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Non-linearity of runoff generation processes in an alpine headwater catchment

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Hydrological systems are often characterized by non-linear behaviours. Particularly, threshold effects due to the complex interactions of many physical controls are frequently observed at the hillslope and catchment scale. The presence of such non-linear behaviours at different scales can reduce our prediction capabilities of hydrological responses. Therefore, investigating the occurrence of hydrological thresholds can help to improve our understanding of the phenomenon and increase our ability to make reliable predictions.
In this study we analyzed the runoff response of the small Bridge Creek Catchment (BBC, 0.11 km^2, North-Eastern Italian Alps). This headwater catchment consists of hillslopes and a distinctive, relatively narrow, riparian zone and is characterized by a fast runoff response. As such, BBC can be considered a representative catchment of the Dolomitic region. Forty rainfall-runoff events occurred between June to mid-October 2005 and 2006 were analyzed. In addition to precipitation and stream discharge measurements, soil moisture at 0-30 cm depth and water table level in 9 piezometers were monitored in two experimental hillslopes located in the lower part of the catchment.
In this work we address the following questions: i) what is the dominant control on the threshold in runoff response at BBC? ii) what is the contribution of the hillslopes and riparian zone to the storage and release of water? iii) what controls do soil moisture and precipitation exert on the runoff volume? iv) what influence do soil moisture and precipitation have on the water table variations and the hysteretic relationship between streamflow and groundwater level?
Results highlight the strong control exerted by soil moisture on runoff in this catchment: a sharp threshold exists in the relationship between soil water content and runoff coefficient, streamflow, and basin-averaged depth to water table. Low runoff ratios were related to the fast response of the nearly saturated riparian zone. During wetter conditions, when a threshold of soil moisture was exceeded, hillslopes started to contribute to runoff. The riparian contribution to total stormflow was assessed and quantified by comparing the potential runoff from the riparian zone to total storm runoff. A decrease in riparian contribution with increasing antecedent soil moisture underlines the essential role of hillslopes and riparian zones as fundamental landscape units in controlling the catchment hydrological response.
A threshold effect was also identified in the relationship between catchment-averaged water table level and antecedent precipitation. Low initial groundwater levels required a slightly larger precipitation depth in order to cause a piezometric response. Finally, a highly non-linear relationship was detected between groundwater level and streamflow at the rainstorm scale. This relation showed a hysteretic behaviour due to the difference in timing of the two responses. The analysis revealed that the extent of the hysteretic loops is dependent on total precipitation and antecedent moisture conditions, with increasing loop size corresponding to higher rainfall and antecedent moisture. These two factors were also related to the total stormflow volume, stressing the importance of soil moisture as a key control in threshold-related runoff generation processes.

Key words: threshold behaviour, riparian zone, runoff generation, soil moisture