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Temporal and Spatial Variability of Runoff on a Mediterranean Agricultural Environment

[1]Safar Marofi, [2]Marc Voltz and [2]Roger Moussa
[1]Department of Irrigation and Drainage Engineering, Faculty of Agriculture,
Bu-Ali Sina University, Azadegan Boulevard (Charmsazy), Hamadan, 65174, Iran
[2]Department of Soil Science, INRA, 2 Place Pierre Viala, 34060, Montpellier, France

Abstract: This study examines the temporal and spatial variability of surface runoff in a 91 hectares cultivated watershed in Mediterranean environment of southern France. Hydrological response at different spatial scale is evaluated during wetness and drier phases included the within-year and the long-terms periods. The temporal analysis is done based on a simple classification of rainfall events of a hydrological cycle: (i) the wintry events, (ii) the summer storms and (iii) the case transitory. The spatial analysis is investigated in the case of main basin, 8 sub-basins and two farms scales, based on a spatial discretization. The experimental design involved monitoring of runoff (streamflow), water tables fluctuations and rainfall events, during hydrological cycles. During the experimental period, 175 storm runoff events were observed. The data analysis show that the annual runoff flows is insured for approximately 40% by floods and about 60% by recession periods. The flood events are classified in three groups, differentiated by the initial water table levels and their occurrence period. The results also show that the annual runoff changes appreciably according to the hydrological cycles and the rainfall variability that varies from 28 to 50% of total precipitation. In addition, the results indicate a non-linear response of runoff to rainfall events. They determine an important role of ditches on water infiltration and surface drainage. This double role varies in time and space as a function of climate and morphological characteristics of the environment.

Key words: Runoff, mediterranean environment, cultivated watershed

INTRODUCTION

A considerable amount of research has focused on the topic of special and temporal variability of runoff. But much of these studies commonly interested to large basins and relatively little research have been conducted on small basins. It is because of this supposition that usually the special variability of precipitation in small areas is negligible. In spite of this hypothesis, some of the recent studies indicated exciting of rainfall heterogeneity (Ambroise and Aduizian, 1989; Faurès *et al*., 1995; Goodrich *et al*., 1995).

Pervious studies have demonstrated the difficulty of determining spatial pattern of runoff (Minshall, 1960; Dooge, 1982; Goodrich *et al*., 1997; Gorokhovich, 2000). There is a number of parameters witch affect spatial variability of runoff. For a fixed rainfall characteristics, the following factors are most important: (i) topography position (Hinton *et al*., 1993; Martinez-Mena *et al*., 1998); (ii) soil condition same as soil texture, topsoil structure and infiltration variability (Bradford *et al*., 1987; Leonard and Andrieux, 1998); (iii) groundwater presence and its influence (Sear *et al*., 1999); (iv) channel losses (Hughes and Sami, 1992; Abdulrazzak and Sorman, 1994; Goodrich *et al*., 1997); (v) land using and its occupation (Lavabre *et al*., 1991; Llorens and Gallart, 1992) and (vi) antecedent moisture conditions (Llorens and Gallart, 1992). The influences of rainfall characteristics on hydrological response of basins are different and rainfall intensity is the major parameter controlling runoff value (Martinez-Mena *et al*., 1998).

The researches have indicated that spatial generation of runoff is strongly non-uniform (Jordan, 1994; Goodrich *et al*., 1997). However, in humid and semi-arid zones spatial variability of runoff is mainly attributed to different factors, basin response dependent to scale of area. There are numerous studies of the hydrological response that concern to the catchment scale (Gallart *et al*., 1994; Jain *et al*., 1998; Martinez-Mena *et al*., 1998) and at the experimental plot scale (Yarnal *et al*.,

Corresponding Author: Dr. Safar Marofi, Department of Irrigation and Drainage Engineering, Faculty of Agriculture, Bu-Ali Sina University, Azadegan Boulevard (Charmsazy), Hamadan, 65174, Iran
Tel: 0098 811 422 7013-14 Fax: 0098 811 422 7012

2000) but relatively few works are done at the terraced watershed, especially of Mediterranean climate (Andrieux *et al*., 1993; Martinez-Mena *et al*., 1998).

