Sediment transport during the snowmelt period in a Mediterranean high mountain catchment

B. Alvera [(1)], N. Lana-Renault [(2,3)], J. M. García-Ruiz [(3)]

(1) Instituto Pirenaico de Ecología, CSIC, P.O. Box 64, 22700-Jaca (Spain). E-mail: balvera@ipe.csic.es
(2) Physical Geography Research Institute, Utrecht University, Faculty of Geosciences, P.O. Box 80115, The Netherlands. E-mail: lana-renault@geo.uu.nl
(3) Instituto Pirenaico de Ecología, CSIC, Campus de Aula Dei, P.O. Box 13034, 50080-Zaragoza, Spain. E-mail: humberto@ipe.csic.es

ABSTRACT

Transport of suspended sediment and solutes during the snowmelt period (May–June, 2004) in the Izas catchment (Central Pyrenees) was studied to obtain a sediment balance and to assess the annual importance of sediment transport. The results showed that most sediment was exported in the form of solutes (75.6% of the total); 24.4% was exported as suspended sediment and no bedload was recorded. Sediment transport during the snowmelt period represented 42.7% of the annual sediment yield.

Key words: experimental catchment, high mountain, suspended sediment, solutes, Spanish Pyrenees.

INTRODUCTION

Snow accumulation and melting play key hydrological roles in high mountain catchments of temperate regions, controlling in part the seasonality of floods, the spatial organization of soil saturation processes and overland flow, the intensity of high flows, and the constant low winter discharges. The snowmelt period also plays a very important geomorphological role, resulting in shallow landsliding, solifluction, rilling and sheet wash erosion. Monitoring of the Izas catchment (in the sub-Alpine belt of the Central Spanish Pyrenees) since 1987 has provided information on various hydrological and sediment transport processes (Martínez-Castroviejo *et al*. 1991; Del Barrio *et al*., 1997; Alvera & García-Ruiz, 2000; Anderton *et al*., 2002). In this study sediment transport was assessed during the snowmelt period to analyze the effect of both daily and seasonal hydrological contrasts on sediment mobilization and export.

THE IZAS CATCHMENT

The Izas catchment (0.33 km^2) is located in the Upper Gállego River valley, Central Spanish Pyrenees, between 2060 and 2280 m a.s.l. The bedrock is composed of carboniferous slates. Solifluction is very active in deep soils (Del Barrio & Puigdefábregas, 1987), while terracettes develop on degraded soils of south facing slopes. A dense and steep gully system occurs on slates close to the divide. This small area is the most important sediment source for the main channel (Díez *et al*., 1988). Mean annual temperature is around 3ºC and total annual rainfall is 1900 mm, with most precipitation occurring between October and May. During the cold season, precipitation falls as snow, which covers the catchment until June. Sub-alpine and alpine grasslands (*Festuca eskia*, *Nardus stricta*) cover most of the slopes.

EQUIPMENT AND METHODS

The Izas catchment is equipped with a gauging station (V-notch weir), with a pressure transducer and a thermistor recording the height and temperature of runoff water, respectively. Sediment transport was monitored using a slot-trap for bedload, an automatic water sampler for suspended and dissolved solid concentrations, a conductivimeter, and a turbidimeter that enabled evaluation of the suspended sediment concentration after calibration. An automatic weather station recorded information on air temperature, the relative humidity of air, radiation, the velocity and direction of wind, and precipitation. Hydrological and sediment transport information for the water year 2003/04 was used for this study. A sediment balance was performed to estimate the relative importance of solutes, suspended sediment and bedload during the snowmelt period and for the whole year.

RESULTS

Figure 1 shows the evolution of daily precipitation, average daily discharge, suspended sediment concentration, and snowpack depth for the water year 2003/04. Information on snowpack corresponds to a snow pillow located close to the flume, where snowmelt ends rapidly compared to the rest of the catchment. The figure shows a period of increasing snow accumulation from the end of October to April, but the falling section of the curve is not representative of the whole catchment. A maximum snow accumulation of about 1.5 m was recorded at the beginning of April. Increases in snow accumulation were directly related to the major rainfall events. Periodic visits to the catchment enabled temporal estimates of the snow-covered area; 99% (14 May), 90% (25 May), 60% (3 June), 50% (10 June), 40% (17 June), 10% (23 June) and 1% (8 July). The evolution of discharge showed (i) large fluctuations in autumn, corresponding to rainfall events accompanied by short snowmelt periods (such as occurred at the end of November); (ii) a long period in winter mainly characterized by low flows, with almost constant discharges in February and March; and (iii) a very significant period of high flows between the end of April and the end of June, coinciding with snow depletion in the catchment. It was notable that the suspended sediment concentration showed small peaks in autumn and during the snowmelt period.

