# Climate response by the ski industry: the shortcomings of snowmaking for Australian resorts

## Author

Pickering, Catherine Marina, Buckley, Ralf C

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REPORT

# Climate Response by the Ski Industry: The Shortcomings of Snowmaking for Australian Resorts

**Catherine Marina Pickering, Ralf C. Buckley**

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**Abstract** Skier numbers, and revenues for the multi-billion-dollar ski industry, are highly sensitive to snow cover. Previous research projected that under climate change, natural snow cover will become inadequate at 65% of sites in the Australian ski resorts by 2020. Resorts plan to compensate for reduced snowfall through additional snowmaking. For the six main resorts, however, this would require over 700 additional snow guns by 2020, requiring ~US $100 million in capital investment, and 2,500–3,300 ML of water per month, as well as increased energy consumption. This is not practically feasible, especially as less water will be available. Therefore, low altitude ski resorts such as these may not be able to rely on snowmaking even for short-term adaptation to climate change. Instead, they are likely to seek conversion to summer activities and increased property development.

**Keywords** Climate change · Mountain tourism · Environmental sustainability · Australian Alps

## INTRODUCTION

Anthropogenic climate change is already affecting the climate of mountain regions worldwide, and much larger effects are projected (Intergovernmental Panel on Climate Change 2007). This includes higher temperatures and reduced precipitation for many alpine regions (Intergovernmental Panel on Climate Change 2007), including those in Australia (Green and Pickering 2002, 2009; Hennessey et al. 2003, 2008; Nicholls 2005). Snow-based tourism is a major industry (Scott and McBoyle 2007), with the Australian ski resorts worth ~US $725,000,000 in 2005 (NIEIR 2006). Reduced snow cover will affect most snow-based recreation, including skiing, snowboarding, snowshoeing, tobogganing and snowmobiling (Scott and McBoyle 2007). These effects have been examined in a range of Northern Hemisphere resorts (Scott and McBoyle 2007) including the Swiss Alps (König and Abegg 1997; Elsasser and Messerli 2001), Austria (Breiling and Charamza 1999), Sweden (Moen and Fredman 2007), the whole of the European Alps (Agrawala 2007), the north-eastern USA (Scott et al. 2008), Quebec (Scott et al. 2007), Ontario (Scott et al. 2003) and Japan (Fukushima et al. 2002). There is much less research in the Southern Hemisphere, including the Australian Alps, the main ski tourism destination in Australia (Hennessey et al. 2003, 2008; Galloway 1998). In this article, we examine the impact of climate change on Australian ski resorts, focussing on their capacity to utilize snowmaking to reduced natural snow cover.

## METHODS

We analyse the implications of potential climate change for ski resorts in Australia using publicly available information. Climate data, projections of climate change, visitation and financial data for resorts are much more limited in Australia than in Europe (Breiling and Charamza 1999; Sievänen et al. 2005; Agrawala 2007; Moen and Fredman 2007; Gonseth 2008; Vanham et al. 2008), North America (Scott et al. 2008; Shih et al. 2009) or Asia (Fukushima et al. 2002). Only four official snow courses are used for modelling snow cover in Australia, and measurements are taken only once every 2 weeks. Available data thus do not always cover the full period that snow is on the ground, and data are often missing. Even basic temperature data are limited, with few weather stations above 1,300 m considered to have reliable long-term (>20 years) data sets

(Hennessey et al. 2003, 2008). Ski resorts in Australia generally treat visitation data, income, expenditure, water and power consumption, and even snow-cover data as commercially confidential. This applies particularly for the privately-owned ski resorts in the state of New South Wales (NSW). Ski resorts in the state of Victoria (Vic) provide some relevant information in their annual reports (Alpine Resorts Co-coordinating Council 2007, 2008), because of compulsory public reporting requirements.

