Magnitude-frequency analysis of bed load data in experimental Andean (Chile) and Alpine (Italy) catchments

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Abstract: The purpose of this study is to analyze and compare bed load transport during floods at the Rio Cordon (Dolomites, Italian Alps) and Rio Tres Arroyos (Chilean Andes) mountain catchments, on the basis of seventeen and six year data records, respectively. Bed load transport at the Andes site appears to be similar to the limited sediment supply period at the Alps site. Control on bed load volumes, exerted by sediment availability, and the persisting long-term impact of major floods on Alpine mountain streams is shown.

Introduction

Measurements of bed load transport in mountain catchments are scarce due to difficulties in carrying out investigations in these remote sites. Alternatively, appropriate bed load transport equations can be applied. However, few equations have been developed for steep boulder-bed channels. Furthermore, the use of these equations typically overestimates bed load transport since unlimited sediment availability is assumed and the presence of strong bed armoring is not considered. Hillslope and tributary processes may donate characteristics of unlimited or quasi-unlimited conditions. The degree of coupling between channel and hillslope processes is a key issue in mountain basins, because its variations over the years impart large interannual differences in bed load yield.

The aim of this paper is to analyze and compare bed load transport in two mountain basins; the Rio Cordon (Dolomites, Italian Alps) and the Tres Arroyos (Andes, central-southern Chile) catchments with, respectively, a seventeen and a six year long data record.

Short scientific paper

Methods

Some characteristics of both mountain basins are presented in Table 1 and are described in Lenzi et al. (1999; 2000; 2003), Lenzi (2001) and Iroumé (1997; 2003).

Runoff at the Rio Cordon site is usually dominated by snowmelt in May and June but summer and early autumn floods represent an important contribution to the flow regime. Usually, late autumn, winter and early spring lack noticeable runoff. At the Tres Arroyos site runoff is dominated by rainfall. During the April-September period more than 72 % of annual total precipitation occurs.

At the Rio Cordon site a fully equipped experimental station with broad monitoring facilities provided a 17 year record of continuous bed load transport. Measurements are taken by separating coarse bed load minimum size (20 mm diameter) from water and fine sediment. The measuring station consists of an inlet flume, an inclined grid where the separation of coarse particles takes place, a storage area for coarse sediment deposi-

Table 1. Main characteristics of the Rio Cordon and Rio Tres Arroyos basins

	Rio Cordon	Rio Tres Arroyos
Catchment area (km^2)	5.00	5.93
Minimum elevation (m)	1763	1080
Maximum elevation (m)	2748	1856
Length main stream (km)	2.84	3.5
Mean gradient main stream (%)	17	22
Annual precipitation (mm)	1100	2203
Maximum water discharge (m^3s^{-1})	10.4	14.0
Mean annual temperature (° C)	2.0	8.5

tion, and an outlet flume to return water and fine sediment to the stream. The volume of coarse bed load is measured at close time intervals of less than 10 minutes by 24 ultrasonic sensors fitted on a fixed frame over the storage area. Important sediment sources were produced in the mountain basin during September 1994 and May 2001. The water level gauging station at the Tres Arroyos basin corresponds to a natural section equipped with a pressure sensor and provides a six year discharge record. In this study, bed load transport is derived from water discharges during flood events by means of the bed load equation established by BATHURST ET AL. (1987). No record on landslides and debris flows are available and did probably not occur during the study period. The return intervals of water peak discharge and corresponding total bed load volumes were derived on the basis of one (Rio Cordon) or three (Tres Arroyos) maximum annual values. Best fit is determined with the use of STATISTICA 6® software.

RESULTS

A total of 20 and 71 floods occurred in the Rio Cordon (1987-2003) and Tres Arroyos (1998-2003) catchment. Best fit for peak discharge and bed load data resulted to be the lognormal and the logpearson Type III distribution (Figure 1).

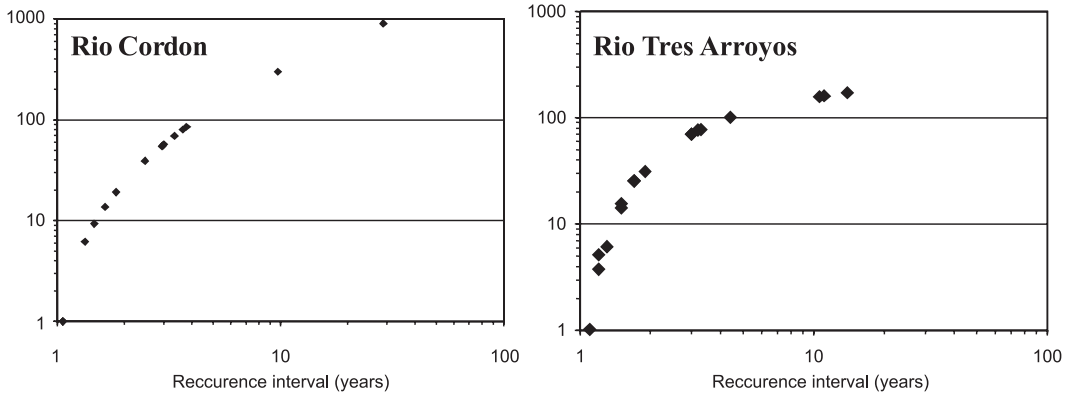

Fig. 1: Return time period of coarse bed load volumes versus return time period for both catchments.

