Garnaut Climate Change Review

Impact of climate change on Australia’s alpine areas

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Contents

1 Introduction

On 30 April 2007 Professor Ross Garnaut was commissioned by Australia's State and Territory Governments to undertake an independent study titled the Garnaut Climate Change Review (GCCR).

This review examines the impacts of climate change on the Australian economy and recommends medium to long-term policies to achieve sustainable prosperity and address key climate change issues.

The Terms of Reference provided by the States and Territories require the GCCR to report on:

> 1) The likely effect of human induced climate change on Australia's economy, environment and water resources in the absence of effective national and international efforts to substantially cut greenhouse gas emissions;
>
> 2) The possible ameliorating effects of international policy reform on climate change and the costs and benefits of various international and Australian policy interventions on Australian economic activity.

To achieve this, the GCCR Secretariat, established to facilitate the review, proposes to undertake an assessment of the impacts of climate change on a range of infrastructure types. Maunsell Australia Pty Ltd (Maunsell) was engaged by the Secretariat to identify and assess the impacts of climate change on Australia's alpine areas.

The purpose of this report is to qualitatively describe the impacts of climate change on Australia's alpine areas and to provide further technical information relating to assumptions made while developing the matrix of impacts.

2 Australian alpine areas

The alpine environment in Australia constitutes approximately 0.2% of the total land mass. Australia's alpine region exists along the south eastern mountain ranges of New South Wales (NSW) and Victoria and in the Central Plateau of Tasmania. The alpine areas range in altitude from 1,200m in Tasmania to 1,850m in NSW (Crowden, 1999).

Climate change is recognised as having a diverse range of potential impacts on the Australian alpine and subalpine species whose dynamics are controlled by temperatures that are particularly sensitive to climate change. Alpine temperature data at four sites over the past 35 years reveals that warming trends are slightly greater at higher elevations (Hennessy, 2003) and are therefore more likely to impact significantly upon the ecological diversity of these sensitive environments (DECC, 2008) and the associated human activity undertaken in these areas. Annual average precipitation has decreased over most of eastern Australia since 1950; leading to a decrease over the southern Alps and an increase over the northern Alps (Hennessy, 2003 p. 11). Consequently, 'global warming impacts on alpine precipitation (i.e. the amount of rainfall and snow), and its impacts on the flora and fauna, and ecosystem functioning are expected to be among the first quantifiable indications of climate change' (Good, et al, 2004).

The combined economic benefit of the alpine resorts across NSW, Victoria and Tasmania comprised an additional $1,319 million of gross state product in 2005 (Alpine Resorts Co-ordinating Council (ARCC), 2006). The quality of snow cover over the duration of the season reflects the number of visitors to the resorts; consequently, climate change has the potential to significantly impact upon the snow industry's viability (ARCC, 2006).

3 Climate change information

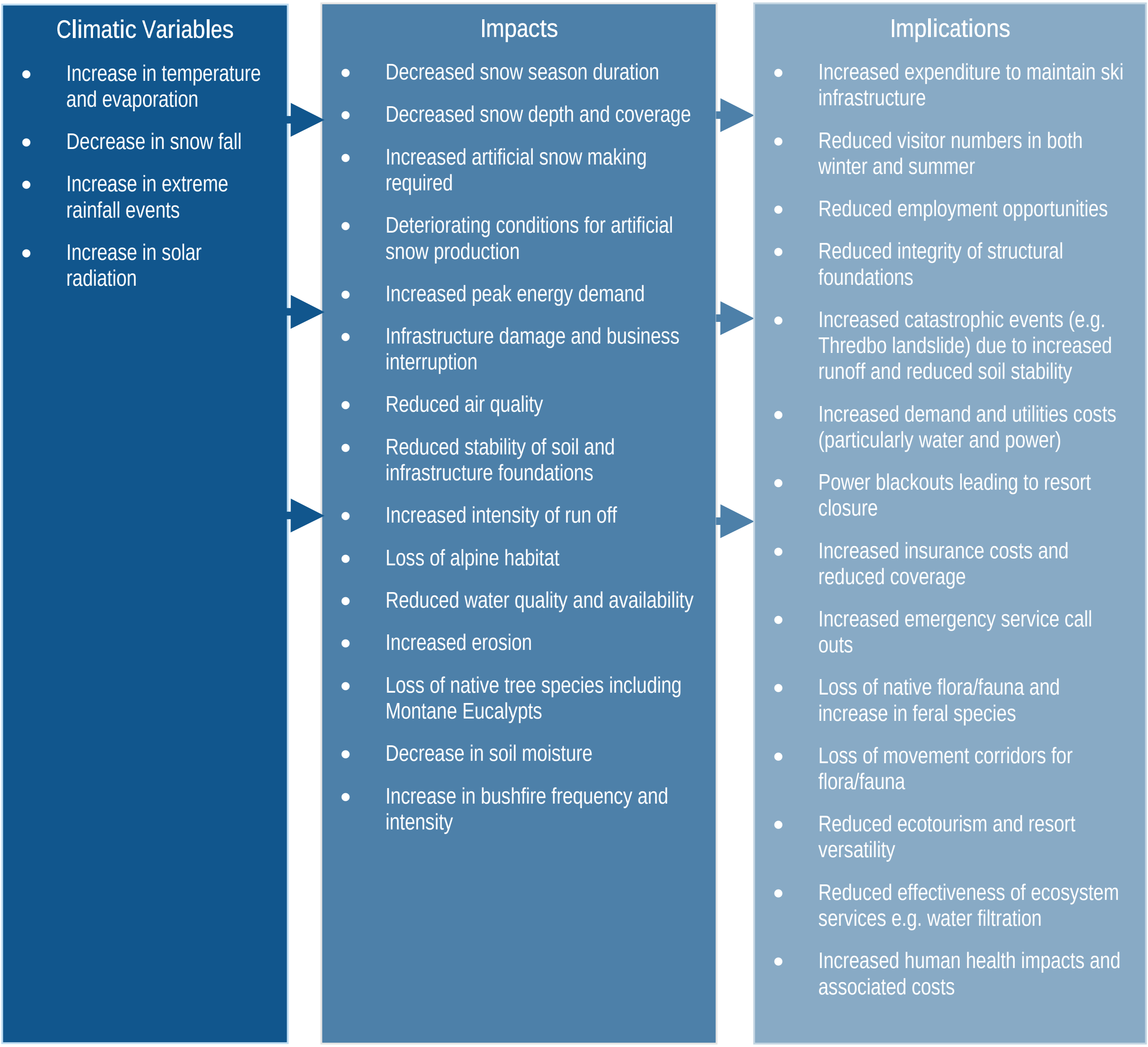
Seven climate change scenarios were used to assess the impacts on alpine areas. The climate scenarios are as follows:

