7th ISE & 8th HIC
Chile, 2009

RIPARIAN ZONE CONTROL ON FLOW REGIME IN A SMALL MEDITERRANEAN FORESTED CATCHMENT NAMED FUIROSOS, CATALUNYA (SPAIN)

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Mediterranean catchments are characterized by strong non-linearities in their hydrological behaviour and reproducing their complex behaviour still presents a great challenge to rainfall-runoff modelling. It has been pointed out for these areas three recognizable periods: a long dry season; a transition period; and finally a wet season. The transition period has been noted as a critical point for the hydrological and hydrochemical behaviour of Mediterranean catchments. The progressive perceptual approach adopted in this study, led to include into a previously developed rainfall-runoff conceptual model a new tank, representing the riparian zone in order to improve the transition period simulation. This allowed modelling successfully the drying-up period and the non-linear hydrological behaviour of this catchment during the wetting-up. Our results show that the graphical fit of the transition period improved significantly with the introduction of the riparian tank.

INTRODUTION

The riparian zone represents a transition compartment between the stream and the catchment where upstream water and groundwater converge.

Field studies have pointed out that the local riparian aquifer can be subjected to seasonal and/or annual hydrological changes which may affect the relationship between biochemistry solute transport and the hydrology of stream-local aquifer system (Cirmo and McDonnell [1]). In this sense, it has been observed that vegetation could have a significant impact on hydraulic processes, particularly during periods of low flow (Tabacchi *et al.* [2]). The riparian vegetation consumes groundwater and streamwater (Chen [3]) so that, during summer, the riparian water table may fall significantly, which cause that the normal hydraulic gradient reverse with discharge from the river to the riparian zone (Butturini *et al*. [4]). In the analysis of an intermittent stream, this may represent an important mechanism to take into account in order to explain its non-linear behaviour.

Moreover, McMahon [5], analyzing several Australian catchments, has postulated that the hydrograph steep recession, for example during the stream drying-up period, is a combination of evaporation from the stream surface and transpiration of the riparian vegetation, which together are greater than the recharge to the stream by local groundwater.

The catchment considered in this study is a small Mediterranean one which drains an intermittent stream called Fuirosos. Mediterranean catchments share hydrological processes from both wet and dry environments, following a seasonal pattern that induces remarkable particularities in their hydrological behaviour (Gallart *et al.* [6]). Several authors have pointed out three recognizable periods during the same hydrological season (Piñol *et al*. [7]; Gallart *et al.* [6]; Latron [8]): a long dry season; a transition period and finally a wet season. The transition period, from dry to wet condition, represents a critical stage for the hydrological and hydrochemical functioning of these regions (Durand *et al.* [9]).) and generally, rainfall-runoff models cannot reasonably reproduce the shape of the associated hydrograph (Piñol et al. [7]; Anderton *et al.* [10]; Latron *et al*. [8]; Bernal *et al*. [11]). The aim of this paper is highlighting the role played by the riparian zone in explaining the non-linear response observed in this catchment, with special attention to the key factor that govern the drying-up and the wetting-up periods.

MATERIAL AND METHODS

Study site

Fuirosos (latitude 41º 42'N, longitudude 2º 34') is a small Mediterranean catchment that drains approximately 13 km^2. It is located in the northern slopes of Catalan Littoral Range, near Barcelona (Spain). The catchment is an almost pristine, undisturbed forested watershed, with little agricultural activity and no urban areas. Within the catchment, there are four small reservoirs for human and cattle water supply. This water consumption can be considered insignificant during the study period. The storage volume of these reservoirs ranges from 5,000 to 18,000 m^3.

The main rock type in the Fuirosos catchment is leucogranite (50.9%) followed by granodiorite (21.1%) and sericitic schists (23.5%) (IGME, [12]), as shown in Figure 1. At the valley bottom there is an identifiable alluvial zone, where a well-developed riparian area flanks the Fuirosos stream channel. In this study, it was taken into account also the Grimola subcatchment, which is tributary of the Fuirosos stream draining approximately 4 km^2 (Fig. 1). In contrast to Fuirosos, Grimola does not have a significant alluvial zone neither a well developed riparian area.

