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Comparison of subsurface connectivity in Alpine headwater catchments

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Saturation at the soil-bedrock interface or the rise of shallow groundwater into more permeable soil layers results in subsurface stormflow and can lead to hillslope-stream connectivity. Despite the importance of subsurface connectivity for streamflow and streamwater chemistry, the factors controlling its spatial and temporal variability are still poorly understood.

This study takes advantage of networks of spatially-distributed piezometers in five small (<14 ha) headwater catchments in the Italian Dolomites and the Swiss pre-Alps to i) quantify and compare the spatial and temporal variability of subsurface connectivity and its relation to streamflow, and ii) assess whether the differences in connectivity between the catchments are related to climatological or morphological characteristics of the catchments (e.g. the presence of a riparian zone).

Shallow groundwater levels were measured for two years from spring to fall in 16 and 12 piezometers in the 14 and 3.3 ha catchments in the Italian Dolomites, and for four years from spring to fall in 7-8 piezometers in three <1 ha Swiss pre-alpine catchments. Subsurface connectivity was quantified by a graph-theory approach, considering linear connections (edges) between the piezometers (nodes). A node was considered to be connected to the stream when shallow groundwater was observed in the piezometer and it was connected by the edges to the stream. Weights were given to each piezometer based on Thiessen polygons to determine the area of the catchment that was connected to the stream.

For the Swiss pre-alpine catchments the duration that nodes were connected to the stream was significantly correlated to the local and upslope site characteristics, such as the topographic wetness index, local slope and curvature. For the dolomitic catchment with the largest riparian zone, the time that nodes were connected to the stream was correlated with downslope site characteristics, such as the vertical distance to the nearest stream. The temporal changes in the area of the catchment that was connected to the stream reflected the streamflow dynamics for all catchments. Subsurface connectivity increased during rainfall events but there was a short delay compared to streamflow, suggesting that other processes (e.g. direct channel precipitation, runoff from near stream saturated areas) contributed to streamflow at the beginning of the event. Groundwater levels declined later and slower than streamflow, resulting in complex but mainly anti-clockwise hysteretic relations between streamflow and the area that was connected to the stream. Threshold-like relations between maximum connectivity and total stormflow and between maximum connectivity and the sum of total rainfall plus antecedent rainfall were more evident for the dolomitic catchments, where the riparian zone is characterized by a groundwater table near the soil surface. A sudden increase in connectivity for these catchments could represent the connection of hillslopes to the stream. These preliminary results suggest that the delayed increase in subsurface connectivity relative to streamflow is likely not affected by the presence of a riparian zone. However, further analyses are needed to determine if the climate and/or morphology of the catchments affect the observed relations between maximum connectivity and total stormflow.

Keywords: subsurface connectivity; headwater catchments; groundwater; graph theory; hysteresis.