Snow, ice and water in the Alpine Region: The system is undergoing radical change

Climate change will dramatically modify the water cycle in the Alpine region. At a recent conference of the Hydrological Commission (CHy), scientists discussed what the future might hold in store for us.

When the river Aare flooded the Matte quarter of the city of Bern in May 1999, this event was considered a once-in-a-century event. The last time a similar flood had happened was before World War I. The next century lasted 6 years and 3 months: in the late summer of 2006, the Matte area was under water once again. The Aare's uncanny repeat messed up long-term flood statistics. The river Lütschine in the Bernese Oberland even had four once-in-a-century events since 2000.

Is this accumulation cyclical or does it follow a trend? Petra Schmocker-Fackel, of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), explored this question in Bern on 5 June 2009, in her paper given at the conference entitled "Snow, Ice and Water in the Alpine Region – more topical than ever". The event was co-organized by the Swiss Hydrological Commission CHy *(see box)*, the Swiss Snow, Ice and Permafrost Society (SEP/SIP), the Swiss Society of Hydrology and Limnology (SCHL/SSHL), and the Swiss Cryospheric Commission. What made the conference theme so topical was like a red thread in all the papers that were presented: the climate is changing and this will have enormous impacts on the water cycle in Switzerland and neighbouring countries.

Among the most serious impacts is a possible increase of floods. There have always been times of increased flood events of the kind we have been observing in the past 30 years: the last one began in the early 19th century and lasted nearly 100 years. But in between, there were always quiet times, as in the mid-20th century. A new trend might now be interfering with this cycle. Predictions show that climate warming will lead to an accumulation of strong rainfall. Such events will have dramatic consequences if the storage capacity of a river's catchment is exhausted by prior rainfall: "this can lead to discharge amounts that exceed any amounts previously measured," said Petra Schocker-Fackel. In order to predict future flood risks, she pointed out, the dynamics of the system need to be taken into account in addition to climatic change: "it is important to know what the maximum amount of precipitation is beyond which water is no longer held back in a catchment."

Today Alpine rivers are regulated by glacial regimes, but by the end of the 21st century, glaciers will only consist of meagre leftovers. At the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the ETH Zurich, models of the future development of glaciers and of their influence on Alpine rivers were developed. Discharge is predicted to increase at first, as water storage will decrease due to the melting of ice. Depending on the size of glaciers, peak flows will be reached after 20 to 60 years. After this, discharge amounts will decrease. Andreas Bauder and Matthias Huss of the VAW concluded: “at the end of the 21st century we have to expect water shortages that will have an influence on the management of water resources beyond the region.”

The supra-regional character of the theme was also clear in Bettina Schlaefli’s presentation of research results. Schlaefli is a hydrologist at the University of Delft in the Netherlands who is working on the influence of climate change on Alpine rivers: from a hydrological point of view, what is happening in the Alps is also influencing the estuary of the Rhine. The climate in future will probably lead to a reduction of annual precipitation; a marked decrease in the summer will overcompensate the slight increase in the winter. This is not the only reason why rivers will carry less water on the whole: as much more precipitation will evaporate on the areas affected by ablation after glaciers have retreated than when they were covered with ice, discharge amounts are likely to decrease much more than precipitation amounts. Some scenarios show that we must expect an up to 7% decrease in productivity of hydropower plants by 2050.

With an increase in debris flows and rockfalls, the consequences of thawing in the Alpine areas covered by ice until now will be just as dramatic, although only local. Glacier retreat and thawing of the permafrost are increasing the volume of loose sediment that can start moving. The debris flow in Guttannen in 2005, totalling a volume of 500,000 m^3, was the result of such a development. The numerous rockfalls that have taken place in the past few years are also probably due to changes in surface ice and permafrost. “However, the processes that lead to a fall are not yet understood well enough,” concluded Christian Huggel of the Department of Geography, University of Zurich, summarizing research results on this topic. Natural hazard management is therefore facing a complex situation and can rely far less on past experience.

Another trend is less of lesser consequence: complete freezing of lake is increasingly rare. The older generations will remember the 1st of February 1963, when the authorities declared the Lake of Zurich fit for ice-skating. H.J. Hendricks Franssen of the ETH Zurich’s Institute of Environmental Engineering, who is a passionate ice-skater, reviewed all available sources on the freezing of eleven lakes in the Swiss Mittelland in the period between 1901 and 2009. The development of a complete ice cover on a lake depends mainly on the number of days during which the air temperature remains below the freezing point and on how many degrees Celsius below zero there are; but the threshold for the sum of the *negative degree days* is different for each lake. The decisive factor is depth: with its maximum depth of 260 m the Lake of Brienz never froze, although it is quite cold in the area. But the Lake of Morat, which lies in a milder climate area but is only 45 m deep, froze 28 times in the 20th century.