Another factor to consideration is the agricultural practices. Most research has been carried out in the neutral basins, situated at arid or semi-arid regions of the United Stated (Murphey *et al*., 1997; Vogel *et al*., 1998; Carpenter *et al*., 1999) and very rare in a cultivated catchment of Mediterranean zones (Llorens and Gallart, 1992; Voltz and Andrieux, 1995; Voltz *et al*., 1998; Louchart *et al*., 2001). In an agricultural environment, such as the Roujan site, in addition to natural factors that influencing the runoff variability, the management activities are also important to take into account.

The present study is undertaken to examine, under sub-basins and field conditions, the runoff generations of different spatial sales. The overall objective is better understands the runoff behaviour and its impacts on water circulation at small scale of a Mediterranean catchment.

MATERIALS AND METHODS

Study area description: Observations are obtained from the 91 hectares Roujan catchment (Andrieux *et al*., 1993) located in the Hérault department in south of France (43°30′ N, 3°19′ E). It has been almost entirely under vines (more than 70%) cultivation. The climate is sub-humid Mediterranean with a long dry season. The mean annual rainfall is approximately 650 mm, but it greatly varies within and between years. Potential evapotraspriation, intensified by frequent winds, exceeds 1000 mm with daily peaks of up to 5 mm (Trambouze and Voltz, 2001).

According to the FAO-UNESCO classification system (FAO-UNESCO, 1989), the site consists of three geomorphological units (Fig. 1): the plateau, the terraced slopes and the glacis-depression sector:

The plateau (25 ha) consists of Chromic Luvisols and Haplic Calcisols soils. In this unit permanent groundwater fluctuates between 1 and 5 m depth depending on the period of the year.

The slopes (30 ha), which are re-profiled into small terraces, consist of loamy Calcaric Regosols soil. The slopes affected by the appearance of seasonal spring due to the drainage of the plateau groundwater.

The footslope-depression sector (36 ha) consists of loamy Calcaric Cambisols and Gleyic Cambisols soils. Shallow groundwater persists throughout the year.

Elevation of the catchment ranges from 75 (at depression) to 125 m (at top of plateau) above mean sea level. The slopes also vary from 2% in depression to about 15-20% on the terraced. Agricultural practices lead to a great fragmentation of space in the some units (ranging from 0.1 to 2 ha). The fragmentation is accentuated by presence to ditches network. Regarding to hydrological characteristic, the main channel has only intermittent streamflow and Horton overland flow process governing runoff production. Two spatially differentiated systems of unconfined permanent groundwater were identified: the groundwater of plateau, which feed springs at top of the slopes and the groundwater of footslope-depression sector.

The pervious studies that were realised within the context of Allegro-Roujan Programme (Local and Integrated Analysis of Water Resources), have been described the hydro-meteorological behaviours of the Roujan catchment and indicate an important variability of the hydrological processes. The rainfall data analyse shows an important standard division of about 40% between the four rainfall recorders of site (Marofi, 1999). Furthermore, the runoff variability can be affected by the groundwater dynamics, located at different geomorphological unites (Marofi, 1999)

Instrumentation and monitoring: The hydro-meteorological equipments have been placed at May 1992. They were completed at October 1996, for this study. The experimental design involved rainfall event observations that occur during the hydrological cycles, measurement of streamflow responses to rainfall and groundwater monitoring. The hydrological cycle is identified based on the period when abundance rainfall are become and consequently the annually water balance parameters become to have significant changes. In the case of Mediterranean climate, the yearly period, approximately become at beginning of autumn and it chased from first of every October to end of another September.

Precipitation events were recorded on continuous basis at 4 sites of the catchment, using the weighing rain gauges recorders. The four rain recorders with tripping bucket device (of PLUVIO91 type) are connected to small data loggers especially designed, which record the time when every movement of the bucket (0.5 mm) is produced instead a reading of the number of movements every time period. This system allows a better computation of instantaneous rainfall intensities without recording null values.

