Runoff generation processes in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees)

J. Latron a,*, F. Gallart b

a Soil Science Unit, University of Girona, Campus de Montilivi, 17071 Girona, Spain
b Institute of Earth Sciences "Jaume Almera", CSIC, Solé i Sabaris s/n, 08028 Barcelona, Spain

Received 8 January 2008; accepted 5 June 2008

Summary This paper analyses the runoff generation processes in a small Mediterranean catchment (Can Vila catchment, 0.56 km²), using limited continuous data on water table and soil water potential dynamics along with rainfall and runoff data collected over 6 years. At daily scale, strong non-linearity between rainfall and runoff volume and the effect of the water table position on how rainfall and runoff volume relate were seen. The higher the water table, the greater the runoff for a given rainfall. The relationship between runoff and depth of water table was not straightforward: water table variations sometimes did not correlate with runoff changes, suggesting somewhat intricate hydrological behaviour. Soil water potential data alongside runoff and water table data showed the relatively frequent development of a perched saturation layer in the profile monitored. Examination of soil water potential and water table dynamics during a collection of representative floods helped to identify three types of characteristic hydrological behaviour during the year. Hydrographs corresponding to type 1 events (dry conditions), type 2 events (wetting-up transition) and type 3 events (wet conditions) had different characteristics: each was associated with different dominant runoff generation processes. Under dry conditions, runoff was generated essentially as infiltration excess runoff in low permeable areas, whereas saturation excess runoff dominated during wetting-up and wet conditions. During wetting-up transition, saturated areas resulted from the development of scattered perched water tables, whereas in wet conditions they were linked to the rise of the shallow water table.

© 2008 Elsevier B.V. All rights reserved.

Introduction

Accurate understanding of the hydrological functioning of a catchment is not possible if only rainfall (input) and discharge (output) data are available, as many different
Runoff generation processes in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees) 207

processes or process combinations may lead to similar hydrographs (Hewlett, 1982; Beven, 1991; Ambroise, 1999). Indeed, rainfall and discharge do not generally provide sufficient information for a single determination of hydrological response through solution of the model inverse problem (Wheater et al., 1991). Therefore, the identification of runoff generation processes requires further observations or investigations within the catchment to characterize dominant water flow pathways. In recent decades, hydrological investigations at the hillslope and small catchment scales (see reviews in Kirkby, 1978; Anderson and Burt, 1990; Ambroise, 1999; Bull and Kirkby, 2002) have led to significant improvements in the understanding of runoff generation processes. Using essentially hydrometric (e.g. Pilgrim et al., 1978; Wilcox et al., 1997; Srinivasan et al., 2002; Peters et al., 2003) and/or hydrochemical (e.g. Pilgrim and Huff, 1978; Sklash et al., 1986; Tanaka et al., 1988; McDonnell, 1990; McGlynn et al., 2002; Wenninger et al., 2004) approaches, in combination with modelling to test hypotheses (e.g. Piñol et al., 1997; Wigmosta and Burgess, 1997; Freer et al., 2004), researchers have acquired a more accurate scheme of water flow pathways from hillslopes to streams.

Nevertheless, the characterization of dominant runoff processes is not an easy task, especially when such processes occur below the soil surface. In consequence, even if surface runoff processes have often been well identified, as infiltration or saturation excess overland flow, processes occurring below the surface are still not properly understood (Beven, 1989). Below the surface, possible simultaneous occurrence of macropore flow, groundwater ridging near the stream, pressure wave effect or the formation of perched aquifers above less permeable layers may increase significantly the complexity of storm-runoff generation processes within a catchment.

Following a purely hydrometric approach, one way to obtain more precise information about runoff generation processes is to obtain continuous information on the evolution of both saturated and unsaturated stores within the soil and to relate this information to the catchment scale runoff response observed at the outlet.

Saturated store dynamics is most often handled by the monitoring of water table position at single locations within the catchment. More than 60 years ago, innovative research by Hursh and Brater (1941) and Hursh and Fletcher (1942) already used water table information to investigate Hortonian runoff generation processes. Even if active processes within the soil were poorly known, water table data were being seen as relevant in small research catchments (seeerry, 2003 for a historical perspective). Water table observations in relation with catchment scale response enabled Cappus (1960) to demonstrate the role played by contributing saturated areas and Betson et al. (1968) to identify the existence of subsurface flow within the soil profile. Dunne and Black (1970a,b) also used water table information to define the concept of saturation excess overland flow. However, the systematic use of water table information to improve the perceptual model (Beven, 1989) of the hydrological functioning of a catchment only emerged in the early 1980’s, following Harr’s (1977) results on subsurface flow on steep forested slopes and other studies (e.g. Sklash and Farvolden, 1979; O’Brien, 1982) that claimed that the water table might make a large contribution to storm-runoff. After more specific studies (Gilham, 1984; Abdul and Gilham, 1984, 1989; Nowakowski and Gilham, 1988), designed to define transfer mechanisms between the water table and the stream and to define the role of the capillary fringe, continuous water table data were progressively incorporated into studies of catchment scale storm-runoff processes (e.g. Bonell et al., 1984; Burch et al., 1987; Hill, 1990; Price, 1997; Myrabø, 1997; Tanaka and Ono, 1998; Biron et al., 1999; Peters et al., 2003). In all these studies, water table information helped to refine authors’ perceptual model of catchment behaviour and to identify possible factors (distance from the stream, macroporosity of the soil, vegetation cover, etc.) that might affect water table dynamics during storms.

Above the saturated store, hydrologists have often used tensiometers to characterize the hydrological state of the unsaturated layer. With these they obtain frequent observations or continuous records of soil water potential at the plot scale, within a catchment. Weyman (1973), Harr (1977), Tanaka et al. (1988) or, more recently, Tanaka and Ono (1998) and Dykes and Thornes (2000) used repeated manual readings of soil water potential during storms to investigate runoff generation processes in humid catchments. Anderson and Burt (1977, 1978) were among the first to develop a continuous recording system for measuring soil water potential in order to investigate variable source areas of runoff generation. Later, McDonnell (1990) combined continuous soil water potential data with storm rainfall, stream-flow and hillslope discharge to infer the nature of sub-surface flow processes in the steep humid Maimai catchment in New Zealand. In the same catchment, tensiometric observations were subsequently used to refine the perceptual model of hillslope flowpaths (see McGlynn et al., 2002 for a review) and to reduce uncertainty in model application (Freer et al., 2004). In NE Scotland, Wheater et al. (1991, 1993) used three-dimensional automatic tensiometer arrays to identify storm-runoff response at the plot scale as a basis for the definition of catchment scale runoff generation processes. More recently, Heppell et al. (2000) used continuous tensiometers to assess the hydrological flowpaths on a clay hillslope.

