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Assessing Debris Flow Susceptibility in Deglaciated Alpine Catchments: A Novel Approach Integrating Flow-path Connectivity and Sediment Availability

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Debris flows pose significant natural hazards in mountainous regions globally, with the potential to cause substantial damage to villages and infrastructure in lowland areas. To effectively mitigate these hazards, it is essential to identify catchments prone to delivering debris flows to fan areas. Topographic metrics such as fan slope and catchment Melton number are useful at a regional scale but in recently deglaciated alpine landscapes do not explain high variability in debris flow frequency among neighboring catchments. Here we assess debris flow susceptibility by quantifying the spatial extent of sediment cover across upstream catchment areas and the connectivity of potential debris flow source areas to fans at catchment outlets.

The Pitztal Valley in the Austrian Alps serves as the study site, benefiting from elevation data (digital terrain model) and historical debris flow event data since the 1950s for 28 catchments, along with sediment cover maps for 18 catchments. To assess the likelihood that debris flows originating within sediment covered areas could reach the fan, we calculated the minimum mean slope angle along every flow path to the fan apex. Source areas with minimum angles lower than a dynamic friction angle are assumed to be disconnected from the fan apex because potential debris flows would come to rest and form coarse deposits upstream of the fan. This concept is utilized to calculate the fractional connectivity for sediment areas in each catchment as a function of dynamic friction angle. Rather than assume a single friction angle, we compare catchments based on the angle corresponding to a connectivity rate of 50% for the sediment covered areas (referred to as the 50% connectivity angle).

We find a highly significant positive exponential correlation between the 50% connectivity angle and the historical debris flow frequency (in units of debris flow events per square kilometer of catchment area) using data from the 18 catchments with sediment cover maps. Validation is performed in 10 additional catchments where we identified sediment covered areas using a new algorithm that can distinguish bare bedrock from sediment deposits from the local topographic roughness. The observed debris flow event frequencies align closely with or fall within the confidence bounds predicted by the 50% connectivity angles, confirming that the combined evaluation of catchment connectivity and sediment availability successfully explains debris flow

frequency in this landscape.

Lastly, the results are compared to models employing previously published metrics of connectivity and debris flow susceptibility, providing insights into the contribution and efficacy of this new approach.