- ‘Business as usual’ scenarios
  - **Unmitigated Scenario 1 (U1).** Hot, dry, business as usual scenario, using A1FI emission path, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.
  - **Unmitigated Scenario 2 (U2).** Best estimate (median) business as usual scenario using A1FI emissions path, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.
  - **Unmitigated Scenario 3 (U3).** Warm, wet business as usual scenario under A1FI emissions path, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.
- Strong mitigation scenarios
  - **Mitigation Scenario 1 (M1).** Dry mitigation scenario where stabilisation of 550ppm CO_2 equivalent (CO_2 stabilised at 500ppm) is reached by 2100, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.
  - **Mitigation Scenario 2 (M2).** Best estimate (median) mitigation scenario where stabilisation of 550ppm CO_2 equivalent (CO_2 stabilised at 500ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.
  - **Mitigation Scenario 3 (M3).** Wet mitigation scenario where stabilisation of 550ppm CO_2 equivalent (CO_2 stabilised at 500ppm) is reached by 2100, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.
  - **Mitigation Scenario 4 (M4).** Best estimate (median) strong mitigation scenario where stabilisation of 450ppm CO_2 equivalent (CO_2 stabilised at 420ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia), 50th percentile temperature surface. Mean global warming reaches ~1.5°C in 2100.

4 Summary of climate change impacts

Figure 1 outlines the impact storyline identified for alpine areas. This storyline was assessed against climate conditions considered in the seven climate scenarios U1, U2, U3, M1, M2, M3 and M4 to develop the matrix of impacts for each alpine area in Victoria, NSW and Tasmania.

Figure 1 Impacts storyline for alpine areas



Key climate change impacts on alpine areas include:

- reduced maximum snow depths
- reduced ski season lengths
- regional extinction and redistribution of flora and fauna due to changing snow conditions and increased temperature.

The economic implications of these impacts on the alpine areas of Australia include the potential for reduced viability of resorts, particularly those at lower elevations as snow coverage decreases with the rising snowline (Hennessy, 2003 p. 16). An increase in climatic related events such as storms, land slides and bushfires is likely to occur placing additional stress on infrastructure. The climatic changes will impact upon the alpine biodiversity, creating flow on impacts upon eco-tourism numbers as landscapes are degraded and the alpine areas are reduced with the uphill migration of species (DECC, 2008). The combined impacts of climate change are likely to reduce the revenue generated in alpine areas, leading to a reduction in the viability of alpine communities. A 1998 survey by three NSW ski resorts found that if there was little natural snow Australian ski resorts would lose 44% of their skiers, mostly to overseas resorts, particularly New Zealand (Pittock, 2003).

Table 1 provides a summary of the impacts for each climate scenario across the three time scales assessed; 2030, 2070 and 2100. The most significant impacts are anticipated to occur under the U1, U2 and U3 climate scenarios in the 2071-2100 timeframe.

Table 1 Summary of magnitude of impacts on alpine areas for seven climate scenarios

	2008–2030	2031–2070	2071–2100
U1	Low to Moderate	Extreme	Extreme
U2	Low to Moderate	Extreme	Extreme
U3	Low to Moderate	High to Extreme	Extreme
M1	Low to Moderate	Low to Moderate	Moderate
M2	Low to Moderate	Low to Moderate	Low to Moderate
M3	Low to Moderate	Low to Moderate	Low to Moderate
M4	Low to Moderate	Low to Moderate	Low to Moderate

5 Climate change impact storyline

The impact storyline identified for alpine areas as described in Figure 1 will place demands on capital and operational expenditure to mitigate against the effects of climate change to maintain current operations (and revenues) over the given time period. Table 2 outlines the magnitude of impacts on the three alpine areas for the seven climate scenarios.

Table 2 Magnitude of impacts on alpine areas for seven climate scenarios

Timeframe 2008 - 2030							
Climate Scenario	**U1**	**U2**	**U3**	**M1**	**M2**	**M3**	**M4**
VIC	M	M	M	M	M	M	M
NSW	M	M	M	M	M	M	M
Tas	L	L	L	L	L	L	L

Timeframe 2031 - 2070							
Climate Scenario	**U1**	**U2**	**U3**	**M1**	**M2**	**M3**	**M4**
VIC	E	E	E	M	M	M	M
NSW	E	E	E	M	M	M	M
Tas	E	E	H	L	L	L	L

Timeframe 2071 - 2100							
Climate Scenario	**U1**	**U2**	**U3**	**M1**	**M2**	**M3**	**M4**
VIC	E	E	E	M	M	M	M
NSW	E	E	E	M	M	M	M
Tas	E	E	E	M	L	L	L

The impacts are a combination of increased capital and operational expenditure and lost revenue over the given time period. Table 3 outlines the scale used to assess the magnitude of impacts.