However, the vast majority of the above-mentioned studies concerned temperate or humid climates, where water table and soil water potential variations generally correlate closely throughout the year with discharge variations at the outlet of the catchment. Nevertheless, as stressed by Bonell and Balek (1993), there are fundamental differences in water table and soil water potential dynamics between humid and less humid or dry regions. In consequence, in drier climate or in regions with more marked climatic seasonality, where the rainfall–runoff relationship is more complex and variable (Beven, 2002), findings from humid regions may only be appropriate for short wet periods. Under Mediterranean climate, which is the general context of this study, only a few studies have used water table or soil water potential information to update a perceptual model of catchment hydrology. Nevertheless, Gaillard et al. (1995) combined water table and soil water potential with soil water content information to investigate runoff generation processes in one of the Real Collobrier sub-catchments, in the south of France. With this approach these authors showed the development of a perched water
table, prone to surface runoff generation, in scattered locations within the catchment. In the neighbouring Mauret catchment, Grésillon et al. (1997) compared a hydrometric approach based on soil water potential data with geochemical and statistical methods to gather information on runoff generation processes. Later, Grésillon and Taha (1998) used water table and soil water potential data along a hillslope in the same catchment to demonstrate the development of temporal saturated areas close to the stream and to investigate their effect on storm-runoff generation. Using the same data, Taha et al. (1997) finally developed a numerical model that simulates the formation of a perched water table at the base of the permeable upper layer. More recently, Lana-Renault et al. (2007) analysed simultaneous stream-flow response and water table dynamics during representative floods to examine runoff generation processes in the Arnás catchment, in the Central Pyrenees.

At the Vallcebre Mediterranean research catchment where this study was conducted, few results on the runoff–water table relationship were available before this study. Some aspects of water table dynamics during wetting-up transition’s runoff events had been observed (Latron et al., 2000), and the water table position had been used to evaluate subsurface contribution to total flow (Gallart et al., 2002, 2007; Latron et al., 2005), but little was known on water table and soil water potential dynamics and on their relationship with catchment scale runoff.

The objective of this paper is, therefore, to investigate runoff generation processes in the Mediterranean Can Vila catchment, using limited continuous data on water table and soil water potential dynamics, and to relate these data to recent findings obtained on the variability of the catchment hydrological response (Latron et al., 2008) and on the seasonal dynamics of runoff-contributing areas (Latron and Gallart, 2007). The analysis concentrates first on water table, soil water potential, rainfall and runoff relationships at a daily scale to define some general characteristics of the response of the catchment. Subsequently, relationships are investigated at the event scale, using a sample of 25 representative ‘simple floods’ to improve the perceptual model of the catchment’s hydrological functioning.

Study area

The Can Vila catchment is located close to Vallcebre village, 130 km northeast of Barcelona, on the southern margin of the Pyrenees. It is one of the research catchments in the Vallcebre research area at the headwaters of the Llobregat River. The catchment (Fig. 1) has an area of 0.56 km² and is oriented in an SW–NE direction. Elevations range from 1458 to 1115 m a.s.l. at the outlet; slopes are moderate, with a mean value of 25.6%.

The catchment is underlain by red clayey smectite-rich mudrocks. The soils that have developed over this lithology are predominantly of silt-loam texture. As topsoils are rich in organic matter and well structured, they have high infiltration capacities, although hydraulic conductivity decreases rapidly with depth (Josa and Roda, 1994; Rubio et al., 2008).

Before and during the 19th century, hillslopes were deforested and terraces, typically 10–20 m wide, were built for agricultural use over more than 70% of the catchment. They were then steadily abandoned, along with their associated drainage ditches, during the second half of the 20th century.

As a consequence of terracing, soil thickness varies a great deal, ranging from less than 50 cm in the inner part of the terraces to more than 2 or 3 m in their outer part. Elsewhere, soil thickness is generally less than 50 cm, especially in the small areas of badlands topography with little or no soil cover that have developed on steep slopes along one section of the stream channel (Fig. 1).

Following land abandonment, spontaneous forestation by *Pinus sylvestris* has occurred (Poyatos et al., 2003) and forest now covers 34% of the catchment (Fig. 1). The remainder of the catchment is largely covered by pasture, with smaller areas of Mediterranean scrub on slopes with thinner soils.

Climate is humid Mediterranean, with a marked water deficit in summer. Mean annual temperature at 1440 m a.s.l. is 7.3 °C and long term (1987–2006) mean annual precipitation is 891 ± 201 mm, with a mean of 90 rainy days per year. Snowfalls account for less than 5% in volume over the period. The rainiest seasons are autumn and spring with mean rainfall amounts above 100 mm in October, November and May and winter is the season with least precipitation. The spatial variability of rainfall within the catchment is limited, except during summer convective storms (with intensities of up to 80 mm h⁻¹ in 20 min), which may provide significant precipitation input. Mean annual reference evapotranspiration, calculated by the Penman-Monteith FAO method (Smith et al., 1992) is close to 700 mm (Gallart et al., 2002).

The combined dynamic of rainfall and evapotranspiration favours the succession of wet and dry or very dry periods (in terms of catchment water reserve) during the year, as shown in Fig. 2. Dry and very dry periods occur in winter and summer, respectively, whereas wet periods correspond to late spring and late autumn. The shift from wet to dry conditions is generally steady as a result of precipitation decrease and/or evapotranspiration increase. The transition from dry to wet conditions is quicker during wetting-up periods (early spring and autumn), which last from 15 to 30 days on average.

Over the period 1995–2002, mean annual runoff in the Can Vila catchment was 386 ± 255 mm, representing 43% of rainfall. Stream-flow shows marked seasonality and often dries in summer for several weeks.

A more complete overview of hydrological findings in the Vallcebre research area can be found in Gallart et al. (1997, 2002, 2005), Latron et al. (2008) and Latron and Gallart (2007).

Data and methods

Data collection

Rainfall in the Can Vila catchment is measured by means of three tipping-bucket rain gauges (Fig. 1), located 1 m above the ground and connected to data-loggers. Rain gauges, which record 0.2 mm precipitation increments at a temporal resolution of 1 s, were calibrated for a wide range of...
rainfall intensities by means of a dynamic calibration method, as in Calder and Kidd (1978). One meteorological station (Fig. 1) located in the upper part of the catchment records air temperature and relative humidity, global and net radiation, soil temperature and wind direction and speed at 2 m height.

Stream-flow is measured at the Can Vila gauging station by means of a 90°/C176 V-notch weir where water level is recorded with a water pressure sensor connected to a datalogger. Mean water level values (measured every 10 s) were recorded every 20 min during low flow periods (i.e. no significant water level change) and every 2 min during floods. Water level conversion to discharge values was obtained by use of the established stage discharge rating curve calibrated by manual discharge measurements.

