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ScienceDirect
Catena 71 (2007) 155–163
CATENA
www.elsevier.com/locate/catena

Bedload transport under different flow conditions in a human-disturbed catchment in the Central Spanish Pyrenees

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Abstract

This paper reports on bedload transport in a small catchment in the Flysh area of the Central Spanish Pyrenees. The Arnás experimental catchment, located in the headwaters of the Aragón River, is affected by natural vegetation regrowth, resulting from farmland abandonment. The main stream is totally covered with coarse and tabular-shaped particles (D_{50}=100), a legacy of intense erosive activity decades ago. Discharge and suspended sediment transport were continuously measured at the outlet of the catchment. Bedload was retained in a trap located upstream of the flume. During most floods, this trap overfilled and the volume of the accumulated bed material was obtained from measurements made by means of a 3 m long profilometer. Twelve floods of different characteristics were studied, making it possible to estimate a critical discharge around 0.4 m^3 s^{-1}. The occurrence of an "exceptional" flood event showed the important role of low-frequency floods in bedload transport. Results show that bedload reasonably depends on peak discharge and, to a lesser extent, on effective runoff. In the Arnás catchment, bedload is never more than 30% of the total sediment yield. This low value can be related to the characteristics of the bed particles and those of the channel slope, but also to a reduction in stream torrentiality, as a consequence of an increase in plant cover.

Keywords: Bedload transport; Floods; Experimental catchment; Profilometer; Central Spanish Pyrenees

1. Introduction

Hydrogeomorphic processes in headwaters have a strong influence upon downstream river dynamics, particularly in Mediterranean environments, where water resources mainly depend on precipitation and runoff generation processes in mountain areas. Besides, most sediment transfer from slopes to the stream network takes place in these areas (García-Ruiz et al., 1990), in a scenario of land-use/land cover changes. Mediterranean mountains have been affected by human activities for centuries. In the Spanish Pyrenees, after a period of agricultural pressure between the 18th century and the first half of the 20th, a decrease in population led to the abandonment of most of the cultivated fields and to a regrowth of scrubs and forest (Molinillo et al., 1997). The geomorphic and hydrological consequences of such land cover change have been widely studied. Thus, streamflow has decreased, regardless of climatic oscillations (Beguería et al., 2003), and sediment sources have shrinked (Beguería, 2005), causing a lowering of sediment production and an increase in channel incision processes (Beguería et al., 2006).

Bedload dynamics in headwater streams are of interest in order to understand channel evolution. However, the study of bedload in these environments poses several problems. It has been observed that bedload transport is characterised by great temporal and spatial variability, as a consequence of variations in both, flow conditions and the supply of bed material (Hayward, 1980; Bathurst et al., 1987; Alvera and García-Ruiz, 2000; Lisle et al., 2000; Gomi et al., 2004). The size of bed particles represents a great constraint since, i) the difficulty of field measurements increases with their size and, ii) the heterogeneity of grain sizes complicates the understanding of transport processes (Klingeman and Emmett, 1982; Ferguson, 1994; Batalla and Martín-Vide, 2000). Finally, the irregular geometry of mountain streams,

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doi:10.1016/j.catena.2006.04.029

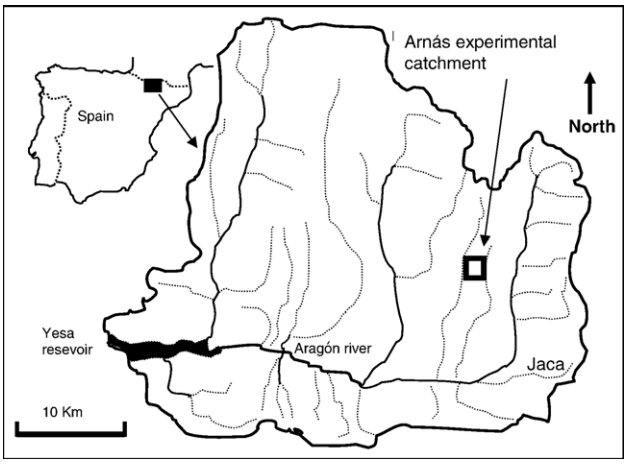

Fig. 1. The Arnás catchment location in the upper Aragón River.

their steep gradient and their often typical step-pool morphology also affects the rate of transport (Whittaker, 1987; Hassan and Reid, 1990). For these reasons, most of the literature on bedload transport focuses on lowland gravel-bed rivers and, in comparison, very few studies are carried out in mountain streams. In Europe, most of the research has been made in small instrumented catchments in the Alpine region (Anselmo et al., 1989; Rickenmann, 1997; Lenzi et al., 1999).

