest Meteorology*, 107(4), 255-278.
- Suppiah, R., Whetton, P. H., and Watterson, I. G. (2004). "Climate change in Victoria. Assessment of climate change for Victoria: 2001-2002." CSIRO Atmospheric Research, Aspendale.
- Trenberth, K. E. (1998). "Atmospheric moisture residence times and cycling: Implications for rainfall rates and climate change." *Climatic Change*, 39(4), 667-694.
- Trenberth, K. E. (1999). "Conceptual framework for changes of extremes of the hydrological cycle with climate change." *Climatic Change*, 42(1), 327-339.
- Victorian Coastal Council (2002). Victorian Coastal Strategy. The State of Victoria and Victorian Coastal Council, East Melbourne.
- Vives, B., and Jones, R. (2003). "Detection of abrupt changes in Australian decadal rainfall variability (1890-1989)." CSIRO Atmospheric Research Technical Paper, Aspendale.
- Watterson, I.G. and Arblaster, J.M. (2005) Patterns of simulated climate change from the new IPCC multi-model data base. Presentation to "Greenhouse 2005" , Melbourne, 13-17 November 2005.
- Wearne, L. J., and Morgan, J. W. (2001). "Recent forest encroachment into subalpine grasslands near Mount Hotham, Victoria, Australia." *Arctic, Antarctic and Alpine Research*, 33(3), 369-377.
- Webb, L., Hennessy, K., Cechet, R., and Whetton, P. H. (2003). "Horticulture and vegetables." An overview of the adaptive capacity of the Australian agricultural sector to climate change- options, costs and benefits, M. Howden, A. Ash, S. Barlow, T. Booth, S. Charles, B. Cechet, S. J. Crimp, R. Gifford, K. Hennessy, R. Jones, M. Kirschbaum, G. McKeon, H. Meinke, S. Park, B. Suthers, L. Webb, and P. Whetton, eds., CSIRO Sustainable Ecosystems, Canberra.
- Whetton, P. H., Suppiah, R., McInnes, K. L., Hennessey, K. J., and Jones, R. N. (2002). "Climate change in Victoria: High resolution regional assessment of climate change impacts." Undertaken for the Victorian Department of Natural Resources and Environment. CSIRO Atmospheric research, Aspendale.
- Wild, M., Gilgen, H., Roesch, A., Ohmura, A., Long, C. N., Dutton, E. G., Forgan, B., Kallis, A., Russak, V., and Tsvetkov, A. (2005). "From dimming to brightening: Decadal changes in solar radiation at earth's surface." *Science*, 308(5723), 847-850.
- Williams, A. A. J., Karoly, D. J., and Tapper, N. (2001). "The sensitivity of Australian fire danger to climate change." *Climatic Change*, 49(1-2), 171-191.

6 Climate impact directory for Gippsland

Much of the information on the impacts of climate change is difficult to access, hence the need for this overview for Gippsland. However, some of the information presented in this report is readily accessible on the internet via the following links: ¹³

General climate change

Summary of Australian impact research:

Pittock, B. (2003). "Climate change: An Australian guide to the science and potential impacts." The Australian Greenhouse Office, Canberra.

<http://www.greenhouse.gov.au/science/guide/index.html>

Victorian climate projections:

Whetton, P. H., Suppiah, R., McInnes, K. L., Hennessy, K. J., and Jones, R. N. (2002). "Climate change in Victoria: High resolution regional assessment of climate change impacts." Undertaken for the Victorian Department of Natural Resources and Environment: CSIRO Atmospheric Research, Aspendale.

<http://www.greenhouse.vic.gov.au/climatechange.pdf>.

Suppiah, R., Whetton, P. H., and Watterson, I. G. (2004). "Climate change in Victoria. Assessment of climate change for Victoria: 2001-2002." CSIRO Atmospheric Research, Aspendale.

http://www.cmar.csiro.au/e-print/open/suppiah_2004a.pdf

CSIRO's regional profiles for Gippsland:

http://www.greenhouse.vic.gov.au/impacts/media/East_Gippsland.pdf

http://www.greenhouse.vic.gov.au/impacts/media/West_Gippsland.pdf

Water resources

Melbourne water climate change study:

Howe, C., Jones, R. N., Maheepala, S., and Rhodes, B. (2005). "Implications of potential climate change for Melbourne's water resources." CSIRO Urban Water and CSIRO Climate Impacts Group.

http://www.melbournewater.com.au/content/library/news/whats_new/Climate_Change_Study.pdf

Climate change impacts on Victorian runoff:

Jones, R. N. and Durack, P.J. (2005). "Estimating the impacts of climate change on Victoria's runoff using a hydrological sensitivity model." CSIRO Atmospheric Research, Melbourne.

<http://www.greenhouse.vic.gov.au/CSIRO%20Report%20-%20Runoff.pdf>

Agriculture

Gippsland land suitability modelling:

Hood, A., Cechet, B., Hossain, H., and Sheffield, K. "Options for Victorian agriculture in a "New" climate: Pilot study linking climate change and land suitability modelling." *Proceedings, MODSIM 2003: International congress on modelling and simulation*, Townsville, 41-46.

<http://mssanz.org.au/modsim03/Media/Articles/Vol%201%20Articles/41-46.pdf>

¹³ accessed 25 November 2005

Impacts on rangelands/pasture:

Howden, S. M., McKeon, G. M., and Reyenga, P. J. (1999). "Global change impacts on rangelands." Working paper series 99/09, CSIRO Wildlife and Ecology, Canberra.