Depth to water table is recorded every 20 min in and close to the Can Vila catchment in three piezometers (Fig. 1) by means of water pressure sensors connected to datalogger. Calibration of the pressure sensors was obtained by taking manual measurements of water table depth directly in the piezometers, at the time data were collected.

Pz1 (200 cm deep) and Pz2 (287 cm) piezometer holes were augered down to the bedrock to insert 55 mm-diameter PVC tubes; Pz3 (422 cm) is an abandoned well. Given their location in downslope areas, all three piezometers may be considered representative of the general aquifer dynamics in the area. During the study period, the temporal evolution of the water table was generally similar between sites, and the linear relationships between the depths to water table measured in the three piezometers were highly significant ($p < 0.001$), with a slope value close to 1. Data used in this study were solely from Pz1, which had the longest data records.

Soil water potential is recorded every 20 min with a set of three automatic ceramic cup soil tensiometers inserted 20, 40 and 60 cm deep. Tensiometers were located in the central part of a small terrace, in the upper part of the catchment (Fig. 1).

Soil water content is measured using the Time Domain Reflectometry (TDR) method at two locations in the Can Vila catchment (Fig. 1). The TDR profiles consisted of sets of four vertical 20 cm-long probes permanently installed in the ground at 0–20, 20–40, 40–60 and 60–80 cm depth. These were read every week with a Tektronix 250-C cable tester. TDR readings were converted into soil water contents using a composite approach (Roth et al., 1990).

Computation and data analysis

This study is based on daily values obtained over a 6-year period and on event scale values from 25 selected events. Selected events were chosen from among those for which rainfall and water table data were available at the three sites (see Fig. 1), in order to take spatial variability into account, and for which tensiometer data were available at all depths during the event. Selected events also corresponded to "simple floods" that occurred during the time period under consideration and were characterized by one single major hydrograph peak with a clear recession limb in response to one uninterrupted rainfall event. The need for a selection of more "simple floods" was justified by the fact that, during more complex rainfall-runoff events, with several successive runoff peaks, dominant storm-runoff generation processes are likely to vary from peak to peak and so make the identification of dominant flowpaths difficult.
Areal rainfall was determined using Thiessen polygons from the three gauges to account for the spatial variability in some summer rainfall events. From rainfall raw data, daily and storm rainfall depths were obtained by adding up the rainfall depth for the appropriate time period. Finally, rainfall intensity (mean and maximum in 20 min) was calculated to characterise the selected rainfall event.

Daily runoff was the sum of runoff during the day. At the event scale, storm-runoff depth and coefficient were derived for each selected rainfall–runoff event, using the classic "constant slope" hydrograph separation method of Hewlett and Hibbert (1967) with a modified slope value of $1.83 \, \text{l s}^{-1} \, \text{km}^{-2} \, \text{day}^{-1}$. For all runoff events included, preceding baseflow (corresponding to discharge value at the start of the rainfall event) and peakflow were also determined. Finally, the response time, defined as the time interval between the centre of the rainfall event (half of the event rainfall depth) and the peakflow, was calculated for all 25 selected rainfall–runoff events.

Depth to water table and soil water potential values were used directly as daily average in the first part of the analysis. Subsequently, original 20-min data were used to characterize water table and soil water potential dynamics during selected events.

The significance of statistical tests was set at $p < 0.05$.

Results

Rainfall, runoff, water table and soil water potential relationships at daily scale

Rainfall–runoff relationship

Fig. 3 shows, for days with rainfall ($P > 2.0 \, \text{mm}$), the relationship observed in the Can Vila catchment between daily rainfall and runoff depths in function of the position of the water table. Considering all cases, the most relevant characteristic of this relationship is its high scattering; for example, days with around 10 mm rainfall generated daily runoff depths ranging between 0.01 and 10 mm (i.e. three orders of magnitude). On the other hand, similar daily runoff values of around 1 mm were observed during days with 1–50 mm of rainfall. A power fit of daily runoff on daily rainfall explained only 16% of variance and was not statistically significant. Clearly, and even if a general increase of daily runoff with daily rainfall is appreciable in Fig. 3, there was no significant general relationship between daily totals of rainfall and runoff in the Can Vila catchment. If a differentiation is made, depending on the position of the water table (below 150 cm, between 150 and 50 cm and above 50 cm deep), the rainfall–runoff relationship increased moderately when the water table was below 50 cm deep (22% and 28% of the variance explained), but more notably for days with a water table above 50 cm. Under these conditions a significant relationship (57% of the variance explained) was found, which illustrates the relevant influence of the shallow water table position in the way runoff relates to rainfall. Finally, even if the rainfall–runoff relationship was only significant for days with shallow water table, the nature of the rainfall–runoff relationship in each condition was relatively identical (similar power fit exponents between 0.7 and 0.8), with the relationship only shifting toward higher runoff values when there were wetter (higher water table) conditions.

Water table–runoff relationship

The relationship observed in the Can Vila catchment between the depth to water table and the runoff occurring the same day is shown in Fig. 4. The general relationship is classically exponential, with lowest runoff values (around 0.1 mm day$^{-1}$) usually occurring when water table was

![Figure 3](image-url) Relationship between daily runoff and rainfall for various water table depths (only days with more than 2 mm of rainfall were included). Dotted lines show power fits for each position of the water table, but the relationship was significant ($p < 0.05$) only when the water table was above –50 cm.

![Figure 4](image-url) Relationship between daily runoff and the depth to water table. Dotted line shows an example of a sequence (16 successive days) of simultaneous rise of the water table and runoff decrease observed during a wetting-up period.
between 150 and 200 cm below the surface, and highest runoff values (higher than 10 mm day\(^{-1}\)) when saturation conditions were observed. Over the 6-year study period, surface saturation or near-saturation conditions (i.e. water table 20 cm below the surface or less) were only observed for 4% of the time at piezometer Pz1. Similarly, as for Pz2 and Pz3 sites, such conditions were never observed for a daily runoff lower than 0.5 mm day\(^{-1}\) (5.8 l s\(^{-1}\) km\(^{-2}\)). Some scattering around the general trend is apparent, especially during days with more than 2 mm of rainfall. During rainy days, actual runoff was sometimes much higher than the value suggested by the general relationship. Day-to-day runoff increases in response to rainfall were generally associated with the water table rising and, conversely, a decrease in daily runoff was accompanied by a fall in the water table. This general dynamic between runoff and water table changes was however sometimes interrupted for periods of several successive days, when a decrease in daily runoff was associated with a steady rise in the water table. An example of this particular dynamic, which occurred occasionally throughout the year, is shown in Fig. 4 for a period of 16 consecutive days. In this period, following a large rainfall event (\(P = 83.0\) mm) that occurred in the wetting-up period, runoff decreased from 5.8 to 0.2 mm day\(^{-1}\) (67.1–2.3 l s\(^{-1}\) km\(^{-2}\)), whereas the water table rose steadily from −177 to −123 cm.

