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Prediction of spatially explicit rainfall intensity-duration thresholds for post-fire debris-flow generation in the western United States

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Population expansion into fire-prone steeplands has resulted in an increase in post-fire debris-flow risk in the western United States. Logistic regression methods for determining debris-flow likelihood and the calculation of empirical rainfall intensity-duration thresholds for debris-flow initiation represent two common approaches for characterizing hazard and reducing risk. Logistic regression models are currently being used to rapidly assess debris-flow hazard in response to design storms of known intensities (e.g. a 10-year recurrence interval rainstorm). Empirical rainfall intensity-duration thresholds comprise a major component of the United States Geological Survey (USGS) and the National Weather Service (NWS) debris-flow early warning system at a regional scale in southern California. However, these two modeling approaches remain independent, with each approach having limitations that do not allow for synergistic local-scale (e.g. drainage-basin scale) characterization of debris-flow hazard during intense rainfall.

The current logistic regression equations consider rainfall a unique independent variable, which prevents the direct calculation of the relation between rainfall intensity and debris-flow likelihood. Regional (e.g. mountain range or physiographic province scale) rainfall intensity-duration thresholds fail to provide insight into the basin-scale variability of post-fire debris-flow hazard and require an extensive database of historical debris-flow occurrence and rainfall characteristics. Here, we present a new approach that combines traditional logistic regression and intensity-duration threshold methodologies. This method allows for local characterization of both the likelihood that a debris-flow will occur at a given rainfall intensity, the direct calculation of the rainfall rates that will result in a given likelihood, and the ability to calculate spatially explicit rainfall intensity-duration thresholds for debris-flow generation in recently burned areas.

Our approach synthesizes the two methods by incorporating measured rainfall intensity into each model variable (based on measures of topographic steepness, burn severity and surface properties) within the logistic regression equation. This approach provides a more realistic representation of the relation between rainfall intensity and debris-flow likelihood, as likelihood values asymptotically approach zero when rainfall intensity approaches 0 mm/h, and increase with more intense rainfall.

Model performance was evaluated by comparing predictions to several existing regional thresholds. The model, based upon training data collected in southern California, USA, has proven to accurately predict rainfall intensity-duration thresholds for other areas in the western United States not included in the original training dataset. In addition, the improved logistic regression model shows promise for emergency planning purposes and real-time, site-specific early warning. With further validation, this model may permit the prediction of spatially-explicit intensity-duration thresholds for debris-flow generation in areas where empirically derived regional thresholds do not exist. This improvement would permit the expansion of the early-warning system into other regions susceptible to post-fire debris flow.