Spatial and temporal variability of piezometric response at the small catchment scale

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Observational hydrology: Recent developments in distributed sensing techniques and experimental catchments

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Objectives, Study Area and Methodology

In this study, we analyze the spatial and temporal variability of piezometric response in the Larch Creek Catchment (LCC, 0.033 km^2), localized in the Italian Dolomites (Fig. 1a, b).

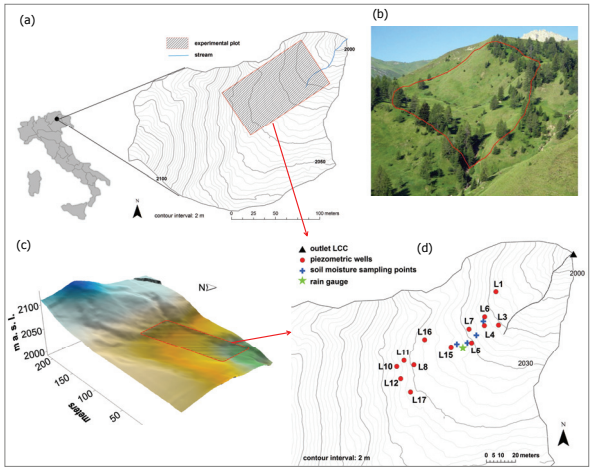

Figure 1. a) map of the cachment; b) picture of the basin (in red the divide); c) DTM of the catchment; d) map of the experimental plot with instrumentation.

The area features a mean annual precipitation of 1220 mm, almost half of which falls as snow. The soil was classified as Cambisoil with mull, characterized by a thick layer of organic matter. On average, field-saturated hydraulic conductivity (measured by means of a Guelph permeameter) amounts to 1.1 x 10^{-6} m/s. The experimental watershed is equipped with one stream gauge, one rain gauge, four soil moisture probes at 0-30 cm depth and 13 piezometric wells (Fig. 1c, d). The maximum depth of wells ranges between 1050 mm and 750 mm from the soil surface. The boreholes were dug as deep as possible but in many cases the soil-bedrock interface was not reached.

We analyze 23 rainfall-runoff events from late spring to early autumn 2009. Event total precipitation ranges between 2.4 mm to 45.4 mm. Water table variations are used to assess: i) the possibility to group the piezometric response on a topographic basis; ii) the relationship with the rainfall forcing; iii) the streamflow - subsurface flow temporal relationship.

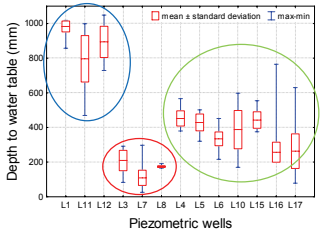

Figure 2. Boxplot of water table level in the piezometric wells for the study period (only data where all piezometers responded were considered). The blue, red and green circles indentify the groups with low, high and intermediate water table level, respectively.

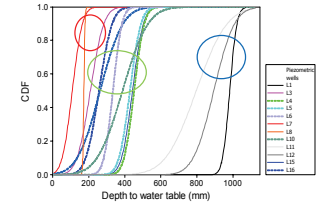

Figure 3. Cumulative Distribution Function of water table level in the piezometric wells for the study period (only data where all piezometers responded were considered). The blue, red and green circles indentify the groups with low, high and intermediate water table level, respectively.

Results 1: Grouping the water table responses

We consider the following variables of piezometric response for each well: mean water table level over the whole study period, the overall peak of water table level, the mean magnitude of response (computed as the difference between the water table peak and the pre-event water table level), the integration area (computed as Detty and McGuire, 2010), the number of responses, the streamflow-groundwater correlation. Topographic features include local slope, contributing area, Topographic Wetness Index, curvature, distance from stream along flow paths. Despite the marked morphological characteristics of the study catchment, a weak correlation exists between the piezometric response variables and topography. The only significant correlation is the negative relationship between slope and number of responses. This is likely due to the particular morphology of LCC, where a clear distinction between riparian area and hillslope area is not evident, to the complex microtopography and, additionally, to the uneven distribution of piezometric wells over the watershed area. This observation agrees with Anderson et al. (2010) who found difficult to group the piezometric responses based on an *a priori* topographic approach.