To investigate further the combined changes in runoff and water table depth, day-to-day variations in both daily runoff and water table position were studied. Results shown in Fig. 5 shows that, during the study period, an increase in daily runoff was most often (i.e. for 90% of the days with increasing runoff) associated with a rise in the water table. Under these conditions, for a similar water table rise, the associated increase in runoff was higher when the water table was already close to the surface than when it was deeper. Conversely, similar increase in runoff resulted from smaller rises in the water table when this was shallow than when it was at a deeper level. An increase in day-to-day runoff was associated with a fall in the water table for 10% of the time; however, under these conditions, decreases in the water table were very limited, generally less than 2 cm.

A decrease in daily runoff was mostly (83% of the days with decreasing runoff) associated with a fall in the water table. Larger day-to-day decreases in runoff and water table position were observed under high water table conditions (water table over 50 cm deep), but the general relationship between runoff and water table variations was similar under all conditions (i.e. similar runoff decrease for similar fall of the water table). In contrast with this general pattern, some decreases in day-to-day runoff were occasionally (17% of the time) associated with a rise of the water table. This particular dynamic, which may lead to a simultaneous water table rise of 50 cm and runoff decrease of 1 mm day\(^{-1}\), was most often observed when the water table was between 50 and 150 cm deep.

Analysis of the water table–runoff relationship (Figs. 4 and 5) shows ultimately that even if day-to-day variations in runoff were generally associated with similar changes in the water table, singular behaviour (i.e. runoff decrease during water table rise) was sometimes observed. This unusual behaviour suggests that, under these conditions, runoff dynamics may be related to factors other than the evolution of the water table position.

### Soil water potential–runoff relationship

To look for other possible factors influencing runoff dynamics, the general relationship between daily runoff and mean daily soil water potential at 20, 40 and 60 cm depth was investigated, using data from the tensiometric profile located in a terraced area (Fig. 1). Results given in Fig. 6 shows that the relationship between soil water potential and daily runoff differed little from one depth to the other. The runoff threshold above which soil saturation could be observed was around 0.3 mm day\(^{-1}\) (3.5 l s\(^{-1}\) km\(^{-2}\)) at all depths. Below this threshold, soil water potential varied

---

**Figure 5** Relationship between day-to-day changes in daily runoff and depth to water table.

**Figure 6** Relationship between daily runoff and soil water potential measured at 20, 40 and 60 cm depth.
widely, but was always far from saturation. Above 0.3 mm day\(^{-1}\), soil water potential ranged frequently between \(-100\) and \(+50\) cm, soils being more often saturated for higher values of daily runoff (>2.0 mm day\(^{-1}\) or 23.1 l s\(^{-1}\) km\(^{-2}\)). Above 0.3 mm day\(^{-1}\), saturation could nevertheless be reached along the whole range of daily runoff values. Positive soil water potentials were, for example, observed at 20 and 60 cm depth during days with no more than 0.4 mm of runoff (4.6 l s\(^{-1}\) km\(^{-2}\)). Over the period, saturation or near-saturation conditions (soil water potential higher than \(-10\) cm) were more frequently observed at 20 and 60 cm depth (9.4% and 11.9% of the time) than at 40 cm (6.5%).

**Soil water potential—water table relationship**

The relationship between the soil water potential at 20, 40 and 60 cm depth and the depth to the water table at Pz\(_1\) is shown in Fig. 7. As for the relationship with daily runoff, soil water potential—water table correlation was different on the two sides of a threshold drawn at a water table position of around 100 cm depth. When the water table was below 100 cm, soil water potential was highly variable, but most often far from saturation (i.e. soil water potential below \(-50\) cm for 72% of the time), except on only a few occasions.

On the contrary, when the water table was above 100 cm, soil water potential was almost always higher than \(-50\) cm and could reach saturation for any position of the water table. Fig. 7 shows that soil saturation in the 60 cm below the surface was more frequent in the terrace than the saturation of the whole soil profile resulting from a rise of the water table to the surface in Pz\(_1\). Indeed, saturation or near-saturation conditions were observed almost 10% of the time according to tensiometer data, but only 4% of the time according to piezometer data. Fig. 7 ultimately shows that saturation at Pz\(_1\), observed only during wet conditions, always coincided with soil saturation at the tensiometer site.

**Rainfall, runoff, water table and soil water potential dynamics at the event scale**

Using available continuous data obtained at short time steps (minutes), characteristic rainfall–runoff events were analysed in order to advance in the understanding of storm-runoff generation processes. Characteristic “simple floods” (see Methods) identified throughout the study period are listed in Table 1. Rainfall depth associated with selected runoff events ranged from 5.2 to 82.7 mm (median \= 22.2 mm), with 20-min maximum rainfall intensities varying from 3.6 to 45.6 mm h\(^{-1}\). Runoff events occurred with contrasting prior hydrological conditions, with baseflow values (at the start of the event) between 1.1 and 58.5 l s\(^{-1}\) km\(^{-2}\). In Pz\(_1\), the depth to water table prior to the event oscillated between \(-197\) and \(-48\) cm below the surface. Owing to the diversity of incoming rainfall events and prior hydrological conditions, observed runoff responses were also very variable, with storm-runoff depths ranging from 0.09 to 50.3 mm; storm-runoff coefficients, from 0.4% to 61.5%; and peakflows, from 5.2 to 966.5 l s\(^{-1}\) km\(^{-2}\).

**Observed hydrological behaviour**

Through the systematic analysis of rainfall characteristics, runoff response at the outlet, soil water potential and water table dynamics during each selected “simple flood” (in addition to particular measurements of soil water content within the first 80 cm), three types of hydrological behaviour occurring during the year could be differentiated at the Can Vila catchment (Fig. 8 and Table 1). Such classification into three types of behaviour was supported by results of an ANOVA test (using the cosine of DOY instead of the raw value to highlight differences between summer and winter) that demonstrated significant differences for all the variables considered in Table 1 except stormflow depth.

Type 1 events (Fig. 8a) were sometimes observed in winter, but more systematically during summer when the catchment was dry to very dry (baseflow around 1.5 l s\(^{-1}\) km\(^{-2}\)), with soil water content values lower than 0.25 cm\(^3\) cm\(^{-3}\). At the start of the event, water table was generally below 1 m deep and soil water potential generally between 50 and \(-150\) cm. Under these conditions, small winter rainfall with low intensities did not produce any significant runoff response at the outlet; during summer, however, short intense rainfall caused higher (though still limited) responses. Owing to dry prior conditions and high rainfall intensity, observed runoff responses were fast and short (a few hours duration) with small storm-runoff depths and coefficients (generally lower than 2%), but with some relatively significant peak-flows (up to 25.3 l s\(^{-1}\) km\(^{-2}\)). During all type 1 events, topsoil saturation never occurred, as soil water potential data showed, and the water table showed no significant reaction.

