Climate Change Effects on Aquifer Recharge in a Glacierised Karst Aquifer System, Tsanfleuron-Sanetsch, Swiss Alps

V. Gremaud and N. Goldscheider

Abstract Alpine glaciers store considerable amounts of freshwater contributing to groundwater recharge in the warm season, but are rapidly retreating and many will disappear within 50 years. The Tsanfleuron-Sanetsch area in the Swiss Alps is an ideal site to study glacier-aquifer interactions; it consists of a vanishing glacier overlying a karst aquifer drained by a spring (Glarey) used for drinking water supply. Between the glacier and the moraine from 1855 (Little Ice Age), the karst surface is polished by ice flow; typical karrenfields are present below the moraine. Geologically, the area consists of folded Jurassic to Paleogene sedimentary rocks forming an anticlinorium limited by a narrow syncline. Relationships between stratigraphic and tectonic setting, recharge processes and aquifer drainage have been studied by means of tracer tests and hydrologic monitoring. The glacier's geometry was investigated by geophysical surveys, using radiomagnetotelluric (RMT): The estimated ice volume is $1.0 \times 108\,\mathrm{m}^3$, corresponding to $0.92 \times 108\,\mathrm{m}^3$ freshwater. Meltwater production displays diurnal and seasonal variability influencing the shape of tracer breakthrough curves and, thus, flow and transport in the aquifer. A preliminary prognosis of water availability when the glacier will have disappeared has been established, predicting more available water in winter, but shortages in long dry summer and autumn periods, due to the absence of meltwater and less estival rainfall. Increased irrigation water demand will aggravate water shortage.

1 Introduction

Rapidly retreating glaciers are clearly visible symptoms of climate changes in the Alps. Many glaciers have lost much of their volume since the maximum of the Little

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Ice Age in the middle of the 19th century (Greene et al. 1999). Climate models predict warmer temperatures and more precipitation during winter, with a snowline at higher elevations, and less rain in summer. The loss of glaciers as intermediate water storage reservoirs will result in local or temporal water shortages, particularly during long dry summer periods (Seidel et al. 1998), with implications for drinking water supply, agriculture and hydropower (Viviroli and Weingartner 2004).

The Tsanfleuron-Sanetsch area in the Western Swiss Alps consists of a karst aquifer overlain and recharged in its upper part by a rapidly retreating glacier. At the lowest point, the Glarey spring drains the major part of the aquifer (Fig. 1). The spring is used for drinking water supply of a community (Conthey) and for irrigation. This site is ideal to study glacier-aquifer interrelations and impacts of climate-change on water resources.

The Tsanfleuron glacier was intensively studied by glaciologist (e.g. Chandler et al. 2008; Hubbard 2002; Hubbard and Hubbard 1998; Hubbard et al. 2000; Sharp et al. 1989). More recent studies investigate the relations between the geological structure and the drainage pattern in the karst aquifer (Gremaud et al. 2009) and glacier-aquifer relations (Gremaud and Goldscheider 2010).

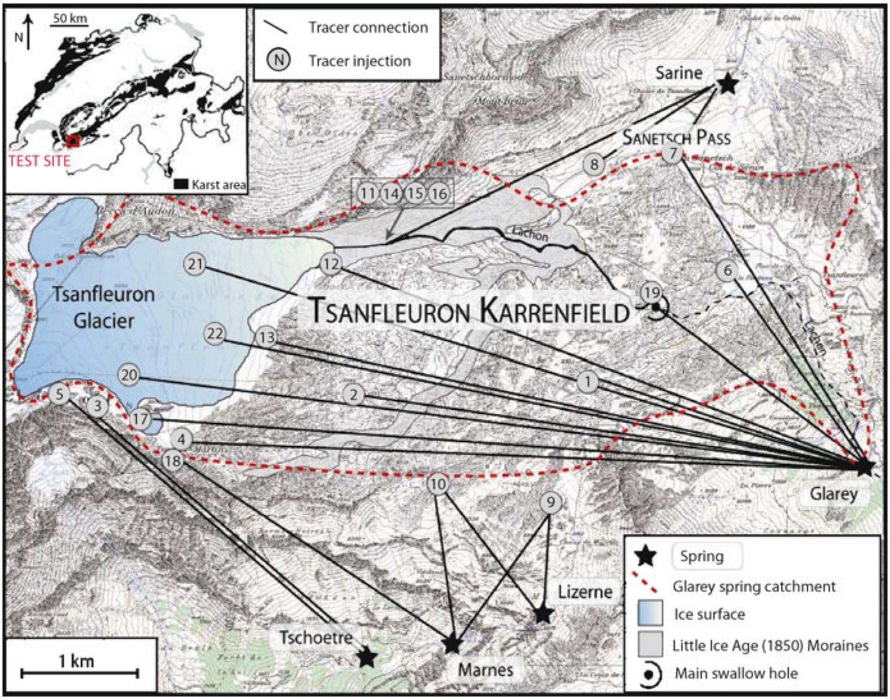

Fig. 1 Location and general overview of the Tsanfleuron-Sanetsch glacier and karst aquifer system in the Western Swiss Alps. 22 tracer tests made it possible to delineate the recharge area of the Glarey spring (modified from Gremaud and Goldscheider 2010)