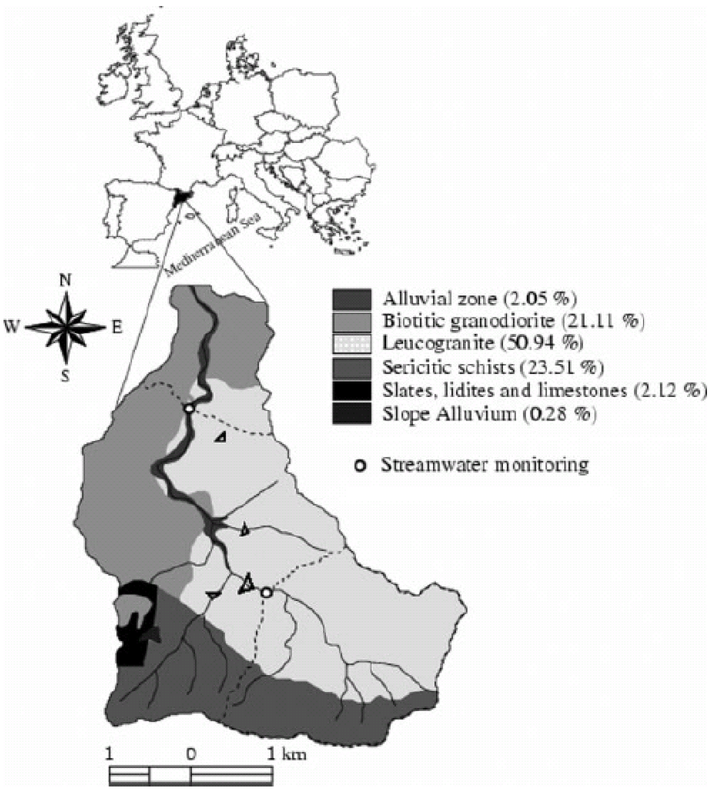

Figure 1. Map of Fuirosos catchment and its subcatchment Grimola (Catalonia, NE Spain) showing lithological units in different shadings and the location of four small reservoirs.

The observed period, at Fuirosos, is from 13/10/1999 to 30/06/2003, while at Grimola subcatchment discharge was measured from 18/09/2000 to 22/08/2002. During the complete observed period, the mean annual precipitation at Fuirosos is about 750 mm. The mean annual potential evapotranspiration (PET) computed with the Penman equation is approximately 975 mm, which is much higher than the precipitation. Therefore, the catchment must be classified as semiarid.

From Figure 2, it can be noticed that Fuirosos catchment shows a clear tendency to get dry easier than Grimola subcatchment. Similarly, Bernal and Sabater [13] showed that during the wetting-up and drying-up periods specific discharge at the Fuirosos stream was several times lower than that estimated at the Grimola stream.

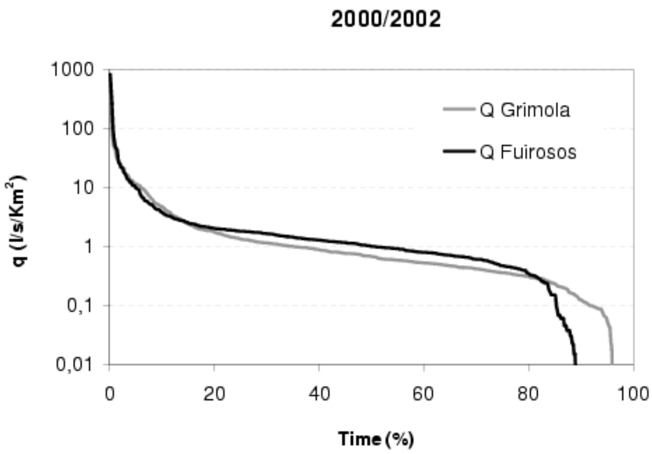

Figure 2. Specific daily stream discharge ordered from the highest to the lowest for the Fuirosos catchment and the Grimola subcatchment for the period from 18/09/2000 to 22/08/2002.

Model description

During this work, the earliest perception of how Fuirosos catchment responds to a rainfall episode progressively changed and, therefore, it changed the related conceptual model (Medici *et al.*, [14]). The initial lumped model structure consisting in a series of four connected water tanks (LU3) progressed to a model with five tanks (LU4), and finally to a semidistributed model structure (SD4) in which spatial variability of the evapotranspiration according to the vegetation cover and to the local aspect was considered. In the final model structure (SD4-R) an additional tank representing the riparian zone was included.