Type 2 events (Fig. 8b) happened during transitions from dry to wet conditions. At the start of the event, soil water potential and water table position were similar as in type 1 events and baseflow ranged from 1.8 to 5.7 l s\(^{-1}\) km\(^{-2}\). During spring and autumn wetting-up periods, however, frequent or large rainfall events produced larger runoff events with moderate storm-runoff coefficients and variable peakflows (from 15.3 to 654.0 l s\(^{-1}\) km\(^{-2}\)). Response times were
also longer than for type 1 events and floods were also more prolonged (2–3 days), with a relatively gentle recession limb. During type 2 events, soil saturation in the first 60 cm was observed on every occasion. Saturation was however temporary, never lasting more than a week in the absence of further rainfall. The delayed response of the topsoil was always temporary, never lasting more than a week in the absence of further rainfall. The delayed response of the topsoil saturation progressive drainage.

Type 3 events (Fig. 8c) were observed during wet conditions that follow the wetting-up transition. At the end of autumn or spring, catchment usually had wet conditions with soil water content higher than 0.40 cm³ cm⁻³, soil water potential close to saturation (soil water potential higher than -10 cm) and water table less than one meter below the surface. Long rainfall events (of low intensity) occurring in these periods of the year generated the largest runoff responses in terms of storm-runoff coefficients (up to 61.5%) and peakflows (up to 966.5 l s⁻¹ km⁻²). Even if the magnitude of the runoff response varied with the amount of incoming rainfall, all type 3 events generally lasted for several days (from 4 to 7 days) and were characterised by a slow recession that may last for 1–2 weeks in the absence of additional rainfall. During type 3 events, tensiometer data confirmed that prolonged saturation was observed in the first 60 cm of the soil; in addition, the water table already close to the surface showed a quick reaction to rainfall and reached the surface, coinciding with the flood peak.

**Storm-runoff coefficient—water table relationship**

The three types of hydrological response identified in the Can Vila catchment illustrate the existence of hydrological behaviour that changed during the year, with different rainfall—runoff and runoff—water table relationships. The non-linearity of these relationships is quite clear in Fig. 9, which shows, for the 25 selected floods, the relation between the storm-runoff coefficient and the depth to water table. During dry conditions (type 1 event), with a water table below 150 cm, runoff coefficient were always lower than 2%, even for larger (and sometimes intense) rainfall events up to 30 mm. In these conditions, no relationship existed between storm-runoff coefficient values and the depth to water table. During wet conditions, with a water table less than 30 mm, in these conditions, no relationship existed between storm-runoff coefficient values and the depth to water table. During type 2 events, the water table showed generally a steady rise for the first 60 cm of the soil; in addition, the water table already close to the surface showed a quick reaction to rainfall and reached the surface, coinciding with the flood peak.