Our approach is as follows. Firstly, we assessed the effects of variation in natural snow cover on skier numbers over the nine ski seasons. Secondly, we compiled data on current snow-making by Australian ski resorts, including the value of current snow-making infrastructure. The principal source of such data is a recent report which models the impacts of climatic warming on snow conditions, with detailed projections of changes in natural snow cover (Hennessey et al. 2003, 2008). Thirdly, we calculate the number of snow guns, the water requirements, and the costs of snow guns and associated infrastructure for each of six Australian ski resorts under one 2020 climate change scenario. The infrastructure comprises pumps, pipes and water storage facilities. We calculated water requirements by converting snow volumes to water volumes using the same methods as in previously published climate-modelling calculations (Hennessey et al. 2003, 2008). Our estimates for the average costs of snow guns and associated infrastructure were calculated using June 2008 values, from the reported investment of US $13 million for 99 snow guns (Australian Ski Areas Association 2008). Australian dollar values (AUD) were converted to United States dollars (USD) at the exchange rate applying at that time, namely 0.8.

## SKIING IN AUSTRALIA

In Australia, regular snow is limited to the Australian Alps and small areas in Tasmania (Fig. 1). Only 5,000 km$^2$ (0.15%) of the mainland regularly experiences any snow cover persisting for more than a month each year, and $<3$ km$^2$ of this lies within existing ski resorts. There are 10 main resorts currently operating in the Australian Alps (excluding Tasmania), ranging from 1,520 to 2,054 m in altitude (Table 1). Revenues in 2005 totalled $\sim$US $725 million (AU $906 million), from just under three million visitor days (Australian Ski Areas Association 2008). Most of the Australian Alps lies within national parks, and the resorts are all within or adjacent to these parks. The ski season extends nominally between two particular public holidays, a period of 113-120 days, but, the actual season is much shorter, as outlined below.

Snow cover in Australian ski resorts is generally much lower than in Northern Hemisphere resorts, which are at higher altitudes or higher latitudes (König 1998; Fukushima et al. 2002; Moen and Fredman 2007; Scott and McBoyle 2007; Scott et al. 2008). This applies whether snow cover is measured using duration, maximum depth or cumulative snow cover for the whole season. The mean maximum snow depth for the four main snow courses in the Australian Alps during the last 55 years ranged from $\sim$0.55 m at 1,460 m altitude, to $\sim$2.2 m at 1,830 m

