Effects of Global Climate Change on Alpine Aquatic Systems

Global climate change has a direct effect on the alpine aquatic cycle. The last decade was probably the warmest period of the last 1000 years. If this trend continues, there will be significant consequences for the water cycle in Switzerland. Predictions are that summers will be drier, while winters will see more precipitation. Snow lines will increase but glaciers will recede dramatically or disappear altogether. What consequences would these changes have for the streams and rivers in the alpine region?

Alpine aquatic systems – streams, rivers, small and large lakes, ground water, water in pores and fractures of the soil – are part of the global water cycle. Through evaporation and precipitation, this cycle links atmospheric, soil, vegetation and aquatic systems. The water cycle is affected by climate and weather, but climate is also a function of the water cycle – an enormously complex system of feed-back loops. Additionally, humans interfere with these loops and cycles through water management, e.g., water is retained in reservoirs or diverted to different watersheds; large tracts of agricultural land are irrigated; wetlands are drained; and groundwater levels are raised and lowered.

At our latitude and under conditions where global climate would not change, interactions between the aquatic cycle, climate and weather would be stable over a period of several hundred years; this would also be true for the alpine environment.

Changes in the Water Cycle – Yesterday and Before Yesterday

In order to assess the effect of future climate change, we have to consider the water cycle and precipitation patterns in particular. All regions of Switzerland have seen significant fluctuations in precipitation over the last 100 years (Fig. 1). For the Ticino watershed, for example, the extremes were 1084 mm in 1949 and 3038 mm in 1977, thus varying by a factor of three. Probst and Tardy [1] have analyzed discharge data for large rivers and shown that such fluctuations have been observed all over the world. They are due to changes in global circulation and general atmospheric conditions.

Discharge is indirectly coupled to precipitation. In the course of several years, discharge reflects precipitation patterns, provided evaporation is relatively constant; however, precipitation does not necessarily run off directly. It can be stored and retained in many different ways: in snow, glaciers, soil, ground water, natural or artificial lakes, just to name a few. The release of water from these storages affects discharge in the short-term. We can distinguish different discharge types depending on the degree of glaciation and snow cover. They differ in their annual discharge pattern. Figure 2 shows a selection of different discharge types. The largest fluctuations are observed for the type "a-glaciaire", i.e., streams that are primarily fed by glaciers and snow melt. In these streams, discharge between summer and winter can easily vary by a factor of 30. The smallest degree of fluctuation is associated with streams of the type "pluvial supérieur" which depend mostly on rainfall.

With respect to extremes in discharge volume between dry and flood conditions, the differences are even more dramatic. In the Rappengraben, a stream with a very small watershed, extremes of less than 0.1 l/s to over 2300 l/s have been observed. For the Rhine, a river with a very large watershed (only including the portion down to Basel), the extremes were 205 m^3/s in the year 1858 and 5700 m^3/s in 1876.

A problem arises when water management circles and society as a whole, consider the extremes that have been observed in the last 100 years to be representative of the range of values we can expect. If we go back more than 100 years, however, we realize that our "representative" range considerably underestimates the true variability. Pfister [2] has analyzed climatic variations over the last 500 years and notes that the 20th Century was a rather atypically "benign" century. Frozen lakes and dry, cold winters were nothing unusual for people of the 18th Century. At the same time, the record shows that summers were exceptionally dry; before 1730, this occurred

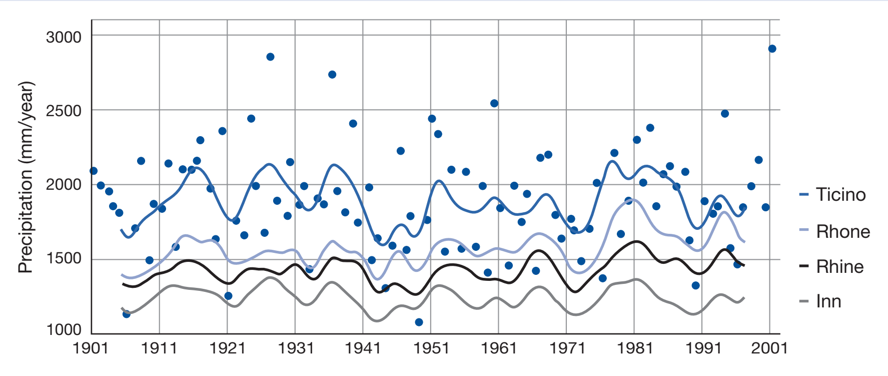

Fig. 1: Temporal pattern of annual precipitation (mm/year) in the watersheds of the Ticino (to Bellinzona), the Rhone (to Lake Geneva), the Rhine (to Basel, Swiss portion of watershed only), and the Inn (to border with Austria). The time series of the annual averages were smoothed with a Gaussian low pass filter over nine-year intervals. For the Ticino, values for individual years are shown as solid circles [7].

every 12 to 15 years. After that time, the interval was roughly every 50 years, and in the 20th century the only such year was 1947. A high incidence of cold and wet summers was recorded between 1576 and 1635, causing glaciers to advance. Since then, such extreme summers have become rather rare.

