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Investigating controls on debris-flow initiation and surge frequency at Chalk Cliffs, USA: initial results from monitoring and modeling

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Recent monitoring of a small (0.3 km2) bedrock-dominated catchment in central Colorado, USA, has revealed distinct differences in debris-flow surge dynamics relative to rainfall intensity. Moderate bursts of rainfall (15-40 mm/hr) typically trigger a set of coarse-grained surges with depths that can exceed 1.0 m. High-intensity bursts of rainfall (40-150 mm/hr), in contrast, often generate only a single moderate-amplitude coarse-grained surge (> 0.5 m depth), followed by several minutes of water-rich flow having comparable or greater peak depth. In both cases, debris flows are observed within minutes of rain bursts due to the rapid concentration of runoff from bedrock cliffs to channels loaded with sediment from dry ravel and rockfall. Video observations have shown that the runoff can initiate debris flows both at a steep (∼40 degree) bedrock-colluvium interface, and in a lower gradient (∼15 degree) section of channel. This latter style of initiation, which has only been observed at moderate rainfall intensity, involves the formation and failure of a highly porous sediment dam created by bedload transport. We speculate that this process may be responsible for the creation of the consistent surge patterns we observe with moderate intensity rainfall, and may explain the relative lack of granular surges with high-intensity rainfall.

To investigate this possibility, we have developed a simple one-dimensional morphodynamic model of the formation and failure of sediment dams in an undulating bedrock channel filled with loose bed sediment. The model consists of a coupled surface-subsurface water flow model, which is used to drive bed-sediment topographic adjustments based on the mathematical divergence of the sediment transport rate. Under certain topographic and water-flow conditions, the shear stress in a section of the channel can fall below the critical shear stress, resulting in local deposition of sediment. Consistent with field observations, the modeled deposit grows in height with the addition of sediment from upstream, while water runoff is sieved through the porous dam. A simple Mohr-Coulomb slope stability model is used to evaluate the balance of forces on the dam and determine when the dam begins to move as a debris flow. Initial model results are in qualitative agreement with our field observations of surge characteristics. The calculations show that, given sufficient sediment supply, multiple episodes of dam failure could occur at the relatively low transport stages associated with moderate intensity rainfall. Rapid in-channel accumulation of sediment needed for dam formation and debris-flow initiation is less likely during the increased runoff associated with high rainfall intensity, because the high shear stress and transport stage inhibit deposition. These observations highlight that for runoff-generated debris flows, moderate rainfall can produce deep and destructive debris flows due to the likely initiation of granular surges.