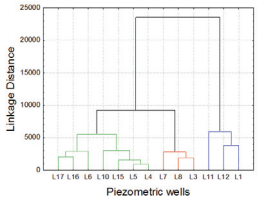

Figure 4. Cluster analysis-derived dendrogram of water table level in the piezometric wells for the study period (only data where all piezometers responded were considered). The complete linkage method and the Euclidean distance were chosen for the analysis. The blue, red and green lines indentify the groups with low, high and intermediate water table level, respectively.

However, despite the high degree of spatial variability of water table variations (Fig. 2), three groups of piezometric wells can be detected: L1, L11, L12 consistently show the lowest water table levels (they also display the highest value of local slope), L3, L7, L8 consistently show the highest water table level and the remaining piezometers display an intermediate behaviour (Figs. 2, 3, 4). The time series of mean water table level for each group is shown in Fig. 5.

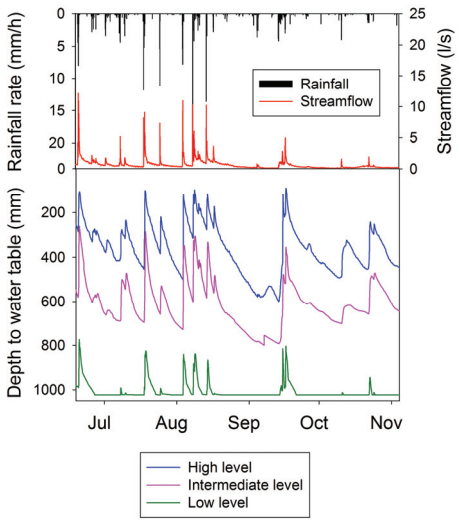

Figure 5. Time series of precipitation, streamflow and mean water table in the three different groups for the monitoring period.

Results 2: Piezometric response among different groups

Different groups tend to respond differently to the precipitation input. Generally, a significant correlation is observable between magnitude of response, integration area and total event rainfall.

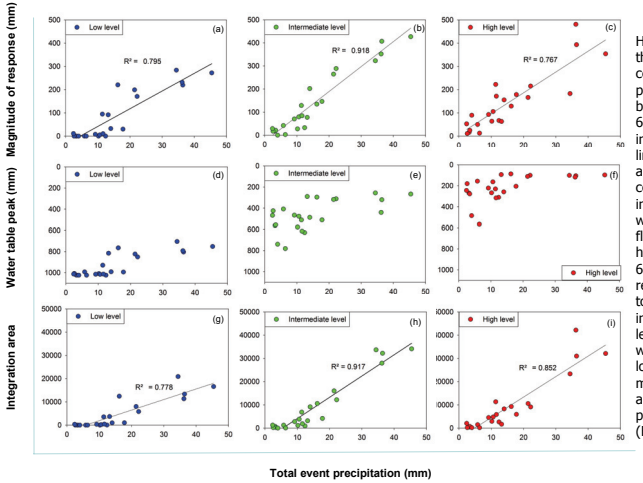

Figure 6. Scatterplot of total event precipitation versus magnitude of response (a-c), water table peak (d-f) and integration area (g-i) for the three groups of piezometric wells.

However, the water table in the low level group needs a certain amount of precipitation to be captured by the instruments (Fig. 6a, 6g) whereas the water table in the high level group is limited by the soil surface above (Fig. 6c, 6i). The best correlation is found for the intermediate level group, where water table is free to fluctuate without being hydraulically limited (Fig. 6b, 6h). Water table peak is reached above 20 mm of total precipitation for the intermediate level and high level groups (Fig. 6e, 6f) while the piezometers in the low level group rise to the maximum when a higher amount of total precipitation is exceeded (Fig. 6d).

