# THE INFLUENCE OF THE SEASONAL VARIATIONS OF CATCHMENT WETNESS ON THE STREAMFLOW RESPONSE (ARNAS CATCHMENT, CENTRAL PYRENEES)

**N. Lana-Renault[1], J. Latron[2], D. Regüés[1], E. Nadal[1], P. Serrano[1]**

[1]*Instituto Pirenaico de Ecología (CSIC), Zaragoza, Spain*
*noemi@ipe.csic.es*
[2]*Unitat de Ciència del Sòl, Universitat de Girona, Girona, Spain*

## Introduction

Numerous studies of streamflow response have reported the complexity and evident non-linearity of rainfall–runoff relationships in many environments, especially in Mediterranean areas. These areas are affected by large-scale changes in land use, and characterised by a marked irregularity in precipitation regime and high seasonal evapotranspiration. Though increasingly studies combined analyses of rainfall, water table and discharge to identify storm-flow pathways and assess the role of catchment wetness in terms of variability in hydrological response (e.g. Peters *et al*., 2003), only a few have been performed in the Mediterranean region (e.g., Grésillon and Taha, 1998; Linde *et al*., 2007).

## Study area

The Arnás catchment (2.84 km$^2$) is located in the central Pyrenees, between 900 and 1340 m a.s.l. The bedrock is Eocene Flysch with alternating sandstone and marl layers sloping northward. The entire catchment has been cultivated until the middle of the 20th, then progressively abandoned and affected by a process of natural plant colonization. The orientation of the stream results in a strong contrast in slope between the steep south-facing slope, with open shrub cover and shallow soils, and the gentle north-facing slope, with denser covering of vegetation and deeper soils. Most of the valley floor is made up of small fluvial terraces, marked by herbaceous vegetation. The climate is sub-Mediterranean with Atlantic influences, especially in winter. Mean annual precipitation over the past 8 water years (October to September) was about 926 ± 215 mm. Rainfall is usually concentrated in autumn and spring. In summer, intense short-duration convective storms are relatively frequent.

## Equipment and methods

Rainfall was collected using three tipping buckets located along the main stream. At the outlet of the catchment, a concrete weir was constructed to measure continuously the discharge of water and sediment. A network of seven piezometers was installed in downslope locations at different distances from the main channel and in areas where field observations indicated significant saturation dynamics. The water table in these seven locations was measured continuously. For the present study, rainfall and streamflow data for 8 water years (1999 to 2006) were used. The water-table depth was analyzed at both daily and 20-min step. Besides, several field surveys were conducted in order to map runoff contributing areas under different hydrological conditions.

## Results

Relationship between rainfall and storm-flow depths for the 75 analyzed flood events was statistically significant, although the data show some scatter (R=0.7 $p<0.01$). For example, similar rainfall events of 34 and 36 mm generated storm-flows of 1 and 13 mm, respectively. Figure 1 shows the seasonal evolution in the storm-flow coefficient (CE) for 75 floods (black dots) and moderate to large rainfalls events (P>10 mm) that failed to generate a streamflow response (grey dots). The figure demonstrates, in one hand, the high variability in the storm-flow coefficient throughout the year and, in the other hand, seasonal differences in the hydrological response of the catchment. For example, the proportion of rainfall events without streamflow response was higher in summer, and the storm-flow coefficient never exceeded 0.07. Conversely, the relative response was always greater in winter and spring, the highest storm-flow coefficients (above 0.3) being recorded in spring. In autumn, there were rainfall events without –or with very low– streamflow response, especially at the beginning of the season, but also storm-flow coefficients could be fairly high, even higher than in winter. A similar seasonal pattern has been reported for other mountainous Mediterranean catchments (Gaillard *et al*., 1995; Latron *et al*., 2008).

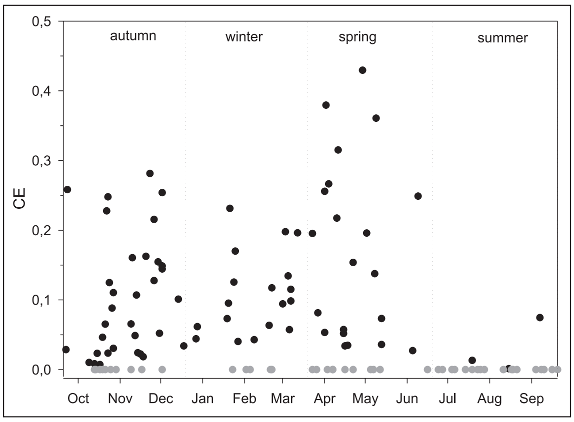


Figure 1. Seasonal evolution of the storm-flow coefficient (CE) throughout the water year (black dots) during the study period (1999-2006). Rainfall events (P>10 mm) that did not generate a hydrological response are also shown (grey dots)

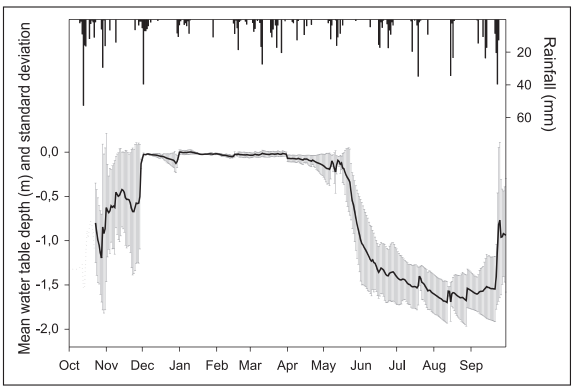


Figure 2. Daily rainfall and mean daily water-table depth measured by piezometers w7, w8, and w9 throughout the hydrological year 2005–2006. Error bars show the standard deviation. The dotted line indicates a period for which data were only available from one piezometer.

