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Seasonal characteristics of the hydrological response in a Mediterranean mountain research catchment (Vallcebre, Catalan Pyrenees): field investigations and modelling

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Abstract Mediterranean catchments often present a particular hydrological behaviour as a consequence of the marked seasonal characteristics of their climate. Within the year, the succession of wet and dry conditions and the existence of transition periods between both, favours the occurrence of a variety of hydrological processes, operating simultaneously or successively. A small research catchment has been monitored in the Catalan Pyrenees for the study of runoff generation mechanisms. Analysis of a four-year period of data allowed the identification of three characteristic types of hydrological events with different runoff generation mechanisms corresponding to wet, dry and transition conditions. The use of a distributed modelling system (SHETRAN) has produced encouraging results for the simulation of each of the hydrological responses identified.

Key words Mediterranean mountain catchment; physically-based distributed model; runoff processes; seasonal control; SHETRAN

INTRODUCTION

Progress towards the identification and modelling of runoff processes in catchment hydrology are mostly derived from humid temperate regions. Bonell (1993) pointed out that the limited number of studies from other climatic regions has often resulted in the unverified extrapolation of findings from humid regions, although the need for different approaches has been sometimes underlined (e.g. Pilgrim *et al.*, 1988).

Catchment hydrology, including process studies and modelling, is relatively undeveloped in Mediterranean regions, where the characteristic occurrence of a summer dry period strongly increases the nonlinearity of the hydrological behaviour of a catchment. Even so, various characteristic features of Mediterranean catchment hydrology have been pointed out in the last two decades (e.g. Topadilis & Curtis, 1982; Cosandey, 1993; Grésillon & Taha, 1998; Gallart *et al.*, 2002). Several studies mention in particular the crucial importance of changing hydrological conditions on the hydrological response of a catchment. Results also emphasize the diversity of hydrological processes governing runoff formation in Mediterranean catchments, depending not only on catchment characteristics but also on antecedent hydrological conditions and characteristics of the rainfall event. From the modelling side, results obtained (e.g. Parkin *et al.*, 1996; Piñol *et al.*, 1997) highlight the problem of properly simulating a whole year of flow data with a single set of parameters, particularly the difficulties of reproducing the first runoff events that follow the summer dry period.

This paper has a twofold objective: first it summarizes findings obtained on the hydrological behaviour of the Can Vila catchment from hydrometric studies, with special attention being paid to runoff generation processes. Second, it presents part of the results obtained from an application of the physically based distributed modelling system, SHETRAN. Complementary information on both aspects of this work can be found in Latron *et al.* (2000), Gallart *et al.* (2002) and Anderton *et al.* (2002a, b).

STUDY AREA

The Can Vila catchment (Fig. 1) is located in the headwaters of the LLobregat river in the Catalan Pre-Pyrenees, northeastern Spain. This sub-catchment of the Cal Rodó catchment, is oriented in a SW–NE direction and has an area of 0.56 km^2, with elevations ranging from 1115 to 1458 m a.s.l. The climate is sub-Mediterranean with a mean annual rainfall of 924 mm, a mean annual temperature of 7.3°C and a mean annual reference evapotranspiration around 700 mm (Gallart *et al.*, 2002). Rainy seasons are autumn and spring, although during summer short intense convective storms may provide significant rainfall amounts. Soils developed over the mudstone lithology have a silt-loam texture and are characterized by the rapid decrease of their hydraulic conductivity with depth. Agricultural terraces (typically 10 to 20 m wide) and a network of artificial drainage ditches were built during the 19th century over more than 70% of the catchment. Small badland areas have developed along the stream channel as a result of localized erosion processes. The catchment is mainly covered by pasture, however, as a result of spontaneous afforestation of agricultural land, forest covers 34% of the catchment.