In the past 40 years Swiss lakes in the lowlands froze much less often than before; in the past two decades this trend has increased. In the case of lakes that freeze rather rarely, this is particularly striking. Climate scenarios for the Alpine area predict an increase in winter temperatures by 2070 that will range betweeen 1.2 and 4.5 °C compared with the status in 1990. It is likely to be too warm for lakes to freeze completely in future; in the coming decades, it will at least still be possible to occasionally do some ice-skating on natural ice across smaller, less deep waters.

The technical term for the sudden emptying of a glacial lake is "jökulhlaup". The term comes from Iceland, where the phenomenon often occurs. We had better practice this tongue-twister, since jökulhlaups are happening more frequently in the Alps as well. The most well-know example in Switzerland is the lake that has regularly been forming at the Unterer Grindelwaldgletscher. Meanwhile the glacier has become the scene of a summer spectacle that occurs every year and displays the whole gamut of consequences that can result from ice melting in the Alps. The glacier is currently losing 10 million m^3 of ice per year; in the area where the lake forms, its surface is 200 m lower than it used to be 150 years ago. The sides of the mountain that used to be supported by the glacier have become unstable, leading to several major earthslides. A spectacular one was the slide on the right-hand flank of the valley in the early summer of 2005, which brought the Stieregghütte – a mountain farm and hut – literally to the edge of a cliff; or, on the other side of the glacier, the collapse of the "Schlossplatten", where an area with a volume of 2 million m^3 of rock fell on the glacier in 2006.

A jökulhlaup has also already occurred in the area: at the end of May 2008, 800,000 m^3 of water were drained into the Lütschine river. The lake is becoming larger every year. At the beginning of June 2009 it already contained 2.5 million m^3 of water. Hansruedi Keusen, who works for Geotest and is meticulously monitoring the events related to the Grindelwaldgletscher dynamics, estimates that the volume of the lake could increase to 10 million m^3 until 2011. This must not happen, as an outbreak with this volume of water would have catastrophic consequences right down to the area around Interlaken. This is why a gallery is being built to allow water to be discharged as soon as the lake reaches a volume of 300,000 m^3. This artificial outlet will be ready by the spring of 2010.

A sudden emptying of glacial lakes can be due to a variety of causes. Meltwater mostly flows out through canals in the ice; these become larger as a result of warming. The VAW of the ETH Zurich explored the mechanisms of the Gornersee above Zermatt (VS), a lake that forms regularly and then breaks out – though always in a different manner. "It is difficult, if not impossible, to predict when a glacial lake will empty and how high the discharge will be," was Martin Funk's conclusion, a glaciologist at the VAW.

But glacial lake outbursts are not a new hazard in the Alps: they have occurred before, at times with catastrophic impacts. What has changed are the causes: in the past it was usually glacier growth that led to dams and glacial lakes; today these lakes are created by the thawing of ice masses.

In view of the major problems that climatic changes and the resulting changing hydrological cycle will cause in relation to natural hazards, hydropower or agriculture, another transformation is slipping out of attention: aquatic biotic communities will also radically change. Beat Oertli and his team at the Institut Terre-Nature-Paysage (ITNP) of the University of Applied Sciences in Western Switzerland (HES) tried to predict future colonization of Swiss ponds, pools and small lakes by water plants, larger invertebrates (macroinvertebrates) and amphibians. Calculations for their model are based on biodiversity data collected in 120 small water bodies in Switzerland. Modelling shows that there will be a marked increase in biodiversity as a result of climate warming. This increase will be particularly striking in alpine water bodies, which are currently still cold and therefore species-poor. As soon as they become warmer, they will become attractive for numerous species that now live in lowland ponds and pools, for example dragonflies: at present, a total number of 58 species have been counted in Switzerland, a large number of which will spread upwards into higher habitats in the coming years. In addition, we can expect that Mediterranean species will migrate northwards. This has already been observed: the heat-loving scarlet dragonfly *(Crocothemis erythraea)* is a recent newcomer in Switzerland.

But there will also be losers: for the azure hawker *(Aeshna caerula)* and all other species that require cold water, the habitat will become too small. Seven species of dragonflies that live in Switzerland today are endangered by climate change.

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