Streamflow also was measured using two types gauging structures that including crested V-notch weirs and Parshall Flumes equipped with the automatic recorder (data logger). Discharge was recorded from 1 to 10 min intervals, depending on the type of equipment.

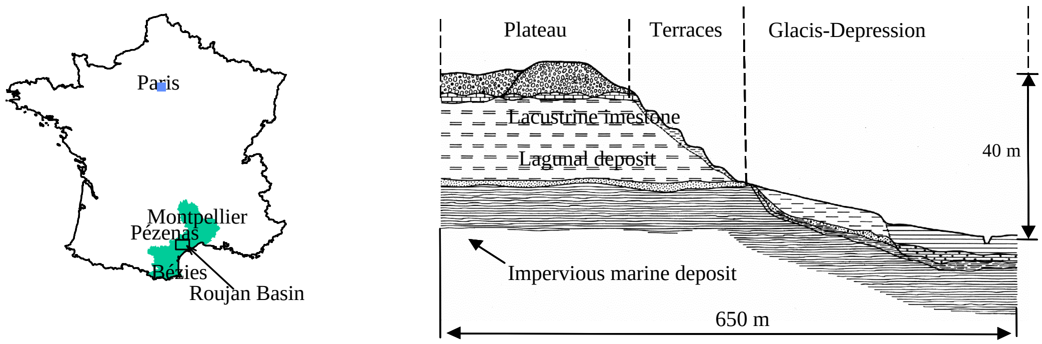

Fig. 1: Site location, cross-section of catchment and the geomorphological units

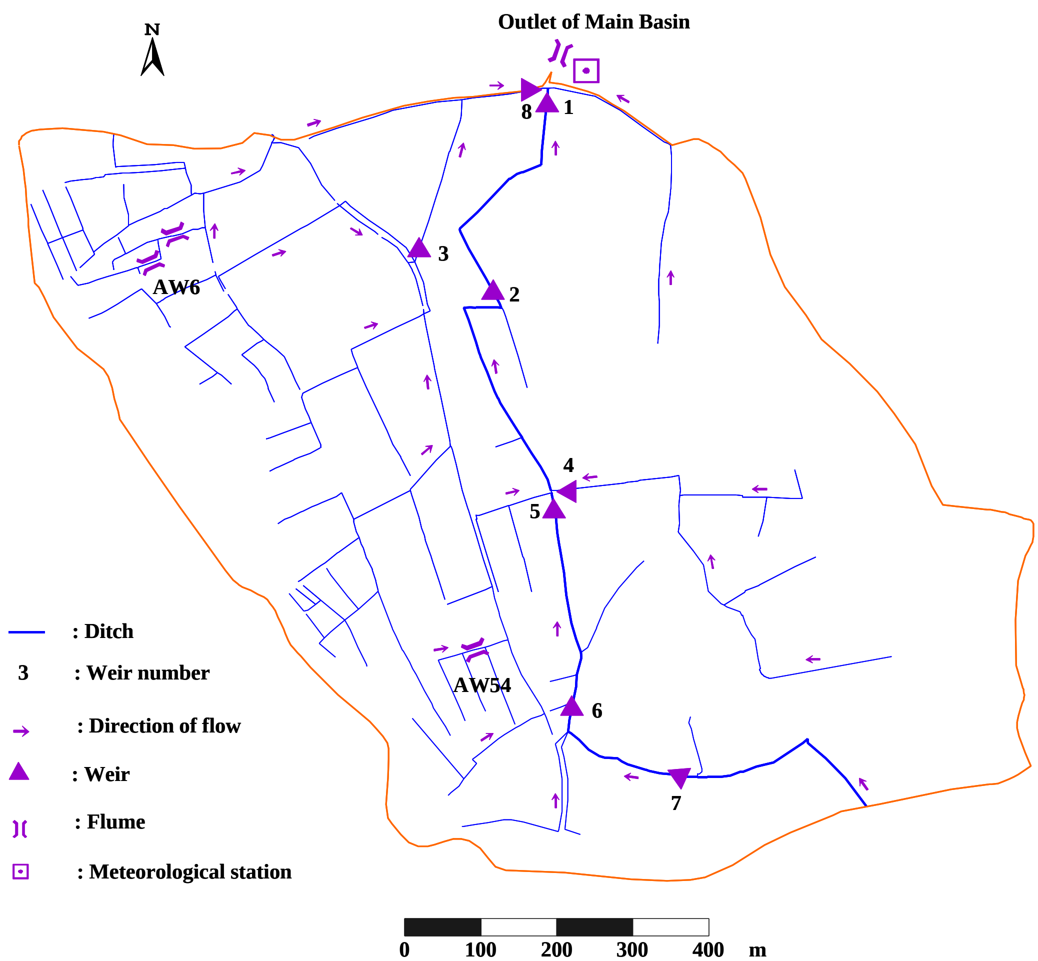

Fig. 2: Study site, showing locations of fields, weirs, flumes and the network of ditches

A network of piezometers, including 15 locations was installed in the site. In some piezometers, the change in water table was read at 10 min intervals. The groundwater stations were connected to the data loggers. All observed data were transferred to a portable computer every 15 days.

For spatial analyses, the watershed was divided on 8 sub-catchments (Fig. 2). Runoff was measured at different sites. In addition to the sub-catchments and outlet of the main basin, the runoff was observed in two vineyard farms that have different situations: AW6 and AW54 (Fig. 2). The farm AW6 has been almost abandoned (no-till), but the AW54 systematically has under the agricultural practices (tilled).

RESULTS

Temporal dynamics of runoff on the main basin scale: The discharges measured at outlet of main basin shows a specific performance of surface water circulation marked by the temporal variability. The intermittent of the recorded discharge, demonstrates that the regime of surface water compound of three principals phases: (i) the phases of floods, that is not longer than several hours only; (ii) the recession period that generally spread by flooding events (out over several springs and winter months that intersected by flooding events) and (iii) the phase without flow that usually is occurred during summer months (Fig. 3).

