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Flood and Debris Flow Hazard Predictions in Steep, Burned Landscapes

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Post-wildfire natural hazards such as flooding and debris flows threaten infrastructure and can even lead to loss of life. The risk from these natural hazards could be reduced if floods and debris flows could be predicted from modeling. Our ability to test predictive models is primarily constrained by a lack of observational data that can be used for comparison with model predictions. Following the 2009 Station Fire in the San Gabriel Mountains, CA, USA, we conducted a study with high-resolution topography and hydrologic measurements to test the effectiveness of two different hydrologic routing models to predict flood and debris flow timing. Our research focuses on comparing the performance of two hydrologic models with differing levels of complexity and efficiency using high-resolution, lidar-derived digital elevation models. The simpler model uses the kinematic wave approximation to route flows, while the more complex model uses the full shallow water equations. In both models precipitation is spatially uniform and infiltration is simulated using the Green-Ampt infiltration equation.

Input data for the numerical models was constrained by time series data of soil moisture, and rainfall collected at field sites as well as high-resolution lidar-derived digital elevation models. We ran the numerical models and varied parameter values for the roughness coefficient and hydraulic conductivity. These parameter values were calibrated by minimizing the difference between the simulated and observed flow timing. Moreover, the two parameters were calibrated in two different watersheds, spanning two orders of magnitude in drainage area. The calibrated parameters were subsequently used to model a third watershed, and the results show a good match with observed timing of flow peaks for both models. Calibrated roughness coefficients are generally higher when using the kinematic wave approximation relative to the full shallow water equations, and decrease with increasing spatial scale. The calibrated effective watershed hydraulic conductivity was low for both models, even for storms occurring several months after the fire, consistent with wildfire-induced water-repellency being retained throughout that time. Both models captured the timing of flow peaks, although neither model correctly simulated the flow depth. This study suggests that a kinematic wave model, which is simpler and more computationally efficient, is a justifiable approach for predicting flood and debris flow timing in steep, burned watersheds. By demonstrating the applicability of these models, this study takes an important step towards the development of process-based methods to assess post-wildfire flood and debris flow hazards.