Water demand for snowmaking under climate change conditions in an Alpine environment

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Abstract

Due to the vulnerability of winter tourism to climate change an increased production of technical snow is anticipated in future. This paper focuses on the impact of snowmaking as a water demand stakeholder on a regional water balance (water resources-water demand), both in the present day and a climate change scenario situation. Two regions around the famous ski resorts of Kitzbühel and Sölden in the Austrian Province of Tyrol have been analysed. Based upon certain assumptions it can be shown no threat exists to any water demand stakeholder within these Alpine areas on a regional basis today or in nearby future.

Keywords: Alpine, climate change, snowmaking, technical snow, water demand, water resource management.

1 Introduction

The winter tourism industry, one of the most important industries in the Alps, has repeatedly been identified as potentially vulnerable to global climate change (Elsasser & Bürki 2002). Snowmaking is generally accepted as the most important adaptation strategy to Alpine climate change for winter resorts, and will therefore increase in future. During the past 20 years, the production of technical snow has become increasingly important in many ski areas of the world (OECD 2007). In Austria today, 55% of the total ski slopes are covered by technical snow (Fachverband der Seilbahnen Österreichs 2007). Snowmaking as a water demand stakeholder and its effect on water resources management is therefore a main important issue at present and in future. In an Alpine environment the winter period is critical to water resource management due to low water availability and high water demand (Vanham et al. 2008b).

For operation of ski resorts the (Swiss) 100-day rule was suggested by Witmer et al. (1986) stating that for the successful operation of a ski area, a sufficient snow cover (snow depth of minimum 30 cm) should last at least 100 days per season. For the present day situation in Switzerland, this rule is fulfilled for natural snow-reliability at an altitude above 1,200–1,300 m (Laternser & Schneebeli 2003). For the Western part of Austria, including Tyrol, Wielke et al. (2004) concluded the same altitude as the baseline of natural snow-reliability. An overview of this altitude for different Alpine regions in 5 Alpine countries is given in OECD (2007). According to this rule, snowmaking is necessary below the baseline of natural snow-reliability.

A major effect of climate change on Alpine winter tourism is the rise in the natural snow line (Breiling & Charamza 1999) and the shortening of the winter season (Elsasser & Bürki 2002). Auer et al. (2005) identified a reduction in the number of frost days during the winter season as problematic, as they are important for snowmaking being dependent on temperatures below zero. As warming progresses in the future, there will be a shift of snow precipitation to rain (IPCC 2007). A warmer climate will also lead to the upward shift of mountain glaciers (IPCC 2007).

2 Case study areas

The Kitzbühel region and Upper Ötztal (figure 1) in the Tyrolean Alps serve as case study areas (case study 1 and 2 respectively) for this analysis. The main difference between both areas is the elevation range and the absence, respectively presence, of a glacier (and glacier-skiing) within the study area (table 1). The winter period for the Kitzbühel region is defined from December to March, in accordance to a methodology described by Vanham et al. (2008b). The winter period for the Upper Ötztal is defined as the period from December to April. Water for snowmaking in Kitzbühel is extracted from streams and rivers, in the Upper Ötztal from springs.

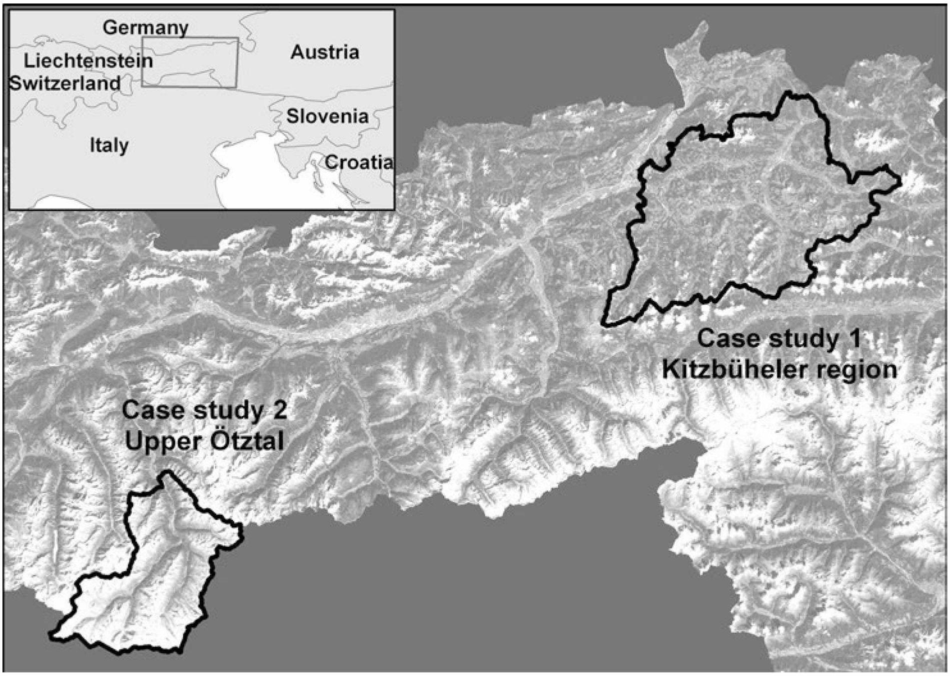

Figure 1: Location of the two case study areas Kitzbühel region (case study 1) and Upper Ötztal (case study 2) in the Tyrolean Alps, Austria.

