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Sediment-water flows in mountain catchments: Variability in response to high-magnitude hydrological events

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Sediment transfer in mountain streams occurs by processes classified as debris flows, hyperconcentrated flows, debris floods, and water flows. One of the most important tasks in investigating floods in mountain catchments is to identify the transport mechanisms since different sediment-water flows induce peculiar geomorphological dynamics and hazards. This study aims at testing how the energy of water and the amount of sediment involved during a high-magnitude hydrological event can modify the mechanisms of sediment transfer with respect to those occurring during ordinary floods.

The selected case study is the Tegnas catchment (Dolomites, Italy), which, in October 2018, was affected by a severe hydrological event (Vaia Storm) with a recurrence interval of about 200 years. The studied catchment drains an area of 51 km^2, with a range in elevation between 2872 and 620 m a.s.l.. The classification of flows that occurred during the Vaia storm was addressed at the sub-reach scale applying a field survey protocol developed to classify the flood deposits based on their sedimentological and morphological features. Following the same approach, we also determined the flow types typifying the stream network during ordinary floods. Additionally, we considered flows predicted by three morphometric approaches for high-magnitude events, and took into account the geomorphological dynamics (e.g., channel changes) and the hydraulic constraints (i.e., unit stream power) that occurred during the Vaia storm.

Water flow was the dominant process during Vaia storm in the Tegnas main steam (12 sub-reaches), although debris flow and debris flood deposits were documented at 3 and 7 sub-reaches, respectively. Water flow was observed in response to ordinary events along the entire Tegnas Torrent. Most of the steep tributaries were affected by debris flows (6 tributaries), but also debris floods were recognized at 3 steep channels. The morphometric approaches had a satisfactory performance in predicting the two end-member flows, but often failed in recognizing sub-reaches affected by debris floods.

The comparison between the occurred high-magnitude flows, and the ordinary flows allowed us to infer the existence of relationships between the transport mechanisms, the hydraulic forcing, and channel dynamics. The upheaval of the ordinary flow types did not occur along the entire stream

network. The transition from water flows to debris floods occurred for unit stream powers exceeding the threshold of 5000-6000 Wm^{-2} or downstream of a channel delivering a large amount of sediment mobilized by debris flow to the receiving stream. The occurrence of debris floods, causing higher channel widening than water flows, appears to be facilitated by the injection of fine material into the flow, which can occur as consequence of channel-bank erosion and overbank floodwater re-entering the channel. Finally, morphometric approaches turned out to be adequate to provide a first-order discrimination of expectable high-magnitude flow types. However, the complex relationships found between flow types and a range of hydraulic, morphological, and geological controlling factors, reveal that a more detailed characterization is necessary for understanding the transport mechanisms and predicting geomorphic hazard that can affect specific channel sites during high-magnitude to extreme hydrological events.