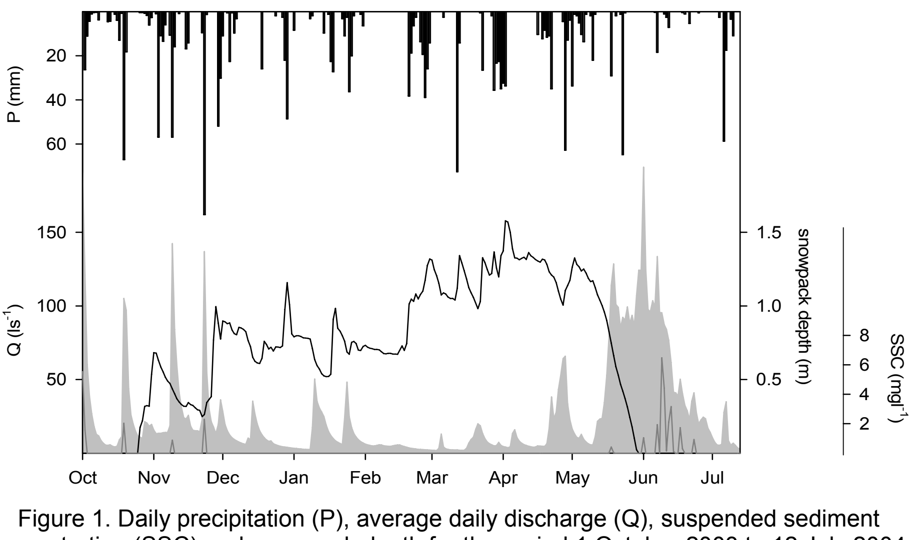

Figure 1. Daily precipitation (P), average daily discharge (Q), suspended sediment concentration (SSC) and snowpack depth for the period 1 October 2003 to 12 July 2004.

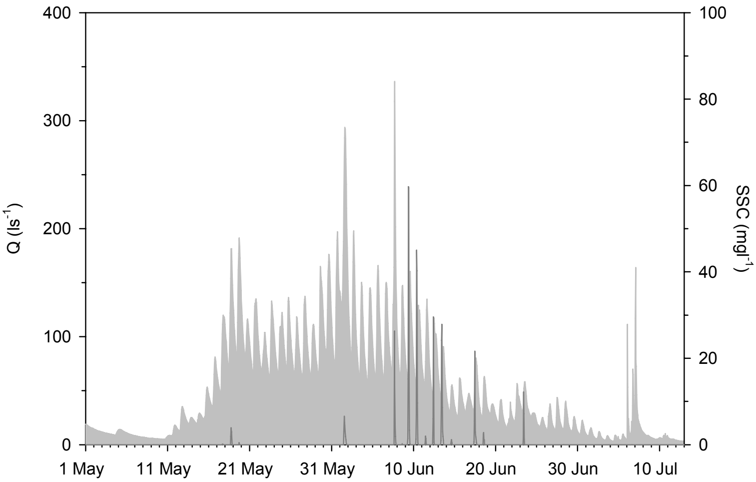

Figure 2. Hourly discharge (Q) and suspended sediment concentration (SSC) during the snowmelt period.

Figure 2 shows the discharge and suspended sediment concentration during the snowmelt period, during which typical daily pulses are evident. The snowmelt period was characterized by a marked discharge increase after 11 May, and a sustained period of continuous high flows between mid May and mid June. Daily hydrographs showed a characteristic wave pattern (Alvera & Puigdefábregas, 1985) reflecting the effect of daily temperature oscillations. These waves remained throughout the second half of June, when the presence of snow was increasingly spatially-limited. The suspended sediment concentration did not follow this daily pattern, with the exception of some days in mid June that coincided with some high discharges.