Table 3 Scale of impacts

	Magnitude of net impact	Description of impact
N	Neutral	No change in, capital expenditure, operational expenditure or net revenues. Alpine flora and fauna capable of adaptation.
L	Low	Minor increase in capital expenditure and operational costs but no significant change to cost structure of industry. Low impact to alpine flora and fauna. For example, minor increase in operational costs associated with maintaining alpine infrastructure.
M	Moderate	Moderate increase in capital expenditure, operational expenditure with a minor change to cost structure of industry. Moderate impact to alpine flora and fauna. For example, moderate increase in capital and operational expenditure for alpine infrastructure due to increased design standards, maintenance regimes and artificial snow making.
H	High	Major increase in capital and operational expenditure with a significant change to cost structure of industry. High impact to alpine flora and fauna. For example, major increase in reliance on artificial snow making.
E	Extreme	Extreme increase and major change to cost structure of industry with an extreme increase in operational and maintenance expenditure. Significant extinction of alpine flora and fauna. For example, extreme impact on alpine industries as revenues from snow season decline along with revenues that once arose from non-snow related tourism relying on unique alpine flora and fauna.

5.1 Business as usual scenarios

The business as usual climate change scenarios provided by the CSIRO on behalf of the Garnaut Climate Change Review Secretariat and considered in the alpine areas storyline are discussed below.

U1 Hot, dry reference scenario—A1FI emissions path, 3°C climate sensitivity, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches 4.5°C in 2100.

The ‘hot and dry’ scenario adopts a ‘business-as-usual’ approach to greenhouse gas emissions, therefore assuming the highest level of temperature increase, along with the greatest decline in rainfall and relative humidity. With this level of emissions mainland Australia experiences a 1°C temperature increase by 2030 and generally exceeds 5°C by 2100. Varying in different regions, rainfall mostly decreases across the country, particularly in the southern regions, in which Australia’s alpine areas are all located.

The A1FI emissions scenario, upon which U1 is based, describes a ‘future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are a convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income’ (IPCC SPM 2007). U1 has a fossil fuel-intensive technological emphasis. It is with this guide that these ‘business-as-usual’ developments are based.

Currently there is no climate change modelling data available for the alpine areas. Consequently, the magnitude of change modelled for Canberra has been used as this is the Australian capital city that most closely resembles the likely alpine climate. Additionally the city is in closer proximity than other capital cities to many of the alpine areas, particularly those in NSW. However, it is noted that the actual levels of temperature, rainfall and humidity modelled for Canberra will vary from those experienced in the alpine areas, in particular due to the discrepancy in altitude. Canberra is located approximately 1,000 metres below the majority of alpine areas, however Hennessy notes warming trends are slightly greater at higher elevations (2003).

The U1 scenario has a more substantial impact upon alpine areas than the U3 scenario, due to the higher temperature increase coupled with decreased precipitation and relative humidity. The U1 climate scenario would likely reduce both the natural and anthropogenic capacity for snow production in association with an increased rate of snow melt, particularly at lower elevations, leading to both a thinning and retreating snowline (Hennessy, 2003).

A wet bulb temperature (a combination of ambient air temperature and humidity) of -2°C or below is generally needed for snowmaking based on current technology (Hennessy, 2008). Natural snow requires similar conditions. However, snow can be made at higher ambient temperatures if the humidity is low. Technological improvements are now allowing snow making to occur at higher temperatures (Mt Buller, 2008). The ski industry is confident that continual technological advancement will facilitate snow making in increasingly hostile conditions (Australian Ski Areas Association, 2008). It is likely ongoing upgrades of snow making technology to keep pace with declining conditions would impact capital costs.

In the U1 scenario, based upon CSIRO climate modelling, the average temperature in the alpine regions (based on data for Canberra) is likely to increase by approximately 1°C by 2030, 3.8°C by 2070 and 5.7°C by 2100 (CSIRO, 2008). The current wet bulb temperatures, based upon 2003 CSIRO data, show there were 630 hours below -2°C at Thredbo (elevation 1,340m) and at Mt Buller (elevation 1,720m) approximately 725 hours between May and September (Hennessey, 2003). Consequently, it can be seen that the modelled temperature increase by 2030 will significantly reduce the number of hours during which natural and anthropogenic snow making could potentially occur, without technological improvements.

In 2003, CSIRO developed scenarios for alpine areas for 2020 and 2050. The high impact scenario used the highest projected warming with the highest estimate of decreased precipitation as outlined in the U1 scenario. Under this scenario, the length of the snow season in 2020 reduced by between 39 and 60%. By 2020 average season lengths are anticipated to reduce by between 30 and 40 days. By 2050 the CSIRO modelling indicates reductions in the snow season of between 85 and 96% (Hennessy, 2003). In addition to reduced snow coverage (as precipitation reduces and snow melt increases with the hotter climate) there will be a dramatic reduction in snow depth in the U1 scenario.

In order for resort operators to remain viable, adaptation strategies must be undertaken particularly at resorts located at lower elevations where the impacts are likely to be most significant and immediate due to the higher existing ambient temperatures. Sites located at higher elevations such as Mt Hotham, could have a reduction in season duration of about 25% by 2020, however, at greater risk are resorts located at lower elevations, such as Mt Baw Baw, with reductions in the region of up to 60% anticipated (Hennessy, 2003).

There is already a heavy reliance on snow making in Australia's alpine resorts. Mount Buller, located at a higher elevation than the majority of Australian resorts relied on snowmaking to maintain the primary ski run, Bourke Street. As a result Bourke Street was open for skiing for 107 days during the 2001 snow season. It is estimated that without snowmaking Bourke Street would have been open for only 27 days (Mt Buller, 2008). The impact on snow availability within resorts and reliance on snow making is evident at Thredbo Resort in NSW. During the 1970s the resort had an average of 6 days per year in which it was possible to ski unimpeded from the top to the bottom of the resort; during 1997 it was possible to ski from the top to the bottom of the resort for 100 days (Australian Ski Areas Association, 2008).

Advancements in technology may ensure that ski runs remain open. However, anthropogenic snow is generally less attractive to skiers, due to it being wetter when produced and then solidifies on contact with the ground (ARCC, 2006). This process allows the snow to stick together more easily and remain compact for longer, as opposed to the fresh natural snow 'powder', which is generally softer. This may have an adverse effect on injuries. In addition to making snow, resorts have the capacity to manipulate the existing snow through grooming or fencing (ARCC, 2006). However, the potential for snow making, grooming and fencing will be reduced by climate change as there will be significantly less available snow to manipulate due to both decreased precipitation and increased melting.