Results 3: Temporal dynamics

The correlation between streamflow and water table level for each piezometric well over the study period is highly variable and apparently not related to the topographic features and to the three groups of piezometric wells previously identified. However, the best correlation is found for piezometers L3 and L5 (r=0.73 and r=0.72, respectively, n=723), localized close to the riparian area, whereas the poorest correlations are generally (but not always) associated to piezometers placed far from the stream (Fig. 7). Overall, all piezometers tend to respond to the rainfall input with a greater response time than streamflow (Fig 8a). This leads to a hysteretic relationship between water table and streamflow (Fig. 8b, 8c), as also found by others (McGlynn et al., 2004). However, groundwater wells localized close to the stream show lower time lags and are more in phase with surface runoff compared with piezometers placed on the hillslope and/or far from the stream. This leads to hysteresis between water table in the near-stream and far-stream zone (Fig. 8d), partially agreeing with previous findings by Seibert et al. (2003).

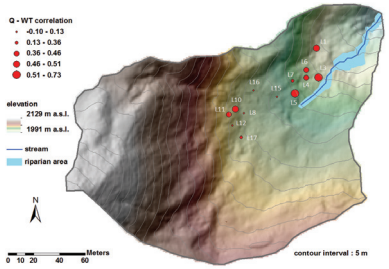

Figure 7. Map of the catchment with the localization of groundwater wells. The size of the dots identifying the piezometers is proportional to the correlation coefficient computed between the water table in each piezometer and the streamflow for the study period (only data where all piezometers responded were considered).

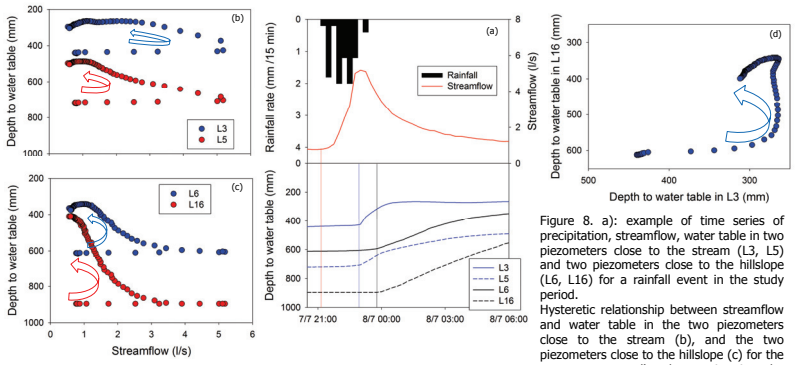

Figure 8. a): example of time series of precipitation, streamflow, water table in two piezometers close to the stream (L3, L5) and two piezometers close to the hillslope (L6, L16) for a rainfall event in the study period.
Hysteretic relationship between streamflow and water table in the two piezometers close to the stream (b), and the two piezometers close to the hillslope (c) for the same event. d): hysteresis in the relationship between water table in the near-stream and far-stream zone for the same event.

Concluding remarks

Observations of water table variations in a small alpine catchment reveal that:
1)despite the marked topography, a priori grouping of piezometric response is difficult likely due to the high spatial variability of piezometric response and to the complex microtopography. However, a sharp discrimination among various piezometers is possible on the basis of water table level;
2)various piezometric groups respond differently to the precipitation forcing according to their relative water table level;
3)different temporal water table dynamics are observable in the catchment, with riparian water table variations generally more in phase with surface runoff with respect to piezometers placed far from the stream.

References
Anderson AE, Weiler M, Alila Y, Hudson RO. 2010. Piezometric response in zones of a watershed with lateral preferential flow as a first-order control on subsurface flow. HYDROLOGICAL PROCESSES, DOI: 10.1002/hyp.7662
Detty JM, McGuire KJ. 2010. Topographic controls on shallow groundwater dynamics: implications of hydrologic connectivity between hillslopes and riparian zones in a till mantled catchment. HYDROLOGICAL PROCESSES, DOI: 10.1002/hyp.7656
McGlynn BL, McDonnell JJ, Seibert J, Kendall C. 2004. Scale effects on headwater catchment runoff timing, flow sources, and groundwater–streamflow relations. Water Resources Research 40, W07504, DOI:10.1029/2003WR002494
Seibert J, Bishop K, Rodhe A, McDonnell JJ. 2003. Groundwater dynamics along a hillslope: a test of the steady state hypothesis. Water Resources Research 39, 1014, DOI: 1010.1029/2002WR001404

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