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# THE SNOWMELT PERIOD IN A MEDITERRANEAN HIGH MOUNTAIN CATCHMENT: RUNOFF AND SEDIMENT TRANSPORT

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***ABSTRACT.*** *Runoff and sediment transport during the snowmelt period (May-June, 2004) in the Izas catchment (Central Pyrenees) were studied to obtain a sediment balance and to assess the relative importance of sediment transport during that period. The results demonstrated the importance of the snowmelt period and showed that most sediment was exported in the form of solutes (76% of the total for the May-June time span); 24% was exported as suspended sediment and no bedload was recorded. Suspended sediment mostly occurred during the second phase of the snowmelt period, when an expanding area of the catchment was free of snow. Sediment transport during the snowmelt period represented 43% of the annual sediment yield.*

***RESUMEN.*** *Se ha estudiado el transporte de sedimento y la escorrentía durante el período de fusión de nieve (mayo-junio de 2004) en la cuenca experimental de Izas (Pirineo Central), con el fin de (i) obtener balance de sedimento y (ii) evaluar la importancia relativa del período de fusión en el transporte total de sedimento a lo largo del año. Los resultados demuestran, por un lado, la importancia hidromorfológica del período de fusión y, por otro, que la mayor parte del sedimento fue exportado en forma de solutos (76% del total durante el período de mayo a junio); el sedimento en suspensión representó el 24%; finalmente, no se registró transporte de carga de fondo. El sedimento en suspensión fue principalmente movilizado durante la segunda parte del período de fusión, cuando una creciente superficie de la cuenca estaba ya libre de nieve. El transporte de sedimento durante el período de fusión de nieve representó el 43% de la producción anual de sedimento.*

**Palabras clave:** cuenca experimental, alta montaña, sedimento en suspensión, solutos, Pirineo español.
**Key words:** experimental catchment, high mountain, suspended sediment, solutes, Spanish Pyrenees.

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## 1. 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 (Soulsby *et al*., 1997; García-Ruiz *et al*., 2001; López-Moreno and García-Ruiz, 2004). This is particularly important in Mediterranean basins, where most of discharge is generated in mountain areas, and where water management is based on reservoirs that largely depend on high flows generated during the snowmelt period (López-Moreno *et al*., 2004). The snowmelt period also plays a very important geomorphological role, resulting in shallow landsliding, solifluction, rilling and sheet wash erosion (Barsch and Caine, 1984; García-Ruiz *et al*., 1990).

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 in a high mountain environment (Martínez-Castroviejo *et al*. 1991; Del Barrio *et al*., 1997; Alvera and García-Ruiz, 2000; Anderton *et al*., 2002). In this study runoff and sediment transport was investigated during the snowmelt period to analyze the effect of both daily and seasonal hydrological contrasts on sediment mobilization and export.

## 2. The study area

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 densely fractured carboniferous slate. Solifluction is very active in deep soils (Del Barrio and Puigdefábregas, 1987), while terracettes develop on degraded soils of south facing slopes, although they do not seem to contribute sediment because, in general, they are disconnected from the fluvial system (Figs. 1 and 2). A dense and steep gully system occurs on slates close to the divide (Fig. 3). This small area (5% of the total catchment) is the most important sediment source for the main channel (Díez *et al*., 1988).

