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Runoff and sediment production in a mediterranean basin under two different land uses

Escorrentía y producción de sedimento en una cuenca mediterránea con dos usos diferentes del suelo

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Abstract

This study analyses the influence of two different land uses on the hydrology of the Vernegà experimental basin between the years 2005 and 2009. It is located in the Northeast of the Iberian Peninsula and is influenced by a Mediterranean climate, with an average annual rainfall of 646 mm. The study of rainfall distribution in the 1982 to 2009 period shows that the majority occurs during autumn, winter, and spring representing 33.2%, 25.5%, and 25.7% respectively of the total annual rainfall. Surface runoff is concentrated from October to June. Between 2005 and 2009, total runoff was 242.38 mm at the "Bosc" gauging station, which drains an area of 1.60 km2, and 298.54 mm at the "Campàs" gauging station, which drains an area of 2.57 km^2 and is located at the outlet of the basin. More than 80% of the total surface runoff yielded during the study period corresponds to the 2005-2006 hydrologic year. Finally, Campàs gauging station registers a higher total runoff than Bosc gauging station. Part of this phenomenon may be due to the interception of rainfall and plant biomass in the forested area of the basin. In relation to the sediment yield, an overall increase in the two basins has been detected. Recent forest management practices undertaken in the catchment area are considered to be one of the most important reasons for this change.

Keywords: rainfall, sediment transport, land use, agriculture, forest, Mediterranean.

Resumen

Este estudio analiza la influencia de dos diferentes usos del suelo (agrícola y forestal) en la hidrología y el transporte de sedimentos de varios eventos de lluvia en la cuenca experimental de la riera de Vernegà, durante el periodo 2005-2009. El área de estudio se localiza en el noreste de la Península Ibérica, en el macizo de Les Gavarres. Esta cuenca está influenciada por un clima mediterráneo y tiene una temperatura media anual de 13°C. La precipitación media anual es de 646 mm, con una desviación estándar de 162.7 mm. El estudio de la distribución estacional de las precipitaciones muestra que la mayoría ocurre durante el otoño seguido del invierno y primavera, con un 33,2%, 25,5% y 25.7% respectivamente, la escorrentía superficial se concentra en los meses de octubre a junio. Los resultados muestran que entre 2005-2009 la escorrentía total fue de 242.38 mm en la estación "Bosc", con un área de 1.60 km^2, y 298.54 mm en la estación "Campàs", con 2.57 km^2 de área, ubicada en la salida de la cuenca. Cabe destacar que más del 80% de la escorrentía total durante el periodo de estudio se recogió durante el año hidrológico 2005-2006. Por último, se observa que la estación de aforo agrícola registra una escorrentía más alta que la de la estación de aforo del bosque. Parte de este fenómeno puede deberse a la interceptación de las precipitaciones y a la biomasa vegetal en la zona boscosa de la cuenca. En relación con la producción de sedimentos ha habido un aumento en las dos cuencas en el período 2005-09, siendo la gestión de los bosques una de las razones más importantes para este cambio.

Palabras Clave: Precipitación, transporte de sedimento, usos del suelo, agrícola, forestal, Mediterráneo.

1. Introduction

The paper presented here is a part of 20 years of research in the Vernegà basin. Monitoring began in 1992 with the construction of two gauging stations: Bosc, with a contribution area of 1.60 km^2, and Campàs, located at its outlet and draining 2.57 km^2, as well as the installation of a complete meteorological station. Bosc gauging station measured the contribution from a very dense Mediterranean forest, and Campàs recorded the values at the outlet, measuring the contribution from extensive agricultural fields.

Determining the water yield under different land uses was the main goal when the experimental catchment was set up. Recently, important land use changes have been detected in the catchment, which have a direct influence on the hydrology and sediment transport dynamics. The most important change took place in 2005, when forest management practices were introduced in the upper part of the basin, that is, the forested area. These practices consisted essentially of shrubland clearcutting to favour the development of cork oaks and pines and have a direct influence on the hydrological dynamics of the basin in terms of rainfall interception, infiltration capacity of the soil, runoff generation, and availability of sediment to be transported.

