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The role of catchment topography on the spatial and temporal dynamics of soil moisture and subsurface flow

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In humid catchments of mountain regions, with shallow soils, steep slopes and relatively impermeable bedrock, the watershed topography acts as a first-order control on runoff generation. The riparian and the hillslope zones, the two fundamental topographic units of catchment structure, host different hydrological processes that interact to produce the stream runoff response. Disaggregating the catchment into these two morphological units and investigating their main physical mechanisms governing surface and subsurface runoff production allows for a more detailed understanding of the watershed functioning. This work focuses on the development of soil moisture and shallow subsurface flow patterns in a small alpine catchment, aiming to assess the role of the watershed topography on i) the spatio-temporal variability of groundwater response; ii) the spatio-temporal variability of soil moisture response and iii) the relationship between groundwater and soil moisture patterns.

Experimental activities were carried out from May to October 2011 in the 0.14 km2 Bridge Creek Catchment, Italian Dolomites (Eastern Alps). The watershed presents a clear topographic distinction between the close-to-stream riparian corridor and the steep hillslopes. The site was instrumented with a rain gauge, a stream gauge, 17 piezometric wells equipped with capacitance rods and 15 Frequency Domain Reflectometry soil moisture sensors installed at 5 cm and 30 cm depth. The piezometers were distributed over three transversal transects, located in the central and lower portion of the catchment, intercepting both the riparian and hillslope zone for each side of the stream. Soil moisture sensors were placed on three sites close to the catchment outlet, in the riparian, mid-slope and up-slope zone.

Results show that, on average, water table level in the riparian zone and along the transect closer to the outlet is higher and exhibits a more variable response compared to the hillslope zone and the middle and upper transects. This indicates the control of the catchment contributing area on the spatial dynamics of groundwater. Soil water content is constantly higher and shows a reduced variability in the riparian zone, close to saturation and therefore upper-limited, with respect to the mid-slope and up-slope zones, where soil moisture values are lower and their variations are more pronounced.
In wet conditions, especially during the most significant rainfall events, the average riparian and hillslope water table levels are closer to each other and temporal patterns are more similar than in dry conditions. Conversely, during relatively dry states, a greater difference in the water table height between the two units exists and a marked time lag occurs, leading to a hysteretic relation. These observations confirm previous results in the study area and indicate a greater contribution of hillslope subsurface runoff to total runoff in wet periods due to the establishment of a hillslope-riparian subsurface connection that leads to a fast runoff response.
A non-linear relation between soil moisture and groundwater characterizes the seasonal response, with lower deviations from linearity in the riparian zone, where groundwater and soil moisture patterns are more temporally consistent.

Keywords: riparian zone, hillslope zone, water table, soil moisture, non-linearity