While snow making may prolong the ski season and its associated ‘economy’, the use of increasingly intensive snow management techniques is likely to have a negative impact upon the flora and fauna (Green & Pickering, 2002). Mosimann (in Mannion, 1991) discussed three key impacts of snow management techniques; erosion, sediment deposition and landslides. These impacts would reduce the amenity of the landscape; deterring summer visitors who are currently being encouraged by the ski resorts to visit outside of the snow season.

An alternative strategy to the use of snow guns is cloud seeding to increase precipitation. Cloud seeding has been undertaken by the NSW Government. However, in the opinion of director Keith Muir, Director of the Colong Foundation for Wilderness, the additional rain created by the process could lead to snow-dependent animals, like the Mountain Pygmy Possum, freezing to death when rain produced by cloud seeding washes away the insulating winter blanket of snow in marginal areas (Bullinger, 2008). Consequently, measures undertaken to maintain ski resort viability could further degrade the alpine environment for native species.

In addition to climatic conditions reducing the capacity for snow at the resorts, the reduced precipitation occurring in the U1 scenario will limit water entering the storage reservoirs located at the resorts that supply the water for snow making. Under the U1 scenario it is projected there will be a 10% reduction in rainfall by 2030, a 30% reduction by 2070 and a 45% reduction by 2100 based on modelling for Canberra. If these reservoirs fail it would still be possible to pump water up to the resorts, however, the associated energy costs would be significant and limit the water available for other uses i.e. environmental flows and human consumption.

Hotter days will increase the demand for power and water (Hennessy, 2003) due to the increased use of air conditioning systems during the summer periods as opposed to the current passive cooling systems used during the summer. It is during this period that alpine resorts aim to attract additional visitors to compensate for lost revenue during the snow season. This summer tourism will be primarily based upon the unique alpine landscape. The increased use of an energy intensive systems approach to temperature regulation creates a greater energy demand leading to raised operating costs and potentially subsequent greenhouse gas emissions pending the energy source (i.e. non-renewable vs. renewable).

Hot and dry periods are conducive to bushfire events (DECC, 2008). As the climate becomes hotter and drier it can be expected that these events will increase in frequency, however, it is noted that the intensity of fires may eventually be reduced due to more frequent fire events limiting the build up of fuel. Bushfires have the potential to reduce visitor numbers during the event due to safety and health related concerns, including reduced air quality and exposure to the fire. Once the fire has burnt out, the landscape loses much of its character, comprised of the topography, flora and fauna that attract many visitors (Mason, 2008).

Tourism Victoria estimates that as many as a third of the visitors to the alpine regions enjoy the resorts outside the traditional snow season (DSE, 2004a) a factor that may be impacted by the threat of fires. The increase in the intensity and predictability of events such as bushfires and landslides may raise insurance premiums as claims become more common place and expensive. In conjunction with reduced visitation numbers, the resorts will likely incur increased maintenance and repair due to fires, increased insurance premiums and potentially be unable to secure insurance for certain activities; further reducing their potential profit.

Fires have the potential to destroy community facilities, depriving small towns of essential services that are costly to replace. Furthermore there is the possibility that as employment is reduced, local people will need re-training with new skills. These factors will place increasing pressure on government resources at a local level at a time when economic returns are already diminishing in these areas due to a potential reduction in visitation to the resorts which are key local and state economic drivers (DSE, 2004b). In some cases alpine towns that rely predominantly upon the snow industry may no longer be viable and migration of residents may occur resulting in stranded infrastructure.

As temperature increases during the extended dry periods projected for U1, groundwater would be reduced leading to a drying out of the soil (Mason, 2008). Reduced levels of soil moisture could alter the areas geomorphology (DECC, 2008), potentially impacting upon the structural integrity of resort infrastructure including communications towers and ski lifts in addition to the integrity of buildings. The integrity of foundations may be compromised by increased ground movement, bushfire and/or reductions in ground water, affecting the chemical structure of foundations, causing more rapid fatigue from extreme weather events (CSIRO, 2007). When intense precipitation events do occur there is increased potential for landslides, due to the destabilising effect created by the dry periods.

The reduced, and in some cases complete loss, of snow coverage in some areas in conjunction with rising temperatures and reduced precipitation will substantially alter the biotic composition of the alpine landscape (DECC, 2008). Changes in the diversity and abundance of plants and animals may be particularly severe due to the minimal area of true alpine habitat, and therefore the limited availability of high altitude refuge. The latter may disappear altogether under the U1 scenario with devastating effects on some alpine species (Green et al, 2002).

The ecosystems of high mountain environments, whose dynamics and functionality are controlled by low-temperature conditions, are considered to be particularly sensitive to climate change and global warming (Green et al, 2002). The thermal life zones of alpine/mountain environments are compressed and their temperature-determined ecotones[1] are narrow, compared with their horizontal/latitudinal transition zones. The modelled changes in the climate are unlikely to occur gradually as depicted by trend lines; rather, changes will take place erratically in many cases, causing major shocks. Erratic changes in the climate will provide natural and human systems with less time to develop adaptive strategies and therefore increase the possible impacts upon these systems. Given the 2°C temperature band in which trees such as the Montane Eucalypt can exist, the temperature increase under U1 is likely to force this species to higher elevation and potentially threaten its viability.

Williams et al (2003) state that it is likely that there will be both positive and negative impacts on the flora, with increases in the occurrence and distribution of several dominant plant communities (tall alpine herbfield, heathland and sod-tussock grassland). As a consequence, decreases in the much smaller areas of the more sensitive communities, particularly short alpine herbfield groundwater communities (including fens, bogs and peatlands), that are of particular significance for catchments. Williams et al (2003) advise these groundwater communities have a number of significant functions including regulating water flow and filtering minerals and organic debris (Williams, Mansurgh, Wahren, Rosengren, & Papst, 2003). The reduction of these areas has the potential to reduce the capacity of natural systems to filter water running from the catchments into reservoirs, leading to diminished water quality.