The use of experimental catchments became firmly established during the 1960's and provided valuable information on controlling runoff and erosional processes operating within the drainage basin (Burt and Walling, 1984). During the 1980's, and especially during the 1990's, there was a great interest in monitoring small basins in order to collect data for establishing water and sediment budgets in Spain. One of the first works was undertaken by Clotet (1984), who found that basins are the best scenario for understanding the geomorphological dynamics and the movement of sediment, which in her case was a 22 km^2 basin located in the Pre-Pyrenees. Similar studies were undertaken by different authors over a wide range of basin sizes and characteristics in order to understand their hydrological dynamics (Llorens, 1991; Batalla, 1993; Rabadà, 1995; Ceballos, 1997; Balasch, 1998; Farguell, 2004 and more recently, Estrany, 2009).

This situation makes land use one of the factors with most direct effects on hydrological response, and this fact is one of the most important aspects studied worldwide. Consequences of land use changes have been highly studied by several authors (e.g. Cernusca *et al*., 1996; Debussche *et al*., 1999; Rabbinge y Diepen, 2000; Taillefumier y Piégay, 2003; Palang *et al*., 2005; Rounsevell *et al*., 2006). These changes take place, in most cases, in the upper parts of the basins or in first order rivers, as is the case in the Vernegà basin, having consequences in the water supply downstream where water becomes a resource (Kundzewic *et al*., 2007); and in other places these consequences are due to an abandonment of pastures and crops and an increase in forest areas (Gallart and Llorens, 2003; García-Ruiz *et al*., 2008). However, in order to improve profits, the forest is subjected to management which can affect catchment conditions (Scott, 1997; Monte *et al*., 2005). One of the consequences is the probability that less quantity of water reaching the main river channels, creating a lack of this resource for longer periods of time during the hydrological year (Parry *et al*., 2000; Milly *et al*., 2005); this situation may worsen due to increasing water demands (MIMAM, 2000; PNUMA, 2000; IPCC, 2007).

Agriculture land use in the Vernegà basin has not disappeared and, moreover, owners are increasing the area dedicated to ryegrass production for two main reasons: the first is to maintain forest discontinuity to avoid fire propagation in case of forest fires, and the second reason is to provide gazing areas for the horses on their properties. This fact is important because it implies the necessity of data continuity in order to understand the role of the agricultural fields in the hydrological dynamics in the basin (Outeiro *et al*., 2010).

Hydrological studies of Mediterranean river basins in Spain show how seasonal variability directly affects water availability, with generally higher rainfall in the fall, winter, and spring, and the correspondence of a dry period with the highest temperatures during the summer (Morán-Tejeda *et al*., 2010; Kirkby, 2005). In Mediterranean basins, runoff processes can change seasonally during the year and there is now a growing interest in studying the changes in this variability and its relationship with quickflows (Outeiro *et al*., 2007; Gallart *et al*., 2008; Estrany *et al*., 2009) and possible increased frequency (Bull *et al*., 1999). The hypothesis is that variability significantly affects the population and existing infrastructure in the watershed (Braken and Kirkby, 2005). This combination of factors and processes involved in runoff generation makes it an interesting study subject, raising questions such as: a) how much water will occur in the catchment areas, b) in which year, c) how significant will the most important precipitation and runoff events be, and d) how much sediment can be mobilized.

The aim of this paper is to characterize runoff generation and load production (dissolved and suspended load) in the Vernegà basin in each of the two land use areas (forest and agriculture) since 2005. Results presented here are for four years starting in 2005, taken as a period following the aforementioned land use changes. The objective is comparing the hydrology and erosive response before and after these practices started, although to obtain a broader perspective, more years of data are still needed. One factor that complicates the comparison of periods of hydrological response caused by changes in land use is the variability of the meteorological conditions in the Mediterranean, and especially the difference in rainfall distribution during the course of the year. Nowadays, there is also a growing interest in finding out how global change can affect the distribution and quantity of water, as well as the frequency of intense rainfall events which can result in quick flows in different environments. Only with long data records will there be a chance to respond to these questions.

2. Study area

The Vernegà experimental catchment is a representative Mediterranean low mountain river basin in the upper part of the River Verneda (tributary of the River Ter) located on the SW side of the Gavarres massif. The basin area is 2.57 km^2, of which 1.60 km^2 is forest land, and 0.97 km^2 are agricultural fields, crossed by unpaved roads (Figure. 1). The height of the basin ranges from 440 m a.s.l. at Puig Gros to 150 m a.s.l. at the Campàs gauging station situated at the basin's outlet. The total length of the river at this point is 4 km, and the average gradient is about 5% (Farguell and Sala, 2002).