Table 1: Current characteristics of the two case study areas (according to information and a DEM provided by the government of Tyrol)

	Kitzbühel region	Upper Ötztal
Total area (km²)	915	517
Glacier area (km²)	0	114 (22%)
Minimum altitude (m a.s.l)	521	1185
Average altitude (m a.s.l)	1217	2625
Maximum altitude (m a.s.l)	2533	3770
Number of municipalities	20	1
Inhabitants in 2001	60632	3128
Average yearly tourist overnight stays in 2000–2006 (mill.)	6.5	2.1
Yearly tourist overnight stays pro inhabitant in 2001	105	676
Percentage of these tourist overnight stays in the winter months	54	78
Area of ski slopes (ha)	2256	382
Lowest elevation ski slopes (m a.s.l.)	627	1350
Average elevation ski slopes (m a.s.l.)	1295	no information
Highest elevation ski slopes (m a.s.l.)	2014	3250
Area of ski slopes covered by technical snow (ha)	882 (39%)	275 (73%)
Area of ski slopes below the baseline of natural snow-reliability (1,200 m)	888 (39%)	0
Water for snowmaking extracted from	streams, rivers	springs

3 Methodology

3.1 Water resources

Available water resources for the 2 case studies are calculated based upon daily flow time series at 5 flow measurement stations (figure 1). The WMO climate normal period from 1961 to 1990 was chosen as a reference period. Total water availability is defined as the difference between the total flow and Q_{95}, the flow that is exceeded during 95% of the time. Groundwater recharge was calculated based upon these time series according to the methodology by Wundt (1958). The available amount of groundwater was calculated according to Vollhofer & Samek (2006), a methodology also used within the report describing the analysis of the current status of the Austrian water bodies for the implementation of the EU Water Framework Directive (BMLFUW 2005).

3.2 Water demand

For the Kitzbühel region, the public water demand is calculated based on the number of inhabitants and persons employed in different sectors, and on the number of tourists (recorded as overnight stays) (Vanham et al. 2008b). For the Upper Ötztal, a methodology as described by De Toffol et al (2008) was used. Unlike the first, the latter methodology encompasses water as used by the water supply undertaking itself (for example for the cleaning of pipes).

For the calculation of the water demand for snowmaking, the ground rule that 2.4 m^3 of snow is generated from 1 m^3 of water (Pröbstl 2006) is used. The author evaluated the water demand for snowmaking in different ski regions of the Bavarian and Tyrolean Alps in similar altitudes as the Kitzbühel region. The temporal water demand differs between base snowing at the beginning of the winter season and improvement snowing during the remaining winter season. For base snowing, a snow height of 30 cm is chosen requiring approximately 120 litre water pro m^2. For improvement snowing, 120% of the base snowing is assumed.

3.3 Climate change scenario

A climate change scenario of an average temperature rise of 2°C without precipitation change (Breiling & Charamza 1999) was chosen. For both case study areas this means a lift of the snowline of 100 m. The baseline of natural snow-reliability therefore rises from 1,200 to 1,300 m. In combination with this scenario, a study on the population dynamics (Statistik Austria 2006) from 2001 to 2031 in Austria predicted a 15% rise for the Kitzbühel region and 0% for the Upper Ötztal. For the Upper Ötztal an increase in tourist overnight stays of 10%, both in summer and winter, is assumed. Keeping the area of ski slopes constant is a simplification, as ski regions tend to expand. Estimations on the extension of future ski slopes, however, are difficult. An overview of the climate change scenario for both case studies is given in table 2 under the assumption that all ski slopes are snowed in future (worst case scenario).

Table 2: Characteristics of the case study areas in a climate change scenario.

	Kitzbühel region	**Upper Ötztal**
Inhabitants (Statistik Austria 2006)	69727	no change
Average yearly tourist overnight stays (mill.)	no change	2.3
Percentage of these tourist overnight stays in the winter months	no change	no change
Area of ski slopes (ha)	no change	no change
Area of ski slopes covered by technical snow (ha)	2256 (100%)	382(100%)
Area of ski slopes below the baseline of natural snow-reliability (1,300 m)	1109 (49%)	0

4 Results and discussion

The values in table 3 representing the reference period are also used for the climate change scenario. An available amount of groundwater (representing spring and subsurface ground water) during winter of 40 mm (36 Mill m^3) for the Kitzbühel region and 30 mm (15 Mill m^3) for the Upper Ötztal was calculated. These values are conservative values, and represent a minimum of groundwater that can be used for different stakeholders. A total available amount of water (groundwater and runoff water) of 65 mm was calculated for the Kitzbühel region. In winter, this groundwater is represented in the rivers as base flow. The small additional amount of runoff constitutes to a high base flow index (BFI), i.e. the relative amount of groundwater to the total flow in the river, a situation typical for Alpine winters.