Over one million people visit the alpine resorts each year. As many as a third of these visitors enjoy the resorts outside the traditional snow season. During 1999–2000 Mount Buller received approximately 350,000 visitors during the snow season and 133,000 outside of this period while Falls Creek received approximately 180,000 snow season visitations and 101,000 non-winter visitors (DSE, 2004a). Participation in a broader range of non-winter alpine experiences is growing. Non-winter visitation to the resorts has at least doubled over the last decade, while winter visitation to the resorts is stable. This is a global trend as recreation choices expand. Mount Stirling is the only Victorian alpine resort to experience greater visitation over the non-winter period than during winter.

The loss of biodiversity has the potential to impact upon the viability of tourist facilities within the alpine areas as many visitors, particularly outside the snow season, come to appreciate the alpine ecosystems. Additionally the loss of flora, particularly trees that have very narrow temperature bands in which they thrive, will reduce the visual amenity of the land (Mason, 2008). As the alpine areas warm and snow cover diminishes, the native alpine species will lose their competitive advantage held over non-alpine species that were previously unable to populate these areas (DECC, 2008). This will result in the further reduction of native species. The combination of these events may reduce the appeal of these areas for a range of visitors, significantly impacting upon visitation numbers.

Hydroelectric schemes have been constructed in the alpine areas of all three states with the Snowy River Scheme in NSW being the largest. The reduced amount of rainfall envisaged by the U1

[1] Ecotones refer to a transitional area between two adjacent ecological communities.

scenario is likely to reduce the economic viability of these large facilities as less water is available to flow through them.

U2 Unmitigated Scenario 2—Best estimate (median) business as usual scenario using A1FI emissions path, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.

The U2 scenario is most closely related to U1 due to the modelled reduction in rainfall. However, the drying and humidity is less extreme than U1 as is the temperature increase. The temperature increase and evaporation is the same as U3.

Compared to the projected impacts under the U1 scenario, the impacts projected under the U2 storyline are similar up to 2030. During the remainder of the century the spread of the impacts is anticipated to be similar to U1 although the magnitude or severity is anticipated to be less primarily due to the lower reduction in rainfall and humidity. The comparatively higher levels of rainfall in the U2 scenario is likely to ensure that there is still water to produce snow by artificial means and the reduced evaporation levels will ensure that ablation is not so significant (Hennessy, 2003). However, it is likely that the 3.2°C by 2070 and 4.7°C by 2100, as predicted for the Canberra climate, is 'likely to decrease the ratio of snow to rain in each precipitation event which is expected as the climate warms i.e. precipitation will tend to fall as rain rather than snow' (Hennessy, 2003 p. 26). This scenario is expected to result in low to moderate economic impacts to 2030, and extreme economic impacts by 2070 and 2100.

Under the U2 scenario mainland Australia experiences a gradual increase in temperature. Between 2030 and 2070 Canberra, along with all the capital cities, exceeds a 2ºC increase. Rainfall decreases in most of the country, with the exception being Greater Hobart and Darwin; the minor changes in precipitation in Hobart are likely to mitigate the impacts of increased temperatures to a certain extent.

As with U1, this scenario leads to a reduction in soil moisture and therefore ground movement, which has the potential to impact on both alpine infrastructure and slope stability (DECC, 2008); particularly in Victoria which is already experiencing greater reductions in precipitation levels comparative to the other alpine areas. The smaller reductions in precipitation in the U2 scenario, as opposed to the U1 scenario, is likely to reduce the bushfire events and erosion of alpine areas created by a drying out of the soil and vegetation. This will ensure that the natural environment is not degraded to the extent that it would be in the U1 scenario, maintaining some appeal for visitors. However, given the 2°C temperature band in which trees such as the Montane Eucalypt can exist, the temperature increase under U2 is likely to force this species to higher elevation and potentially threaten its viability.

U3 Warm, wet reference scenario—A1FI emissions path, 3°C climate sensitivity, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches 4.5°C in 2100.

The U3 scenario will reduce the natural and anthropogenic potential for snow, however due to the levels of precipitation and humidity being higher, it will not be as great as during the U1 or U2 scenarios. Rainfall is projected to rise by approximately 2.2% by 2030, 8.1% by 2070 and 11.9% by 2100. Humidity will rise marginally over these time periods in the U3 scenario. Although temperatures are between 0.5 and 1°C lower snow cover will still be reduced, particularly at lower elevations, due to the rising temperature which follows a similar warming to the U1 scenario. This process has already started to occur across the alpine areas of Australia.

In the U3 scenario there is the potential for increased storm events and winds created by the large temperature gradients and potentially high humidity. This combination of factors would lead to blizzards of increased severity, particularly at higher elevations where natural snow fall will still be viable.

The variable nature of increased precipitation during storm events has the potential to create landslides through large amounts of water falling onto the ground already destabilised by extended dry periods or experiencing loss of vegetation cover. The increase in storm events and the potential for catastrophic events such as landslides will lead to increased periods during which facilities will be closed, reducing revenue and degrading the visitor experience. Rainfall intensity is likely to increase during storm events allowing little time for natural and man-made systems to adapt which could lead to potential shocks and catastrophic events.

The increased precipitation is increasingly likely to fall as rain as opposed to snow. The simulated ratio of snow to rain was calculated for Mt Hotham and illustrates that with increasing temperatures the ratio declines (Hennessy, 2008). Increased heavy rainfall events have the potential to rapidly melt snow; consequently, the temperature gradient that leads to snowfall as opposed to rainfall contributes significantly to the area of snow cover (Australian Ski Areas Association, 2008).

The projected rise in temperature will lead to precipitation increasingly falling as rain and sleet as opposed to snow. The water contained as snow is released slowly creating a more graduated run off, except during periods of intense warming. Consequently, increased rainfall is likely to lead to more rapid runoff, both in terms of through flow and overland flow. Rapid runoff at high velocities will lead to increased erosion of the soil, denuding it of topsoil and flora. Once vegetation has been disturbed or removed, the alpine soils are very susceptible to erosion from wind, water and frost (Williams et al, 2003). Consequently, the soil quality and structure will become increasingly degraded.

