HYDROLOGICAL AND SEDIMENTOLOGICAL BEHAVIOUR OF AIXOLA CATCHMENT (BASQUE COUNTRY) DURING RUNOFF EVENTS

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Introduction

Different parameters measured during runoff events in Aixola catchment (4.8 km^2) have been studied in order to identify the factors that control hydrological and sedimentological response of the catchment in the event scale and also to describe the general behaviour of the basin during events. To that aim precipitation (mm), discharge (dm^3·s^{-1}), turbidity (FNU), suspended sediment concentration (mg·dm^{-3}) and electrical conductivity (µS·cm^{-1}) of river waters were measured with different intervals during two years (2003-2005) in the gauging station located at the outlet of the catchment.

Study area

Aixola River is located in the west of the Gipuzkoa County (Basque Country) and drains a headwater catchment of 4.8 km^2 into the Aixola water reservoir (Figure 1). The highest peak is at 750 m a.s.l., the outlet at about 340 m a.s.l. and mean elevation is 511 m a.s.l. The slopes are gentle in general, smaller than the 30%. This basin is mostly (>80%) reforested with *Pinus radiata* trees. It can be said that from the lithological point of view is a homogeneous basin as the main bedrock in almost the whole catchment is Upper Cretaceous Calcareous Flysch with alternating marl and sandy limestone layers. Average annual precipitation for this area is about 1480 mm distributed along the year, with totals of 1450 and 1375 mm per year during the study years 2003-2004 and 2004-2005. mean annual discharge is about 600 mm, and it was respectively 667 and 810 mm for the study years. Discharge has a conductivity of about 370 µS·cm^{-1} which is considerably lower (200 µS·cm^{-1}) during runoff events. For the period 2003-2005 the estimated average suspended sediment yield is 35t per square kilometre with mean concentrations of 128 mg·dm^{-3} during events. Since significant sediment loads are transported during most of the events, sediment export occurs along the whole year, but is mostly concentrated from November to April. Different types of relationships between discharge and concentration of suspended sediments through runoff events have been found in Aixola, each of these types (linear, clockwise hysteretic loop, counter clockwise, eight-shaped) associated with different event and pre-event factors (Zabaleta *et al.*, 2007).

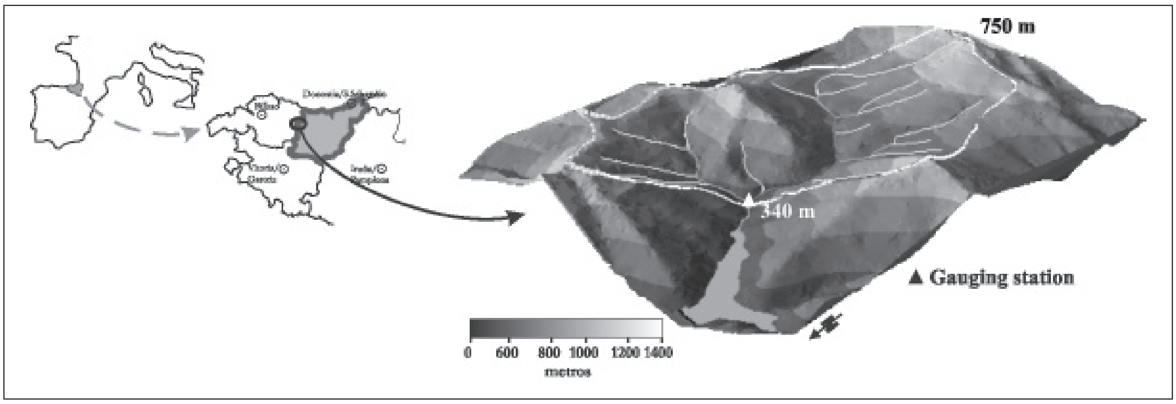

Figure 1. Location of Aixola catchment

Materials and methods

Turbidity (FNU), discharge ($dm^3{\cdot}s^{-1}$) and precipitation (mm) were measured every 10 minutes in the gauging station located at the outlet of the catchment since October 2003. Turbidity is measured using Solitax infrared backscattering turbidimeter (Dr. Lange devices, 0-1000 FNU). Additionally, an automatic water sampler was installed in the station and programmed to take water samples of about 600 ml when discharge rises. Electrical conductivity was measured in these samples before they were carried to the laboratory. Once in the laboratory turbidity was again measured (wtw 555IR device) and suspended sediment concentration was calculated by means of filtration of the samples through 0.45μm filters. In this way, relation of turbidity to suspended sediment concentration (SSC) was calibrated (Zabaleta *et al.*, 2006) and continuous time series of SSC are efficiently derived from *in situ* continuous turbidity series (Lewis, 1996).

