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# Bedload transport in steep glacier-fed streams: from incipient motion to floods

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The current understanding of bedload dynamics in mountain channels is rather scarce, and the capability to predict it over a range of discharges and under different morphological conditions is still very poor despite the headways made during the last decade. Indeed, there has been an increased recognition of the highly stochastic nature of bedload transport in steep streams, especially at low to medium flows (i.e. up to ordinary events). On the other hand, considerable efforts have been made to model the effective energy available for bedload in steep channels, in order to reduce the large overestimation in bedload rates produced by transport capacity equations. Nonetheless, because high-gradient channels are notoriously sediment supply-limited, largely varying bedload rates can be observed at the same stream cross-section under nearly identical morphological and hydraulic conditions, as a consequence of different sediment supply regimes/events. Therefore, the use of a single bedload transport equation even for the same stream is becoming strongly questioned by researchers, whereas most river agencies and consultants – and numerical models – still rely on "classical" transport capacity equations. Remarkably, glacial streams offer the possibility to investigate how seasonal changes in sediment supply at the basin scale – deriving from the periglacial and glacial areas – affects bedload transport rates in the main channel. However, little quantitative bedload data from these systems are available.

This contribution intends to share the recent results obtained in two glaciarized basins in the Eastern Italian Alps, which range from about 10 km$^2$ (upper Saldur river basin) to 130 km$^2$ (Sulden river basin) in drainage area. Different monitoring methodologies encompassing PIT-tagged clasts tracking (by both portable and stationary antennas), geophone plates, acoustic pipe sensor and direct sampling by portable traps have been deployed in these two mountain streams. Our results indicate that numerous and well-conducted direct bedload samples are key to assess bedload discharges, and rates up to 0.2 and 0.5 kg m$^{-1}$ s$^{-1}$ were directly measured in the Saldur and Sulden rivers, respectively. Based on the acoustic pipe/geophone plate calibration curves (based on the number of impulses exceeding a given voltage threshold), max unit bedload rates up to about 5 and 15 kg m$^{-1}$ $^{-1}$ were estimated in the two rivers during the highest flood events occurred so far, featuring recurrence interval of 5-10 yr. Despite these unit bedload discharges rates are seemingly high, they are at least one order of magnitude lower than those predicted by several bedload equations, also accounting for reduced energy slopes. Indirect monitoring devices proved also extremely useful to investigate incipient motion conditions and the variation of transport intensities over the years. Indeed, the upper Saldur River (monitored at nearly proglacial conditions) exhibited a marked seasonal trend, with higher bedload rates (at identical water discharges), lower motion thresholds and counter-clockwise hysteresis loops (between water and bedload) during glacier melt flows. Preliminary data indicate for the Sulden River a more complex bedload temporal dynamics, likely in response to its larger basin featuring several active sediment sources beside the glacier and the proglacial areas.