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Critical channel runoff as direct trigger of debris flows in mountainous terrain.

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As a natural hazard in mountainous terrain, debris flows cause considerable disruptions, human casualties and economic damage in many regions world-wide. However, the spatially localized nature of debris flows together with the lack of data at sufficient temporal and spatial resolutions make the triggering processes difficult to describe. As a result, debris flows are problematic to predict. Effective regional and local early warning systems, built on both process-based or statistical models, have therefore so far remained elusive. Even more, common statistical models, such as precipitation-intensity threshold models, rely on precipitation. As debris flows are essentially in-channel processes, precipitation is an indirect predictor and proxy for in-channel processes. As such it is not surprising that precipitation has limited predictive power. In spite of recent progress, general and detailed descriptions of in-channel processes that control debris flow triggering only start to emerge. Most generally, sediment supply and channel flow magnitudes can be considered major direct controls on debris flow occurence. As both are difficult to observe, they have so far not been systematically exploited and quantitatively described for their role as debris flow triggers.

Based on 20-year records of hydro-climatic data, several dozens of well documented debris flow events in three contrasting head-water catchments in the Central Alps and a semi-distributed, process-based hydrological model, the objectives of our analysis are to (1) quantify the critical channel runoff magnitudes that have triggered past debris flows and to establish whether characteristic magnitudes can be found as a function of topography, soils, geology and other factors, (2) identify the relevance of snow melt vs. rainfall for the generation of debris flow triggering critical channel runoff, and (3) to test whether modelled critical channel runoff has higher power to predict debris flows than standard precipitation-intensity models.

Overall, we have found that indeed, relatively well-defined minimum critical channel flows as lower limits above which debris flows occur feature each of the three study catchments. It was also found that the general magnitudes are highly site specific. In spite of that, no obvious relation between the average critical flow magnitudes and landscape characteristics, such as local terrain or channel slopes, vegetation cover, soil type or geology at the three sites could be identified. In general, it was found that flow peaks, generated by short-duration, high-intensity rainfall events, mostly during summer, dominated the debris flow trigger dynamics at the study sites. In addition, several instances when debris flows were triggered by flow peaks of similar magnitudes but generated by high-intensity snow melt in combination with rain-on-snow were observed, highlighting the importance of quantifying liquid water input dynamics instead of bulk precipitation as system input that causally leads to the occurrence of debris flows. Intrinsically accounting not only for this distinction but also additional effects by evaporation, modelled channel flow magnitudes were found to be better predictors of debris flows, with respect to both, higher rates of true positives (correctly predicted debris flows) and lower rates of false positives (predicted but not occurred in reality), than traditional precipitation thresholds.