In the next paragraphs it will be describe just the last conceptualization adopted (SD4-R model), being the only one that include the stream-riparian aquifer system and being the one that gave the best fit to observed data. It is worth pointing out that the model represents the hydrological processes at catchment scale, rather than at the point scale. Moreover, a daily time step was adopted for the simulation.

The SD4-R model conceptual scheme consists in a series of connected tanks, each one representing different water storages in the soil column (Fig. 3): static (interception, water detention in puddles and retained water by upper soil capillary forces), surface, gravitational (upper soil water content above field capacity), perched shallow aquifer (quick base flow) and deep aquifer (slow base flow). The quick base flow represents the flow that occurs into the upper part of the weathered bedrock (horizon B) due to the formation of a perched shallow aquifer. The slow base flow considered in this study is associated with the permanent saturated zone within the deeper weathered bedrock layer (called deep aquifer in this paper). This new four-response structure is coherent with results obtained in previous field works at Fuirosos (Butturini *et al.*, [4]). The vertical connections between tanks describe the precipitation, evapotranspiration, infiltration and percolation processes. It is worth to highlighting that percolation to the deep aquifer occurs only when soil water content exceeds a threshold value.

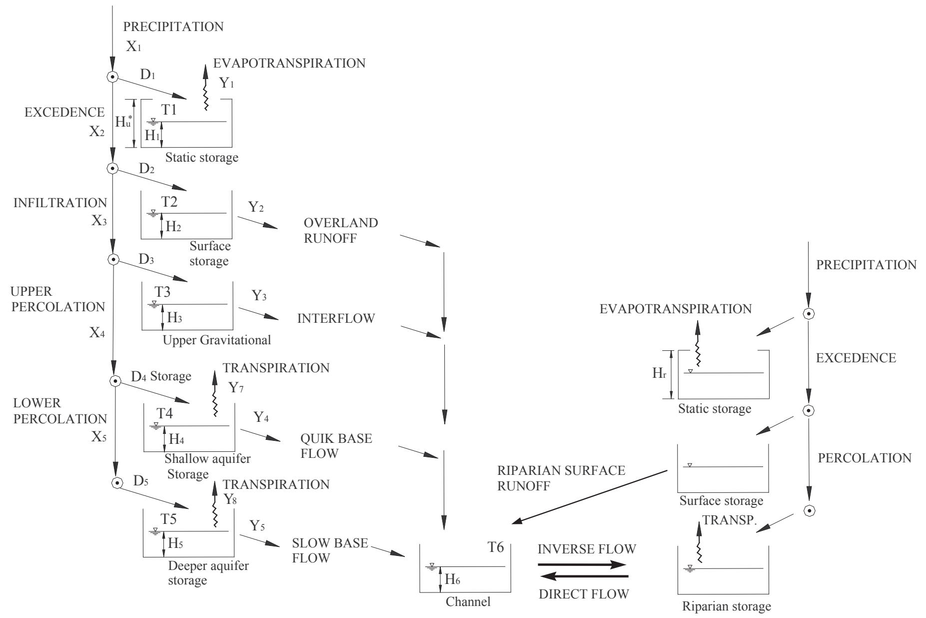

Figure 3. SD4-R conceptual scheme.

The stream is described as a linear tank, which receives directly the contribution of all the HRUs taken into account and it is characterized by a discharge coefficient (α) to be calibrated. In addition, the effect of the four small reservoirs on the catchment response was included into the model. In case of overflow, it was checked that flood routing was not significant at daily scale.

The riparian tank allows simulating bi-directional water flux (F_{sr}) between the stream channel and the riparian zone. Exchanges of water are generated according to the difference between the river stage d (m) and the riparian water table e (m), following equation 1. When d is higher than e, water will flow from the stream to the riparian zone until the recover of the local riparian water table. In this case, F_{sr} will be negative and it has been called "inverse flow". On the contrary, when e is higher than d, water will flow from the riparian zone to the stream and F_{sr} will be positive, representing the "direct flow".

$$F_{sr} = \pm K_{sr} \cdot \left(\frac{e-d}{m} \right) \cdot (2 \cdot f \cdot c) \quad (1)$$

where: K_{sr} is the saturated conductivity between the riparian zone and the stream channel (13 m/day, Butturini *et al.*, [4]); m is one side riparian zone width (15 m); f is the estimated length of the riparian zone (2,000 m) and c is the estimated elevation of the stream bed over the bedrock (3 m).

