Journal of Hydrology 541 (2016) 99–115

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Flash floods in Mediterranean ephemeral streams in Valencia Region (Spain)

Ana M. Camarasa-Belmonte *

Department of Geography, University of Valencia, Avda. Blasco Ibáñez, 28, 46010 Valencia, Spain

ARTICLE INFO

Article history:
Available online 19 March 2016

Keywords:
Event
Rainfall intensity
Flash flood
Mediterranean
Ephemeral streams
Semi-arid

SUMMARY

Ephemeral streams are typical Mediterranean fluvial systems with high risk of flash flooding, and few data are available about these systems in most locales. However, the SAIH network (Automatic Hydrological Information Systems) of the Jucar River Water Authority has been providing detailed information about ephemeral streams in Spain every 5 min since 1988. Using these data, we evaluated the processes of rainfall–runoff conversion and flood generation in five Mediterranean ephemeral streams ranging in size from 25 to 450 km^2. To provide a general framework for hydrological analysis, the study included 142 flash flood events registered between 1989 and 2007. A more detailed analysis was conducted for the Carraixet Basin under the dry antecedent moisture condition (AMC I) to evaluate the influence of rainfall on the basin's response. A simple index called Momentum of Maximum Intensity (MMI) was developed to describe the influence of rainfall intensity on hydrograph. Correlations between the main indicators of precipitation and flow also were assessed. Results showed that flash floods were generally generated by average accumulated rainfall of around 100 mm at high intensities that could exceed 300 mm/h. Initial abstractions and average water losses during the rainfall–runoff conversion processes were very important (runoff coefficients of 6% and runoff thresholds of 62 mm). No correlation was found between initial abstractions (I_a) calculated from the basin characteristics and runoff thresholds (P_0) empirically obtained, which create some doubts about the validity of I_a method for predicting floods in ephemeral streams. Accumulated rainfall was very important for flood volume, peak flow and water balance indicators, whereas intensity indicators were more related to the response times of the basins. Rainfall intensity variables influenced lag time. Accumulated rainfall, in combination with high reduced mean intensity and low persistence, were a good predictor for high peak flow. Finally, the analysis revealed two types of events. The first type, typical of summer and early autumn, consists of fast events characterized by intense rainfall concentrated at the beginning of the storm and high values of persistence and irregularity. The basin responds quickly and generates hydrographs that resemble the pattern of rain. The second type, representative of winter and spring, corresponds to less intense events. Although they accumulate more rain, maximum intensities are lower and occur at the end of the episode. The response of the basin is late, and hydrographs are quite different from hyetographs and very influenced by the basin.

1. Introduction: flood generation in ephemeral streams

Ephemeral streams are fluvial systems typical of Mediterranean and semi-arid zones. In these environments, ephemeral streams together with perennial rivers drain a large quantity of water from local areas. Catchments are small (hundreds of km^2) and have steep slopes and braided channels. The vegetation cover is sparse and soils are thin and poorly developed (Camarasa and Segura, 2001; Bull and Kirkby, 2002; Cammeraat, 2004; Conesa-García, 2005; Cudennec et al., 2007). From a hydrological point of view, water flow is intermittent because channels are hydraulically disconnected from aquifers; the flow is perennial only in sections where channels intersect aquifers.

Therefore, the channel flow depends almost entirely on event rainfall (Beven, 2002; Lange et al., 2003; Costa et al., 2012; Borga et al., 2014) and it is very conditioned by antecedent moisture (Longobardi et al., 2003). In the Spanish Mediterranean area, antecedent soil moisture conditions have already been simulated for semi-arid catchments using models from standard climate data (Conesa-García and Alonso-Sarriá, 1997) and concluded that

* Tel.: + 34 963864237, +34 680 24 74 83.
E-mail address: ana.camarasa@uv.es

http://dx.doi.org/10.1016/j.jhydrol.2016.03.019
0022-1694/

antecedent rainfall was of great importance to explain the variability in the catchment response.

The processes that generate floods in semi-arid environments differ from those operating in wet environments. For example, Mediterranean rainfall can reach very high intensities that exceed the initial capacity of soil infiltration. This fact, together with the hydrophobicity of certain Mediterranean soils (Doerr et al., 2003; Cerda and Doerr, 2007), may cause overland flow even though soils are not saturated. The processes of rainfall–runoff conversion are therefore highly influenced by the intensity of precipitation itself and by the storm moment in which the maximum intensity occurs. The situation differs if maximum values are reached at the beginning versus the end of the storm (Yair and Raz-Yassif, 2004; Xue and Gavin, 2008; Dunkerley, 2012; Camarasa-Belmonte and Soriano, 2014).

Furthermore, flood generation depends on the hydrological connectivity into the basin, which is necessary to ensure flow all the way to the outlet. This connectivity is largely determined by the morphoclimatic context. In temperate humid environments, connectivity depends on the connection between saturated areas of hill slopes and stream channels, whereas in semi-arid environments it occurs by the interaction between a mosaic of patches with different hydrologic soil behavior (Bracken and Croke, 2007; Bracken et al., 2008; Wainwright et al., 2011; Bracken et al., 2013). Thus, in semi-arid conditions the local character of the rain and the heterogeneity of the territory can prevent runoff generated at the headwaters from reaching the outlet. Additionally, sedimentary transitional forms, such as piedmonts and alluvial fans, at intermediate sectors favor run-on processes, when hills did not produce enough runoff to overcome run-on infiltration at the base of the slope (Bracken and Croke, 2007). Dry torrential channels also yield transmission losses to groundwater (Camarasa and Segura, 2001; Beven, 2002; Bull and Kirkby, 2002; Costa et al., 2012).