The frequency of floods has changed accordingly: in the mountain cantons of Valais, Uri, Ticino and the Grisons, the periods of 1550–1580 and 1827–1875 saw an especially high occurrence of floods. Floods were a rather rare event in the years 1641–1706 and 1927–1975. In the 20th Century, flooding has occurred more often since about 1977. It is not a surprise then that Schmidli et al. [3] have noted an increase in winter precipitation, while Frei and Schär [4] have observed increased intensity of individual precipitation events for the same time period.

The Water Cycle Tomorrow and After Tomorrow

The 1990s was probably the warmest decade of the last 1000 years. The third report of the "Intergovernmental Panel on Climate Change" (IPCC) is the first document to state this very clearly [5]. At the same time, the report noted that the largest part of the temperature increase of the latest 50 years was probably due to human activity. With regard to Switzerland, the "Advisory Body on Climate Change" ("Organe consultatif sur les Changements Climatiques", OcCC) [6] has summarized the most important conclusions from the IPCC reports. Assuming temperatures continue to rise, which is a likely scenario, the consequences for the water cycle in Switzerland within the next 50 years would be as follows:

- decreasing precipitation in summer, increasing precipitation in winter, larger fluctuations in annual rainfall;
- more frequent heavy precipitation events in winter (see Fig. 3);
- less precipitation in the form of snow;
- snow lines increasing by 200 m;
- complete melting of a large number of glaciers;
- an increase in discharge volume north of the Alps by 10 %, a decrease by 10 % south of the Alps;
- shift in the discharge regime by one regime level (see Fig. 2);
- increased frequency and severity of floods, especially in the winter months in the middle and lower regions;
- increasing dry periods during the summer, especially in the lower reaches;
- larger fluctuations in discharge dynamics;
- increased occurrence of debris flows in steep zones of rock and gravel debris that become exposed after the melting of permafrost areas and recession of glaciers.

We have to emphasize, however, that the predicted changes for our region still are somewhat uncertain. This is primarily due to the fact that global climate models cannot reliably calculate regional scenarios.

Consequences for Water Resource Management

Progressive global climate change may lead to situations whereby elements of the water

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A debris flow in action.

B. Schädler, BWG

The result. More debris flows due to global warming?

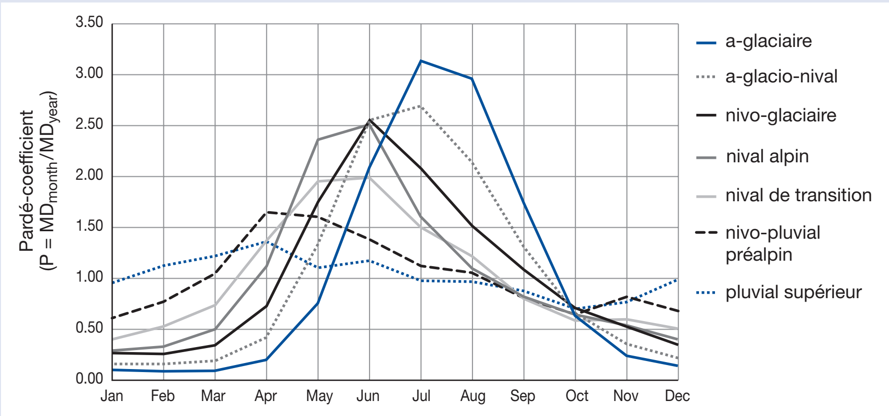

Fig. 2: Average discharge pattern for Swiss watersheds at varying elevation, ranging from "pluvial supérieur" (average elevation 800 m a. s. l.) to "a-glaciaire" (2700 m a. s. l.) [after 8]. MD = mean discharge.

cycle assume values that exceed current experimental values; therefore, we need to anticipate the consequences of various aspects of water resource management:

