

Vulnerability of the Alpine landscape in the light of ongoing climate change

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Climate plays an important role in modulating fluvial and hillslopes erosion rates and largely controls sediment discharge. Here, we present evidence of changes in hydroclimatology which have been observed in the instrumental record of the past 30-70 years in the Swiss Alps, and we develop scenarios about potential consequences on landscape forming processes and surface erosion in general, and landsliding in particular.

The analyses of trends in mean daily streamflow, air temperature and precipitation records from undisturbed watersheds in the Swiss Alps show a significant change in the natural streamflow regime since the 1960s. In particular, about 60-70% of the gauging stations have recorded an increase in winter maximum streamflow and in spring moderate and low flows. Changes in air temperature, most notably a general warming with a substantial increase in the number of days with minimum daily temperatures above 0°C, explain some of the observed increases in streamflow in the winter and spring seasons, because the retention effect related to snowfall has decreased. In contrast to the general public perception, however, there are no distinct trends in summer high and maximum streamflows.

The results of the streamflow trend analyses suggest that the most vulnerable environments, from the point of view of runoff generation and landscape response, are mountainous drainage basins with seasonal snow cover that are located at the border of the Alps. In these segments, observed increases in spring moderate and low flows due to more snowmelt and liquid precipitation will likely lead to higher soil moisture content for extended periods of time, particularly for areas below 1300-1600 m where a significant drop in the duration of the snow cover is predicted.

The potential geomorphological consequence of the hydromorphological changes is an increase in landslide activity due to soil saturation, both in terms of the occurrence of shallow translational slides as well as the slip rates of large slow-moving earth flows. Because slip rates of landslides critically depend on the dynamic viscosity and the mechanical strength of the involved matrix, higher moisture contents due to more liquid precipitation in winter and spring will promote hillslope instability particularly at the northern foothills of the Alps where lithotectonic units susceptible for landsliding (Flysch and Molasse) are abundant.

A prediction of a trend in magnitudes and frequencies of debris flows is difficult at this stage. However, because landslides are potential sources for mass flows, it is tempting to predict an increase in the magnitudes and frequencies of sediment transfer by debris flow processes. Nevertheless, we tentatively discard the possibility of such a scenario, because sediment discharge of debris flows with sources in landslides tends to be transport-limited, which implies a strong control of hydrology on the magnitudes and frequencies of mass flows. Accordingly, any increase in sediment discharge would require an equivalent trend in summer high and maximum water runoff, which, however, has not yet been recorded at gauging stations. Consequently, except for landscapes affected by permafrost conditions, we predict that enhancement of landsliding particularly in Flysch regions is the largest response to ongoing climate change. There is no evidence for predicting an increase in sediment discharge by processes in channels in general, and for debris-flow activities in particular.