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Linking spatial heterogeneity of geomorphic properties, flow persistence and hydrological connectivity

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Headwater drainage networks have a key role in the transport of water and nutrients from the uplands to the sea. The presence of intermittent and ephemeral tributaries makes the river network highly dynamical, with expansion-contraction cycles that are observed in response to precipitation variability. Both the drainage density and the dynamics of the river network, however, are spatially heterogeneous, reflecting the patterns of geomorphic and physiographic features of the contributing catchment. One of the major effects of river network dynamics is that the hydrological connectivity between a hillslope site and the outlet changes through time, with shorter unchanneled lengths and faster drainage pathways when the network is expanded.

Using the empirical data gathered in a small alpine catchment in northern Italy, we present some analyses about the heterogeneity in the river network persistence and the catchment hydrological connectivity under different flow conditions encompassing dry and wet periods. Different areas of the catchment exhibit very different drainage densities, mirroring the spatial heterogeneity in the geomorphological properties of the catchment. In particular, the most ephemeral stretches of the network are associated with thinner soil layers, steeper slopes, and shallow bedrocks, while the most persistent tributaries emerge in regions characterized by thicker soil layers and moraine deposits. The frequency distribution of the unchanneled lengths is used as a tool to characterize the hydrological connectivity between hillslope sites and the river network. Our results show that network expansion affects the length of unchanneled pathways in a very heterogeneous way, with local variations associated to changing hydrological conditions ranging from 0 to one kilometer. Furthermore, we show that the drainage density is more heterogeneous during wet conditions, with an increase in the spatial variability of the unchanneled length of about 20%. These results hint at the importance of studying intermittent and ephemeral streams to enhance the understanding of the hydrology and biogeochemistry of headwater catchments.