The underlying bedrock lithology is granite which is often highly weathered, forming accumulations of material with a very weak structure (Úbeda *et al*., 1998). Within this basin, two distinct areas can be identified: a) a mountainous area belonging to the SW of the Gavarres massif and b) an area of gentle topography consisting of colluvial fans and river terraces, where the crops and main constructions are established. Some steep slopes are caused by fractures and recent orogenic uplifts (Outeiro *et al*., 2010).

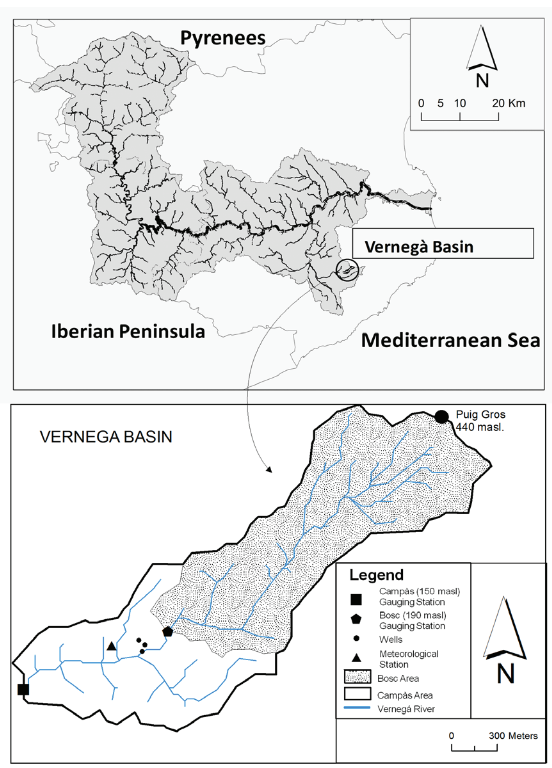

Figure. 1. The Vernegà basin in the context of the Iberian Peninsula. Gauging sites are presented for the two monitoring sub-catchments.
Figura 1. La cuenca del río Vernegà en el contexto de la Península Ibérica. Se representan las estaciones de aforo de las dos subcuencas estudiadas.

The climate is Mediterranean sub-humid with an average annual rainfall of 650 mm, of an intermittent or seasonal type related to Mediterranean seasonal variability. The largest rainfall events occur during autumn and spring, while the most arid conditions occur during summer. This rainfall pattern causes greatest runoff during late autumn, winter, and the beginning of spring (Sala and Farguell, 2002).

Two groundwater levels can be distinguished in the area: the high water table is in the quaternary alluvial sand deposits, which coincide with the area of the Bosc station while the lower and deeper water table is located on the river terraces which are covered with agricultural fields. Land use within the study catchment is divided into two sub-basins. The first one is called Bosc, which is a dense Mediterranean forest composed mainly of *Quercus suber* and *Quercus ilex* (with accompanying species of *Pinus pinaster*, *Pinus pinea* and *Pinus halepensis*), and the sub-basin Campàs, located in an area of lower slope which was traditionally used for agriculture. Currently, it is used for growing barley (*Hordeum vulgare*) and ryegrass (*Lolium multiflorum Lam*).

3. Methods

Data presented here correspond to the hydrological years 2005-2006; 2006-2007; 2007-2008 and 2008-2009 (i.e. beginning on October 1st and ending on September 30th). Hydrological years are used instead of natural years to have the same year division used by water authorities and thus findings can be compared with those in other basins.

3.1. *Data collection*

In the Vernegà river basin, two nested gauging stations were installed in 1992 with the aim of measuring the total amount of water passing through these points and collecting samples for the quantification of sediment transport. The first one is called 'Bosc' (UTM=31TDG944362), located at an altitude of 190 m a.s.l. with a catchment area of 1.60 km^2 completely covered by a typical dense Mediterranean forest (figure 1). The measuring section has a thin crest spillway section composed of a 45° triangle and a rectangular opening on top. The V-notch has an estimated capacity of 0.255 m^{3}s^{-1}. The decision to construct this type of station was based on flows recorded during the October 1992 to June 1993 period, for which the maximum drainage was calculated to be around 0.180 m^{3}s^{-1}. The entire experimental basin is defined by the gauging station called 'Campàs' which closes the lower end of the 2.57 km^2 study area at an altitude of 150 m a.s.l. (UTM=31TDG94358), where the main land use is a combination of forest and agriculture fields. This point is equipped with a channel section composed of a triangle V-notch and rectangle. To estimate the flow, the formula from the V-notch thin crest for the triangular section has been used. The theoretical values obtained fit well with those measured in situ by means of an OTT type current meter.