The September 14th 1994 flood can be considered "exceptional", due to the high bed load rate and very high flow rate (Table 2). However, total bed load volume is elevated but not that extraordinary (return interval of 29 years). This event altered the stream geometry and the sediment-supply characteristics of the basin. Limited and unlimited sediment supply conditions are present before and after the September 1994 event respectively. Other important new sediment sources were produced on 11 May 2001 during an intense snowmelt event following a very snowy winter. A shallow landslide which then turned into a mud flow resulted in a debris fan, feeding the main channel at the Rio Cordon site. About 94 percent of all floods in the Rio Tres Arroyos catchment are ordinary (return interval of liquid peak discharge < 5 years). Ordinary events are estimated to transport variable volumes of coarse bed load material, ranging from irrelevant (0,5 m^3) to considerable amounts (161 m^3). This is caused by hydrograph characteristics, such as duration and/or mean hourly discharge, since coarse bed load transport is estimated on the basis of water discharge during each flood event. Mayor floods (n=4) occurred during southern hemisphere winter and coarse bed load transport was esti-

Table 2. Main hydrological and hydraulic features of the major recorded floods at Rio Cordon

	Q_p ($m^3 s^{-1}$)	BL (m^3)	T_{BL} (h)	BL_R ($m^3 h^{-1}$)	Q_{cr1} ($m^3 s^{-1}$)	Q_{cr2} ($m^3 s^{-1}$)
11/10/1987	5.2	54.8	8.0	6.9	1.80	3.80
03/07/1989	4.4	85.0	27.0	3.1	2.20	2.70
17/06/1991	4.0	39.0	20.0	2.0	2,00	2.40
05/10/1992	2.9	9.3	10.0	0.9	1.90	2.10
02/10/1993	4.3	13.7	6.0	2.3	2.30	3.70
18/05/1994	1.8	1.0	12.0	0.1	1.60	1.61
14/09/1994	10.4	900.0	4.0	225.0	1.80	3.30
13/08/1995	2.7	6.2	1.0	6.2	1.80	2.00
16/10/1996	3.0	57.0	15.0	3.8	1.80	2.00
07/10/1998	4.7	300.0	17.0	17.6	1.98	2.50
20/09/1999	3.7	19.2	6.4	3.0	1.68	1.98
12/10/2000	3.3	55.6	35.0	1.6	1.23	1.56
11/05/2001	1.5	80.0	13.0	6.2	1.14	1.33
20/07/2001	2.0	20.9	4.7	4.5	1.59	1.64
04/05/2002	2.3	27.4	20.0	1.4	1.51	1.55
16/11/2002	2.3	10.1	14.5	0.7	1.55	1.57
27/11/2002	2.8	69.1	30.0	2.3	1.55	1.82

Q_p: peak discharge; *BL*: coarse bed load volume; T_{BL}: duration of coarse bed load transport; BL_R: mean bed load rate; Q_{cr1}: critical discharge for bed load entrainment; Q_{cr2}: end of bed load transport critical discharge.

mated to range from 77 to 172 m^3. Coarse annual sediment transport at the Rio Cordon (n=17 years) accounts for 57 % of mean bed load at the Andes site (n=6 years). Bed load volumes at the Andes site are estimated assuming unlimited sediment supply, a condition that is hardly plausible, and as a consequence are typically overestimated. It is suggested that sediment transport at the Tres Arroyos catchment is not necessarily higher compared with the Rio Cordon site. Mean bed load transport at the Rio Cordon site (Q_{mean} = 109 m^3, n = 16, Stdev = 55.54) is higher and more variable on an event basis compared with the Andes site (Q_{mean} = 30 m^3, n = 38, Stdev = 7.64). However, when only floods before the 14 September 1994 event are considered, bed load transport is similar for both sites (Rio Cordon: Q_{mean} = 40 m^3, n = 5, Stdev = 13.92). This indicates that sediment transport amounts and conditions at the Andes site are similar to the period during which sediment supply was limited at the Alps' site.

CONCLUSIONS

Bed load transport at the Andes site appears to be similar to the limited sediment supply period at the Alps site. Control on bed load volumes, exerted by sediment availability, and the persisting long-term impact of major floods on Alpine mountain streams is shown.

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