### Table 1: Characteristics of the 25 representative “simple floods” observed at the Can Vila catchment

<table>
<thead>
<tr>
<th>D.O.Y.</th>
<th>P (mm)</th>
<th>Imean (mm h⁻¹)</th>
<th>lmax (mm h⁻¹)</th>
<th>Rx (mm)</th>
<th>Cₜ (%)</th>
<th>Qb (l s⁻¹ km⁻²)</th>
<th>Qp (l s⁻¹ km⁻²)</th>
<th>Rt (min)</th>
<th>Pz₁ (cm)</th>
<th>Type of hydrological response</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>82.7</td>
<td>2.0</td>
<td>9.6</td>
<td>50.3</td>
<td>60.8</td>
<td>34.4</td>
<td>966.5</td>
<td>152</td>
<td>-53</td>
<td>³</td>
</tr>
<tr>
<td>28</td>
<td>44.5</td>
<td>1.4</td>
<td>5.4</td>
<td>27.4</td>
<td>61.5</td>
<td>58.5</td>
<td>497.3</td>
<td>130</td>
<td>-48</td>
<td>³</td>
</tr>
<tr>
<td>34</td>
<td>5.2</td>
<td>1.0</td>
<td>3.6</td>
<td>0.38</td>
<td>7.3</td>
<td>36.9</td>
<td>47.1</td>
<td>146</td>
<td>-70</td>
<td>³</td>
</tr>
<tr>
<td>113</td>
<td>58.0</td>
<td>2.4</td>
<td>12.6</td>
<td>18.9</td>
<td>32.6</td>
<td>5.4</td>
<td>654.0</td>
<td>264</td>
<td>-113</td>
<td>²</td>
</tr>
<tr>
<td>131</td>
<td>33.3</td>
<td>1.2</td>
<td>4.2</td>
<td>15.4</td>
<td>46.2</td>
<td>20.3</td>
<td>205.0</td>
<td>174</td>
<td>-69</td>
<td>³</td>
</tr>
<tr>
<td>137</td>
<td>12.8</td>
<td>2.4</td>
<td>7.2</td>
<td>0.09</td>
<td>0.7</td>
<td>2.3</td>
<td>7.0</td>
<td>160</td>
<td>-179</td>
<td>³</td>
</tr>
<tr>
<td>139</td>
<td>17.4</td>
<td>2.9</td>
<td>12.0</td>
<td>3.4</td>
<td>19.4</td>
<td>30.3</td>
<td>204.3</td>
<td>82</td>
<td>-70</td>
<td>³</td>
</tr>
<tr>
<td>171</td>
<td>20.0</td>
<td>15.1</td>
<td>34.5</td>
<td>0.3</td>
<td>1.4</td>
<td>4.1</td>
<td>20.0</td>
<td>116</td>
<td>-154</td>
<td>³</td>
</tr>
<tr>
<td>179</td>
<td>45.1</td>
<td>3.5</td>
<td>11.4</td>
<td>3.88</td>
<td>8.6</td>
<td>2.9</td>
<td>114.9</td>
<td>190</td>
<td>-176</td>
<td>³</td>
</tr>
<tr>
<td>201</td>
<td>29.9</td>
<td>17.9</td>
<td>36.6</td>
<td>0.3</td>
<td>0.9</td>
<td>1.8</td>
<td>25.3</td>
<td>110</td>
<td>-189</td>
<td>³</td>
</tr>
<tr>
<td>210</td>
<td>29.1</td>
<td>10.9</td>
<td>45.6</td>
<td>0.1</td>
<td>0.4</td>
<td>1.2</td>
<td>10.9</td>
<td>156</td>
<td>-188</td>
<td>³</td>
</tr>
<tr>
<td>220</td>
<td>18.3</td>
<td>2.6</td>
<td>24.3</td>
<td>0.2</td>
<td>1.0</td>
<td>1.1</td>
<td>13.9</td>
<td>120</td>
<td>-194</td>
<td>³</td>
</tr>
<tr>
<td>239</td>
<td>15.6</td>
<td>4.7</td>
<td>25.2</td>
<td>0.1</td>
<td>0.7</td>
<td>1.1</td>
<td>9.1</td>
<td>200</td>
<td>-193</td>
<td>³</td>
</tr>
<tr>
<td>253</td>
<td>15.4</td>
<td>7.7</td>
<td>16.2</td>
<td>0.2</td>
<td>1.2</td>
<td>1.1</td>
<td>13.6</td>
<td>142</td>
<td>-191</td>
<td>³</td>
</tr>
<tr>
<td>255</td>
<td>54.6</td>
<td>6.3</td>
<td>36.3</td>
<td>13.3</td>
<td>24.3</td>
<td>4.3</td>
<td>297.3</td>
<td>180</td>
<td>-180</td>
<td>³</td>
</tr>
<tr>
<td>261</td>
<td>14.1</td>
<td>3.0</td>
<td>9.6</td>
<td>0.1</td>
<td>0.6</td>
<td>1.2</td>
<td>5.2</td>
<td>198</td>
<td>-197</td>
<td>³</td>
</tr>
<tr>
<td>261</td>
<td>22.2</td>
<td>2.6</td>
<td>9.6</td>
<td>8.6</td>
<td>38.6</td>
<td>17.8</td>
<td>271.1</td>
<td>110</td>
<td>-80</td>
<td>³</td>
</tr>
<tr>
<td>288</td>
<td>81.9</td>
<td>3.1</td>
<td>11.4</td>
<td>12.1</td>
<td>14.7</td>
<td>11.1</td>
<td>146.5</td>
<td>172</td>
<td>-196</td>
<td>³</td>
</tr>
<tr>
<td>309</td>
<td>52.0</td>
<td>2.0</td>
<td>8.7</td>
<td>2.38</td>
<td>4.6</td>
<td>2.3</td>
<td>44.4</td>
<td>452</td>
<td>-195</td>
<td>³</td>
</tr>
<tr>
<td>313</td>
<td>9.2</td>
<td>2.3</td>
<td>7.2</td>
<td>0.29</td>
<td>3.2</td>
<td>5.7</td>
<td>15.3</td>
<td>194</td>
<td>-138</td>
<td>³</td>
</tr>
<tr>
<td>329</td>
<td>58.0</td>
<td>3.2</td>
<td>9.6</td>
<td>10.2</td>
<td>17.5</td>
<td>1.8</td>
<td>265.2</td>
<td>192</td>
<td>-176</td>
<td>³</td>
</tr>
<tr>
<td>342</td>
<td>60.2</td>
<td>1.7</td>
<td>8.4</td>
<td>35.7</td>
<td>59.2</td>
<td>6.6</td>
<td>432.4</td>
<td>138</td>
<td>-77</td>
<td>³</td>
</tr>
<tr>
<td>356</td>
<td>14.9</td>
<td>2.2</td>
<td>6.6</td>
<td>1.4</td>
<td>9.3</td>
<td>30.2</td>
<td>67.8</td>
<td>176</td>
<td>-83</td>
<td>³</td>
</tr>
<tr>
<td>357</td>
<td>8.0</td>
<td>1.3</td>
<td>6.6</td>
<td>1.98</td>
<td>24.8</td>
<td>43.0</td>
<td>92.6</td>
<td>158</td>
<td>-50</td>
<td>³</td>
</tr>
<tr>
<td>364</td>
<td>9.1</td>
<td>1.8</td>
<td>4.8</td>
<td>1.1</td>
<td>12.2</td>
<td>21.9</td>
<td>38.5</td>
<td>124</td>
<td>-63</td>
<td>³</td>
</tr>
</tbody>
</table>

D.O.Y., day of year; P, rainfall; Imean, mean rainfall intensity; lmax, maximum rainfall intensity (in 20 min); Rx, storm-runoff depth; Cₜ, storm-runoff coefficient; Qb, baseflow (at the start of the flood); Qp, peakflow; Rt, response time; Pz₁, depth to water table in piezometer Pz₁ at the start of the flood. Type of hydrological response: ³, ², ³ defined in the text.
smaller values of water table depth). In the Can Vila catchment, this relatively common behaviour (dry–wet conditions), observed for example by Cappus (1960) in a temperate catchment, was disrupted during wetting-up periods, when, in spite of the low water table (often below 150 cm), significant storm-runoff coefficients (3.2–32.6%) were seen for type 2 events. Independently of the magnitude of incoming rainfall, storm-runoff coefficients observed for type 2 events were broadly in between small values of type 1 events and large values of type 3 events. Finally, no clear relationship existed between storm-runoff coefficients and the depth to water table during the wetting-up period.

Analysis of response time
Even if some caution is necessary in the analysis of response time, principally because of the strong influence of rainfall characteristics on its calculation, it provides a useful indication on how rapidly rainfall is converted to runoff at the catchment scale. The relationship between the response time associated with each selected flood and its corresponding storm-runoff coefficient is shown in Fig. 10. It demonstrates that response times observed in the Can Vila catchment (average value $T_{\text{mean}} = 169$ min), even if somewhat longer than those usually reported for catchment with dominant surface runoff processes (see Jones, 1997), were generally shorter than when subsurface runoff processes dominate. This relatively rapid “transfer” of rainfall to catchment outlet suggests a probable large contribution of surface runoff for all conditions. Nevertheless, the three
The non-linearity of the rainfall–runoff relationship for Mediterranean catchments, which contrasts with rainfall–runoff dynamics described for more humid or temperate catchments (Cappus, 1960; Jordan, 1994; Peters et al., 2003), seems mainly related to the seasonality of catchment water reserves, varying under dry, wetting-up and wet conditions (Fig. 2). Indeed, examination of the position of the water table explained most of the variability observed in the rainfall–runoff relationship (Fig. 3). This variability appears to be ultimately linked to the dynamics of saturation zones within the catchment, which correlate closely, for most of the year, with the position of the water table (Latron and Gallart, 2007). It may be concluded that, even for the Mediterranean catchment considered here, the position of the water table was a relevant factor in explaining the magnitude of the runoff response to a given rainfall.

In the Can Vila catchment, runoff measured at the outlet generally increased with the rise of the water table (Fig. 4), but the scatter of this relationship was large. This result is consistent with findings generally reported for Mediterranean catchments (Gaillard et al., 1995; Lana-Renault et al., 2007), where runoff variations are often fairly independent of water table dynamics. It contrasts however with observations made in humid catchments: Skslah and Farvolden (1979), for example, reported similar runoff and water tables responses in eastern Canada and Myrabø (1997) found very close correlation between runoff and water table position in a small Norwegian catchment. Similarly, Peters et al. (2003) showed comparable dynamics of runoff and water table during the dormant season at the humid continental-to-subtropical Panola Mountain Research Watershed (PMRW).