Table 1: Components of the flood runoff (F_R): direct surface runoff (D_r) and baseflow (B_R), observed during the three types of events (October 1992-October 1998)

Type of floods	No. of events	F_R/Y_r (%)	F_R/P (%)	D_R/P (%)	B_R/P (%)
Winter	95	31.5	24.12	17.12	7
Summer	50	1.5	2.4	2.4	0
Transitional	30	7	8	7	1

The results also show that the total yearly (annual) runoff (Y_R) is ranged between 28 to 50% of the yearly precipitation (P). It is insured for approximately 40% by the instantaneous floods, which occur during or a few hours only after precipitation and for approximately 60% that take place for the long period of recession.

The flood events are classified in three groups based on the initial water table level and the period from occurrence. The winter floods that are spread out generally from December to May (end of spring) occur during high water table conditions. The summer floods that are observed normally between June and September, during dry initial conditions of the basin. The transitional floods that occur during September to November cause the fast increasing of water table from their low positions (at the end of the summer) towards the ground surface.

For each type of event, the number of indexed flood and their runoff (F_R) components such as: direct surface runoff (D_R) and baseflow (B_R) are presented as a percentage of total yearly (annual) runoff (Y_R) and rainfall (P), in Table 1. These contributions of flow (D_R and B_R) are