This article focuses on climate change impacts on the glacier and aquifer dynamics, and also presents estimations on glacier volume and meltwater availability in the near future.

2 Geologic, Hydrogeologic and Glaciological Setting

2.1 Geology

The study area belongs to the Helvetic zone of the Alps and consists of Jurassic to Paleogene limestone, sandstone and marl. The Tsanfleuron glacier overlies 100–120 m thick Cretaceous limestone (Urgonian or Schrattenkalk) that outcrops on large parts of the land surface. This formation is a very karstifiable geologic unit in the Alps, due to its mechanical strength and high mineralogical purity (Goldscheider 2005). The underlying formation mainly consists of marl, about 100 m thick. The strata are folded, with SW-NE trending fold axes (Steck et al. 2001). The entire zone between the glacier and the Sanetsch pass is formed by a large and wide anticline dipping toward the NE with an angle of about 10°. The southward bordering narrow syncline forms the limit of the karst system.

2.2 Hydrogeology

The hydrogeology of this karst system has been studied by means of multi-tracer tests with a total of 22 injections (Gremaud et al. 2009; Gremaud and Goldscheider 2010). The system is drained by five springs. The major part of the karst surface and glacier is drained by the Glarey spring in the SE (Fig. 1), with transit times of 5–57 h (peak times of tracer breakthrough curves) and recoveries of 5–80%. Water flow is parallel to the strata, from the crest of the wide anticline, downward its SE limb toward the narrow syncline, which collects all water and conducts it to the spring at 1550 m a.s.l. altitude. The other springs drain only marginal parts of the karrenfield. The water of the three springs in the S crosses the entire stratigraphic sequence, including several marl aquicludes, probably along deep fractures, with transit times of 15–32 h. The Sarine spring drains a small strip of karst limestone in the NE part of the area, with transit times around 12 h (Gremaud et al. 2009).

2.3 Glaciology

Tsanfleuron glacier has a mean thickness of 35 m (Gremaud and Goldscheider 2010) and can be subdivided in two parts. A thick northern part filling a valley with a maximum thickness of 138 m, and a central and southern zone consisting of a thin layer of ice (locally only 15 m thick) on top of the aquifer (Fig. 2).

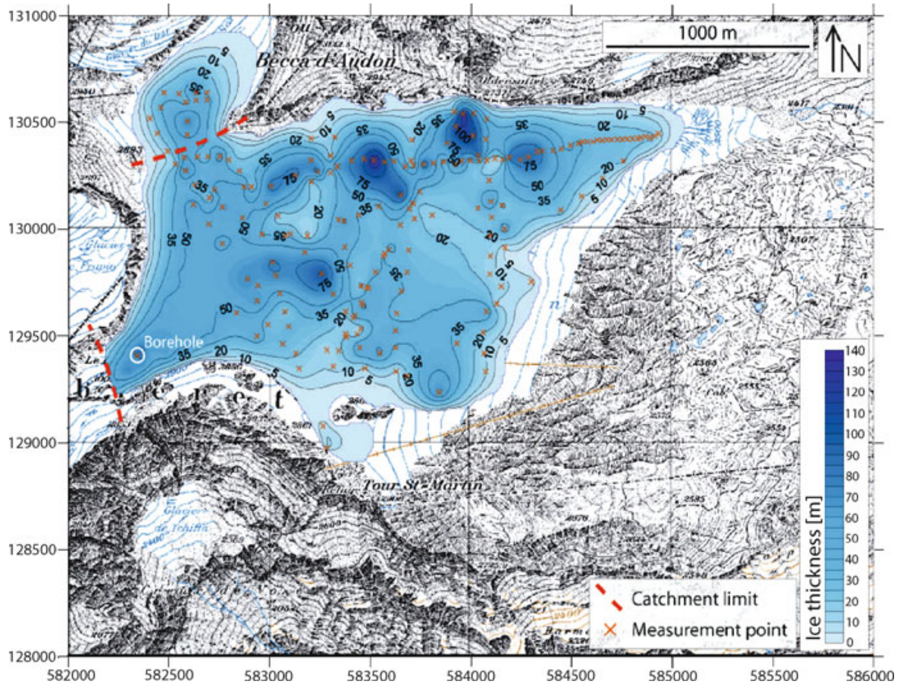

Fig. 2 Ice-thickness map of the glacier (2007/2008), based on RMT measurements and a borehole. The thick northern part of the glacier forms a glacier tongue; the southern sector is a thin ice layer overlying limestone. The heterogeneous pattern of ice thickness reflects the uneven morphology below the glacier (Gremaud and Goldscheider 2010)

