Flow and Bed Conditions jointly control Debris-Flow Erosion and Bulking, Illgraben (CH)

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Debris flows are water-laden masses of soil and rock, which are common geological hazards in mountainous regions worldwide. They can grow greatly in size and hazardous potential by eroding bed and bank materials. However, erosion mechanisms are poorly understood because debris flows are complex hybrids between a fluid flow and a moving mass of colliding particles, bed erodibility varies between events, and field measurements are hard to obtain. Here, we combine detailed flow measurements, rainfall data, and high-resolution UAV measurements of channel-bed erosion and deposition for 13 debris flows in the Illgraben (CH), to identify the key controls on debris-flow erosion. We show that flow conditions and bed wetness jointly control debris-flow erosion. Flow conditions that describe the cumulative forces exerted at the bed over the full event (flow volume, cumulative shear stress, and seismic energy) have the strongest correlations with measured erosion and deposition. However, we also find statistically significant correlations between erosion and deposition and frontal flow properties, including frontal velocity, flow depth, shear stress, and peak discharge. Antecedent rainfall over a period of 2-3 hours prior to the debris-flow events strongly correlates to erosion and deposition, while the correlation decreases in strength and diminishes towards shorter and longer time periods of antecedent moisture. Shear forces and particle-impact forces are strongly correlated and act in conjunction in the erosion process. A shear-stress approach accounting for bed erodibility may therefore be applicable for modelling and predicting debris-flow erosion.