The monitoring equipment in the gauging stations consists of water-stage recorders for using a float that raises and lowers with the water stage, which is graphically recorded on a weekly basis. At the Campàs site there is an additional automatic probe device (Diver type) installed to measure the water column pressure. There, atmospheric pressure measured by a barometer is subtracted from water pressure records to obtain the water stage. Water samples are collected at both Bosc and Campàs gauging stations of by means of an ISCO type automatic pump sampler. The automatic sampler contains 24 bottles of 1 l at Campàs and 0.5 l at Bosc. They were programmed to take samples at hourly intervals during floods, starting when river stage was 0.10 m. After each flood, the filled bottles were collected and taken to the laboratory in a cooler. In periods of high base flow, manual samples were taken weekly.

The meteorological station is located halfway between the two gauging stations, at an altitude of 170 m a.s.l. (UTM=31TDG949360). It contains an automatic rainfall gauge recording rain at 5 mm intervals. It also measures air moisture, air temperature, global and net radiation, and wind speed and direction.

Finally, the height of water in three wells located in the central part of the basin (Fig. 1) was measured weekly to determine the depth of the water table throughout the study period.

3.2. *Data analysis*

Data analysis was based firstly on classification and organization of all data collected from the field. The description of the basin areas have been calculated using a DEM in ArcGIS with data available from the Cartographic Institute of Catalonia.

To determine the discharge flow at the Bosc station, it was first calibrated using a combination of mathematical formulas and measurements. To calculate the flow at the triangular weir, the next equation used was:

$$\frac{8}{5}\, Ce \sqrt{(2g)\ (\tan][1/2)\ he^{\ 2.5}} \qquad (1)$$

where, CE = Coefficient of effective expenditure (in this case Ce = 0.5782); he = effective load = h + kn, and kn varies depending on the angle of the flume, in this case 45°, corresponding to a kh of 0.00015m.

In the case of the rectangular weir the expression used was:

$$\frac{2}{3}\, Ce \sqrt{(2g) be(h\text{-}0.4) + he^{1.5}} \qquad (2)$$

where, Ce = 0.597 0045 (h/p) with p = vertical distance from the bottom of the bed to the top of the ridge; be = effective width = b + kb in this case 1.6 m + 0.00427 m; he = effective load = h + kn, kn = 0.001m.

In the case of subjects comprising a triangular section, the formula is well suited for thin ridge landfill, to which the same rectangular weir equation has been applied to calibrate the station, where: CE = 0.58 and kh = 0.00076m.

Finally, once the stations were calibrated, the followed steps were: a) water level is taken from both stations, b) level is transformed into m^3s^{-1} using the rating curve given by the calibration of the stations, c) discharge is transformed into volumetric units (m^3) and d) it is related to watershed area resulting in mm (i.e. units shown in this paper) (Table 1). Results presented in the tables have been summarized from hourly to monthly values using units of measurement that can be compared to one another; in the case of runoff, these results have been presented in mm in order to be contrasted with precipitation records (Table 1). Data on well depth measurements is used to estimate water table levels at the time of runoff initiation.

The sediment transport has been calculated from the weight of the retained sediment sieved at 0.45µm after vacuum-filtering the water samples. The concentration of sediment (g l^{-1}) has been extrapolated to the total amount of water in the moment of sampling with a result given in kg m^{-3}. The sum is the result of the total suspended load expressed in kg. The dissolved load undergoes the same steps beginning with the sum of the total dissolved load in g l^{-1}. Table 3 presents the suspended load (kg), the dissolved load (kg) and the total yield (t km^{-2} yr^{-1}).