One of the main aims of bedload studies has been the attempt to equate bedload transport to specific hydraulic and sedimentological variables; for instance, much of the research has focused on the identification of initial motion thresholds related to critical discharges (Schotlitsch, 1930) or to shear stress (Shields, 1936). A variety of formulae have been developed in order to predict bedload transport under given flow conditions (see Gomez and Church, 1989; Yang and Huang, 2001 for a review) but all of them are, to some extent, empirical and none universally accepted. Gomez and Church (1989) criticized the proliferation of bedload transport formulae and they encouraged the validation and consolidation of the existing ones as well as the need to gain a complete understanding of bedload processes. These authors also pointed to the scarcity of data referring to channels with bed material outside the sand to fine gravel size range.

In Spain, bedload studies have been undertaken in the Mediterranean coastal ranges (Batalla et al., 1995; Martín-Vide et al., 1999; García et al., 2000; Rovira et al., 2005) and in high mountain environments in the Central Pyrenees (Martínez-Castroviejo et al., 1991; Alvera and García-Ruiz, 2000). However, all of them focused on bedload in gravel-bed rivers, confirming the lack of data in coarser bed rivers.

The purpose of this study is to examine bedload transport and flood characteristics in a human-disturbed catchment of the Spanish Pyrenees, characterised by a coarse particle bed stream. The authors aim to contribute to the knowledge of bedload transport in mountain streams and to provide valuable information for the understanding of fluvial response to land cover changes.

2. Catchment characteristics

The Arnás catchment is located in the central part of the Spanish Pyrenees, in the basin of the upper Aragón River, a northern tributary of the Ebro River (Fig. 1). The main physiographic characteristics are reported in Table 1. The average annual rainfall is about 1000 mm, mostly concentrated in autumn and spring. Mean discharge during floods is above 0.2 m^3 s^{-1}. The bedrock is Eocene Flysh, with alternating sandstone and marl layers sloping northward. The W–E orientation of the ravine results in a strong contrast between the south- and north-facing slopes. In the former there are some old debris flows disconnected from the drainage network. The gentler, north-facing slope is characterized by old scars and tongues belonging to deep mass movements, nowadays inactive. The catchment was totally cultivated until the middle of the 20th century, then abandoned and affected by a process of natural plant colonisation with *Genista scorpius*, *Buxus sempervirens*, *Rosa* gr.*canina*, *Juniperus communis* and *Echinospartum horridum*. At present, the catchment is grazed by cows and sheep.

Sediment sources were mapped through field surveys, indicating that the main sediment contributing areas are the bare sections of the slopes flanking the main stream. These areas, where the Flysh lithology crops out, cover a surface of approximately 2200 m^2 and represent less than 1% of the catchment. The lack of vegetation and the occurrence of small slumps suggest that they are permanently eroded (González et al., 1997).

The main channel is narrow and totally covered with coarse material derived from the Flysh lithology, indicating that there is a constant bedload supply. The upper part is steeper and dominated by step-pool morphology, characteristic of mountain streams and considered as a very stable structure. The flatter and lower part of the stream is characterised by material that accumulates in relatively

Table 1
Main physiographic characteristics of the Arnás catchment

Catchment area (km^2)	2.8
Minimum elevation (m.a.s.l.)	900
Maximum elevation (m.a.s.l.)	1340
Mean slope gradient of the sunny aspect (%)	27
Mean slope gradient of the shady aspect (%)	16
Length of the main stream (m)	2400
Mean gradient of the main stream (%)	11
Mean annual precipitation (mm)	1000
Maximum water discharge measured (m^3 s^{-1})	4.2
Geology	Flysh
Forest cover (%)	20
Scrubs cover (%)	73
Grassland cover (%)	5.5
Bare land (%)	1.5