As well as the relatively high scatter of the relationship between the position of the water table and the runoff in the Can Vila catchment, Fig. 4 also shows the possible occurrence of particular conditions during periods (of 2 to more than 10 days) with simultaneous rise of the water table and runoff decrease. This particular dynamic, illustrated in Fig. 5, was observed occasionally (17% of the days with decreasing runoff) and was always associated with a delayed response of the water table in days following the runoff response. The significantly delayed water table response observed in the Can Vila catchment may be considered a characteristic of seasonally dry catchments such as Mediterranean ones. Indeed, in wetter tropical environments, Bonell reported only shortly delayed water table responses, similar to those observed by Peters et al. (2003) at PMRW; and in more humid conditions, water table rise has been often observed prior to runoff response (Jordan, 1994; Myrabø, 1997). In terms of runoff generation processes, this much-delayed water table response means that throughout several floods the water table response was null or very limited, and that consequently most of the runoff that reached the Can Vila outlet during these floods did not correspond to saturation excess runoff associated with the rise of the water table, but was caused by other processes.

The examination of tensiometer data (Fig. 6 and 7) demonstrates that, apart from infiltration excess runoff observed only locally within the catchment, on bedrock outcrops or badlands areas (see Fig. 1), saturation excess runoff associated with surface saturation was likely to be
the primary runoff generation process in the absence of water table response. Fig. 6 shows that soil profile saturation was frequently reached on days with more than 0.3 mm day⁻¹ (3.5 l s⁻¹ km⁻²), whereas under similar conditions the water table was only occasionally within the first 50 cm below the surface (Fig. 4). Only for runoff values higher than 10 mm day⁻¹ did soil profile saturation in the terraced area coincide with saturation at Pz₁ location. Comparison of soil water potential data and water table depth (Fig. 7) reveals that soil profile saturation in the first 60 cm below the surface was rather common, even when the water table at Pz₁ was 100 cm below the surface. At 50 cm below the surface was rather common, even when the water table at Pz₁ was 100 cm below the surface. At the tensiometer plot, the development of a layer of saturation limited to the terrace topsoil was supported by occasional observations of the water table (often located below 150 cm) on days with topsoil saturation. During wet conditions, saturation of the soil profile matched the rise of the water table. However, the simultaneous occurrence of saturated conditions in the terrace topsoil, but not in the whole soil profile at Pz₁, was relatively frequent and ultimately suggests that topsoil saturation could be locally reached on several occasions without saturation of the whole profile. Such conditions linked to the rapid reduction of soil hydraulic conductivity with depth in the terraced area (Josà and Roda, 1994; Rubio et al., 2008) facilitated the development of a perched water table at several locations within the Can Vila catchment. Similar development of perched water tables promoting surface runoff have been observed elsewhere in a wide range of conditions varying from temperate catchments (Bonelli et al., 1984; Biron et al., 1999), tropical rainforest (Bonell and Gilmour, 1978; Cassells et al., 1985; Dykes and Thornes, 2000) to drier environments (Topadilis and Curtis, 1982). In Mediterranean areas, similar results to those described for the Can Vila catchment were found by Gaillard et al. (1995), Taha et al. (1997) and Grésillon and Taha (1998).

Event scale analysis

Even if the analysis of daily scale relationships between rainfall, runoff, water table and soil water potential data offers a general scheme of runoff response to rainfall, a study on a shorter time scale is required to further investigate the way rainfall converts to runoff (e.g. Peschke and Sambale, 1999; Kirnbauer et al., 2001). In the Can Vila catchment, more detailed results obtained through the analysis of 25 representative ‘simple flood’ events supplied additional information on dominant runoff processes, which improves the perceptual model of the catchment’s hydrological functioning. At the event scale, three types of characteristic responses were identified during the year:

- In dry conditions, with low baseflow values, low water table and relatively dry soils (owing to soil water content and soil water potential data), only limited storm-runoff responses were observed at the catchment outlet (Figs. 8a, 9 and Table 1). This type of response (defined as type 1 event) was always fast (Fig. 10) and short and neither topsoil saturation nor water table rise were observed during the flood. As shown by Latron and Gallart (2007), there was no saturated area in the catchment in dry conditions and the only possible runoff-contributing areas in type 1 events were local low permeable areas (bedrock outcrops or badlands, see Fig. 1) close to the stream. In consequence, for short intense rainfall occurring in (summer) dry conditions, infiltration excess runoff was probably the dominant runoff process and could explain both relatively significant peakflows and high suspended sediment concentrations (Soler et al., 2008) associated with type 1 events. In addition, response times of around 150 min determined for type 1 events were conditioned only by the location (i.e. distance from the outlet) of low permeable areas (see Fig. 1). Several authors (Anderson and Burt, 1990; Beven, 2002) point out that occurrence of infiltration excess runoff is not unusual, even if, as stressed by Dunne (1983), it is largely restricted to localized low permeable areas within one catchment. In dry or Mediterranean climates, infiltration excess runoff occurrence has been often reported (Topadilis and Curtis, 1982; Cosandeý, 1993; Ceballos and Schnabel, 1998; Lanza-Renaud et al., 2007), especially during dry conditions. The hydrological functioning of the Can Vila catchment for type 1 events, conditioned by both its hydro-climatic dynamics (catchment water status, type of incoming rainfall, etc.) and soil characteristics (infiltration capacity), is close to the partial area concept defined by Betson (1964).

- During transitions from dry to wet conditions, with similar prior wetness conditions as for type 1 events, larger runoff events with moderate storm-runoff coefficients and variable peakflows were observed in response to more frequent or larger rainfall events (Figs. 8b, 9 and Table 1). In type 2 events, characterised by a long response time (Fig. 10) and a relatively gentle recession, topsoil saturation and delayed water table response were observed every time. Wetting-up periods, frequently identified in Mediterranean climates (Gaillard et al., 1995; Grésillon et al., 1997; Piñol et al., 1997), are phases of progressive restoration of catchment water reserves. In consequence, at the start of type 2 events, storm-runoff was still produced mainly in impervious areas (as for type 1 events), although in less quantity due to lower intensities of incoming rainfall. However, generally larger rainfall volumes helped the formation of a perched saturation layer that could reach the surface from place to place within the catchment. This scattered saturation pattern, owing to soil characteristics and terraced topography, observed by Latron and Gallart (2007), favoured the progressive contribution of saturation excess runoff during type 2 events. The longer response time observed for type 2 events (around 235 min) could be related to the delay necessary for the formation of a perched saturation layer before significant saturation excess runoff was produced. The contribution of scattered perched saturated layers to stream-flow was facilitated by the presence of man-made ditches that connect terraces with the stream. In view of flood characteristics and storm-runoff coefficients, saturation excess runoff on perched saturated layers was probably the dominant runoff process in the Can Vila catchment during wetting-up periods. The lower contribution of infiltration excess runoff occurring in badlands areas during type 2 events is also confirmed by the lower sediment concentrations observed (Soler et al., 2008) during floods in wetting-up periods. As stated above, the development of a perched saturation layer throughout the catchment is not exclusive to Mediterranean conditions, and has been reported elsewhere.
However, the seasonality of Mediterranean climate in middle mountain areas, with a succession of marked dry and wet periods confers on this process (in combination with soil characteristics) a more important role in runoff generation during wetting-up periods. The hydrological behaviour of the Can Vila catchment during transitions from dry to wet conditions is indeed close to that observed in other Mediterranean catchments (Gaillard et al., 1995; Taha et al., 1997), even if the terraced topography covering most of the Can Vila catchment area seems to be an additional factor that promotes significantly the formation of perched saturation layers and the associated production of saturated excess runoff.