**Fig. 1** Location of ski resorts in the Australian Alps in mainland Australia

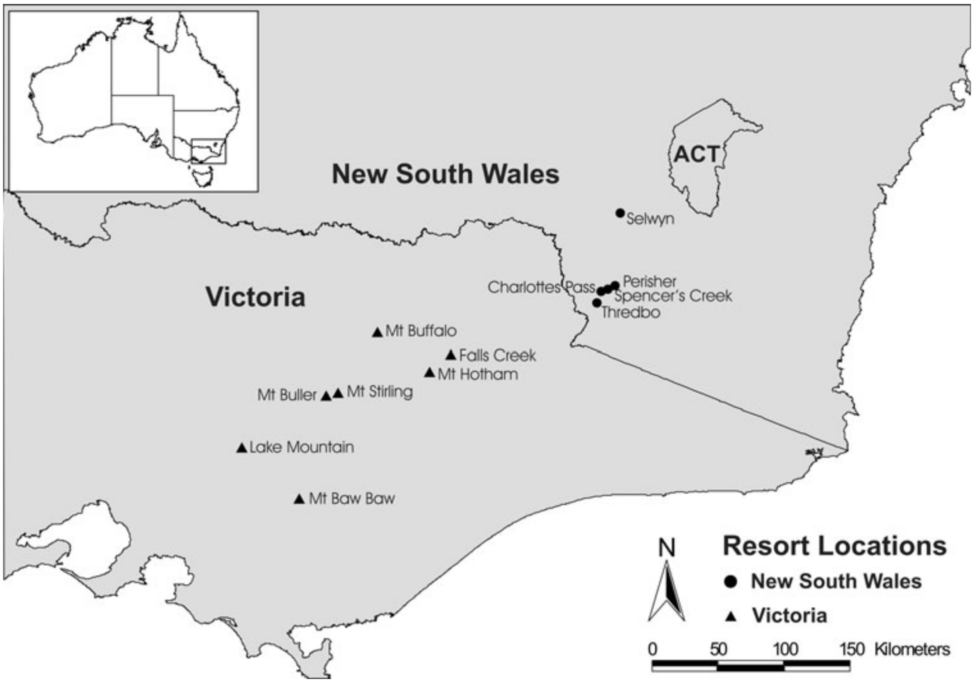

**Table 1** Characteristics of ski resorts in mainland Australia in 2008

| | Altitude (max in m) | Skiable area (ha) | Snow making (ha) | Number snow guns |
|---|---|---|---|---|
| New South Wales | | | | |
| Perisher Blue[a] | 2,034 | 1,245 | 40.4 | 154 |
| Thredbo[a] | 2,037 | 480 | 60 | 155 |
| Charlotte Pass | 1,954 | 50 | NA | 4 |
| Selwyn Snowfields[a] | 1,614 | 45 | 35 | 27 |
| Victoria | | | | |
| Mt Buller[a] | 1,805 | 180 | 70 | 81 |
| Falls Creek[a] | 1,780 | 451 | 100 | 210 |
| Mt Hotham | 1,845 | 320 | 17 | 75 |
| Mt Baw Baw | 1,563 | 30 | 9.9 | 10 |
| Mt Buffalo | 1,595 | | NA | NA |
| Lake Mountain[a,b] | 1,520 | | | 6 |
| Mount Stirling[b] | 1,747 | | | |
| Total for all resorts | | 2,801 | ~332 | ~716 |

*Sources*: Alpine Resorts Co-coordinating Council (2008), Australian Ski Areas Association (2008) and individual ski resort web sites

*NA* Not available as Mt Buffalo currently closed, and not clear whether it will reopen as ski destination

[a] Six resorts for which detailed information is available on climate change projections on natural snow cover

[b] No accommodation, no downhill ski facilities

altitude (Hennessey et al. 2003). Corresponding figures for natural snow cover at ski resorts in Victoria ranged from ~40 cm at 1,234 m altitude to ~1.45 m at 1,845 m altitude (Australian Ski Areas Association 2008). The mean number of days with 20 cm or more of natural snow, over the past 10 years, ranged from 38 days at the lowest of these six resorts, to 113 days at the highest (Australian Ski Areas Association 2008). Corresponding figures for 30 cm cover range from 4 to 107 days (Alpine Resorts Co-coordinating Council 2007, 2008). Even with snowmaking, the number of days with 20 cm or more of snow only increased slightly. During 2007, there were 42 such days at the lowest altitude resort and 111 days at the highest. Mean maximum snow depth is less than 1.5 m at any of these resorts, even with snowmaking.

There exists a very close and statistically significant ($P = 0.034$) relationship between the cover of natural snow and the number of visitors at these resorts (Fig. 2). The numbers of winter visitor days for all resorts open in each year in NSW and Victoria increased linearly with cumulative daily snow depth at the highest-altitude snow course. On average, during 2000–2008 inclusive, every additional metre of cumulative natural snow cover was associated with ~3,000 additional winter visitor days. Not only are skiers highly sensitive to annual variation in natural snowfall, but this sensitivity is increasing. In 1996, when skiers were asked how they would react to reduced natural snow cover, 37% said they would ski elsewhere, and a further 37% that they would ski less often (König 1998). In 2007, however, only 16% said that they would travel overseas to ski, and 74% said that they would ski less often (Pickering et al. 2009).