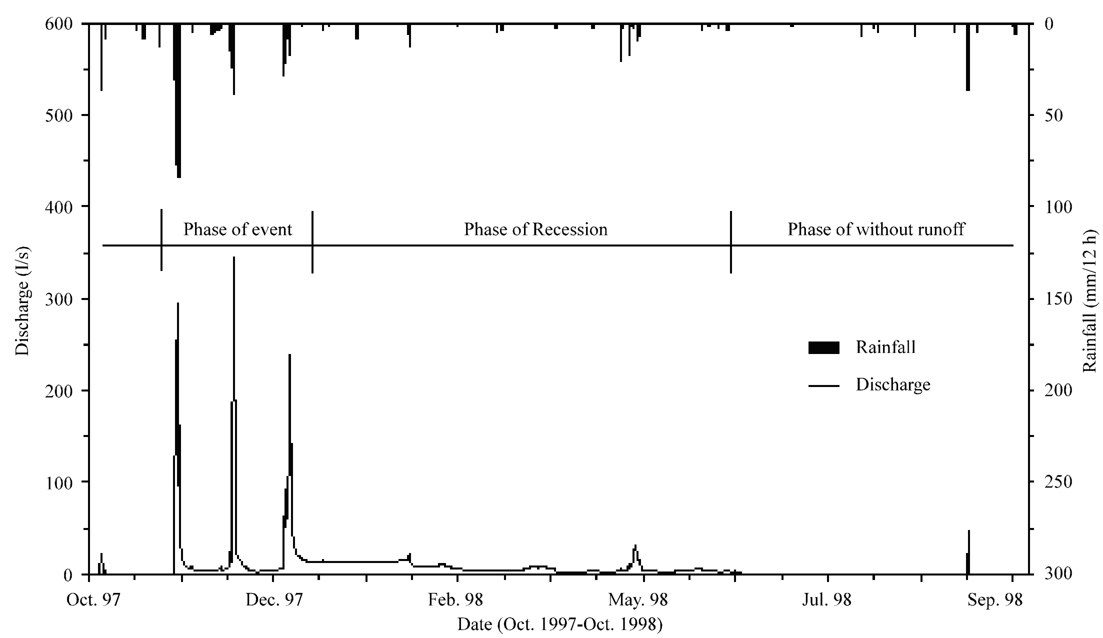

Fig. 3: The hydrological regime of site with the three phases of annual water circulation