Taking into account parameters measured every 10 minutes 76 rainfall-runoff events have been characterised by four groups of variables (Zabaleta *et al.*, 2007): antecedent conditions to the event, precipitation causing the event, discharge during the event and suspended sediment delivered during the event. A correlation matrix and a factorial analysis that include those variables have been completed in order to analyze the factors that control suspended sediment yield during runoff events in Aixola.

Electrical conductivity couldn´t be introduced in these statistical analyses because continuous measuring of this parameter is not available. However, evolution of electrical conductivity during events and its relationship with discharge and suspended sediments were also analysed.

Results

Antecedent conditions are described by accumulated precipitation of one hour before the event (aP1, mm), one (aP1d, mm), seven (aP7d, mm) and twenty-one days (aP21d, mm) before the event and average discharge of the day before the beginning of the event (aQ1d, $dm^3{\cdot}s^{-1}$). Precipitation that caused the event is characterised by total precipitation (Pt, mm), average intensity of the precipitation during the rainfall event (IP, $mm{\cdot}h^{-1}$) and maximum intensity of the precipitation (IPmax, $mm{\cdot}10min^{-1}$). IPmax is the maximum precipitation registered in the 10 minutes interval series. Discharge during the event is expressed by the total specific water volume of the runoff event (Qt, mm), the average (Qav, $dm^3{\cdot}s^{-1}$) and the maximum discharge (Qmax, $dm^3{\cdot}s^{-1}$), and the relationship between this maximum discharge and the initial discharge prior to the event (Qmax/Qb). Sediment load has been explained with the average of the suspended sediment concentration data registered every 10 minutes during the event (SSCav, $mg{\cdot}dm^{-3}$), the maximum suspended sediment concentration of the event (SSCmax, $mg{\cdot}dm^{-3}$) and the total suspended sediment yield of the event (SSt, Kg). In order to analyze the factors that control suspended sediment yield during events in Aixola a correlation matrix and a factorial analysis that include all the variables mentioned above have been completed.

Discharge variables, are well correlated with total precipitation during the event. Total sediment yield of the event is also strongly related to Pt (R^2 = 0.58), while SSCav and SSCmax are much better correlated with

Table 1. Pearson correlation matrix between parameters calculated for Aixola catchment (n=76). Correlation is significant at the 0.01 level for bold numbers and 0.05 for italics

	Pt	Ip	Ipmax	aP1	aP1d	aP7d	aP21d	aQ1d	Qav	Qt	Qmax	Qp/Qb	SSCav	SSCmax	SSt
Pt	1.00														
Ip	0.15	1.00													
Ipmax	*0.28*	**0.92**	1.00												
aP1	0.07	-0.12	-0.10	1.00											
aP1d	-0.01	-0.18	-0.15	**0.49**	1.00										
aP7d	-0.06	*-0.27*	*-0.25*	**0.32**	*0.27*	1.00									
aP21d	-0.15	**-0.33**	**-0.34**	**0.30**	*0.24*	**0.64**	1.00								
aQ1d	-0.04	-0.21	-0.20	**0.31**	**0.34**	**0.71**	**0.61**	1.00							
Qav	**0.50**	-0.10	-0.03	**0.38**	**0.31**	**0.51**	**0.40**	**0.67**	1.00						
Qt	**0.62**	-0.15	-0.06	*0.23*	0.18	**0.33**	*0.23*	**0.45**	**0.88**	1.00					
Qmax	**0.66**	**0.30**	**0.43**	0.20	0.14	*0.26*	0.04	**0.30**	**0.78**	**0.68**	1.00				
Qp/Qb	**0.54**	**0.54**	**0.70**	-0.12	-0.14	-0.21	**-0.37**	*-0.28*	0.11	0.13	**0.65**	1.00			
SSCav	**0.34**	**0.63**	**0.72**	-0.07	-0.09	-0.15	**-0.35**	-0.17	0.10	0.03	**0.61**	**0.84**	1.00		
SSCmax	**0.33**	**0.40**	**0.55**	-0.06	-0.11	-0.10	*-0.29*	-0.17	0.07	0.03	**0.57**	**0.85**	**0.92**	1.00	
SSt	**0.58**	0.22	**0.37**	0.05	0.00	0.09	-0.11	0.01	**0.49**	**0.51**	**0.83**	**0.76**	**0.72**	0.80	1.00