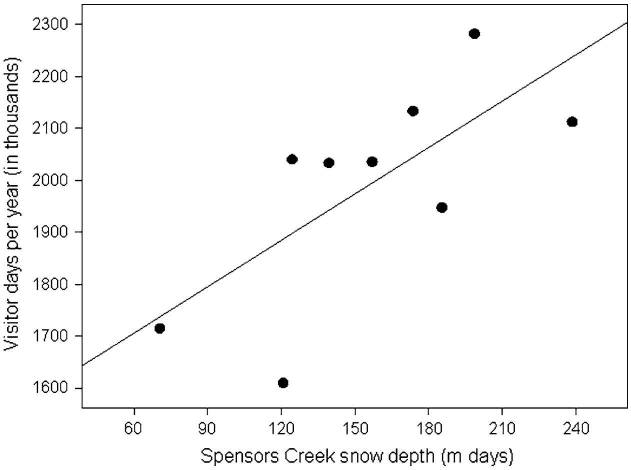

**Fig. 2** Relationship between snow metre days at Spencer's Creek Snow Course (Dr. Ken Green, NSW NPWS, pers. commun) and number of visitors days to all resorts in the Australian Alps (Alpine Resorts Co-coordinating Council 2007, 2008) for 2000–2008. Linear regression, $F = 6.960$, $P = 0.034$, $r^2 = 0.499$. $y = 1527 + 2.9776x$

According to ski-resort CEO's and other industry commentators (Bicknell and McManus 2006; Department of Sustainability and Environment 2004), the Australian ski resorts nevertheless see snowmaking as their principal response to low natural snow in the future. In the following sections, therefore, we examine what this involves and how feasible it may be.

## SNOWMAKING

In order to improve snow cover, resorts rely on: snowmaking; snow grooming and farming; and the modification of the underlying terrain, known euphemistically as supergrooming (Scott and McBoyle 2007; Australian Ski Areas Association 2008; Pickering and Hill 2003). Snowmaking involves pumping stored water into the air under pressure, often with a nucleating agent, when wet bulb temperatures are below −2.5°C (Australian Ski Areas Association 2008). In Australia, snowmaking is used principally to provide snow cover at the start of the season, to maintain cover on high use areas at lower altitudes, and to extend the season at the end (Australian Ski Areas Association 2008). Over the past 15 years, areas serviced by snowmaking infrastructure within the larger Australian ski resorts have increased by a factor of 2.75 times, from ~120 to ~330 ha (Table 1). Even with this increase, however, snowmaking areas cover <12% of the total skiable area in the resorts, which is 2.8 $km^2$. Corresponding proportions in European resorts range from 11.5% in the German Alps, to 80% in the French Alps (Agrawala 2007; Vanham et al. 2008; Gonseth 2008). In North America, the proportions are higher still: 50–100% in some parts of Canada (Scott et al. 2003) and 62–98% in the USA (Scott and McBoyle 2007).

Snowmaking infrastructure differs considerably between the various Australian resorts. There are differences in the numbers, sizes, types and locations of water reservoirs, pipes, compressors and snow guns (Australian Ski Areas Association 2008). Snow guns themselves are only one component of the capital costs of snowmaking infrastructure. Ski runs at lower altitude need considerably more guns and water than those at higher altitude [Table 2, data from Hennessey et al. (2003, 2008)]. Lower altitudes receive less natural snowfall, and have fewer nights that are cold enough for snowmaking (Hennessey et al. 2003, 2008), so the resorts need to operate more guns simultaneously to compensate. In practice, therefore, snowmaking is subject to significant physical, economic and environmental constraints. In the following sections, we examine how these constraints will affect the ability of Australian ski resorts to make more snow under a changing climate.

## CLIMATE CHANGE PROJECTIONS

The Australian Alps are at particular risk from climate change. The most recent projections (Hennessey et al. 2003, 2008) indicate that by 2020, just over a decade from now, mean annual temperatures will increase by up to 1.0°C, and precipitation will decrease by up to 8.3%. We refer to this projection as the +1°C scenario. During Australia's usual skiing months from June to the end of September, mean temperatures at ski resorts range from 0.7°C at 1,701 m altitude down to −1.55°C at 1,957 m altitude, considerably warmer than most resorts in Europe, Japan and North America (Hennessey et al. 2003, 2008). The projected 1°C rise in annual average temperatures will thus have substantial effects both on natural snow cover and on the number of nights suitable for snowmaking (Hennessey et al. 2003, 2008).