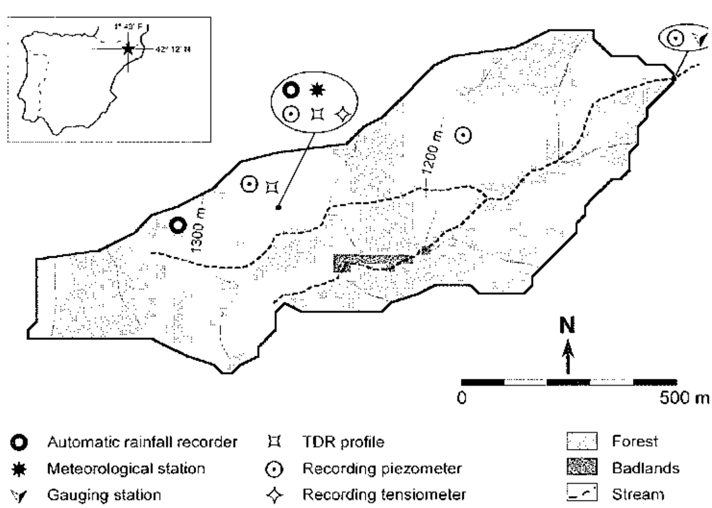

Fig. 1 Map of the Can Vila catchment, showing locations of instrumentation.

In addition to the flow gauging and meteorological stations, the hydrological monitoring of the catchment (Fig. 1) initiated in early 1995, includes several recording piezometers and tensiometers as well as TDR probes for the weekly measurement of soil water content.

RESULTS AND DISCUSSION

Runoff generation processes

Detailed process studies, using information on rainfall, discharge, depth to the water table, soil water content and tensiometry, combined with mapping of saturated areas, allowed the identification of three typical runoff response modes (Fig. 2), each associated with a different dominant runoff generation process.

Typical summer runoff events occurred as a result of short-duration, high-intensity convective storms over dry soils. Soil moisture slightly increased, but tensiometers indicated no soil profile saturation during these events, and no response of the deep water table was observed. Associated runoff coefficients were very low, as infiltration excess runoff, restricted to the low permeability badlands area, was the only active process, resulting in a flashy hydrograph and low peak flow rates.

Wetting-up transition events were characteristic of spring and autumn, and typically resulted from prolonged, lower intensity frontal rainfall over an initially dry catchment. During these events, soil profile saturation was frequently observed in the inner part of agricultural terraces with thinner soils, whereas the deep water table did not rise significantly until several days after the rainfall event. Saturation excess runoff, produced on a large number of small saturated areas connected to the stream

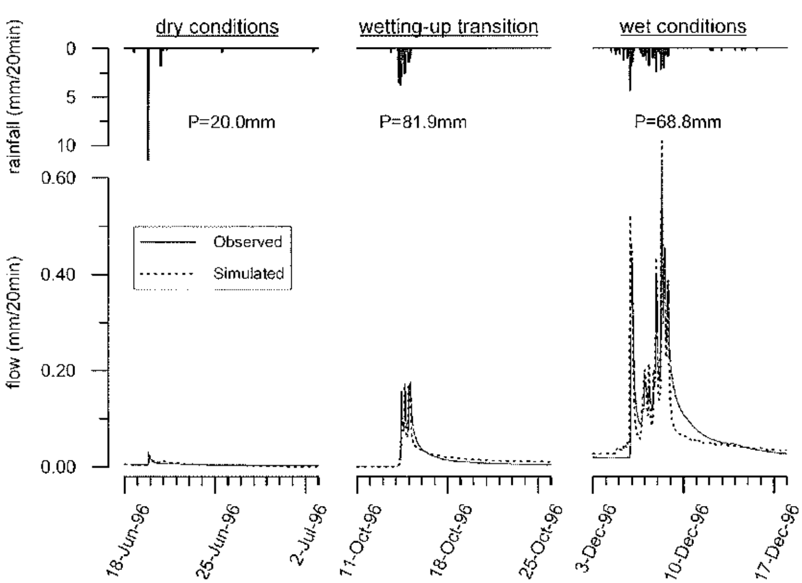

Fig. 2 Time series of observed and simulated (evaluation period) flow for three events with different dominant runoff processes.

through the artificial drainage network, was the dominant runoff generation process. Runoff coefficients were intermediate and recession limbs were relatively short.

