Landslide monitoring using reactive sensor networks with high-speed local positioning

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High infiltration capacities associated with the residual soil mantle of steep, humid hillslopes and the presence of less permeable bedrock at depth create conditions that favour the mobilisation of shallow landslides. Typically, rainwater and snowmelt permeate the subsoil under gravity and capillary forces to an underlying low conductivity layer. The permeability contrast leads to the development of a perched water table, and downslope saturated flow ensues. In regions where shallow subsurface storm flow is the dominant means by which water reaches the channel all incident precipitation must pass through a largely unsaturated soil profile before contributing to runoff. Hence unsaturated zone processes may directly control the timing and magnitude of positive pore pressure development and slope instability. This paper presents the results from a series of field experiments designed to investigate the mechanisms by which rainfall signals propagate through an unsaturated soil profile and ultimately trigger slope failure.

The behaviour of a small unchannelled headwater basin, driven to quasi-steady state by sprinkler-irrigation, was monitored by a network of wireless probes with high-speed local positioning embedded within the regolith. A novel sprinkler programme was devised to produce a long period of steady flow conditions, during which tracer studies were conducted to verify subsurface flow paths and effluent geochemistry, followed by high-intensity storm simulations. Analysis of the hydrologic response reveals that unsaturated zone dynamics play a primary role in dictating the spatio-temporal evolution of pore pressures and discharge from the hillslope. Runoff is controlled by a dynamic subsurface region just upslope from the channel head where there is interplay between exfiltrating bedrock flow and vertical percolation through the mantle. Owing to the steep characteristic curve for these soils, even relatively light rainfall tends to drive pressure heads to zero whilst remaining far from saturation. With the onset of steady discharge the vadose zone, saturated zone, and groundwater flux became delicately linked, such that a rapid increase in rainfall intensity led to a saturated zone response and peak discharge which occurred much faster than could have happened through advection alone. The precipitation spike produced a transient pressure wave that travelled relatively rapidly through the unsaturated zone, inducing a large change in hydraulic conductivity and the rapid effusion of stored pore-water. This groundwater redistribution was sufficient to induce localised dilation within the

colluvium, triggering a translational landslide which mobilised rapidly into a debris flow.

Infiltration tests on intact soil cores show that momentum dissipation dominates flow in soils with highly non-linear soil-water retention properties when input rates and antecedent soil-water contents are high. A slight pressure head increase in the near-zero pressure head range can lead to the release of stored soil-water into larger macropores, setting up conditions that favour the initiation of preferential flow. Hence, minor rainstorms which fall on nearly-saturated hillslopes can produce small variations in pressure head that are accompanied by correspondingly large changes in water content, giving rise to the transmission of pressure waves in response to increased rainfall intensity and a relatively rapid response in the vadose zone. Such a coupled dynamic process is believed to be the underlying mechanism that enables short bursts of rainfall to induce slope instability, and supports the hypothesis that storm sequencing may have a greater effect on pore pressure development than cumulative rainfall.