Current evidence indicates that temperatures are already increasing, and winter snow cover is already decreasing, particularly at higher altitudes (Green and Pickering 2002, 2009; Hennessey et al. 2003, 2008; Nicholls 2005). Under the +1°C scenario, the area experiencing at least 60 days with at least 1 cm of natural snow would decrease by 60% (from 1990 to 2020). This would reduce the period with at least 1 cm of natural snow cover to below the key threshold of 60–70 days per year at the lower altitude sections of almost all the ski resorts concerned [Fig. 3, data from Hennessey et al. (2003)]. The projected number of days with at least 1 cm snow cover under the +1°C scenario has been modelled at 20 individual locations within the resorts. Only seven of these, i.e. 35%, are expected to retain 70 days or more with 1 cm or more of natural snow cover by 2020 [Fig. 3, data from Hennessey et al. (2003)]. Two more will have 60-70 days, and 11 are likely to have <60 days snow cover per year under climate change scenarios as currently projected.

## SNOWMAKING AS A RESPONSE

In order to make enough snow to keep existing runs skiable under the +1°C scenario, ski resorts in the Australia Alps would need to increase both the number of snow guns and how often they are used (Table 2). This means they would need more water and more electricity to keep runs open, with the greatest increases in the lowest altitude resorts. At higher altitudes, the yield of snow from each gun is higher, because there are more nights when it is cold enough for the gun to operate. At lower altitudes, there are fewer nights suitable for snowmaking, so more guns are needed to produce the same volume of snow. In addition, at lower altitudes, the total volume of snow needed to provide adequate cover is greater than at high altitudes, because there is less natural snow and because more snow melts and evaporates. At present, the highest resort in the Australian Alps operates only one gun per ski run, consuming 15,535 $m^3$ of water per season and yielding 38,838 $m^3$ of

**Table 2** Current and projected numbers and costs of snow guns for six Australian ski resorts

| | Altitude (m) of ski run | Current conditions | | | | | High impact 2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Per ski run | | | Per ski resort | | Per ski run | | | | Per snow gun | | Per ski resort | | |
| | | Mean no. of guns[+] | Snow yield (m$^3$)[+++] | Water needed (m$^3$)[a] | No. of guns[++] | Value of guns (US $ millions)[b] | Increase in snow %[+++] | Snow yield (m$^3$)[c] | Increase in snow guns[+++] (%) | Mean no. of guns[+] | Snow yield (m$^3$)[d] | Water needed (m$^3$)[a] | No. of guns[e] | Value of guns (US $ millions)[b] | Water needed (m$^3$)[e] |
| Mt Perisher | 1,720 | 1 | 38,838 | 15,535 | 154 | 20.2 | 42 | 55,141 | 73 | 1.7 | 31,879 | 12,751 | 266.4 | 35.0 | 3,397,238 |
| Mt Thredbo | 1,340 | 1.8 | 42,947 | 17,179 | 155 | 20.3 | 43 | 61,414 | 85 | 3.7 | 16,598 | 6,639 | 286.8 | 37.6 | 1,903,841 |
| Mt Selwyn | 1,550 | 3 | 57,326 | 22,930 | 27 | 3.5 | 34 | 76,817 | 94 | 5.8 | 13,244 | 5,298 | 52.4 | 6.9 | 277,494 |
| Mt Buller | 1,720 | 3 | 41,587 | 16,635 | 81 | 10.6 | 61 | 66,955 | 181 | 8.4 | 7,971 | 3,188 | 227.6 | 29.9 | 725,697 |
| Falls Creek | 1,642 | 1.8 | 59,046 | 23,618 | 210 | 37.6 | 62 | 95,654 | 142 | 4.4 | 21,740 | 8,696 | 508.2 | 66.7 | 4,419,239 |
| Lake Mountain | 1,340 | 15 | 67,710 | 27,084 | 6 | 0.8 | 23 | 83,283 | 200 | 45 | 1,851 | 740 | 18 | 2.4 | 13,325 |
| Total | | 25.6 | 307,454 | 122,981 | 633 | 83.1 | | 439,264 | | 69 | 93,283 | 37,312 | 1359 | 178.3 | 10,736,834 |

Projections refer to the 2020 high impact scenario (+1°C) (Hennessey et al. 2003, 2008). Calculations are based on the most common (Brand A) air water gun (Hennessey et al. 2003). Costs expressed in August 2008 US $, converted from AU $ at a rate of AU $1.00 = US $0.8