Table. 1. Monthly distribution of precipitation, runoff, and runoff coefficient during the hydrologic years 2005 to 2009 in the two gauging stations of the Vernagà basin.
Tabla 1. Distribución mensual de precipitación, escorrentía y coeficiente de escorrentía de los años hidrológicos 2005 a 2009 en las dos estaciones de aforo en la cuenca del Vernagà.

	2005-2006					2006-2007				
		Bosc		Campàs			Bosc		Campàs	
	Pp. (mm)	Runoff (mm)	Rf. Coef. (%)	Runoff (mm)	Rf. Coef. (%)	Pp. (mm)	Runoff (mm)	Rf. Coef. (%)	Runoff (mm)	Rf. Coef. (%)
October	256.8	123.28	48.01	139.30	54.25	109.2	1.83	1.63	4.58	4.09
November	82.6	18.48	22.37	30.28	36.65	4.4	0	0	0	0.00
December	4.2	1.60	38.13	1.84	43.81	42.0	0	0	0	0
January	133.8	56.86	42.50	68.75	51.38	11.8	0	0	0	0
February	10.6	11.51	100.00	13.14	100.00	102.2	1.72	1.70	1.53	1.50
March	43.6	1.76	4.04	0.005	0.01	38.8	0.21	0.55	0.38	0.96
April	1.2	0.07	6.13	0.0	0.05	124.0	11.57	9.30	19.48	15.66
May	3.6	0	0	0	0	68.8	0.18	0.26	0.56	0.81
June	0.2	0	0	0	0	38.8	0.41	1.05	0.67	1.74
July	2.2	0	0	0	0	7.4	0	0	0	0
August	70.6	0	0	0	0	65.2	0	0	0	0
September	108.2	0	0	0	0	25.8	0	0	0	0
TOTAL	**717.60**	**213.57**		**253.31**		**638.4**	**15.92**		**27.18**	
MEAN			**21.77**		**23.85**			**2.48**		**4.23**

	2007-2008					2008-2009				
		Bosc		Campàs			Bosc		Campàs	
	Pp. (mm)	Runoff (mm)	Rf. Coef. (%)	Runoff (mm)	Rf. Coef. (%)	Pp. (mm)	Runoff (mm)	Rf. Coef. (%)	Runoff (mm)	Rf. Coef. (%)
October	90.8	0	0	0	0	49.8	0	0	0	0
November	6.2	0	0	0	0	71.8	0	0	0	0
December	61.6	0	0	0	0	137.2	0.07	0.05	1.26	0.92
January	28.8	0	0	0	0	71.8	0.41	0.61	2.33	3.45
February	54	0	0	0.16	0.31	61.4	8.75	14.53	4.80	7.97
March	93	0	0	0.10	0.11	59.0	0.00	0.01	1.88	3.45
April	54	0.04	0.07	0.18	0.34	114.0	1.07	0.97	3.45	3.14
May	108.8	2.30	2.12	2.26	2.08	59.6	0.08	0.13	1.17	1.97
June	96	0.16	0.16	0.44	0.46	11.0	0	0	0	0
July	20	0	0	0	0	4.8	0	0	0	0
August	12.2	0	0	0	0	14.6	0	0	0	0
September	20.8	0	0	0	0	43.2	0	0	0	0
TOTAL	**646.2**	**2.50**		**3.15**		**698.2**	**10.39**		**14.90**	
MEAN			**0.39**		**0.49**			**1.36**		**1.74**

4. Results

4.1. *Runoff*

For the 2005-09 study period, the total runoff at the Bosc gauging station was 242.4 mm, and 298.5 mm at the Campàs station (Table 1). Specifically, in 2005-2006 the total runoff production was 213.6 mm in Bosc and 253 mm in Campàs. These values are highly unusual and are clearly due to the events that took place in October 2005, in which 256.8 mm of rain was recorded in three days, in addition to the snow storm that occurred in January 2006. It is notable that in these situations the runoff coefficient was also very high (48% and 54.3% respectively) because these kinds of events have a high rainfall intensity which easily surpasses the infiltration capacity of the soil.

The following year, 2006-2007, showed a special trend. Although October started with runoff in both catchments (1.83 in Bosc and 4.58 mm in Campàs), the river dried up before the end of autumn. It was not until the rainfall period in winter (February recorded 102.2 mm) when the basin started to have a permanent flow which lasted until June, with the largest amount recorded in April (11.6 mm and 19.5 mm at Bosc and Campàs, respectively).