When considering the concept of hydrological connectivity, Bracken and Croke (2007) distinguished between static and dynamic connectivity. Static connectivity refers to spatial patterns, which can be estimated from topography, land use, and geology, whereas dynamic connectivity refers to long-term landscape evolution as well as variations in inputs of rainfall (duration and intensity) and antecedent humidity. Recent studies (Conesa-García and Alonso-Sarría, 1997; Yair and Raz-Yassif, 2004; Dunkerley, 2012; Bracken et al., 2013) have highlighted the important role of spatial and temporal variability of rainfall in flood generation in semi-arid environments, where temporal fragmentation of high intensity rainfall is so important.

These previous studies indicate that studying hydrology using averaged measures of precipitation and discharge is not meaningful in Mediterranean environments. The analysis of single episodes seems to be a more appropriate key approach (Martin-Vide system et al., 1999; Alonso-Sarria et al., 2002; Millan et al., 2004), because, as Brakenridge (1988) noted, Mediterranean climates are dominated by extreme events. Examples of this sort of study include Müller et al. (2009), who performed an analysis of extreme hydrological events that occurred in Central Europe from 1951 to 2002; Gaume et al. (2004) and Vinet (2008) in France; Borga et al. (2010, 2014) in Italy; Hugues (2005) in South Africa; Yair and Kossovosky (2002) and Yair and Raz-Yassif (2004) in Israel; and Camarasa and Segura (2001), Cammerat (2004), Bracken et al. (2008), Latron et al. (2008) and Camarasa-Belmonte and Soriano (2014) in Spain.

Deepening our understanding of ephemeral streams will require focusing analysis on specific flash flood events. As Shannon et al. (2002) stated, "there is still a lack of understanding of the rainfall–runoff processes in semi-arid environments and it is only through observation of events (....) that a better understanding of the processes will be obtained."

To date, these systems are poorly understood because data recorded at a detailed scale are lacking. This deficiency of hydrological data is due to: (1) technical difficulties in gauging ephemeral stream channels; (2) the low economic interest in these fluvial systems; and (3) the low relative frequency at which runoff occurs. Furthermore, the frequency of data collection at gauging systems is usually daily, which is not adequate because hydrological processes that occur in a matter of hours can be masked.

However, the situation is changing in Spain. Since 1988, the SAIH network (Automatic Hydrological Information Systems) of the Jucar River Water Authority has been in operation, providing rainfall and runoff detailed information (every 5 min), in real time. The installation of this system has been very useful, as the time scale of data collection can be adapted to the very short intervals in which flash floods are generated. After several decades of operation, we have collected enough information to allow a sound study of flash floods in ephemeral streams.

The aim of this paper is to analyze the processes of rainfall–runoff conversion and flash flood generation in five Mediterranean ephemeral streams, in order to improve the understanding of these semi-arid fluvial systems. The investigation was conducted in two phases. To provide a general framework for hydrological behavior, the first part of the study was based on the analysis of 142 episodes that produced flash floods (between 1989 and 2007) in the five catchments.

During the second phase, a more detailed analysis were conducted using data from the Carraixet Basin (selected as representative catchment), under dry antecedent moisture condition (AMC I). Thirteen flash floods were thoroughly tested to examine the influence of rain on the response of the basin, avoiding the influence of antecedent rainfall.

2. Area of study and data

2.1. Area of study

The study area included the following five pilot basins, with dimensions varying from 102.5 to 454 km^2, located in the Valencian Region along the Mediterranean coast of Spain: Barranc de Carraixet; Rambla de Poyo; Rambla Castellana; Rambla Gallinera, and Riu Vernissa. They are all ephemeral streams and are monitored by the SAIH. As the aim of this paper addresses the rainfall–runoff conversion, the study only refers to the areas controlled by the streamflow gauges, ranging from 27 to 444 km^2 (Fig. 1).

The region has a typical Mediterranean climate with hot, dry summers and mild winters. Averaged annual precipitation is 500 mm, ranging from 300 mm in the south to over 800 mm in the north. Intense rainfall events are more frequent in autumn, and a secondary maximum occurs in spring (Camarasa-Belmonte and Soriano, 2014).

Geomorphologically, these basins can be divided into three sectors: (1) the mountainous headwaters sector; (2) an intermediate area of transition that connects the headwaters to coastal plains; and (3) the downstream sector, which is dominated by floodplains. The headwater sectors are usually formed by permeable rocks (limestone, dolomites, and sandstone) and show a typical faulted relief that is highly karstified. Runoff occurs first in this area of the catchment. The intermediate section is formed by sedimentary transitional forms (e.g., alluvial fans, piedmont, glacis) generated when torrential streams lose transport capacity because the slope decreases and the courses are no longer confined by the relief. Here, run-on processes are probable due to overland flow generated at headwaters, which is reabsorbed by sedimentary deposits (Yair and Kossovsky, 2002; Yair and Raz-Yassif, 2004; Bracken and Crocke, 2007). Finally, floodplains appear downstream. The