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Temperature-forcing of sediment flux and geomorphic response in an Alpine river basin

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Alpine river basins have a very particular hydrological signal, associated with the importance of snow and/or ice melt for a range of elements of hydrological response, and notably the impacts of winter storage of precipitation in the snow pack. This storage can have two important implications for river flow: (1) snow (and ice) melt can sustain low flows through the summer and autumn period; and (2), during the transition from winter to summer, there is an increased probability of convective rainfall events, often orographically-enhanced, which can lead to rapid snow melt and so exceptionally high river flows. Thus, snow cover dynamics can strongly influence the frequency distribution of river flow. In turn, snow cover is influenced by the interaction between precipitation and temperature, both the altitude-dependent percentage of winter precipitation that is solid and the rate of snow melt. We have recently reconstructed hourly river flows from the 1940s to present for a nivo-glacial Alpine basin (c. 5% glaciated) using the WaSIM-ETH model, which includes a full cryosphere representation. The basin is interesting because over this time-period it has had no change land use, relatively stable land cover, and no river or catchment management: it is thus an ideal basin for understanding the interactions between climate variability, hydrology and geomorphic response. Our work confirms that the variability in snow cover has a significant effect upon both low flows and highs and hence the shape of the flow duration curve, with this variability strongly forced by temperature. Given that sediment transport relations for rivers in Alpine systems are threshold-based and non-linear, such changes in flow duration could impact significantly sediment transport capacity and hence geomorphic response, independently of changes in flux from hillslopes. In this paper, we couple our hydrological reconstruction to the Rickenmann and Recking sediment transport model which has been shown to be an effective model for estimating sediment transport capacity in a range of rivers similar to ours; and we compare these results with information on river morphological changes in the basin, reconstructed using archival digital photogrammetry. Our results show that during the 1970s and 1980s, a period of wetter and cooler winters, there was a significant increase in the annual sediment transport capacity of the system, and that this was related to snow cover driven shifts in annual flow duration curves. This same shift was also observed in the geomorphic response of the river, with image analysis showing clear river channel erosion and entrenchment and the development of a stable vegetation cover on the terraces that formed. This was reversed from the 1980s onwards, with the onset of warmer winters, higher winter percentages of liquid precipitation and earlier snow melt, a modelled reduction in sediment transport capacity and clear evidence of the onset of sedimentation in the river system. It appears that temperature-driven changes in hydrological response, regardless of both rainfall variability and sediment delivery, are able to force river response. The basic theoretical reason for this can be traced to differences in the shape of the sediment transport duration curves for river and non-river systems in Alpine environments which makes the former much more sensitive to climate forcing than the latter.