The hydrological year 2007-2008 was a year of drought in Catalunya. In the Vernegà basin there was no runoff generation until April. In total, the river was dry for 9 months. The rainfall in April (54 mm) and May (108.8 mm) generated runoff only during three months (April, May, and June), producing an annual runoff of just 2.50 mm in Bosc and 3.15 mm in Campàs.

Table. 2. Seasonal precipitation distribution in the Vernagà basin.
Tabla 2. Distribución estacional de la precipitación en la cuenca del Vernagà.

	(1982-2009) (%)	(2005-2009)(%)
Autumn	33.2	28.7
Winter	25.5	26.5
Spring	25.7	33.0
Summer	15.6	11.7

The 2008-2009 year started off with little rainfall in October (49.8 mm) which was not enough to generate runoff in the Vernegà River. It was December with 137.2 mm that caused the stream flow to return and remained permanent due to winter and spring rainfall.

The four studied years showed different trends in terms of runoff generation. 2005-2006 had 5 months without water (from May to September); 2006-2007 had 6 months (Autumn and Summer months); 2007-2008 had 9 months; and 2008-2009 had 6 months (October and November and the Summer months).

The Vernegà basin has an annual average rainfall of 646.1 mm based on 28 years of data (1982-2009). The mean annual rainfall in the study period (2005-2009) is 675.1 mm, which is a regular value in the basin, with a maximum of 717.6 mm (2005-2006) and a minimum of 638.4 mm (2006-2007) (Table 3). Therefore, rainfall that the basin received during the whole of the study period can be considered homogeneous and is not a specific factor on which to identify differences between these years concerning the quantity of runoff generated in the basin.

Grouping the seasonal distribution of the total rainfall (Table 2), it is clear that rainfall concentration is very similar in autumn (33.5%), winter (26.7%), and spring (26.0%), leaving only summer with less quantity of rainfall (13.8%). Comparing with the study period (2005-2009), there is a slight change regarding autumn (28.7%) and spring (33.0%). It does not seem that the distribution of total rainfall in each season is responsible for the variations in runoff generation. Nevertheless there is a situation that is regular in the entire study period which is the lack of water in the channel during the summer months due to the typical Mediterranean summer drought.

Table. 3. Suspended and dissolved sediment transport during the four studied hydrological years, along with the overall performance of the two gauging stations in the Vernagà basin.
Tabla 3. Transporte de sedimentos en suspensión y disueltos durante los cuatros años hidrológicos de estudio, a lo largo de toda la serie de las dos estaciones de aforo en la cuenca del Vernagà.

	2005-2006						2006-2007					
	Bosc			Campàs			Bosc			Campàs		
	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}
October	5049.72	3945.09	5.62	10597.11	7160.21	6.91	2344.51	261.51	1.63	1217.06	1294.67	0.98
November	1064.29	682.92	1.09	17896.48	7781.08	9.99	0.00	0.00	0.00	0.00	0.00	0.00
December	76.88	28.19	0.07	47.29	47.29	0.04	0.00	0.00	0.00	0.00	0.00	0.00
January	2711.29	1810.56	2.83	4417.18	4717.54	3.55	0.00	0.00	0.00	0.00	0.00	0.00
February	226.55	267.07	0.31	425.35	371.34	0.31	35.83	303.18	0.21	7.45	635.47	0.25
March	2.82	28.18	0.02	0.06	0.06	0.00	5.25	46.02	0.03	4.83	172.04	0.07
April	0.59	1.18	0.00	0.01	0.01	0.00	111.73	2011.21	1.33	2137.22	4970.54	2.77
May	0.00	0.00	0.00	0.00	0.00	0.00	0.57	31.07	0.02	0.71	235.13	0.09
June	0.00	0.00	0.00	0.00	0.00	0.00	1.83	84.50	0.05	34.66	389.54	0.17
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	**9132.13**	**6763.19**	**9.93**	**33383.46**	**20077.52**	**20.80**	**2499.72**	**2737.49**	**3.27**	**3401.93**	**7697.37**	**4.32**

