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Runoff generation processes and fraction of young water for streamflow and groundwater in a pre-alpine forested catchment

Giulia Zuecco (1), Daniele Penna (2), Ilja van Meerveld (3), and Marco Borga (1)

(1) Department of Land, Environment, Agriculture and Forestry, University of Padova, Legnaro (PD), Italy (giulia.zuecco@unipd.it), (2) Department of Agricultural, Food and Forestry Systems, University of Florence, Firenze, Italy, (3) Department of Geography, University of Zurich, Switzerland

Understanding of runoff generation mechanisms and storage dynamics is needed for sustainable management of water resources, particularly in catchments characterized by marked seasonality in rainfall. However, temporal and spatial variability of hydrological processes can hinder a detailed comprehension of catchment functioning.
In this study, we use hydrometric data and stable isotope data from a 2-ha forested catchment in the Italian pre-Alps to i) identify seasonal changes in runoff generation, ii) determine the factors that affect the hysteretic relations between streamflow and soil moisture and between streamflow and shallow groundwater, and iii) estimate the fraction of young water in stream water and shallow groundwater. Streamflow, soil moisture and groundwater levels were measured continuously between August 2012 and December 2015. Soil moisture was measured at 0-30 cm depth by four time domain reflectometers installed at different locations along a riparian-hillslope transect. Depth to water table was measured in two piezometers installed at a depth of 2.0 and 1.8 m in the riparian zone. Water samples for isotopic analysis were taken monthly from bulk precipitation and approximately biweekly from stream water and groundwater. The relations between streamflow (independent variable), soil moisture and depth to water table (dependent variables) were analyzed by computing a hysteresis index that provides information on the direction, the extent and the shape of the loops for 103 rainfall-runoff events. The temporal variability of the hysteresis index was related to event characteristics (mean and maximum rainfall intensity, rainfall amount and total stormflow) and antecedent soil moisture conditions. We observed threshold-like relations between stormflow and the sum of rainfall and the antecedent soil moisture index and an exponential relation between the change in groundwater level and stormflow. Clockwise hysteretic relations were common between streamflow and riparian soil moisture, suggesting quick contributions from shallow soil layers in the riparian zone to streamflow. The relations between streamflow and hillslope soil moisture and between streamflow and depth to water table in the riparian zone varied seasonally, with clockwise loops being typical for large rainfall events in autumn and anti-clockwise hysteresis being more common in spring and summer. This indicates that hillslope soil water and riparian groundwater dynamics and their contribution to stormflow varied seasonally and depended on event size and antecedent moisture conditions. There was a marked seasonal variability in the isotopic composition of precipitation but a much more damped variability in the isotopic signature of stream water and groundwater. A sine curve was fitted to the seasonal variation in isotopic composition of weighted precipitation, stream water and groundwater to estimate the fraction of young water in stream water and groundwater. The fraction of young water in streamflow was about 14% when considering baseflow conditions only (23% using the entire isotopic dataset). This was similar to the fraction of young water in riparian groundwater.

Keywords: runoff generation; hysteresis; isotopes; young water fraction; forested catchment.