Figure 2 shows the high water demand in winter in relation to the annual water demand for both study areas due to a concentration in tourist overnight stays (represented by the public seasonal water demand) and snowmaking during this period. The other water demand stakeholders are not connected to public water supply (e.g. industry, small trade). Both study areas have no water demand for irrigation. In the Kitzbühel region, typical for the Alpine region, all water demand stakeholders, except snowmaking, are covered by ground and spring water. In the region of Upper Ötztal, only spring water is used for public water supply. Today, in terms of a regional water balance between water supply and demand in winter, no water scarcity exists.

In the Kitzbühel region, the climate change scenario considerably increases the winter water demand assuming that all existing ski slopes are covered with artificial snow. In the Upper Ötztal, the increase in winter water demand is less. However, despite the anticipated higher water demand in future winters, no water deficits are predicted in the study areas on a regional basis.

On a local basis, water stress triggered by snowmaking could occur. However, water storage and distribution infrastructures could mitigate local water stress. Presently, a total reservoir volume of 0.9 Mio. m^3 for snowmaking water storage is installed in the Kitzbühel region, divided in about 20 reservoirs. The largest has a volume of 180,000 m^3. This total reservoir volume of 0.9 Mio. m^3 almost covers the total water requirements for the base snowing in the existing situation (40% of the total snowmaking water demand of 2.3 Mio. m^3). Thus when filled in spring or autumn, when water availability is higher, the actual winter water demand for snowmaking as shown in figure 2 diminishes. To solve local problems, a regional water resources

Table 3: Water resources (in mm/y and mm/w) in the two case study areas in the present situation (reference period 1961–1990).

	Kitzbühel region	**Upper Ötztal**
Average annual precipitation (mm/y)	1557	1540
Average annual discharge (mm/y)	1073	1156
Average winter discharge (mm/w)	200	88
Low flow (Q95) (mm/y)	308	141
Yearly groundwater recharge (Wundt 1958) (mm/w)	637	615
Yearly available amount of groundwater (Vollhofer and Samek 2006) (mm/y)	119	71
Available amount of groundwater during winter (mm/w)	40 (36 mill m^3/w)	30 (15 mill m^3/w)
Total available water (including surface water) during winter (mm/w)	65	n/a

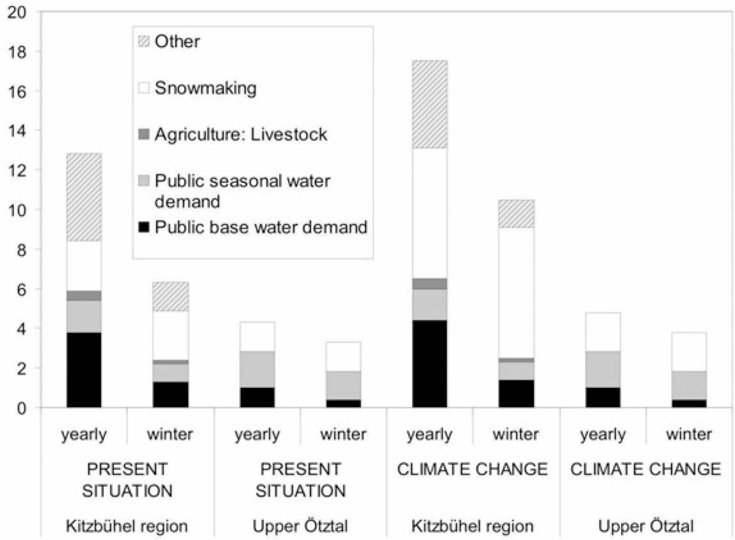

Figure 2: Water demand (mm per year and winter) in the two case study areas in the present situation and the climate change scenario.

management plan is recommended. In the region Upper Ötztal, the total reservoir volume is 0.23 Mio. m^3 representing about 25% of the total snowmaking volume required in the climate change scenario. The largest reservoir in the region of the Ötztaler Glacier has a volume of 150,000 m^3.

5 Conclusions

The water balance analysis between available water resources and water demand stakeholders in two different regions in the Tyrolean Alps indicated that, on a regional basis, there is no water scarcity resulting from snowmaking neither today nor in nearby future. The water abundance allows snowmaking on all existing ski slopes within the assessed climate change scenario.

Climate change affects the winter tourism industry in Kitzbühel due to the region's low elevation. With the rise of the natural snowline, the production of more artificial snow to maintain snow reliability will be necessary. A more detailed analysis for the Kitzbühel region see Vanham et al. (2008a). For the Upper Ötztal, the rise of the snowline has a minimal effect, as all ski slopes are located above this elevation. However, as they are partly located on glaciers they could be affected by climate change impacts on glaciers as described by IPCC (2007).

This study shows that an increase in technical snow production in the nearby future is possible with regards to water availability. Another important requirement for snowmaking, however, is the air temperature below zero. The question whether an increase in snowmaking will be possible facing a future reduction in the number of frost days is subject to further research.

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