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# Spatial and temporal variability of subsurface flow patterns at the hillslope scale: an experimental analysis

Daniele Penna (1), Luisa Hopp (2), Giancarlo Dalla Fontana (3), and Marco Borga (3)

(1) Swiss Federal Institute of Technology (ETH), Dept. of Environmental Systems Science, Zurich, Switzerland (daniele.penna@usys.ethz.ch), (2) Department of Hydrology, University of Bayreuth, Germany, (3) Department of Land, Environment, Agriculture and Forestry, University of Padova, Italy

Despite the importance of subsurface flow in regulating catchment runoff and slope stability, the dominant controls on the spatial and temporal variability of subsurface flow patterns on hillslopes of headwater catchments are still poorly understood. In this work, we used groundwater data from spatially distributed piezometric wells on two alpine hillslopes to investigate the main factors controlling the water table response to precipitation. Particularly, we tested the following hypotheses: i) piezometric response triggering is jointly controlled by antecedent moisture condition and rainfall depth; ii) contrasting hillslope topographic features affect the magnitude and dynamics of piezometric response, and iii) soil depth controls the timing of piezometric response.

Two steep hillslopes of similar size, soil properties and vegetation cover but contrasting topography (divergent-convex and relatively planar morphology) in the 0.14 km2 Bridge Creek Catchment (Dolomites, Central-Eastern Italian Alps) were instrumented with 24 piezometric wells, ranging in depth between 0.7 m and 1.5 m from the soil surface. The analysis was conducted for 63 rainfall-runoff events selected over three years in the snow-free months.

Results show that piezometric response, although very variable both in space and in time, was clearly distinct for events that occurred during wet or dry conditions, distinguished on the basis of a threshold relation between stormflow and an index combining antecedent soil moisture and rainfall depth. Correlation analysis based on two metrics of transient water table response (percentage of well activation and piezometric peak) revealed that antecedent soil water content alone was the poorest predictor of piezometric response whereas the highest degree of variance was explained by the combination of rainfall and antecedent soil moisture. Hillslope topography played a significant role on water table peak only for the site characterized by an overall convex-divergent morphology. As at other experimental sites, groundwater was found to not rise in unison throughout the hillslope, violating the steady-state assumption. However, in contrast with many other studies, we observed that water table level at the top of the hillslope typically peaked earlier and was less variable than at the hillslope toe. We related this behaviour to the control exerted by soil depth that increased in downslope direction. The temporal structure of the piezometric response, mainly driven by the soil depth and hillslope topography, led to consistent hysteretic behaviour, characterized by the highest variability for intermediate groundwater levels and the lowest during wet conditions.

On the one hand, this work contributes to improve the comprehension of the hydrological behaviour of the study catchment, adding new information on the effect of topography of individual hillslopes and of soil depth on the spatial and temporal dynamics of subsurface flow patterns. On the other hand, these results offer insights, previously missing, on the main controls governing the water table response in alpine hillslopes, and likely in other hillslopes of humid catchments worldwide, that are generally poorly investigated due to practical difficulties in monitoring groundwater variations.

Keywords: water table dynamics; hillslope topography; antecedent conditions; hysteresis; soil depth, steady state.