<http://www.cse.csiro.au/publications/1999/rangelands-99-09.pdf>

Dairy cattle:

Jones, R. N., and Hennessy, K. J. (2000). "Climate change impacts in the Hunter Valley: A risk assessment of heat stress affecting dairy cattle." CSIRO Atmospheric Research, Aspendale.

http://www.dar.csiro.au/publications/jones_2000a.pdf

Temperate forests:

McMurtie, R., and NGAC Project Team. (1999). "What are the likely implications of climate change for future forest production?" Impacts of global change on Australian temperate forests, S. M. Howden and J. T. Gorman, eds., Working paper series 99/08, CSIRO Wildlife and Ecology, Canberra.

<http://www.cse.csiro.au/publications/1999/temperateforests-99-08.pdf>

Fire**Climate change and fire weather:**

Hennessy, K., Lucas, C., Nicholls, N., Bathols, J., Suppiah, R., and Ricketts, J. (2005). "Climate change impacts on fire-weather in south-east Australia." Climate Impacts Group, CSIRO Marine and Atmospheric Research and the Australian Government Bureau of Meteorology, Aspendale.

Soon to be published - check the Climate Impact Groups website at

<http://www.dar.csiro.au/impacts/consult.html>

Fire and forests:

Noble, I. R. (1999). "Impacts of global change on Australian forests: fire." Impacts of global change on Australian temperate forests, S. M. Howden and J. T. Gorman, eds., Working paper series 99/08, CSIRO Wildlife and Ecology, Canberra.

<http://www.cse.csiro.au/publications/1999/temperateforests-99-08.pdf>

Biodiversity**General climate change:**

Howden, M., Hughes, L., Dunlop, M., Zethoven, I., Hilbert, D. W., and Chilcott, C. (2003). "Climate change impacts on biodiversity in Australia. Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October, 2002." CSIRO Sustainable Ecosystems, Canberra.

<http://www.deh.gov.au/biodiversity/publications/greenhouse/>

Impacts on alpine biodiversity:

Green, K. (2003). "Impacts of global warming on the Snowy Mountains." Climate change impacts on biodiversity in Australia. Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October, 2002., M. Howden, L. Hughes, M. Dunlop, I. Zethoven, D. W. Hilbert, and C. Chilcott, eds., CSIRO Sustainable Ecosystems, Canberra.

<http://www.deh.gov.au/biodiversity/publications/greenhouse/>

Coasts and marine**CSIRO's reports for the Gippsland Coastal Board:**

McInnes, K. L., Abbs, D. J., and Bathols, J. A. (2005a). "Climate change in Eastern Victoria, stage I report: The effect of climate change on coastal wind and weather patterns." CSIRO Atmospheric Research, Aspendale.

http://www.cmar.csiro.au/e-print/open/mcinnnes_2005a.pdf

McInnes, K. L., Macadam, I., Hubbert, G. D., Abbs, D. J., and Bathols, J. (2005b). "Climate change in Eastern Victoria, stage II report: The effect of climate change on storm surges." CSIRO Atmospheric Research, Aspendale.

http://www.cmar.csiro.au/e-print/open/mcinnnes_2005b.pdf

Climate change and the Gippsland Lakes:

Bird, E. (2002). "The effects of a rising sea level on the Gippsland Lakes." Gippsland Lakes Shore Erosion & Revegetation Strategy, E. Sjerp, B. Martin, P. Riedel, and E. Bird, eds., Gippsland Coastal Board, Bairnsdale.

<http://www.gcb.vic.gov.au/shorestrategy.pdf>

Alpine

Climate change impacts on snow:

Hennessy, K., Whetton, P., Smith, I., Barthols, J., Hutchinson, M., and Sharples, J. (2003). "The impact of climate change on snow conditions in mainland Australia." CSIRO Atmospheric Research, Aspendale.

http://www.greenhouse.vic.gov.au/impacts/The_Impact_of_Climate_on_Snow_Conditions.pdf

Socio-economic impacts

Climate change and human health:

McMichael, A., Woodruff, R., Whetton, P., Hennessy, K., Nicholls, N., Hales, S., Woodward, A., and Kjellstrom, T. (2003). "Human health and climate change in Oceania: A risk assessment 2002."

Commonwealth Department of Health and Ageing, Canberra.

[http://www.health.gov.au/internet/wcms/Publishing.nsf/Content/health-publth-publicat-document-metadata-env_climate.htm/\\$FILE/env_climate.pdf](http://www.health.gov.au/internet/wcms/Publishing.nsf/Content/health-publth-publicat-document-metadata-env_climate.htm/$FILE/env_climate.pdf)

Ross river virus and climate:

Kelly-Hope, L. A., Purdie, D. M., and Ky, B. H. (2004). "Ross River virus disease in Australia, 1886-1998, with analysis of risk factors associated with outbreaks." *Journal of Medical Entomology*, 41(2), 133-150.

<http://pcwww.liv.ac.uk/~hranson/Kelly-Hope2004.pdf>

Economic costs of natural disasters:

Bureau of Transport Economics. (2001). "Economic costs of natural disasters in Australia." Bureau of Transport Economics Report no. 103, Canberra.

<http://www.btre.gov.au/docs/reports/r103/r103.aspx>

Impacts on road infrastructure:

Harvey, M., Whetton, P., McInnes, K. L., Cechet, B., McGregor, J. L., Nguyen, K., Houghton, N., Lester, C., Styles, E., Michael, N., Martin, T., Heaney, A., Beare, S., and Norwell, G. (2004). "Impact of climate change on road infrastructure. Austroads, Report no. AP-R243/04." Austroads and the Bureau of Transport and Regional Economics, Sydney.

http://www.onlinepublications.austroads.com.au/script/Details.asp?DocN=AR0000048_0904