[+] Data directly from Hennessey et al. (2003) and refers to the number of guns needed for adequate snow cover as defined by resorts per ski run under current conditions, and not necessarily the number of guns currently installed

[++] Data from Table 1

[+++] Data directly from Hennessey et al. (2003)

[a,b,c,d,e] Calculated here. Snow volumes were converted into water volumes for resorts using the same methodology as Hennessey et al. (2003)

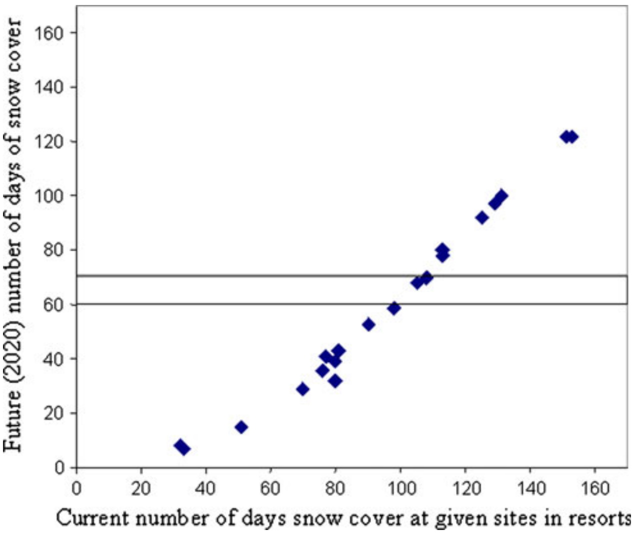

**Fig. 3** Number of days with at least 1 cm snow cover for 20 sites in ski resorts under current climatic conditions (*x* axis), and for the same sites, under a +1°C scenario as predicted for 2020 (*y* axis). The two *horizontal lines* represent the threshold of 60–70 days snow cover that is required for a viable skiing season. Data from Hennessey et al. (2003)

snow per run per season (Table 2). The lowest resort, in contrast, uses 15 guns per ski run, consuming a total of 27,084 $m^3$ per season of water and yielding 67,710 $m^3$ of snow per run per season.

Under the +1°C scenario, there will be: less natural snow; fewer nights and fewer hours per night sufficiently cold and humid for snowmaking; and increased rates of evaporation and ablation, i.e. loss of snow and ice from existing cover (Hennessey et al. 2003, 2008). Under the +1°C scenario, to achieve the same overall level of snow as currently, these six resorts would need to install a further 1.7–45 guns per run, and increase total water consumption by factors of around 23–62% per run. The lowest altitude resort would need >25 times as many new guns per run as the highest, for the reasons outlined above. The highest resort is also the largest, however, with more runs, more snowmaking facilities and more visitors than the lowest. Total water consumption would thus increase by 42% at the highest resort but only 23% at the lowest (Table 2). For these six ski resorts in aggregate, maintaining sufficient snow cover under the +1°C scenario would require a further 726 snow guns in total (Table 2).

## INVESTMENT IN INFRASTRUCTURE

The cost of installing snow guns varies considerably, depending on the type and location of the guns and the cost of piping, water storage facilities, pumps and control systems. Estimates of average costs can be derived from recent snowmaking expenditure by ski resorts. The resorts recently installed a total of 99 snow guns and associated infrastructure at a cost of US $13 million (Australian Ski Areas Association 2008). Therefore, the cost of a single snow gun and associated infrastructure is of the order of US $131,000 in 2008. Using this figure, the total investment in current snowmaking infrastructure at the six resorts can be estimated to be around US $82 million. This compares to investments of around US $61 million on snow making in the French Alps, US $1,005 million in Austria, and US $415 million in Switzerland (Agrawala 2007).