The runoff process will become increasingly severe as flora is stripped from hill sides and its capacity for re-growth is diminished by increasingly poor soils. The erosion of the landscape, particularly on hills with sharp gradients raises the potential for landslides as stability is reduced while limiting biodiversity and the amenity of the land. These impacts will affect visitor numbers due to the reduced visual appeal of the land and the increase in potential catastrophic events leading to loss of life and property.

The rapid runoff and erosion associated with the U3 scenario has the potential to impact upon water quality both within the alpine areas and beyond, due to many of these areas contributing to the water catchments to service urban areas. The increased rate of run off and erosion will lead to increased debris and chemicals entering water supplies (Williams et al, 2003). Without upgrading the water treatment facilities there is the potential to have increased levels of health problems and the associated healthcare costs.

The occurrence of the range of impacts may create a loop of diminishing returns as visitors are increasingly dissuaded from going to Australia's alpine areas in favour of overseas destinations less affected by climate change.

5.2 Strong mitigation scenarios

The four climate change scenarios with mitigation provided by CSIRO, on behalf of the Garnaut Climate Change Review Secretariat and considered in the alpine areas storyline are discussed in turn below.

M1 Dry mitigation scenario where stabilisation of 550ppm CO_2 equivalent (CO_2 stabilised at 500ppm) is reached by 2100, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.

This scenario adopts a policy intervention that leads to a greenhouse gas emissions trajectory that stabilises atmospheric greenhouse gas concentrations at a level that constrains the temperature increase to 2.0°C in 2100; as compared to 4.5°C in 2100 under the reference scenario U1.

Under this scenario, the changes in rainfall (decline), humidity (decline), temperature (increase) and evaporation (increase) are similar to U1 until around 2030. From the middle of the century the M1 temperature and rainfall changes begin to level out. The temperature and rainfall changes modelled in U1 significantly outpace the M1 scenario after this time period. The M1 temperature increases at 2100 are reached in the middle of the century under the U1 scenario. The temperature and rainfall changes for M1 are approximately 55% of the U1 changes at 2070 and 40% of U1 at 2100. This scenario is anticipated to result in low to moderate impacts up to 2070 and moderate impacts up to 2100.

The reduced rate and level of temperature increase relative to the U1 scenario lessens the impact of increased extreme rainfall, flash flooding and associated landslides. The projected levels of rainfall and humidity in scenario M1 is anticipated to drop. However, the decrease is minimal comparative to scenario U1. Consequently, the snow coverage and depth is likely to reduce with the associated negative impacts as described under U1, although in comparison to the U1 scenario it will be minimised due to the lower temperature increases. The levels of snow in comparison to the U3 will be more difficult to forecast as temperatures will rise far less; however, rainfall and humidity will not rise as modelled in a U3 situation. Temperature driven storm energy in the climate system is likely to be reduced relative to U1 resulting in a comparative lessening of impacts due to storms and bushfires during this period.

The reduced snow coverage and warmer soils at higher elevations is likely to result in the alpine areas becoming suitable for lower altitude plant species to grow. The advancing tree-line upwards leads to alpine habitats becoming smaller even with the reduced temperature increases comparative to the U scenarios, thereby reducing the endemic alpine plants and animals to even smaller areas of land. These changes in the diversity and abundance of plants and animals may be particularly severe because of the minimal area of true alpine habitat and, therefore, the limited availability of high altitude refuge within Australia (Mason, 2008). The reduced alpine landscape has the potential to impact upon tourist numbers and therefore income generation for business that relies upon visitation associated with the unique environment.

M2 Best estimate (median) mitigation scenario where stabilisation of 550ppm CO_2 equivalent (CO_2 stabilised at 500ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.

The modelled M2 climate changes are similar to the U2 climate changes. For the M2 scenario, the changes in rainfall (decline), humidity (decline), temperature (increase) and evaporation (increase) are anticipated to be greater than U2 at 2030. From the middle of the century the M2 temperature and rainfall changes begin to level out. The temperature and rainfall changes modelled in U2, however, significantly outpace the M2 scenario after this time period. The M2 temperature increases at 2100 are reached in the middle of the century under the U2 scenario. The temperature and rainfall changes for M2 are approximately 55% of the U2 changes at 2070 and 40% of U2 at 2100. This scenario is anticipated to result in low to moderate impacts across all three time periods.

As with U2, this scenario leads to a reduction in snowfall and a raised snow line due to the reduced precipitation and increased temperatures. It is likely that given Hobart's much smaller decreases in rainfall and reduced temperature increases the Tasmanian alpine areas will experience a reduced impact comparatively to NSW and Victoria. However, it is likely that given the temperature increase of 2°C by 2100 the advancements in snow making technology currently occurring will allow the ski industry to continue to operate in its current locations, although operational costs are likely to increase due to the raised demand for utilities and increased extreme events such as avalanches and landslides impacting upon operational hours and infrastructure maintenance. However, the impacts on the flora and fauna are likely to be similar to scenario M1.

M3 Wet mitigation scenario where stabilisation of 550ppm CO_2 equivalent (CO_2 stabilised at 500ppm) is reached by 2100, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.

This scenario adopts a policy intervention that leads to a greenhouse gas emissions trajectory that stabilises atmospheric greenhouse gas concentrations at a level that will likely constrain the temperature increase to 2.0°C in 2100; as compared to 4.5°C in 2100 under the reference scenario U3. The scenario assumes an increase in temperature, along with an increase in rainfall and relative humidity.

Under this scenario, the changes in rainfall (increase), humidity (increase), temperature (increase) and evaporation (increase) are anticipated to be greater than U3 at 2030. From the middle of the century the M3 temperature and rainfall changes begin to level out. However, the temperature and rainfall changes modelled in U3 significantly outpace the M3 scenario after this time period. The M3 temperature and rainfall increases at 2100 are reached in the middle of the century under the U3 scenario. The temperature and rainfall changes for M3 are approximately 55% of the U3 changes at 2070 and 40% of U3 at 2100. This scenario is anticipated to result in low to moderate impacts across all three time periods.