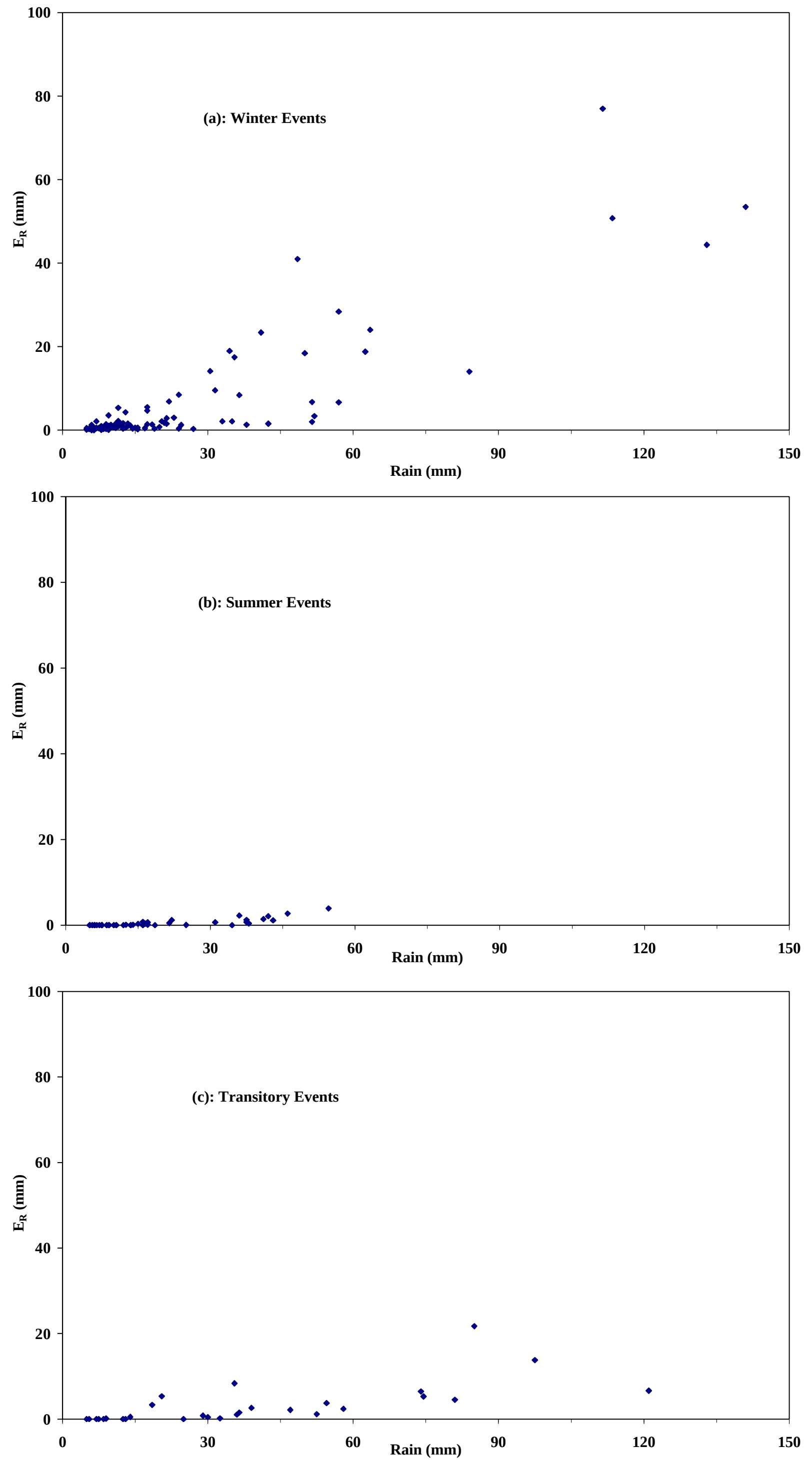

Fig. 4: The relation between the rainfall (P) and the runoff (F_R) of the different types of events (October 1992-October 1998)

Table 2: Comparison of the runoff flood (F_R) and direct surface runoff (D_R) of the different event types, observed at the outlet of the fields and the main catchment (October 1992-October 1998)

			Main basin comparing to the fields	
Comparison	Type of floods	No. of events	$F_{R\ Basin}/F_{R\ Field}$	$D_{R\ Basin}/D_{R\ Field}$
Main basin /AW6	Winter	53	0.70	0.48
	Summer	24	0.07	0.07
	Transitory	19	0.22	0.20
Main basin /AW54	Winter	44	1.19	0.81
	Summer	14	0.14	0.14
	Transitory	15	0.42	0.38

Table 3: Runoff characteristics of the sub-basins during the period October 1997-October 1998

					F_R		R_R	
Weir	Sub-basins	Duration of flow (day)	A (hectare)	Y_R (mm)	(mm)	(%)	(mm)	(%)
No. 7	No. 4	112	8.5	236	130	55	106	45
No. 6	No. 3+4	145	13.9	248	141	57	107	43
No. 5	No. 3+4+5	121	19.9	230	114	49	116	50
No. 4	No. 6	80	13	181	87	48	94	52
No. 2	No. 3+4+5+6+7	180	41.9	114	80	70	34	30
No. 1	No. 3+4+5+6+7+8	200	51.1	163	82	51	81	49
No. 3	No. 2	130	26	193	103	53	90	47
No. 8	No. 2	75	27	103	65	63	38	37
Flume	Outlet of main basin	210	90.3	225	81	36	145	64

calculated by a using the hydrograph separation techniques.

The winter floods insure the principal part of the annual runoff. In spite of some events, the summer floods normally deliver a low amount volume of annual flow that is relatively insignificants. The relation between rainfall and runoff of the different types of events has presented in Fig. 4.

Spatial variability of runoff within the main basin and the fields: Based on the runoff measurements carried out of the main catchment outlet and of the experimental fields: AW6 (no-till) and AW54 (tilled), it is possible to compare the hydrological behaviors of these various entities. The objective of this comparison is to illustrate the value and variability of the losses by infiltration and percolation that occur between the fields and the outlet of the main catchment. The flows measured at the outlet of the fields correspond strictly to surface runoff (AW6, no-till) and to surface runoff or hypodermic in the till horizon (AW54, tilled). These two types of fields are the witnesses of the extreme behaviors of the vineyard fields of the catchment: the no-till field and tilled field present maximum and minimal runoff, respectively. The comparison of the flows measured at the outlet of these two fields to the flows of the main basin makes it possible to restrict the average value of the losses between field and catchment area. In order to refine the analysis, the comparison is made not only to the total runoff flood of the main catchment (F_R), but also to the specific component of the runoff, which is direct surface runoff (D_R).