Wet condition events generally occurred in late autumn or early winter in response to large rainfall events over wet soils. The shallow water table responded quickly to precipitation and promoted widespread saturation of downslope areas. Saturation excess runoff, produced on several large saturated areas close to the stream, was the main runoff generation process. Corresponding runoff coefficients were high and recession limbs contributed more significantly to the flow volume.

Simulation of characteristic runoff events

The distributed modelling system SHETRAN (Ewen *et al.*, 2000) has been applied to the Cal Rodó catchment and its sub-catchments (including Can Vila) in order to evaluate the performance of this distributed physically based model in simulating the hydrological functioning of a Mediterranean catchment. Full details of the model application are given by Anderton *et al.* (2002b). Only the results relating to the simulation of two sets of characteristic runoff events described above are presented here (the first set of events occurred during the period of data used to calibrate the model; the second set occurred during the period used to evaluate model results). Results corresponding to the events of the evaluation period are illustrated in Fig. 2, whereas Table 1 presents a summary of results obtained for both calibration and evaluation periods.

SHETRAN provided generally reasonable results, in terms of efficiency as well as in terms of runoff coefficients of the simulated flow, for the three kinds of events in the calibration period. It was only for the wet conditions event (28 January 1996) that the simulated runoff coefficient was significantly lower than the observed one. For the events corresponding to the evaluation period, results were satisfactory for both wetting-up, transition, and wet conditions events, with efficiency values of 0.89 and 0.86 respectively. For the wet conditions event, the runoff coefficient of the simulated flow showed the same underestimation as for the calibration period, mainly due to the difficulty of the model in reproducing properly the hydrograph recession (Fig. 2). The negative value of efficiency for the dry conditions event is more the result of a shift in time (2 h) between the simulated and observed flow than from an incorrect estimation of the flow volume.

Table 1 Summary of comparison of observed and simulated flow for three events with different dominant runoff processes, for the calibration and evaluation periods.

Date	Observed flow: Runoff coefficient (%)	Simulated flow: Runoff coefficient (%)	Efficiency*	Event type	Period
30/07/95	2.1	2.1	0.71	Dry conditions event	Calibration
12/09/95	24.3	20.6	0.87	Wetting-up transition	Calibration
28/01/96	61.5	48.5	0.61	Wet conditions event	Calibration
19/06/96	1.4	4.6	−0.45	Dry conditions event	Evaluation
14/10/96	14.7	14.6	0.89	Wetting-up transition	Evaluation
05/12/96	68.8	42.3	0.86	Wet conditions event	Evaluation

* Efficiency (Nash & Sutcliffe, 1970) calculated on a 20 min time step.

CONCLUSIONS

Monitoring of a small Mediterranean catchment allowed the identification of three types of runoff events throughout the year, each characterized by a different runoff generation pattern. Infiltration excess runoff on low permeability areas was dominant during dry conditions, whereas saturation excess runoff on more permeable soils was dominant during both wetting-up, transition, and wet periods. The pattern of saturated areas prone to saturation excess runoff was, however, different between these two states; during wetting-up transitions, scattered small saturated areas resulted from soil profile saturation, whereas during wet periods the whole soil profile downslope was saturated.

The application of the physically based modelling system SHETRAN produced satisfactory results when simulating the flow response at the outlet for each of the three characteristics types of runoff event. However, reasonable simulation of the response at the catchment outlet may not always necessarily imply that the catchment internal dynamics are being satisfactorily simulated. Further work on this theme, including sensitivity analysis of the subsurface flow component of SHETRAN (Anderton *et al.*, 2002a) indicates that this may not be always the case.

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