RESULTS

Observed mean daily stream flow at Fuirosos from October 1999 to August 2002 and the corresponding simulated mean daily stream flow are shown in Figure 4.

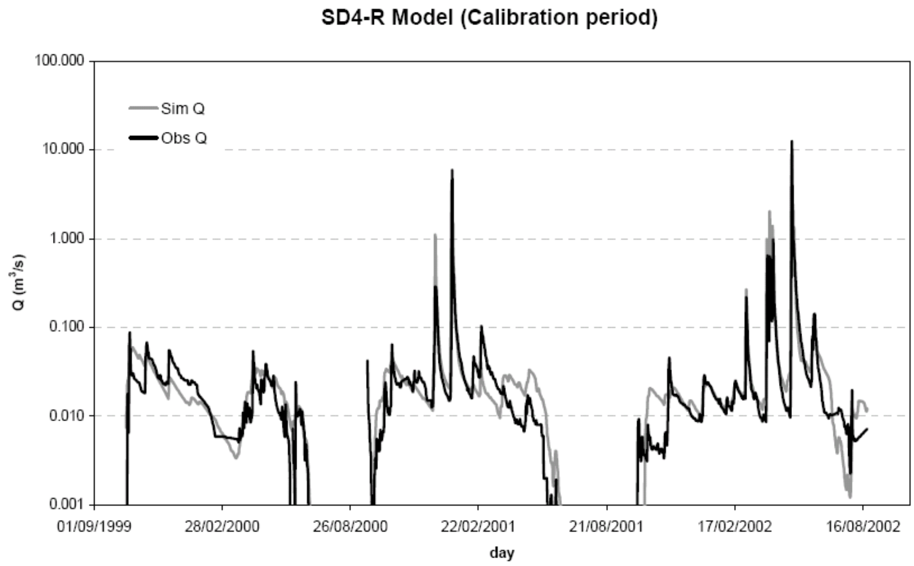

Figure 4. SD4-R ouputs and mean daily discharge (m3 s-1) for the calibration period (13/10/1999 to 22/08/2002). The red line represents the simulated discharge, while the black one the observed one.

The Nash index is equal to 0.77, global BE is less than 5% and the greatest simulated peak flow (8.6 m3/s) is quite close to the observed one (10.9 m3/s) considering the daily time step used in the simulation. The main goal of the SD4-R, respect the previous conceptualizations analyzed, is that the graphical fit of the transition period improved significantly with the introduction of the riparian tank. Figure 5 shows the graphical fit obtained with one of the previously developed semidistributed model (SD4), which is based on the same SD4-R model conceptual scheme but does not include the riparian tank, and the one obtained with the SD4-R model. The number of days with a simulated discharge lower than 0.001 m^3/s increased from 92 (model SD4) to 212, that represents a value fairly close to the observed 220. Interestingly, the riparian tank gave rise to steeper hydrograph recessions during the drying-up period as suggested by McMahon, [5]. In addition, the stream response was delayed in the wetting-up period, since the tank needs to be refilled by inverse flow before generating direct flow. Because of that, simulated stream responses to precipitation episodes, occurring just after the drought period, fall far below the general trend obtained for the remaining part of the year.

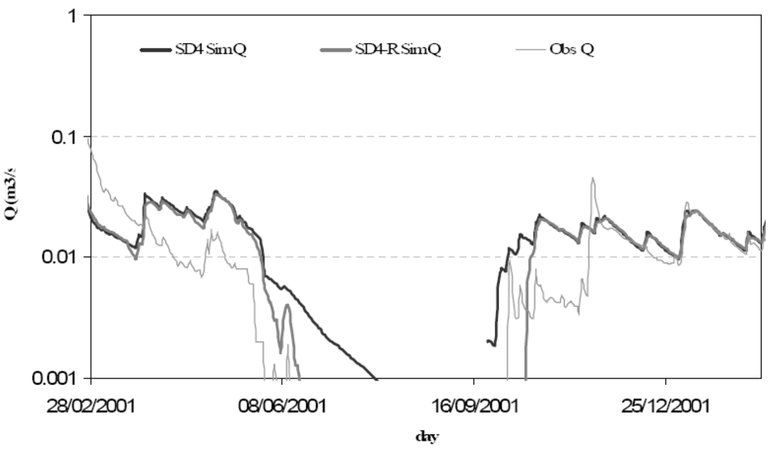

Figure 5. Influence of the riparian zone on the transition period simulation. The thick black line represents the simulated discharge obtained with the SD4 model, which does not include the riparian tank; the thick grey line represents the simulated discharge by the SD4-R model and the thin grey line represents the observed discharge.