- Due to a reduction in precipitation during the summer months, lakes and streams will carry less water. At the same time, agricultural crops will have to be irrigated, leading to an even more pronounced water shortage. A water shortage would, in turn, have consequences for water quality; pollutants would no longer be diluted, and water temperatures would increase. Normally, water temperatures change in concert with air temperatures (Fig. 4). When discharge volumes are reduced, however, we have to assume that water temperatures will rise more than proportionally, especially in smaller streams.
- We cannot preclude that there would not be some impact on the ground water near streams since infiltration of rain and stream water would be reduced, and evaporation would be expected to increase.
- The management of all larger lakes in Switzerland (with the exceptions of Lake Constance and Walensee) is based on experimental values established in the 20th Century that balance the interests of all lake users. Increased precipitation during the winter could lead to more demand for flood protection. This could create a need for different operational procedures or even new structural measures. Since such changes require a long lead time for planning and implementation, we have to move quickly to develop scenarios for these problems.
- The temporal pattern for recharge flow to reservoirs and demand for electricity are expected to change. There could be, however, new demands on reservoir operators in terms of water retention during high water periods. Substantial political, legislative and technical groundwork would have to be laid before our reservoirs could be operated as multi-purpose installations.
- If the increased number of flood events translates to more flooding in downstream countries, we have to expect a demand for more retention of water in our Swiss reservoirs and lakes during those periods. This would definitely add a very strong political dimension to the two issues discussed above.
- Finally, navigation of the Rhine could be affected: we would anticipate very low water levels all the way to The Netherlands, especially during the summer and fall, while we would expect high water surges to move through the system in the winter. As a result, barges would reach Switzerland only partially loaded or not at all, which would result in increased prices for high volume goods such as oil.

The water resource management field is accustomed to reacting to extreme situations and to finding workable solutions. The predicted climate changes, however, are a type of challenge where we can and should take proactive measures before major problems arise, following the principle of "no regret". These are measures that will minimize the effects of global climate change and are, at the same time, desirable for other reasons, such as changes in land use politics or a more flexible management of our large lakes.

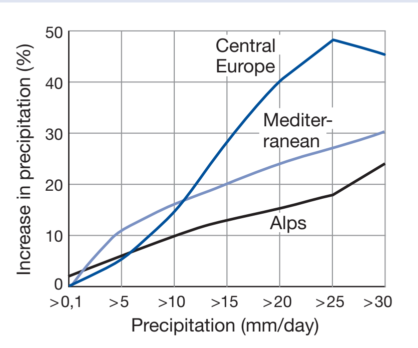

Fig. 3: Calculated increase in winter precipitation for three mid-European regions assuming an atmosphere that is 2 °C warmer and 15% more humid than the current atmosphere [after 9].

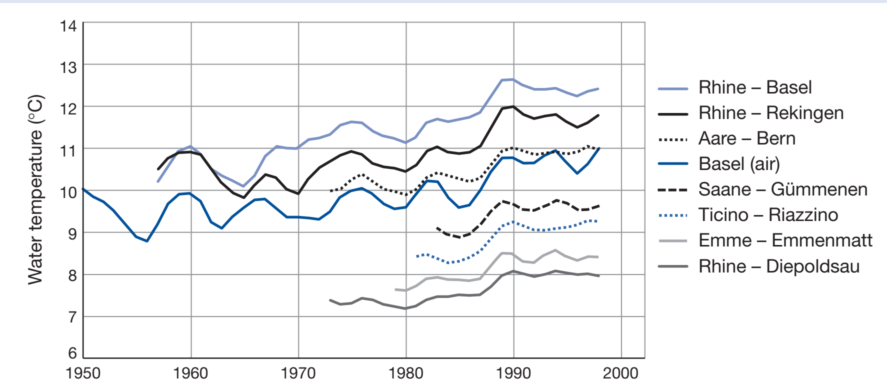

Fig. 4: Observed annual average water temperatures (1954–2001) for a number of Swiss rivers in comparison to air temperature in Basel. The time series of the annual averages were smoothed with a Gaussian low pass filter over seven-year intervals [after 10].

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[1] Probst J.L., Tardy Y. (1987): Long range streamflow and world continental runoff fluctuations since the beginning of this century. Journal of Hydrology *94,* 289–311.

[2] Pfister C. (1999): Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen. Verlag Haupt, Bern, 304 p.

[3] Schmidli J., Schmutz C., Frei C., Wanner H., Schär C. (2002): Mesoscale precipitation variability in the region of the European Alps during the 20th century. International Journal of Climatology *22,* 1049–1074.

[4] Frei C., Schär C. (2001): Detection probability of trends in rare events: Theory and application to heavy precipitation in the Alpine region. Journal of Climate *14,* 1564–1584.

[5] IPCC (2001): Climate Change 2001: The Scienific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 944 p.

[6] OcCC (2002): Das Klima ändert – auch in der Schweiz. Die wichtigsten Ergebnisse des dritten Wissensstandsberichtes des IPCC aus der Sicht der Schweiz. Bern, 48 S.

[7] Schädler B. (1987): The Water Balance of Switzerland, Communication No. 6a, Berne, 70 p.

[8] Weingartner R., Aschwanden H. (1992): Discharge Regime – the Basis for the Estimation of Average Flows. In: Hydrological Atlas of Switzerland, map 5.2, Berne.

[9] Frei C., Schär C., Lüthi D., Davies H.C. (1998): Heavy precipitation processes in a warmer climate. Geophysical Research Letters *25,* 1431–1334.

[10] Jakob A., Liechti P., Schädler B. (1996): Temperatur in Schweizer Gewässern – Quo vadis? Gas Wasser Abwasser *76,* 288–294.