Table 1 shows sediment exports during the snowmelt period and over the whole year. Whereas precipitation during the snowmelt period was 10.6% of the annual amount, runoff was 48.1% (a consequence of previous snow accumulation), suspended sediment was 60.5%, and solutes were 41.2%. If the snowmelt period is considered in isolation, sediment transport was dominated by solutes (75.6%) followed by suspended sediment (24.4%). During the two-month snowmelt period, suspended sediment and solutes comprised a total of 29.7 Mg, or 42.8% of the annual yield. No bedload was recorded during the snowmelt period but 3.1 Mg was recorded during the rest of the year, which is a typical figure for the Izas catchment (Alvera & García-Ruiz, 2000). Sediment outputs during the snowmelt represented an erosion rate of 90 Mg km^{-2} yr^{-1}, but on an annual basis were 210.9 Mg km^{-2} yr^{-1}. This figure is consistent with the annual sediment yield estimated for the Izas catchment since 1987 (200–320 Mg km^{-2} yr^{-1}; Alvera & García-Ruiz, 1987).

Table 1. Outputs from the Izas catchment during the snowmelt period and overall for the year 2003/04.

	Water year 2003/04	Snowmelt period	% snowmelt period
Precipitation (mm)	2155	228	10.6
Runoff (mm)	1983	955	48.1
Susp. Sedim. (Mg)	11.9	7.3	61.1
Solutes (Mg)	54.6	22.5	41.2
Bedload (Mg)	3.1	-	-

DISCUSSION AND CONCLUSIONS

Sediment transport in high mountain catchments is partially conditioned by snowmelt accumulation and melting periods. Almost no fluctuations occur in sediment transport and discharge during the cold season. The snowmelt period represents a major increase in discharges and daily discharge pulses, due to both seasonal and daily temperature increases. During the water year 2003/04, the two-month snowmelt period discharge represented almost 50% of the total annual runoff, and sediment transport (the sum of suspended sediment and solutes) was 42.8%. These figures indicate the hydrological and geomorphological importance of this brief period during the year. It is also notable that: (i) bedload was not detected during the snowmelt season, suggesting that the daily pulses in discharge were of insufficient energy to move coarse sediments, and (ii) most of the suspended sediment was carried in the second part of the snowmelt period, when an expanding area of the catchment was free of snow. This reflects the importance of sediment mobilization from the ravine banks and saturated areas close to the snowmelt front. During the snowmelt period, most sediment was exported in the form of solutes (75.6%) and not suspended sediment (24.4%). Erosion rates determined for the water year 2003/04 were within the long-term typical values for the Izas catchment. These values are slightly higher than those obtained in other mountain catchments, which suggests the need for a detailed analysis of prevailing geomorphic processes and sediment accessibility from the hillslopes.

ACKNOWLEDGMENTS

Support for this research was provided by the following projects: PROBASE (CGL2006-11619/HID CONSOLIDER) and RESEL, financed by the Spanish Government.

REFERENCES

- Alvera, B. & Puigdefábregas, J. 1985. Pulsación diaria de la carga suspendida y disuelta en la escorrentía de fusion nival. *Cuadernos de Investigación Geográfica*, 11, 5-20.
- Alvera, B. & García-Ruiz, J. M. 2000. Variability of sediment yield from a high mountain catchment, Central Spanish Pyrenees. *Arctic, Antarctic, and Alpine Research*, 32 (4), 478-484.
- Anderton, S.P., White, S.M. & Alvera, B. 2002. Micro-scale spatial variability and the timing of snow melt runoff in a high mountain catchment. *Journal of Hydrology*, 268, 158-176.
- Del Barrio, G. & Puigdefábregas, J. 1987. Mass wasting features above the timberline in the Central Pyrenees and their topographic controls. *Pirineos*, 130, 3-25.
- Del Barrio, G., Alvera, B., Puigdefábregas, J. & Díez, J. C. 1997. Response of high mountain landscape to topographic variables: Central Pyrenees. *Landscape Ecology*, 12, 95-115.
- Díez, J. C., Alvera, B., Puigdefábregas, J. & Gallart, F. 1988. Assessing sediment sources in a small drainage basin above timberline in the Pyrenees. *IAHS Publ.*, 174, 197-205.
- Martínez-Castroviejo, R., García-Ruiz, J. M., Díez, J. C. & Alvera, B. 1991. Coarse sediment transport in an experimental high mountain catchment of Central Pyrenees, Spain. *Zeitschrift für Geomorphologie Suppl Bd*, 83, 105-114.