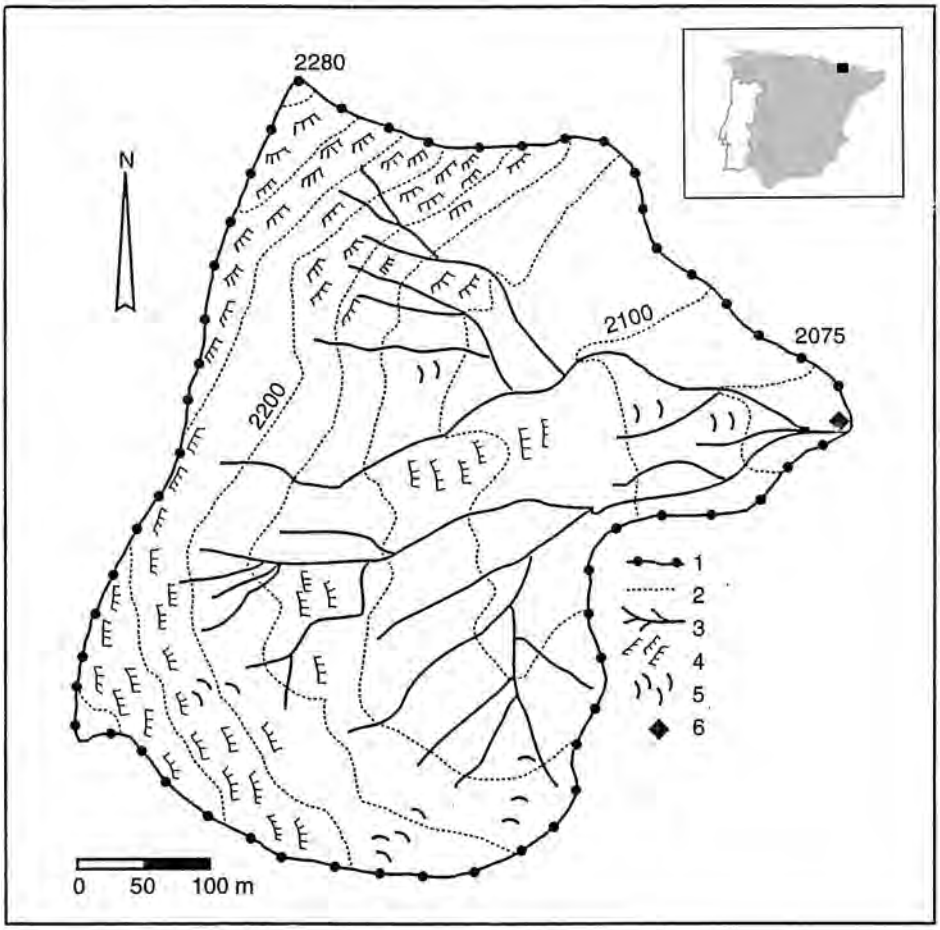


*Figure 1. The study area and its geomorphic features.*

Mean annual temperature is around 4°C and total annual precipitation is about 2000 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 (Fig. 4).

## 3. 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 and dissolved solid concentrations are obtained using an automatic water sampler, active during the high flow periods, a conductivimeter, and a turbidimeter that enabled evaluation of the solute and suspended sediment concentration

*Figure 2. Terracettes in a steep slope of the Izas catchment.*

*Figure 3. The headwater of the Izas catchment, showing the dense gully network on carboniferous slates.*

*Figure 4. General perspective of the Izas catchment, with alpine and sub-alpine grasslands.*

after calibration. Bedload transport was monitored with a slot-trap located in the stream bed. Periodically, in particular after heavy rainstorms and at the end of the snowmelt period, the trap was emptied and the volume of sediment weighted. An automatic weather station recorded information on air temperature, the relative humidity of air, radiation, the velocity and direction of wind, and precipitation. Information on the snowpack corresponds to an ultrasonic ranging sensor and a snow pillow located close to the flume, at the lowest end of the catchment, where snowmelt ends rapidly compared to the rest of the catchment. 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 yield during the snowmelt period and for the whole year.

## 4. Results

Figure 5 shows the evolution of daily precipitation, average daily discharge, suspended sediment concentration, and snowpack depth for the water year 2003/04. The figure shows a period of increasing snow accumulation from the end of October to April. Nevertheless, the falling section of the curve does not represent the behavior of the whole catchment, because snowmelt ends earlier at the position of the snow pillow than in the rest of the 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 snowfalls 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 6 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 and 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, with a declining intensity of the daily peak flows. Some peak flows related to greater increases in temperature were recorded, occasionally accompanied by rainfall events. The maximum discharge was registered on 7 June, when a temperature increase of 10°C and a 19 mm rainfall produced a peak flow of 336 l $s^{-1}$. The suspended sediment concentration did not follow exactly this daily pattern, with the exception of some days in mid June that

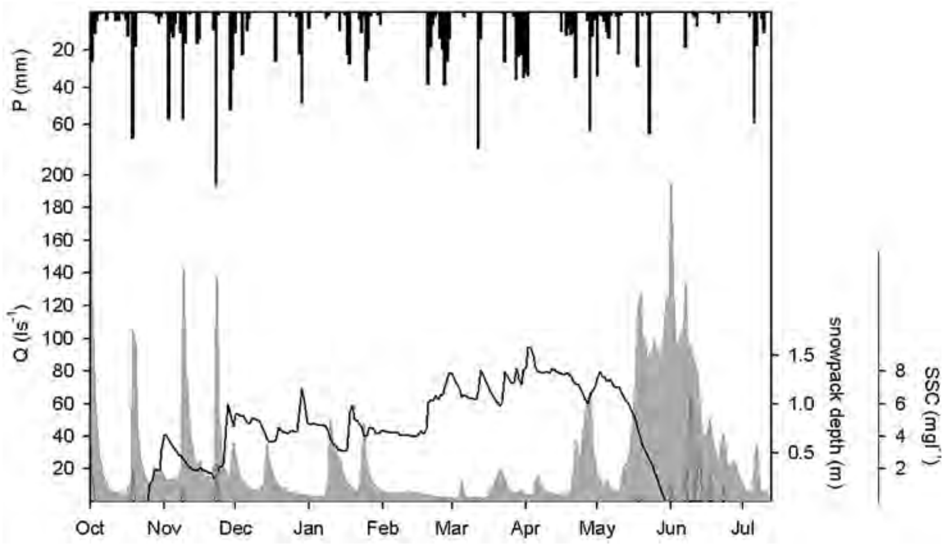


*Figure 5. Daily precipitation (P), average daily discharge (Q), suspended sediment concentration (SSC) and snowpack depth for the period 1 October 2003 to 12 July 2004.*