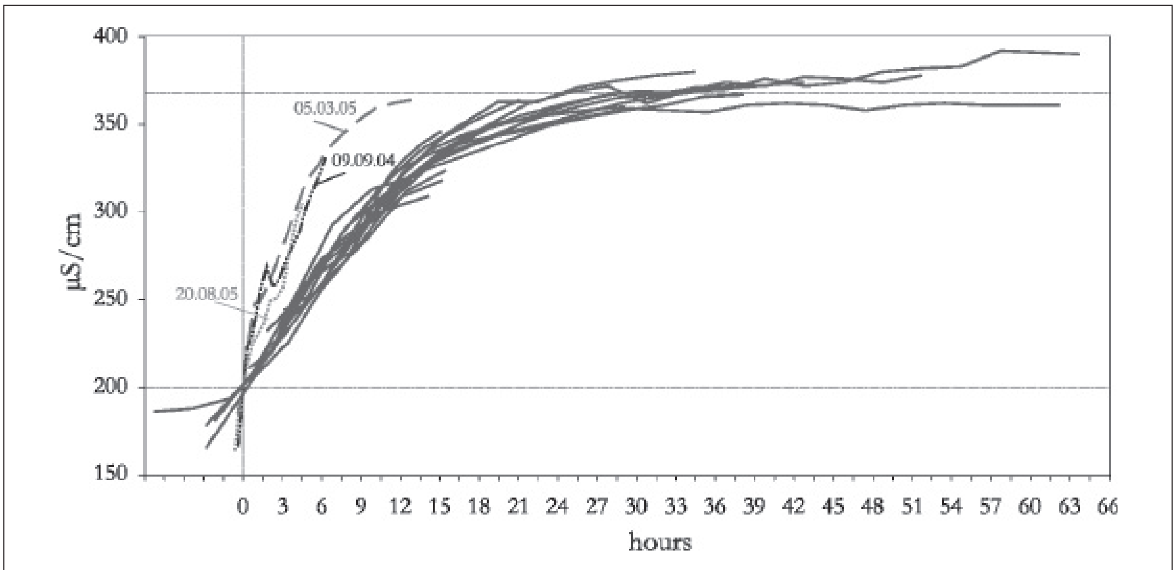

Figure 2. Evolution of electrical conductivity (µS·cm⁻¹, in hours) in river waters after maximum discharge of runoff events registered in Aixola catchment. t = 0 hours corresponds to electrical conductivity minimum.

maximum intensity of the precipitation (R^2 = 0.72, 0.55 respectively). Suspended sediment yield and concentration are also well correlated with Qmax and, particularly, with the Qmax/Qb parameter. In the same way, suspended sediment average concentration and sediment yield are interrelated. As Seeger *et al.* (2004) showed other important factors that control the transport of suspended sediment in catchments are the antecedent conditions. In the case of Aixola, a very disturbed catchment, antecedent conditions are not significantly correlated with suspended sediment variables.

Taking into account all these data, a principal component analysis with Varimax rotation was performed with SPSS programme package. This analysis grouped in the first factor (29% of the variance explained), IP, IPmax, SSCav, SSCmax and Qmax/Qb variables and in the second factor (23% of the variance explained), Pt, Qt and Qav. In the I-II factorial plane, total sediment yield of the event (SSt) shows a high relationship with both factors, even if the correlation is better with factor I, and no significant relationship is shown with antecedent conditions to the event.

Apart from these, evolution of electrical conductivity during runoff events was examined. Behaviour of conductivity through events was very homogeneous. In all cases a very rapid increase of electrical conductivity after the decrease registered during the rising limb of the hydrograph is observed (Figure 2). Maximum conductivities measured before and after runoff events are about 370 μS·cm^{-1}. This gives an idea of the chemical properties of waters that usually are present in the catchment, "the old waters". Besides, minimum conductivities measured during events are always comparatively high, about 200 μS·cm^{-1}, indicating that a relatively high proportion of old waters (40-45%) is present in discharge during runoff events.

On the other hand, relationship between minimum electrical conductivity (related to maximum new water percentage present in river waters) and maximum suspended sediment concentration (related to maximum capacity of runoff for sediment exportation) registered during events was also studied. However no clear correlation between parameters was found in this catchment. Only during events with very intense precipitations, that occurred under dry conditions, in summer, high suspended sediment concentration (>2000 mg·dm^{-3}) and very low electrical conductivities (<200 μS·cm^{-1}) were observed. Further work is planned for this subject.

Conclusions

The correlation matrixes and factorial analysis produced with the events recorded in Aixola catchment show that there is a strong correlation between precipitation, discharge and suspended sediment variables during the event, but no significant correlation between these and antecedent conditions. These results suggest a direct response of the catchment to rainfall events, in the discharge as well as in the sediments, so that the kind of runoff events that take place in Aixola catchment are of the flash flood type.

While event suspended sediment yield is related to total precipitation, suspended sediment concentration is related to precipitation intensity. The relationship between discharge and sediment yield is high and also positive. But suspended sediment parameters don't show any dependence on antecedent conditions to the event and sediment response takes place in any of the hydrological situations of the year.

Evolution of electrical conductivity of waters during events shows that even if in Aixola catchment discharge and sediment response to rainfall events are very rapid in all hydrological situations, the catchment has a considerable regulation capacity (in soils, mainly) observed in the relatively high electrical conductivity of the waters present in the river. Moreover, old waters always appear in a high percentage in total discharge, also during maximum discharge.

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