Modeling hydrologic processes associated with soil saturation and debris flow initiation during the September 2013 storm, Colorado Front Range

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Abstract: Five days of extreme rainfall in September 2013 resulted in more than 1,100 debris flows in the Colorado Front Range, about 78% of which were initiated on south-facing slopes (SFS). In-situ soil moisture measurements during the storm show that soil saturation was more common on SFS compared to north facing slopes (NFS), which may partially explain the debris flow occurrence pattern. This soil moisture pattern contrasts with observed soil moisture patterns during dry conditions, which instead document wetter conditions on NFS. Various causes have been hypothesized for this pattern of soil moisture reversal, but it is unclear whether these causes are sufficient to explain the observed pattern. The objective of this study is to determine the hydrologic processes that contributed to the saturation of the SFS during the September 2013 event. Fine (horizontal scale) resolution soil moisture patterns are simulated using the Equilibrium Moisture from Topography, Vegetation, and Soil (EMT+VS) model for six large Front Range watersheds (Cache la Poudre, Big Thompson, Little Thompson, Saint Vrain, Lefthand, and North Boulder). We explore the effects of 5 different hydrologic factors on the observed soil moisture pattern: (1) higher rainfall rates, (2) lower interception rates, (3) lower porosity, (4) thinner soils, and (5) reduced percolation to groundwater on SFS. The relative importance of each of our 5 hydrologic factors is tested by comparing the soil moisture patterns from the model to soil moisture observations and debris flow initiation sites. The EMT+VS model is also coupled with an infinite slope stability model to produce a factor of safety map that identifies potential debris-flow initiation sites during the event. The results suggest that differences in interception and percolation to groundwater were primarily responsible for producing wetter SFS and drier NFS. The observed debris flow locations were also found to be in areas that were predicted to be unstable by the model.