The various components of these respective floods are analysed according to three modes of events considered previously. The analysis is established for more than hundred events flood, selected from October 1992 at October 1998 for which, simultaneously exist recording flows of the main catchment outlet and of the two experimental field's outlet. The synthetic results are given in Table 2.

It is very logically notable that the runoff ratio calculated between the main catchment and outlets of the farms ($F_{R\ Basin}/F_{R\ Field}$) decrease relatively for all the events. During the winter events runoff ratio is also highest, because of discharge of the main catchment that formed the footslope-depression water table drainage.

The ratio ($D_{R\ Basin}/D_{R\ Field}$) calculated from the surface runoff of the fields and main catchment make it possible to evaluate the intermediate losses between these two spatial scales. These losses are always significant: on average they vary between 19 to 93% of the field runoff, whatever the type of event of flood. It is noted particularly that the losses are minimal in the winter events and maximum during the summer events. Thus, they vary between 19 and 52% during the winter events, between 86 and 93% on the case of summer events and between 62 and 80% during the transition events period. These different losses between the three types of events are to be linked to the differences in initial conditions of groundwater. During the winter events, the water tables generally are at high level and the possibilities of infiltration, during the flood circulation in the hydrographic network are reduced. Particularly, the

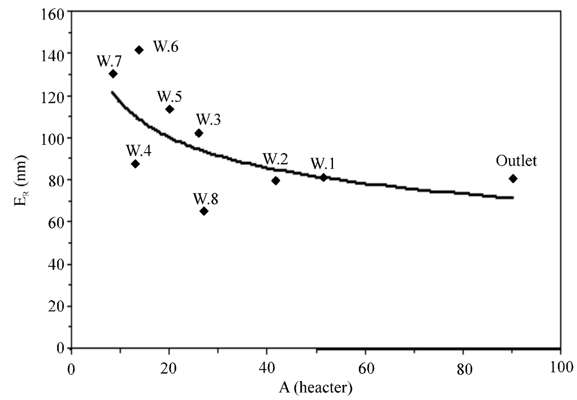

Fig. 5: Relation between the blade of event runoff f (E_R) and the surface of the sub-basins (A) during the period from October 1997 to October 1998

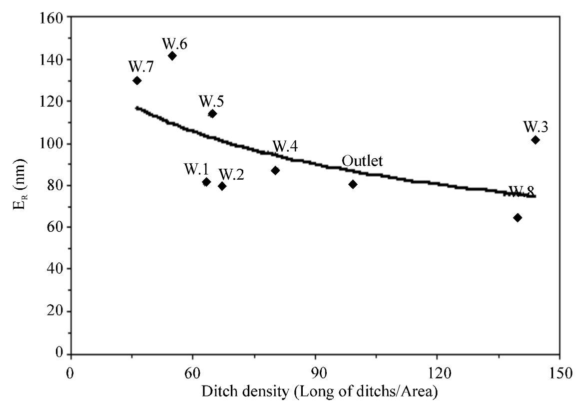

Fig. 6: Relation between the blade of streamflow and the ditch density during the period from October 1997 to October 1998

surface runoff transmission towards the outlet of the main catchment is maximal. Conversely, in summer or autumn, during the flood events, generally the water tables are located at low level, supplied by infiltration of passing flood in the hydrographic network. Although, in certain cases surface runoff is noted on the farm scale, but no flow arrived at the outlet of the main basin.

Spatial variability of runoff in the hydrographic network: The runoff variability analysis in the ditches network is carried out from the limnimetric data that was observed during the period October 1996-October 1998, on the various installed weirs (Fig. 2). Based on the weirs, which were installed in October 1996 and 1997, the basin is divided into 8 sub-basins, of 8.5 to 51.1 hectares surface. For each sub-basin, the total yearly runoff (Y_R), runoff during the floods (F_R) and runoff during the recession periods (R_R) are calculated (Table 3) by using of area (A).