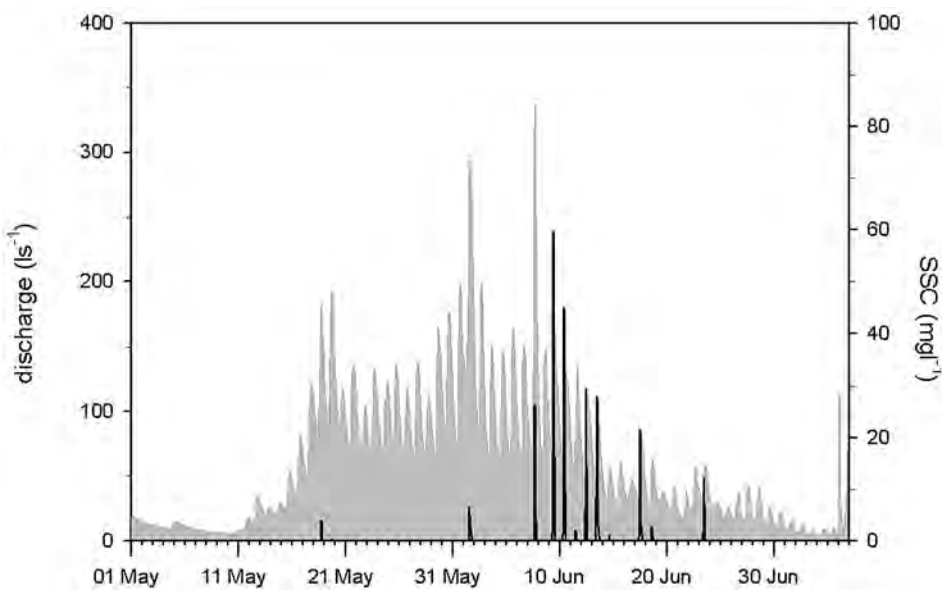


*Figure 6. Hourly discharge and suspended sediment concentration (SSC) during the snowmelt period.*

coincided with some high discharges. It is interesting to note that suspended sediment mostly occurred during the second phase of the snowmelt period, when an expanding area of the catchment was free of snow.

Table 1 shows sediment exports during the snowmelt period and over the whole year. Whereas precipitation during the snowmelt period was 11% of the annual amount, runoff was 48% (a consequence of previous snow accumulation), suspended sediment was 61%, and solutes were 41%. If the snowmelt period is considered in isolation, sediment transport was dominated by solutes (76%) followed by suspended sediment (24%). During the two-month snowmelt period, suspended sediment and solute outputs indicate an erosion rate of 90.2 Mg $km^{-2}$ or 43% of the annual yield. No bedload was recorded during the snowmelt period but 9.3 Mg $km^{-2}$ was recorded during the rest of the year, which is a typical figure for the Izas catchment (Alvera and García-Ruiz, 2000). Sediment outputs at annual basis represented an erosion rate of 210.9 Mg $km^{-2}$ $yr^{-1}$, which is consistent with the annual sediment yield estimated for the Izas catchment since 1987 (200-320 Mg $km^{-2}$ $yr^{-1}$; Alvera and García-Ruiz, 2000). According to previous papers (Díez *et al*., 1988), the main sediment source was the channel itself and a dense gully network in the headwater. Periglacial terracettes did not contribute with sediment to the channel, even if they are scarcely protected by the plant cover, neither shallow landslides, which were not connected to the fluvial network.

*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 | 11 |
| Runoff (mm) | 1983 | 955 | 48 |
| Suspended sediment (Mg $km^{-2}$) | 36.1 | 22.0 | 61 |
| Solutes (Mg $km^{-2}$) | 161.5 | 68.2 | 41 |
| Bedload (Mg $km^{-2}$) | 9.3 | 0 | 0 |
| *Total sediment (Mg $km^{-2}$)* | *210.9* | *90.2* | *43* |

## 5. 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 discharge during the two-month snowmelt period represented almost 50% of the total annual runoff, and sediment transport (the sum of suspended sediment and solutes) was 43%. 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 (Alvera and García-Ruiz, 2000), 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 (76%), followed by suspended sediment (24%). The predominance of solutes has been attributed to the high weathering rate of slate (Nadal-Romero *et al*., in press) and to the importance of infiltration during the snowmelt period

Erosion rates determined for the water year 2003/04 were within the long-term typical values for the Izas catchment. For high mountain catchments, few balances have been estimated due to difficulties for monitoring. Besides, the variety of high mountain environments (altitude, aspect, gradient, bedrock and, particularly, connectivity between snow avalanches and the stream) impedes adequate comparisons in most of cases. The values obtained for the Torlesse catchment, New Zealand, are about 30 Mg km$^{-2}$ yr$^{-1}$ (Hayward, 1980). Similarly, from the Iron Crag catchment, in northern England, sediment yield was estimated around 45 Mg km$^{-2}$ yr$^{-1}$ (Evans and Warburton, 2005). These values are somewhat lower than those from the Izas catchment, what could be due to the location and connectivity of sediment sources, as well as the type bedrock outcrops. This suggests the need for a detailed analysis of prevailing geomorphic processes and sediment accessibility from the hillslopes.

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