	2007-2008						2008-2009					
	Bosc			Campàs			Bosc			Campàs		
	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}	Suspended Load (kg)	Dissolved Load (kg)	Total Yield TKm^{-2}yr^{-1}
October	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00	12.38	39.86	0.03	65.55	729.03	0.31
January	0.00	0.00	0.00	0.00	0.00	0.00	5.94	256.40	0.16	492.00	3208.06	1.44
February	0.00	0.00	0.00	2.10	41.94	0.02	126.04	4489.31	2.88	73.99	4545.86	1.80
March	0.00	0.00	0.00	1.32	26.42	0.01	0.04	0.75	0.00	24.20	483.90	0.20
April	0.30	5.95	0.00	7.55	150.63	0.06	1.71	730.66	0.46	978.91	3819.56	1.87
May	59.68	784.06	0.53	103.23	1722.78	0.71	0.00	0.00	0.00	15.08	0.00	0.01
June	1.37	117.12	0.07	6.27	93.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	**61.35**	**907.13**	**0.61**	**120.47**	**2034.89**	**0.84**	**146.10**	**5516.99**	**3.54**	**1649.73**	**12786.42**	**5.62**

One factor that contributes to enabling of runoff is the water table level at the beginning of the hydrological year. It is considered that when the water level in the lowermost well, which is connected to the channel, is at -3.75 m below the surface, runoff begins to flow continuously. In October 2005, the depth was -4.57 m, 0.82 m below the runoff initiation; October 2006 was -3.88 m, 0.13 m below; October 2007 was -4.43 m, 0.68 m; and October 2008 was -4.52 m, 0.77 m below. The total rainfall in October must be enough to reach this point (-3.75 m) in order to have runoff in the channel. If this does not happen, as was the case in 2007-2008, it is unlikely that water will remain in the channel during autumn.

In addition, another characteristic that repeated along the four years is that monthly rainfall needed to produce flow in the river channel is higher than 100 mm, regardless of the month in which rainfall takes place. It is clear thus that rainfall is the most important factor in understanding the dynamics of runoff generation in the basin.

4.2. *Sediment load*

Sediment transport monitored in the basin has been focused on suspended and dissolved load. Floods caused by high-intensity rainfall are responsible for most of the suspended sediment movement in the river. Total dissolved sediment is higher in Campàs with 42,596 kg compared with Bosc (15,924 kg). Furthermore, in both gauging stations these values exceed the total suspended sediment with 38,555 kg in Campàs and 11,839 kg in Bosc.

In 2005-2006 the total yield at Bosc gauging station was 9.93 t km^{-2}yr^{-1}, while at Campàs gauging station it was 20.80 t km^{-2}yr^{-1} (Table 3). Due to the important amount of rainfall in October, there was a high quantity of sediment that was transported (5.62 t km^{-2}month^{-1} in Bosc and 6.91 t km^{-2}month^{-1} in Campàs) as dissolved and suspension load. In this kind of situation the suspension load is higher than the dissolved load in both catchments. At Campàs, in November there was even more load production than in October, a total of 9.99 t km^{-2}month^{-1}. The snow in January also caused high sediment production in both catchments (2.83 t km^{-2}month^{-1} in Bosc and 3.55 t km^{-2}month^{-1} in Campàs).

The 2006-2007 year had an annual total sediment production of 3.27 t km^{-2}yr^{-1} in Bosc and 4.32 t km^{-2}yr^{-1} in Campàs. The main contribution is due to the rainfalls in April, the wettest month of this year and with the most discharge. In 2007-2008, there was very little sediment production (0.61 t km^{-2}yr^{-1} in Bosc and 0.84 t km^{-2}yr^{-1} in Campàs) and it was mainly dissolved sediment due to the fact that flow was minimal. Only during May was there any significant movement of suspended sediment. The hydrological year 2008-2009 has an important load production (3.54 t km^{-2}yr^{-1} in Bosc and 5.62 t km^{-2}yr^{-1} in Campàs) but these were mainly dissolved sediments.