The land surface below the glacier is not plane but presents several wide depressions and mounts, with a subglacial morphology similar to the karst landscape in the glacier forefield. The ice volume was estimated at $1.0 \times 108\,\mathrm{m}^3$, corresponding to $0.92 \times 108\,\mathrm{m}^3$ freshwater available for aquifer recharge (Gremaud and Goldscheider 2010), assuming an ice/water density ratio of 0.92 (Benn 1998).

3 Outlook

Glaciers accumulate snow and ice in winter and release meltwater in summer. Under equilibrium conditions (no retreat or advancement), glaciers do not change much the annual water budget of a basin, but mainly influence the annual variability of flow by delivering meltwater during warm periods. However, data of the Swiss Glacier Monitoring Network (2009), satellite data (Paul et al. 2004) and models show that glaciers are shrinking and will continue to do so.

For Tsanfleuron glacier, field observations indicate that it loses about 15 m length and 1.5 m thickness per year. In 2008, the glacier covered a surface of $2.8\,\mathrm{km}^2$, so

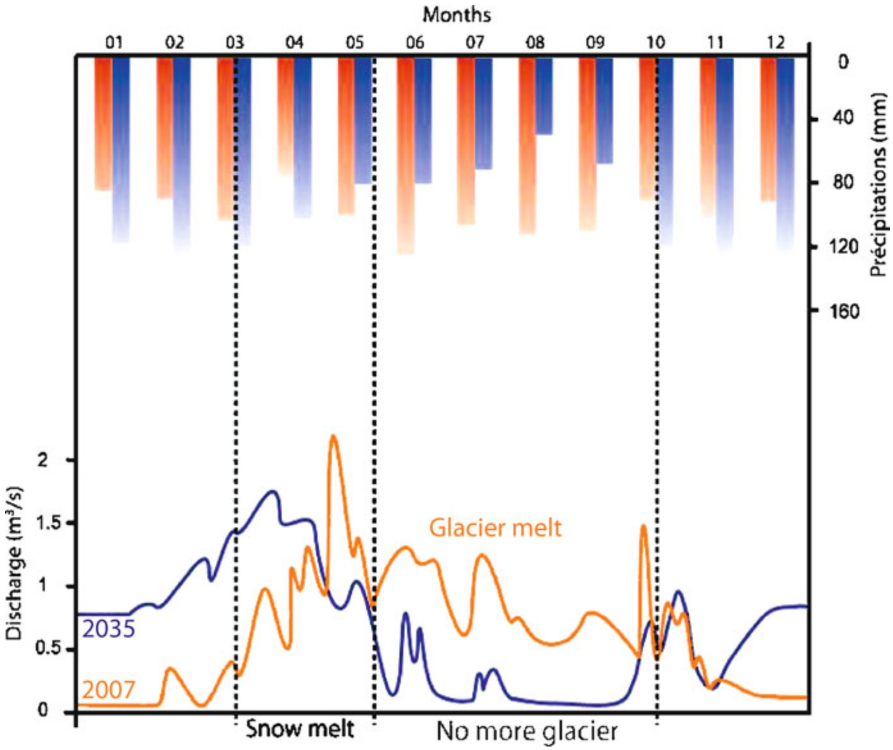

Fig. 3 Comparison of hydrograph at Glarey spring in 2006 (available data) and 2035 (prognosis). Water availability will decrease during summer season, but increase during winter by more snowmelt and more rain at high elevation

the estimated ice loss is 4.2 × 106 m^3/year, corresponding to a freshwater volume of 3.9 × 106 m^3/year or a mean flow rate of 120 L/s (Gremaud and Goldscheider 2010). Evaporation losses from glaciers are small compared to meltwater production (Musy and Higy 2004). Thus, most of this flow is supposed to contribute to aquifer recharge. This quantity represents a transient surplus of water that is available now but will be missing when glacier will have disappeared (Fig. 3).

As a conclusion, water shortage has to be expected during long dry summer and autumn periods in the future, when at the same time, water demand for irrigation and others purposed will increase.

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