The SD4-R model resembles quite satisfactorily the non-linear runoff-rainfall relationship shown in Fig. 6 and described by Butturini *et al.* [15], reproducing the correspondent inverse flow observed by Butturini *et al.* [4] due to the first autumnal storms.

Moreover, the temporal dynamics of the water level observed in a well located in the riparian area was compared with the temporal dynamics of "e" (Fig. 7). Taking into account "e" is a general level for the entire riparian zone, this represents a validation of the model behaviour, since the information about this well and its water table dynamics was not included in the calibration process.

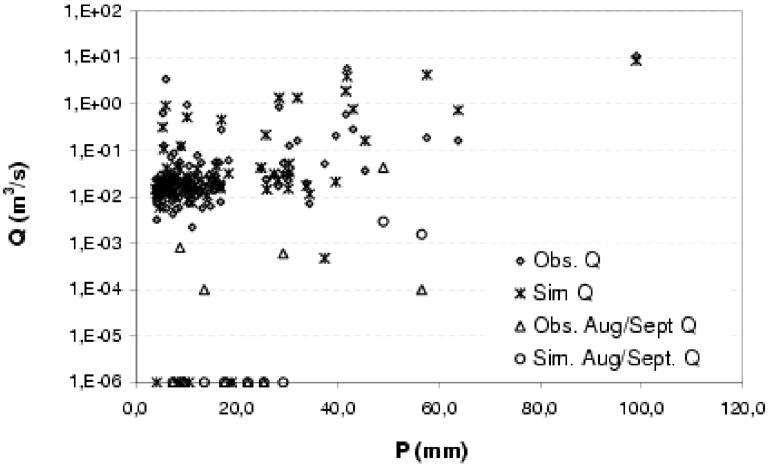

Figure 6. Relationship between precipitation inputs against observed and simulated discharge (for precipitation episodes > 4 mm) obtained with the SD4-R model.

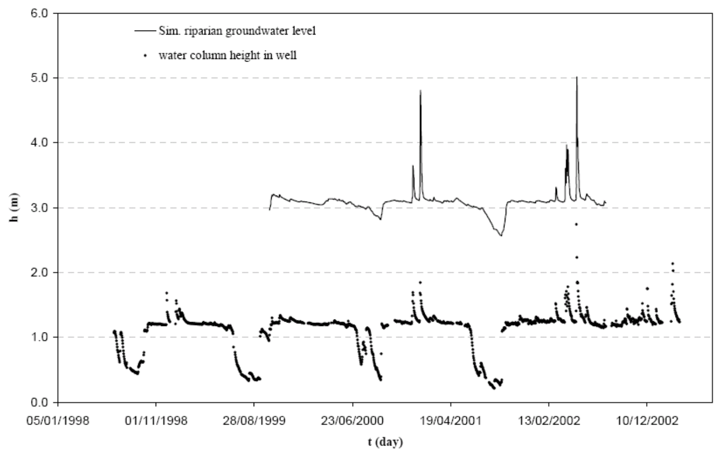

Figure 7. Comparison of the temporal dynamics between the point water column observed in a well located in the riparian zone near the Fuirosos stream channel and the riparian groundwater table simulated by the model SD4-R.

CONCLUSIONS

Our results suggested that the riparian tank exerted an important control on low streamflow, despite the fact that evapotranspiration by riparian vegetation represented a small fraction of water loss in annual terms (only 0.7%). In particular, it was highlighted the riparian zone as a key compartment for modelling successfully the drying-up period and the non-linear hydrological behaviour of semiarid systems during the wetting-up period. On the other hand, the sensitivity analysis of the riparian submodel parameters revealed that they exerted a very limited influence on the total flow (for a reduction by 50% the effect on total flow was less than 1%).

A spatial validation was carried out for the SD4-R model, considering the measured discharge at the Grimola stream from 18th of September 2000 to 22nd of August 2002. The obtained Nash index was approximately 0.7 and the total volume error was -4.17%. It is worth pointing out that for the spatial validation at Grimola subcatchment, the riparian tank did not represent a key compartment, as it was for the Fuirosos catchment. This result was coherent with our catchment perception: at Grimola (where there is not a well-developed riparian area exerting a great control on low flow), there is no need to include a riparian tank in the model in order to successfully represent the stream dry period.

