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Granular sheetflow at steep slopes

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Steep mountain streams are important components of the river network; these channels provide important aquatic habitat, are conduits for sediment delivered by debris flow and fluvial processes to lower gradient channels, and comprise much of the channel network in mountainous regions. However, relatively little is known about the mechanisms of sediment transport, particularly for intermediate channel slopes (i.e. $10\% < S < 30\%$), where both fluvial transport and debris flows are known to occur. To address this knowledge gap, we performed flume experiments in a 12-meter long recirculating flume with bed slopes ranging from S = 10% to 30% and a uniform gravel bed. For each experiment, we allowed the flow and sediment transport to come into steady-state and documented the flow depth, flow velocity, sediment fluxes into and out of the flume, water and bed surface long profiles, and bedform geometry. We found for S = 20% and 30%, under steady, uniform flow conditions, sheetflows, rather than debris flows or fluvial transport occurred. Under sheetflow conditions, a relatively thin layer of colliding grains, with a solids concentration approaching that of the stationary bed, is transported below a dilute shear flow. Sheetflow thicknesses ranged from four to ten particle diameters, increased on steeper bed slopes, and was not an independent function of the Shields stress, unlike sheetflows at lower bed gradients. Maximum particle velocities within the sheetflows occurred at their upper surface and increased with the fluid bed shear velocity. Particle velocity profiles within the sheetflow layer were linear in the upper 40% of the flow, like sheetflows on lower slopes, but were concave down below, similar to dry avalanches, which suggests a hybrid behavior where downslope gravitational forces acting on particles, shear from the overriding water, and seepage flow through the granular bed were all important.