In the annual scale, a variability of the runoff duration is considered between the different weirs. For example, the runoff period of the weir No. 5, located at the downstream of weir no. 6, is shorter. Conversely, between the weir no. 2 (upstream) and the weir no. 1 (downstream), the runoff period is longer. The runoff value decreases between upstream and downstream of the basin, toward the outlet of catchment (Fig. 5). This decreasing clearly shows the existence of infiltration during passage of water in the network of ditches. It proves that the network of ditches have a dual role with infiltrating and draining zones. Runoff value of all the events varies between 36 and 70% of the total yearly runoff.

The evolutions of the runoff values are demonstrated a non-linear decreasing relation between the runoff and surface of the sub-catchments (A). This decreasing is classically noted (Milville, 1990) and illustrates the existence of a scale effect on the runoff value coming from infiltration phenomena of the upstream flows. Nevertheless, the decrease is prone to strong variability, since for the neighbour drained surfaces, the runoff blade can vary until 100%. The origins of this variability are to be connected to the differences of the sub-basins in terms of soils, topography and network of ditches. For this last factor, the density of the network is undoubtedly an important variable. Figure 6 shows the variations of the event runoff (F_R) according to the density of ditches. It shows a decline relation between runoff and the density of ditches.

DISCUSSION

The experimental and theoretical studies carried out in the hydrological context of natural and cultivated basins show the existence of a space variability of the flow of surface (Yair and Lavee, 1985; Loague and Gander, 1990; Jordan, 1994). However, the origin of this variability can be very different. It is always related to difference of soil infiltrations. In moderated area, often allots the variability of runoff within the catchment area to the existence of saturated zones, generated by the fluctuations and the expansions of water table (Dunne *et al*., 1975; Troendle, 1985; Mérot and Cann, 1994). Indeed, the saturated zones not only form the privileged zones of surface runoff, but also of filtration water. In arid or semi-arid climates, because of the least extension and persistence of saturated zones, the strong rainfall intensities, the soil surface qualities that are frequently not very permeable, the variability of the flow within the catchment area is rather related to the variability of the properties of intrinsic infiltrometrical properties of the soils (Yair and Klein, 1973; Yair and Lavee, 1985; Lavee and Yair, 1987; Loague and Gander, 1990). Moreover, on the all climatical situations, a variability source of the runoff is due to the properties of transfer from the hydrographical network, within the catchment area.

In this paper, the surface runoff variability within the Roujan basin is analyzed, in connection with the network of ditches. Initially, the scale effects existing between runoffs of the fields and the main basin is quantified and than within the network of ditches and finally between the sub-basins. In this regard, it supposed that the variation of rainfall on the scale of basin is weak and thus it is not the origin (source) of the differences in surface runoff, which are observed at the different scales of area. This assumption is acceptable because of the rainfall variability analyses done for annual scale.

The different losses of flow calculated during the three considered types of events are to be linked to the differences in initial conditions of groundwater. During the winter events, the water tables generally are at high level and the possibilities of infiltration, during the flood circulation in the hydrographic network are reduced. Particularly, the surface runoff transmission towards the outlet of the main catchment is maximal. Conversely, in summer or autumn, during the flood events, generally the water tables are located at low level, supplied by infiltration of passing flood in the hydrographic network. Although, in certain cases surface runoff is noted on the farm scale, but no flow arrived at the outlet of the main basin.

The runoff decrease between upstream and downstream of the basin demonstrates existence of infiltration during passage of water in the network of ditches. It proves that the network of ditches have a dual role with infiltrating and draining zones.

The relation calculated between runoff and the density of ditches show that ditches density, as well as the surface of sub-basins, are characteristics making it possible to explain the variability of the runoff during the events. This is coherent. Since increasing in surface and density of ditches cause the both possibilities of infiltration and of the surface runoff. It must remember that the surface runoff represents the major part of the flood. Nevertheless, the results obtained would require to be completed by the observations on other basins to achieve a statistical representative.

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