If snowmaking is used to offset losses in natural snow cover under climate change, then the investment in additional snowmaking infrastructure as calculated above would be US $95.2 million (in 2008 dollars) over the next decade, bringing the total to more than double the current figure. Even without considering the increased costs of running the snow guns, this represents an additional cost of ~US $5 per person per day, based on the average visitation of 1.67 million winter visitors days per season to these six resorts. If passed on directly to visitors, then this would produce a noticeable but not prohibitive increase in prices. This estimate does not include the increased cost of power to run the snow guns, which would lead to further price increases. Financial aspects, however, are not the only barrier. There are also significant physical constraints, notably the availability of water. These are considered below.

## WATER AVAILABILITY AND ENERGY COSTS

With the proposed increase in snowmaking under the +1°C scenario, by 2020, these six ski resorts would consume a total of 10,000 ML of water over a 3–4 month season (Table 2), i.e. 2,500–3,300 ML per month. For comparison, the average monthly water consumption in Canberra, the Australian capital and the closest large city to the resorts is about 2,800 ML per month (ACTEWAGL 2008). Would such a huge increase for the resorts actually be feasible?

There prevails a strong competition from various industry sectors for water from the Australian Alps. In addition to tourism, water is in heavy and increasing demand from irrigated agriculture, urban residential use, power generation and a variety of other industrial uses. Widespread droughts in south eastern Australia have demonstrated clearly that water resources are a limiting constraint on the regional economy. Under these circumstances, government and private water resources agencies have two principal options: quotas or charges. Either way, water prices are likely to increase to a level set by the sector with the highest economic or political yield. Water for snowmaking will therefore become more expensive, perhaps considerably so.

Water costs for ski resorts will be reduced if the resorts can capture and re-use snowmelt runoff, and use recycled water from accommodation and other facilities. Resorts are indeed starting to use these approaches, but they are unlikely to substitute completely for the consumption of raw water from natural riverflow. Most of the runoff from the Australian Alps is already captured through a giant series of dams and diversions associated with the Snowy Mountains Scheme, which generates hydroelectric power and supplies irrigated agriculture in drier inland regions. The Australian Alps lie largely within national parks, and there are minimum ecological streamflow requirements for conservation. Therefore, resorts are unlikely to be able to obtain the large volumes of water for snowmaking except by purchasing water in competition with other sectors. Even then, they may not be able to access enough water, as there is limited waterflow in creeks to harvest. Water catchments in the ski resorts in the Australian Alps are small relative to those of Europe and North America.

Snowmaking requires electricity to operate pumps and compressors, and energy costs will consequently increase in line with water consumption (Agrawala 2007). In addition, energy prices in Australia are expected to increase steeply for a variety of reasons, including decreased availability of water for hydroelectric power generation, and a variety of climate change mitigation measures. This will further decrease the financial viability of snowmaking as a strategy for ski resorts to adapt to climate change.

## DISCUSSION AND CONCLUSIONS

Current projections of short-term climate change indicate that ski resorts in the Australian Alps will face several simultaneous pressures over the next decade. If current climate trends continue as projected under the +1°C scenario, many ski areas would fall below the minimum financially viable threshold if they were to rely on natural snowfall alone. Accordingly, they plan to increase reliance on snowmaking. Our calculations here, however, show that ski resorts may simply be unable to gain access to the additional volumes of water which would be required; and if at all they could, the costs of additional infrastructure, water and electricity are likely to render ski operations uneconomic. Their financial situation could also be exacerbated if higher prices and lower snow quality lead many of their current clients to travel overseas to ski, or simply ski less often.

The financial sensitivity of the Australian ski industry to these effects can be gauged from the consequences of low-snow years. Effectively, predicted climate change simply equates to a higher proportion of low-snow years. During the 2006 ski season, natural snowfall was at a 20-year low (Green and Pickering 2009; Alpine Resorts Co-coordinating Council 2007), and the net incomes of ski resorts fell heavily as visitor numbers decreased and operating costs increased (Mt Baw Baw Alpine Resort Management Board 2007; Falls Creek Alpine Resort Management Board 2007; Mt Hotham Alpine Resort Management Board 2007; Mt Buller and Mount Stirling Alpine Resort Management Board 2007). For some resorts, this resulted in significantly reduced profits, while for others it resulted in a loss (Mt Baw Baw Alpine Resort Management Board 2007; Falls Creek Alpine Resort Management Board 2007; Mt Hotham Alpine Resort Management Board 2007; Mt Buller and Mount Stirling Alpine Resort Management Board 2007). Australia's major ski resorts are operated by corporations with a history of significant profits, a number of parallel income streams, and large net financial assets, and so they were able to weather the 2006 season relatively unscathed. A series of such years in succession, however, could have more serious financial consequences.

