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Hydrological response at increasing spatial scales: controls and dynamics in Alpine catchments

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Identifying the controls on how catchments store and release water is essential to develop effective and sustainable water resources management strategies. This is particularly critical in mountain environments where the harsh topography and multiple water inputs (rainfall and snowmelt) interact and produce complex hydrological dynamics. Mesoscale catchments (around 100 km2) represent the typical management scale, but often detailed field measurements and observations of hydrological variables besides precipitation and discharge are available only in experimental sites at the small spatial scale (< 10 km2). In this work we compare the runoff response of three Alpine catchments in Northern Italy spanning spatial scales of three orders of magnitude (0.14, 7.3 and 109 km2) aiming at i) understanding the physical and hydrometeorological controls on hydrological dynamics at increasing scales, and ii) assessing whether the runoff generation processes observed in small catchments are representative for those occurring in larger basins. We collected and analyzed hydrometeorological data from June to September of 12 successive years (2005-2016) for the three catchments, identifying 54 rainfall-runoff events in common at the three scales. Results show consistent temporal patterns of the precipitation-runoff relationship for the three catchments, with inter-annual variability mainly related to the different snowmelt inputs, impacting more strongly the two catchments at the smaller scales, characterized by a higher fraction of high-elevation areas compared to the largest catchment. The overall slope of the cumulative double-mass curves, integrating all observation years, decreases as catchment size increases. Analogously, the event runoff coefficients, well described by a beta distribution, as well as their variability, decrease as catchment size increases. This reveals a higher hydrological reactiveness of the smaller catchments and suggests a larger storage capacity of the mesoscale catchment. The variability of runoff coefficients among the three spatial scales is mainly related to the catchment topographic properties, mostly in terms of the ratio between the hillslope zone and the riparian zone, reflecting different storages. Flood volumes and runoff coefficients increase non-linearly as a function of rainfall amount and duration, with a smaller influence of rainfall intensity, especially at the largest scale. Pre-event discharge as a proxy for initial conditions reveals not to be a reliable predictor of runoff coefficient variability whereas a similar threshold behavior in the antecedent soil moisture-runoff relationship suggests that the same runoff generation processes might operate at different spatial scales. This denotes the possibility of using detailed (other than precipitation and discharge) hydrological measurements of initial conditions collected at the small catchment scale, at least in the context of the study area, as indicators of the runoff production of larger, mesoscale basins.

Keywords: hydrological response; spatial scales; runoff coefficients; mountain catchments; rainfall-runoff transformation