The 2°C temperature increase and increased precipitation and humidity is likely to result in a maintenance of snow depth and coverage at the higher elevations. However, the alpine areas at lower elevations are likely to experience a loss of snow coverage as the snow line moves to higher elevations due to degraded conditions for snow production and increased snow melt and temperatures.

The limited increase in temperature coupled with small increases in humidity and rainfall are likely to limit the potential increase in bushfires. The dry conditions modelled in the U1 and M1 scenarios that lead to the drying out of the soil and vegetation are lessened by the increased levels of rainfall and likely temperature increases are reduced, further reducing the bushfire risk compared to U1 and M1.

The rise in temperature and increased rainfall and humidity is likely to lead to extreme rainfall events and the associated impacts upon alpine areas, however, the intensity and frequency is likely to be less than in an U3 scenario given the smaller climatic changes reducing storm energy.

M4 Best estimate (median) strong mitigation scenario where stabilisation of 450ppm CO_2 equivalent (CO_2 stabilised at 420ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia), 50th percentile temperature surface. Mean global warming reaches ~1.5°C in 2100.

This scenario is the ‘best-case’ of the group of scenarios assessed. The temperature and rainfall changes are modelled to stabilise around 2080 and begin to reverse toward 2100 therefore reducing the pressures generating increased storm related impacts. Of the scenarios that result in a decline in rainfall and relative humidity (scenarios U1, U2, M1, M2 and M4), this scenario would have the least impact of climate change induced reduced snow fall, coverage and depth in addition to less storm and bushfire events. This scenario is anticipated to result in low to moderate impacts across all three time periods.

This scenario is likely to result in the lowest level of climate change impacts on alpine areas over time with snow depth and coverage dropping only marginally. Under this scenario it is likely that alpine resorts could continue their current operations with minimal technological advance to aid adaptation. It is likely that the alpine flora and fauna would receive minimal impacts in relation to numbers and spatial distribution due to climate change.

6 Opportunities for adaptation

Snow making through the use of snow guns and grooming in the Australian Alps currently plays a critical role in keeping the industry viable by extending the season and quality of the snow surface. Based upon the CSIRO model, the average number of hours suitable for snow-making by snow guns declines by 17-54% for the U1 scenario, while the potential snow-making volume is reduced by 18-55% by 2020 leading to a massive increase in the required snow gun use (CSIRO, 2003).

The potential for snow making, grooming and fencing will be reduced by climate change particularly in the U1 and U2 scenarios as there will be significantly less available snow to manipulate due to both decreased precipitation and increased melting. However, technological advances may mitigate these impacts to a certain extent. Currently used examples include winch grooming machines that facilitate the maintenance of steeper and more difficult areas a thereby, significantly expanding useable terrain (Mt Buller, 2008).

As pressure grows on resort operators it can be expected that technology will be looked to in order to maintain the industry. Thus far operators have been innovative in their methods to maintain the industry's viability; however, as climate change impacts increase the associated costs will correspondingly grow. Future demand for snow making will be influenced by:

- fewer hours with temperatures cold enough for making snow
- less natural snow cover; faster ablation of snow
- possible water supply limitations
- increased demand for water and power.

An alternative strategy to snow making and grooming is the transfer from a purely snow related activity destination to four season uses. Current operations include spa/health resorts; education/research facilities; and active holidays with a program of events including walking and cycling. A recent study of winter visitors to the NSW alpine resorts demonstrated that the potential exists to redefine the use of Australia's alpine areas as 58% of visitors stated that they would consider visiting the resorts at other times of year (ARCC, 2006). It should be noted however that these areas have found building out of season visitation challenging and would likely continue to under U1 or U2.

7 Conclusion

The greatest magnitude of climate change impacts on alpine areas are anticipated to occur in the U1 scenario. The combined effect of increased temperature and reduced precipitation is projected to significantly impact on snowfall and ablation. These factors are likely to result in a reduced cover and depth of snow. The reduced snow cover will minimise areas for recreation and habitat for alpine dependent species. The denuded landscape and increased storm events associated with the U3 scenario will raise the potential occurrence of catastrophic events such as avalanches and landslips due to the higher intensity precipitation, particularly falling as heavy rain on ground containing less vegetation that can reduce overland and through flow of water.

Under the mitigation scenarios it is anticipated that resorts and native species are likely to be impacted by reduced snow cover to the greatest extent over the next 20 years. After this time impacts are expected to moderate as snow making and retention technologies improve and some species are able to adapt to the changing conditions. However, it is likely that resort operational costs will increase due to greater demand for power and water due to increased snow making. Under all scenarios certain species will be unable to adapt to the changes and their spatial distribution will be diminished with the shrinking alpine areas and increased competition for scarce resources.

8 Key assumptions

- Technology, particularly in relation to the resorts' snow making capacity is likely to continue to improve. However, it is assumed that these technological improvements will entail additional utility costs and higher capital costs.

- Damage costs, due to increased extreme events, may reach a threshold that warrants increased expenditure to achieve higher resilience standards and reduce vulnerability and remediation costs. This would reduce vulnerability to subsequent events.

- The impacts of reduced snow depth and coverage are already being felt by the snow tourism industry with snow making, grooming and fencing occurring on a regular basis. It is anticipated, based on CSIRO modelling for the U1 scenario, that the length of the snow season will be reduced by between 39 and 60% by 2020 (Hennessy, 2003). Also for U1, average season lengths are anticipated to be reduced by 30 to 40 days under the U1 scenario and by 2050 with reductions in the snow season of between 85 and 96%.

- Given that Mount Buller already had a modelled season length of 27 days for 2001 without the use of snow guns, future snow season length will need to be maintained through large scale snow gun use. This has been estimated at an increase of between 73-200% in the use of snow guns by 2020 on 2003 levels and the subsequent economic costs associated with this.

- It is envisaged that an increase in bush fires will occur within the time period leading up to 2030 as precipitation levels fall and temperature rises, leading to a drying out of vegetation (DECC, 2008). Additionally increased storm events and the associated lightning will provide a more frequent ignition for fires.