- In wet conditions, when water content, water potentials and water table data indicate that soils were saturated or close to saturation, large (in terms of storm-runoff coefficients) and lasting runoff responses were always measured at the outlet (Figs. 8c, 9 and Table 1). During low-intensity but generally long rainfall episodes, the shallow water table rose quickly and promoted more extensive surface saturation within the catchment. The quick expansion of saturated areas favourable to saturation excess runoff generation provides an explanation for the relatively rapid response times (mean = 139 min) associated with type 3 events (Fig. 10). Field surveys show (Latron and Gallart, 2007) that larger extents of saturated areas were observed in wet conditions, resulting mainly from water table rise but also from perched saturation. As a result, saturation excess runoff in saturated areas was most probably the main runoff generation process, as confirmed by visual observations in the catchment during rainfall events. Infiltration excess runoff contribution (limited to low permeable areas) was less in wet conditions and, consequently, sediment concentrations observed at the outlet were generally low (Soler et al., 2008). The contribution of sub-surface runoff processes was not assessed in this study, but the rapid response time of the catchment in wet conditions suggests that surface runoff processes were dominant in the overall hydrological response. The hydrological behaviour of the Can Vila catchment during wet conditions, sometimes observed in other Mediterranean catchments (Cosandey, 1993; Lana-Renault et al., 2007), was finally similar (to some extent) to that generally reported in more humid climates, where the extent of saturated areas for saturation excess runoff generation is closely related to the position of the water table (Cappus, 1960; Dunne et al., 1975; Bonell et al., 1984; Cosandey, 1986; Ambroise, 1986; Peschke and Sambale, 1999). However, field observations show (Latron and Gallart, 2007) that saturation patterns mapped at the Can Vila catchment are always much more scattered than is usually reported, mainly because of its terraced topography. In addition, recession limbs described in more humid catchments (Tanaka et al., 1988; Myrabø, 1997) are usually not so rapid as in this study, suggesting the greater contribution of sub-surface runoff processes than in the Can Vila catchment.

**Summary and conclusions**

Using limited continuous data on water table and soil water potential dynamics, as well as rainfall–runoff data, this study shows certain characteristics of the hydrological behaviour of the Can Vila Mediterranean catchment. Using daily scale information, the strong non-linearity between rainfall and runoff values is shown, as well as the influence of the water table position on the way they relate. The relationship between runoff and the depth to water table showed much more scatter than is usually observed under more humid conditions. Likewise, water table variations (rise or fall) were on some occasions not in phase with runoff changes, suggesting somewhat more intricate hydrological behaviour. Soil water potential data in relation with runoff and water table data revealed that the development of a perched saturation layer was a relatively frequent process.

Investigation of soil water potential and water table dynamics during a collection of representative ‘‘simple floods’’ resulted in the identification of three types of characteristic hydrological behaviour during the year, relating mainly to the seasonality of catchment water reserves, but also to rainfall characteristics (intensity, duration). The type 1 event identified during dry conditions, the type 2 event (wetting-up transition) and the type 3 event (wet conditions) each had different characteristics and were associated with different dominant storm-runoff generation processes. In dry conditions, storm-runoff was generated essentially as infiltration excess runoff on low permeable areas, whereas saturation excess runoff dominated during wetting-up and wet conditions. However, corresponding saturated areas prone to saturation excess runoff resulted from different processes. During wetting-up transition, they resulted from the development of scattered perched water tables in the terraced area, whereas under wet conditions they were linked to the rise of the deep water table.

Unlike water table dynamics, which were measured at three locations, the spatial variability associated with soil water potential dynamics could not be considered in this study, as only one site was monitored. The observed dynamics were, however, similar to those in a neighbouring catchment located 2 km away. Results obtained in this study can, therefore, be considered broadly representative of the dynamics of water in the topsoil in the terraced area of the catchment. In the end, and even if more spatially distributed information would have benefited the analysis, results obtained in this study provided some new and relevant information on the way runoff is generated in the Can Vila Mediterranean catchment. The results reported in this study complete previous findings on the rainfall–runoff response observed at the outlet (Latron et al., 2008) and on the spatio-temporal dynamics of runoff-contributing areas (Latron and Gallart, 2007) and improve the perceptual model of the hydrological functioning of this Mediterranean catchment.

Current research aimed at assessing the spatio-temporal variability of water table dynamics in the Can Vila catchment, along with the use of complementary approaches (environmental tracing) to support some of the findings obtained here through a purely hydrometric approach, will contribute to further updating of this perceptual model. Owing to the relatively few studies of Mediterranean catchment hydrology, all the knowledge garnered from the Can Vila catchment should ultimately help the elaboration of more process-based modelling in similar seasonal environments. Using results like those given here, modelling activity should
involves hypothesis testing (e.g. Piñol et al., 1997; Vivoni et al., 2007) of a flexible model structure able to integrate the strong seasonality of Mediterranean catchments’ hydrology.

Acknowledgments

This research was conducted with the support of the CANOA (CGL2004-04919-C02-01) and PROBASE (CGL2006-11619/ HID) projects funded by the Spanish Government, and the TEMPQSIM (EVK1-CT-2002-00112) project funded by the European Commission. Research at the Vallcebre catchments is also supported by the agreement between the CSIC and the Spanish Ministry of the Environment (RESEL). J. Latron was the beneficiary of a research contract (Juan de La Cierva programme), funded by the Spanish Ministry of Education and Science. Support provided by C. Salvany, P. Llorens, C. Rubio, M. Soler, D. Regués, R. Payotos, O. Avila and X. Huguet during fieldwork and data acquisition is acknowledged. The authors would also like to acknowledge the helpful comments made by M. Sivapalan and another anonymous reviewer.

References

Runoff generation processes in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees)