5. Discussion

The Vernegà basin is a typical Mediterranean intermittent river. Flow is continuous during winter months while it dries up in summer. Ephemeral flows take place during autumn and spring, which represent the transition from one season to another. Flow dynamics are marked by the distribution of the rainfall as well as by extreme rainfall events. Flow is also conditioned by evapotranspiration rates, which play an important role in the baseflow response in small catchments (Estrany *et al*., 2010). In relation with this, one of the most typical trends that can be observed is the high runoff variability produced from year to year. In the case study, each year is different in terms of runoff production. The level of the water table is one of the main factors controlling runoff. It has been established that at -3.75 m depth from the closest well to the stream, runoff starts flowing into the channel. This trend is common in many Mediterranean rivers as quoted by García Ruiz *et al*. (2008) in three catchments in the Pyrenees, where the authors register runoff only when rainfall events take place and the water table is close to the soil surface. In a study involving seasonal changes in the hydrological and erosional response of a hillslope under dry-Mediterranean climatic conditions in Málaga (Southern Spain), the authors found an extreme seasonal data variability in terms of runoff generation and sediment transport with a CV>100%, situation that is frequent in Mediterranean environments (Martínez-Murillo and Ruiz-Sinoga, 2007).

The area covered by agriculture fields, which is also covered by several unpaved tracks, seems to generate more runoff than the forest catchment. In a study in the same area done by Úbeda *et al*. (1998), runoff generated by the unpaved roads was higher than in the forest area. Outeiro *et al*. (2010) also studied not only the generation of runoff, but also the influence of land use in the generation of peak flows. He found that the most denudated areas were occasionally responsible for generating peak flows of one order of magnitude greater than in the forested areas, despite the role of topography in quickflow generation, which was steeper in the forested areas than in the lower areas of flat agricultural fields.

Concerning sediment production, García Ruiz *et al*. (2008) quoted, in three different catchments in the Pyrenees, that the majority of sediment was transported as dissolved load (73.5%), while suspension was only 26.5%. In the present study, the sediment transported as dissolved load is also higher during a large part of the year. Only when high flows occur, like in October 2005 and January 2006, the transport of sediment in suspension is greater. The differences between suspended load and dissolved load production were higher at Campàs than at Bosc due to a greater contribution of fine sediment coming from slopes.

Mean annual sediment yields measured contrast with those stated by Sala and Farguell (2002) in the same basin during the 1993-1997 period. While the mean sediment yield in the 1993-1997 period at Bosc was 0.1 t $km^{-2}yr^{-1}$, in the 2005-2009 period it was 4.34 t $km^{-2}yr^{-1}$. In Campàs it was 0.7 t $km^{-2}yr^{-1}$ in 1993-1997 and 7.89 t $km^{-2}yr^{-1}$ in 2005-2009. Such differences may be attributed to forest management operations undertaken in the basin since 2005-2006, and the occurrence of extreme events in October 2005 and January 2006. Although more data is necessary to conclude that the forest management operations are responsible for these changes, it seems that such practices contribute to an increase of sediment mobilization. This fact has also been reported by Croke *et al*. (2001) who said that the maximum transport happens when events of high rainfall intensity occur after thinning. Scott *et al*. (2001) found that the work done by machinery removes the upper layers of topsoil, increasing the availability of fine particles to be washed downslope. This was the situation in October 2005, just after the forest management practices took place, and may be the reason for the large differences between sediment yields in the two compared periods. Furthermore, it has been observed that this extraordinary event not only transported large quantities of sediment, but also prepared sediment to be eroded in future events. Mount *et al*. (2005) found in a study in Wales that the forestry activities such as harvesting and logging increase bedload production. In the Vernegà basin, although this phenomenon has been observed in the form of accumulation of sand particles in the gauging station, it has not been computed yet.

6. Conclusions

Overall, total runoff is greater in Campàs (forest and agricultures) than in Bosc (forest) during the entire study period, and in both cases, the 2005-2006 hydrological year generated more than 80% of the total runoff. Autumn registered the largest rainfall volumes including the highest precipitation value in the study period (i.e. October 2005, 256.8 mm), and also the most important runoff response of the watershed with 139.30 mm in Campàs and 123.28 mm in Bosc. There is a seasonal variability of runoff at the two stations, which register water flow from October to June. However, runoff production was different from year to year, and also at a monthly scale. Both suspended and dissolved sediment loads increased during the study period, possibly due to forest management tasks, which have reduced ground cover at the top of the basin. Dissolved sediment concentrations were higher than suspended at both stations, with total dissolved sediment three times in Campàs compared to Bosc; while total suspended sediment four times higher in Campàs than Bosc. Only when high peak flows occur, the transport of sediment in suspension is larger than the dissolved (2005-2006).

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