- It is anticipated that as snow coverage, perceived snow quality and depth decline, winter visitation numbers will fall based upon the sensitivity of tourists to snow coverage. Analysis illustrates that the quality of snow cover over the duration of the season reflects the number of visitors to the resorts; consequently, climate change has the potential to significantly impact upon the ski industry's viability (ARCC, 2006).

- A study of winter visitors to the New South Wales alpine resorts demonstrated that the potential exists to redefine the use of Australia's alpine areas as 58% of visitors stated that they would consider visiting the resorts at other times of year (ARCC, 2006). This may not necessarily translate to realised visitation.

- Seasonal snow cover is recognised as a major determinant of the faunal composition of the alpine areas. Consequently, temperature rises and reduced precipitation already occurring will reduce the distribution of alpine species. Faunal impacts are likely to be first seen in the decreased distribution and abundance of the alpine endemic Mountain Pygmy Possum and the Broad-toothed Rat, both of which have narrow environmental tolerances (Green, R & Pickering, C, 2002).

- It is unlikely that significant loss of tree species will occur in the short term. However, as temperatures increase further it is likely that the integrity of trees will be further reduced, given the 2°C temperature band in which trees such as the Montane Eucalypt can exist. The U3 scenario has the potential to prolong the life of vegetation due to the higher precipitation levels in comparison to U1. However, increased run off could reduce the stability and integrity of soil and floral cover, in addition to heavy rainfalls melting snow.

- The viability of infrastructure will be reduced as ground moisture decreases and snow coverage reduces, both in relation to ski infrastructure being located beyond the bounds of the snow covered areas and reduced soil stability impacting upon the integrity of structures. This will be particularly prevalent post 2050 in the U1 scenario.

9 Knowledge gaps

- Current CSIRO climate modelling is based upon Australia's major population areas. The alpine regions have particular climatic characteristics based primarily upon their increased elevations. A model based upon southern Australia's inland climate at higher altitudes would provide a more accurate picture of the likely impacts of climate change upon the alpine areas.
- There is currently a lack of information relating to the future intensity and frequency of storm events. These events have the potential to be particularly damaging to infrastructure in alpine areas which already experience high winds during storm events.
- Alpine resort operators are currently relying on technology advances to improve snow making capacity. The extent of technological advances in this area is not known, consequently, the future viability of alpine resorts relying on the snow is difficult to accurately forecast.
- There is little research into the long term biodiversity and water quality impacts of artificial snow making which often contains high salt levels.

10 Case studies

10.1 Case study 1: Impact on flora and fauna

This case study illustrates the changes in the diversity and abundance of plants and animals that will potentially occur as a result of climate change. Changes in Australia are likely to be particularly severe due to the limited scale of alpine habitat (Good, Green & Pickering, 2004) and the sensitivity of ecosystems of high mountain environments, whose dynamics and functionality are controlled by low-temperature conditions (Good et al, 2004).

Potential effects of global warming on the biota of the Australian alps

Australian Greenhouse Office, (Good et al, 2004)

The distribution of flora and fauna is expected to change under the influence of climate change due to the implications of snow conditions, depth and snowline on the distribution and persistence of biodiversity in the alpine area. The following subsections highlight some of these changes to Flora and Fauna.

Flora

Climate change may affect the distribution of the plant communities directly through changes in temperature and precipitation, and indirectly through the depth and distribution of snow cover. Climate change may also have indirect effects through resulting longer growing seasons, changes in prevailing soil moisture and changes in vegetative competition (Good 1998a; Pickering 1998). The response of vegetation to climate change will be influenced by the rate and degree of temperature and precipitation change.

Climate change models show that some native species will benefit from climate change by colonising areas from which other species or communities have been lost as a result of changed environmental conditions. Shrub species are particularly likely to expand in range, along with some herbs and grasses of the tall alpine herbfield. Given the 2°C temperature band in which trees such as the Montane Eucalypt can exist, the temperature increase under U1 is likely to force this species to higher elevation and potentially threaten its viability.

Fauna

Seasonal snow cover is recognised as a major determinant of the faunal composition of the sub-alpine and alpine areas. Faunal impacts are likely to be first seen in the decreased distribution and abundance of the alpine endemic Mountain Pygmy Possum and the Broad-toothed Rat, both of which have narrow environmental tolerances. The diversity and abundance of birds at a specified altitude may increase with increasing warming. However, research to date has been limited by small sample sizes. Little or no information is available in the literature on the possible responses of the alpine invertebrate populations and the soil fauna to climate change. These aspects require additional research.

The warming of the alpine regions resulting in declining snow cover may have a major impact upon the faunal composition of the alpine/subalpine areas with far greater access by feral animals, reducing the competitive advantage of the higher altitude species. As such, while possibly increasing the numbers of species this process may reduce the biodiversity through the loss or serious reduction of populations of endemic species. Such a loss would be very significant at a local, regional, national and international scientific level.

10.2 Case study 2: Ski resort adaptation strategies

Mt Buller—snow making

www.mtbuller.com.au (2008)

Snowmaking began on Mount Buller in the 1970s as a pilot scheme. The current snowmaking system is based around a central reservoir holding 70 million litres of water obtained from the Boggy Creek Catchment, a pump station and air compressor station. Water and air are distributed throughout the resort via pipelines located along the edge of the runs where the snow guns are coupled using flexible snowmaking hoses. There are currently 223 snow gun connection hydrants around the mountain, with 81 snowmaking guns, 57 fan guns and 58 air/water guns.

Large quantities of water and wet bulb temperatures (a combination of ambient air temperature and humidity) of -2°C or below are required for snow making. The system is coordinated by three weather stations that monitor temperature and humidity across the mountain. This data is then fed to a control station where it is used to commence snowmaking as temperatures drop.

Alternatives to snow making include physical measures such as grooming or fencing to retain and improve snow quality. Chemical measures such as cloud seeding are also being undertaken to attempt to increase precipitation. Results of this technology are highly debated.

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