ACKNOWLEDGMENTS

This study was funded by the Ministerio de Ciencia y Tecnología of Spain (project CGL2005-06219/HID).

REFERENCES

[1] Cirmo C.P. and McBonnell J.J., “Linking the hydrologic and biogeochemical controls of nitrogen transport in near=stream zones of temperate=forested cacthments: a review”, *Journal of Hydrology*, (1997).

[2] Tabacchi E., Lambs L., Guilloy H., Planty-Tabacchi A., Muller E. and Décamps H., “Impacts of riparian vegetation on hydrological processes”, *Hydrological Processes*, No. 14, (2000), pp 2959-2976.

[3] Chen X., “Hydrologic connections of a stream-aquifer-vegetation zone in south central Platte River valley, Nebaska”, *Journal of Hydrology,* No. 333, (2007), 554-568.

[4] Butturini A., Bernal S., Nin E., Hellin C., Rivero L., Sabater S. and Sabater F., “Influences of the stream groundwater hydrology on nitrate concentration in unsaturated riparian area bounded by an intermittent Mediterranean stream”, *Water Resources Research,* Vol. 39, Vol. 4, (2003).

[5] McMahon T., “Australian perspectives on predictions in ungauged basins”, In: Franks S., Sivapalan M., Takeuchi K. and Tachikawa Y. (eds.), *Prediction in Ungauged Basins: Intenetional Perspectives on the state of the art and Pathways Forward,* IAHS Publication, Vol. 301, (2005), pp 30-45.

[6] Gallart F., Llorens P. and Regüés D., "Hydrological processes and their seasonal controls in a small Mediterranean mountain catchment in the Pyrenees", *Hydrology and Earth System Sciences*, Vol. 6, No., 3, (2002), pp 527- 537.

[7] Piñol J. Beven K. and Freer J., "Modelling the hydrological response of Mediterranean catchments, Prades, Catalonia. The use of distributed models as ids to hypothesis formulation", *Hydrological Processes*, Vol. 11, (1997), pp 1278-1306.

[8] Latron J., Anderton S., Lorena O. and Gallart F., "Seasonal characteristics of the hydrological response in a Mediterranean mountain research catchment (Vallcebre, Catalan Pyrenees): Field investigations modeling", *Hydrology of Mediterranean and Semiarid Reagions, IAHS Publ.,* Vol., 278, (2003), pp 106-110.

[9] Durand P., Neal M. and Neal C., "Variation in stable oxygen isotope and solute concentrations in a small submediterraean montane streams", *Journal of Hydrology,* Vol. 114, (1993), pp 283-290.

[10] Anderton S., Latron J., White S., Llorens P., Gallart F., Salvany M., C. and O'Connell E., "Internal evaluation of a physically-based distributed model using data from a Mediterranean mountain catchment", *Hydrology and Earth System Sciences,* Vol. 6, No. 1, (2002), pp 67-84.

[11] Bernal S., Butturini A., Riera J. L., Vázquez E. and Sabater F., "Calibration of the INCA model in a Mediterranean forested catchment: the effect of hydrological inter-annual variability in an intermittent stream", *Hydrology and Earth System Sciences,* Vol. 8, No. 4, (2004), pp 729-741.

[12] Instituto Geológico y Minero de España (IGME), "Mapa geológico de España 1:50.000", Map#365, 38-15, Blanes, Madrid.

[13] Bernal S., and Sabater F., "The role of lithology, catchment size and alluvial zone on the hydrogeochemistry of two intermittent Mediterranean streams", *Hydrological Processes,* Vol. 22, No. 10, (2008), pp 1047 – 1418. DOI: 10.1002/hyp.6693.

[14] Medici C., Butturini A., Bernal S., Vazquéz E., Sabater F., Vélez J.I. and Francés F., "Modelling the non-linear hydrological behaviour of a small Mediterranean forested catchment", *Hydrological Processes,* Vol. 22, (2008), pp 3814-3828. Published online. DOI: 10.1002/hyp.6991.

[15] Butturini A., Bernal S., Sabater S. and Sabater F., "The influence of riparian-hyporheic zone on the hydrological responses in an intermittent stream", *Hydrology and Earth System Sciences*, Vol. 6, No. 3, (2002), pp 515-526.