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Modeling the interaction between perched aquifer and unsaturated soil cover for the prediction of shallow landslides triggering in pyroclastic-covered slopes

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Slopes covered with shallow deposits of pyroclastic materials, laying upon fractured limestone bedrock, are widespread in the mountains around Naples (southern Italy). As the soil cover is usually unsaturated, the stability of steep slopes is ensured by the contribution of soil suction to shear strength. Rainfall infiltration wets the cover, thus reducing soil suction, eventually leading to shallow landslide triggering. While drastic reduction of suction is unanimously recognized as the triggering mechanism, there is still debate about the hydrological processes causing the establishment of landslide predisposing conditions. In fact, the pyroclastic materials (mostly ashes with particle size in the range of sands to loamy sands) usually exhibit high porosity (up to 75%) and saturated hydraulic conductivity (in the order of 10-5m/s). During the rainy season, when soil suction between 1kPa and 10kPa is observed, the mean water content of the cover fluctuates around 35-45%, implying that a considerable storage of water is still required for the complete vanishing of suction (e.g. up to 700-800mm for the saturation of 2m of soil cover). Even during the maximum ever observed rainy periods, such a rainfall amount falls in weeks (the mean annual rainfall in the area is around 1600mm), a time interval long enough to let the cover drain out much of the infiltrating water. Nonetheless, in soil covers around 2m thick, landslides were triggered by rainfall events of 250-350mm in 36-72hours. This highlights the dynamic nature of the hydraulic boundary conditions at the interface between soil cover and bedrock, in some cases hampering the fast drainage of water out of the slope.
A possible interpretation of the dynamic behavior of the soil-bedrock interface is given by the monitoring carried out at the slope of Cervinara, allowing the assessment of the water balance of the slope. Monitoring results show that the mean annual rainfall almost completely infiltrates into the ground (overland runoff, developing only during intense rainstorms, sums 100-150mm yearly). The mean annual evapotranspiration is around 700mm, indicating annual leakage through the soil–bedrock interface about 750-800mm. Along the slope, several ephemeral streams are present, drained by a network of streams. The monitored discharge of two streams suggests the springs being supplied by a perched aquifer in the upper part of the fractured limestone, temporarily storing water. The annual subsurface drainage is estimated around 400-500mm, the remaining amount constituting deep groundwater recharge.
A physically-based model has been developed, in which the unsaturated flow in the soil cover is coupled with the saturated flow in the perched aquifer. The application of the model to the simulation of the slope hydrologic behavior over 11 years provides realistic results in terms of soil storage, perched aquifer storage, spring discharge, and groundwater recharge. The different response times of soil and aquifer to precipitation input allow distinguishing the hydrological predisposing causes of landslides (some months of persistent rainfall) from the triggers, which are represented by single intense rainfall events, and offers a possible interpretation of the processes which led to the landslide occurred in December 1999.