We reach these conclusions from publicly available documents. If we can recognise the risks facing these resorts and the shortcomings of snowmaking as the sole response, then the ski resorts can certainly do likewise. In fact, therefore, it seems highly unlikely that they are in reality relying solely on snowmaking as a response to climate change. It seems more probable that whilst resorts do indeed plan to increase snowmaking in the short term, they may have other strategies for the longer term and may be focussing on snowmaking principally as a political tool: to gain access to additional water; to gain taxpayer-funded government subsidies for new infrastructure and cheap electricity; and to lobby for access to higher-altitude terrain inside protected areas. In addition, it seems highly likely that the higher-altitude resorts anticipate that their lower-altitude competitors will be unable to continue operating ski lifts, so that in the short term, visitor numbers at the higher-altitude resorts may be boosted by a contraction of the industry.

The most likely scenario, however, is that the Australian ski resorts plan to follow the example of their North American and European counterparts, and move their business models away from winter ski-lift tickets as the principal source of revenue, to year-round resort-based activities and a focus on residential property sales and associated retail activities. It appears that this shift has already occurred at a number of European and North American resorts (Scott and McBoyle 2007; Agrawala 2007; Scott et al. 2008), even though they have longer and more reliable ski seasons than those of their Australian counterparts.

Visitor data indicate that many people visit the Australian Alps National Parks in summer as well as winter (NIEIR 2006). Australia's ski resorts are starting to capitalise on this. Currently, some of the major resorts close down almost completely in summer. The key reason is that since most of these resorts are inside or surrounded by protected areas, they have limited legal scope for on-site residential development, and most of their skier accommodation is in gateway towns outside the parks at lower altitudes. These gateway towns do indeed provide tourist accommodation and activities year-round, with high visitor numbers in summer as well as winter. A small number of the ski resorts such as those at Thredbo in NSW and Falls Creek in Victoria do have accommodation on site and can offer a variety of activities in summer. These resorts have successfully made the transition to four-season mountain resorts. Arguably, it is only planning restrictions on further residential developments which limit their transition to mountain resort-residential towns comparable to Aspen, Banff or Chamonix. Residential developments close to ski areas, such as Dinner Plains near Mount Hotham in Victoria, seem to have been highly successful in economic terms (Buckley et al. 2006).

We conclude, therefore, that whilst ski resorts are likely to promote increased snowmaking as a short-term solution to climate change, this is in fact financially realistic only for the higher-altitude resorts. Those at lower altitude are likely to lobby strongly to increase access to land for residential subdivision and for high-cost summer tourist activities such as golf and watersports. We can, therefore, foresee a period of increasing contention between the corporations which run ski resorts, and the public agencies responsible for protected areas and water supplies. Whatever the precise outcome, it seems likely to involve increased social, economic and environmental costs. The Australian ski industry thus provides an example of the many indirect mechanisms by which human social responses to climate change can generate more complex impacts beyond the direct biophysical consequences of changing temperatures and precipitation.

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## AUTHOR BIOGRAPHIES

**Catherine Marina Pickering** (✉) is an associate professor at the International Centre for Ecotourism Research (ICER), Griffith University. She has published extensively in the fields of recreation ecology, climate change, alpine ecology and park management with over 140 publications including more than 60 refereed papers.

*Address:* International Centre for Ecotourism Research, Griffith University, Gold Coast, QLD 4222, Australia.
e-mail: c.pickering@griffith.edu.au

**Ralf C. Buckley** is the Director of ICER. He has ~750 publications including 15 books and 190 refereed articles on ecotourism, and environmental management. His current research focus is on tourism, conservation and climate change.

*Address:* International Centre for Ecotourism Research, Griffith University, Gold Coast, QLD 4222, Australia.