The seasonal trend of the storm-flow coefficient may be linked to seasonal dynamics in the catchment water reserves. Figure 2 shows, for the hydrological year 2005–2006, the daily rainfall and the seasonal trend in mean daily water-table depth obtained from piezometers w7, w8 and w9, together with its standard deviation, which is indicative of the degree of variability between different sites. Three main periods can be differentiated during the year: a) from the beginning of December to the middle of May, water was high at all locations; b) the catchment began to progressively dry down from May–June to the end of the summer season, reflecting, to some extent, increasing evapotranspirative demand. Over this drying period, the standard deviation of the mean water-table value increased markedly as different drying dynamics were observed between locations; c) the catchment wetting-up period started with the first autumn rainfall events (October) and lasted until the end of November or later. The wetting-up period was the time of greatest variability in the water table among different sites, indicating spatial variability in the refilling of the catchment water reserves.

An analysis of the observed flood hydrographs and associated water table dynamics, altogether with an examination of the runoff contributing areas field maps allowed the distinction of several representative types of streamflow response according to the catchment wetness conditions and rainfall characteristics:

– During summertime dry conditions, infiltration excess runoff over localized areas close to the stream was found to be the only active runoff process, occurring in response to short and intense rainstorms.
– During the wetting-up transition, the magnitude of the streamflow response was highly variable, depending mainly on the water-table level prior to the event and to a lesser degree on rainfall depth and intensity. The strong non-linearity in the rainfall–runoff relationship observed in these conditions, which is likely to be related to the extent of saturation reached within the catchment, suggests the existence of a threshold effect, as reported in other Mediterranean catchments (Cosandey, 1993); however, this possibility requires further investigation.
– During wet periods, both saturation excess runoff and subsurface flow were probably the dominant runoff processes operating within the catchment, generating slower and moderate streamflow responses.

## Conclusions

This study documents the complexity of the hydrological response of a sub-Mediterranean mountain catchment by investigating the relationships among rainfall, streamflow and water-table depth, and by studying the spatial and temporal variability of the runoff contributing areas. The analysis shows the non-linearity of the rainfall–runoff relationships and their high seasonality, which is largely related to the catchment wetness. The results reported here are the basis for catchment diagnosis and thereby could be used to asses some of the assumptions derived from more theoretical approaches (e.g. McGrath *et al.*, 2007) as well as to improve hydrological model simulations.

## Acknowledgements

This research was financially supported by the following projects: "Modelling hydrological processes in gauged catchments for predictions in non-gauged catchments" (CANOA, CGL2004-04919-C02-01/HID) and "Processes and sediment balances at different spatial scales in Mediterranean environments: Effects of climate fluctuations and land use changes" (PROBASE, CGL2006-11619/HID), both funded by the Spanish Ministry of Education and Science. Monitoring of the catchment was supported by an agreement between the CSIC and the Spanish Ministry of Environment (RESEL).

### References

Cosandey C., 1993: *Forêt et écoulements: Rôle de la forêt sur la formation des crues et le bilan d'écoulement annuel. Impact d'une coupe forestière*. Rapport sectoriel de recherche du Programme CEE "suivi des conséquences d'une coupe forestière sur les phénomènes hydrologiques, hydrochimiques et d'érosion solide dans un bassin-versant de Lozère": 81 pp.

Gaillard, E., Lavabre, J., Isbérie, C., Normand, M., 1995: *Etat hydrique d´une parcelle et écoulements dans un petit bassin versant du massif cristallin des Maures*. Hydrogéologie, 4: 41-48.

Grésillon, J.M., Taha, A., 1998: *Les zones saturées contributives en climat méditerranéen: condition d´apparition et influence sur les crues*. Hydrological Sciences -Bulletin- des Sciences Hydrologiques, 43 (2): 267-282.

Latron, J., Soler, M., Llorens, P., Gallart, F., 2008: *Spatial and temporal variability of the hydrological response in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees)*. Hydrological Processes, 22(6): 775-787.

Linde, N., Revil, A., Bolève, A., Dagès, C., Castermant, J., Suski, B., Voltz, M., 2007: *Estimation of the water table throughout a catchment using self-potential and piezometric data in a Bayesian framework*. Journal of Hydrology, 334 (1-2): 88-98.

McGrath, G.S., Hinz, C., Sivapalan, M., 2007: *Temporal dynamics of hydrological threshold events*. Hydrology and Earth System Sciences, 11(2): 923-938.

Peters, E., Freer, J., Aulenbach, B.T., 2003: *Hydrological Dynamics of the Panola Mountain Research Watershed, Georgia*. Ground Water, 41(7): 973-988.