Non-linearity in erosion response of a small mountainous and marly basin: the Laval in the Draix experimental catchments, South East, France.

Mathys N.*, Richard D.*, Grésillon J.M.**
*Cemagref Grenoble, BP 76, 38402 Saint Martin d'Hères, France
** Cemagref Lyon, 3bis Quai Chauveau, CP 220, 69336 Lyon Cedex 09, France
Corresponding author : nicolle.mathys@grenoble.cemagref.fr

Abstract
The Draix experimental basins are located on black marls, a very erodible outcrop where erosion and gullying result both in a badlands topography and high levels of solid transport. The sediment yield measured for 16 years at the outlet of the Laval basin (0.86 km^2) reveals that the erosion response to a rainfall event is highly nonlinear. Two field experiments (topographical surveys and use of marked pebbles) have highlighted the importance of deposition and scouring processes in the channel network.

INTRODUCTION

In the southern French Alps, the Black Marl formation, or "Terres Noires" in French, covers a large area. Subjected to Mediterranean and mountainous climate, with freezing in winter and high-intensity rainfall in summer, erosion and gullying in this erodible outcrop produce both a badlands topography and high levels of solid transport, bringing heavily loaded floods downstream and silting up reservoirs. This type of landscape is found throughout the Mediterranean Sea area, where it poses a number of management problems. Many studies that have been done in badlands terrain in southern Europe, on research basins such as Tabernas (Canton et al., 2001; Sole-Benet et al., 1997) and Valcebre in Spain, and "calanchi" in Tuscany, Italy (Torri et al., 1999), demonstrated the variability of this terrain's erosional response to a rainfall event. The Draix experimental basins have been monitored since 1984 in order to quantify and analyze the erosion process in small basins in this kind of badlands terrain, not only on an annual scale, but also during individual events (Richard and Mathys, 1999). The data sets of the observation period brought out the non-linearity of the catchments' response to rainfall events. Field experiments in the main reach of the Laval basin, with a sparse vegetation cover of 32%, were carried out in 1993, from March to September, to study the main effect of deposition and scouring processes in the channel network.

METHODS AND DATA

Each watershed is equipped for rainfall, discharge and sediment yield measurements (Richard and Mathys, 1999). The sediment production of a basin is measured at the outlet for each storm event: the coarser part of the sediment yield is measured in a sediment trap, the finer part is sampled in the gauging section or monitored continuously with an optical fiber sensor.

From March to September 1993, additional field measurements were conducted. First, the distance traveled by individual pebbles during floods was measured. These natural or artificial pebbles were labeled by magnets so that they could be recovered with a magnetometer. The artificial pebble sample was always installed in the same starting cross section, situated about 1 km upstream of the sediment trap; six recovery surveys were done after different flood sequences. Second, topographical surveys were carried out along a 1-km distance of the stream after each large flood. From the digital elevation models built with these topographical data, it was possible to evaluate the variations in the sediment stocks in the different parts of the main stream.

RESULTS AND DISCUSSION

Non-linearity of erosion responses to rainfall inputs

Figure 1a shows that there is no relationship between the total amount of rainfall and the corresponding volume of sediments deposited in the sediment trap. Figure 1b illustrates that this non-linearity is also observed with the peak discharge of the flood, despite certain limits in this observation: the four floods over 10 m^3/s brought more than 400 m^3 of sediment and all the floods under 0.5 m^3/s brought less than 300 m^3. However, for floods between 1 and 5 m^3/s, the deposits ranged from 20 to 700 m^3. The highest value (865 m3 for 186 mm of rain) corresponds to a long flood in autumn (20/11/96) with a moderate peak discharge (0.6 m^3/s). But from February to June 1985, 338 mm of rain, generating four floods lower than 1 m^3/s, brought only 170 m^3. In April 1993, two storm events (1.1 and 0.5 m^3/s) deposited 560 m^3, for a total amount of rain of 136 mm. Therefore, the rainfall input and the runoff characteristics are not sufficient to explain the sediment production at the outlet of the catchment: the availability of sediments in the basin also plays a major role.

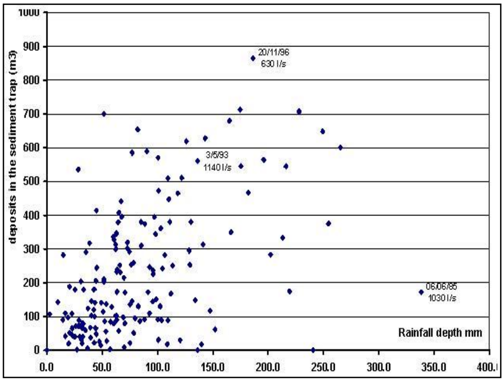

Fig 1a: Deposit in the trap versus rainfall

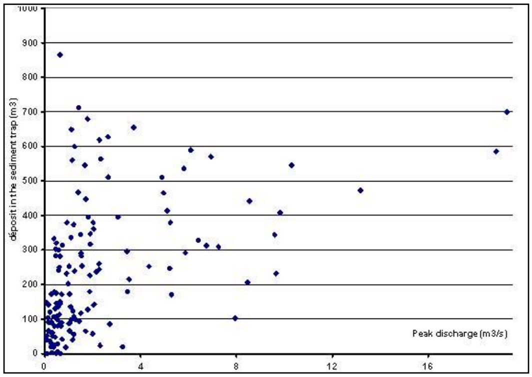

Fig 1 b:Deposit in the trap versus discharge

Travel distance of individual pebbles

The samples surveyed were composed of 45 and 103 pebbles, ranging from 2 to 10 cm in diameter, from which 93–100% were recovered at each survey. Figure 2 presents the rainfall and flood sequence of the period, with the dates of the surveys. No relation was found between the pebble weight and the final longitudinal position, except during the 01/09/93 recovery where a tendency for longer travel distances for heavier particles was observed. The travel distances of the entire sample, with no distinction in size, are shown in Fig. 3. Six surveys were conducted after the six main floods of the period, with at times secondary small floods during the interval studied. The three smaller floods (0.7 to 1.1 m^3/s of peak discharge) left 30–55% of the pebbles in the upper section and carried less than 32% to the sediment trap. The highest flood (15/8, 5.2 m^3/s) left a few marked blocks in the upper stream and deposited 45% all along the main channel. This flood was induced by intense summer storms and presented two secondary peaks (3.7 and 2.1 m^3/s), but the duration of the flow was short. The deposit in the sediment trap was only 250 m^3, nearly the same as the volumes recorded for the two other storm events in May and July. The long rainfall event of September 23rd, with a lower peak discharge (2.4 m^3/s), had a different effect: no marked pebble remained in the origin section, nor were any deposited in the upper stream: most of the sample was transported down to the sediment trap.

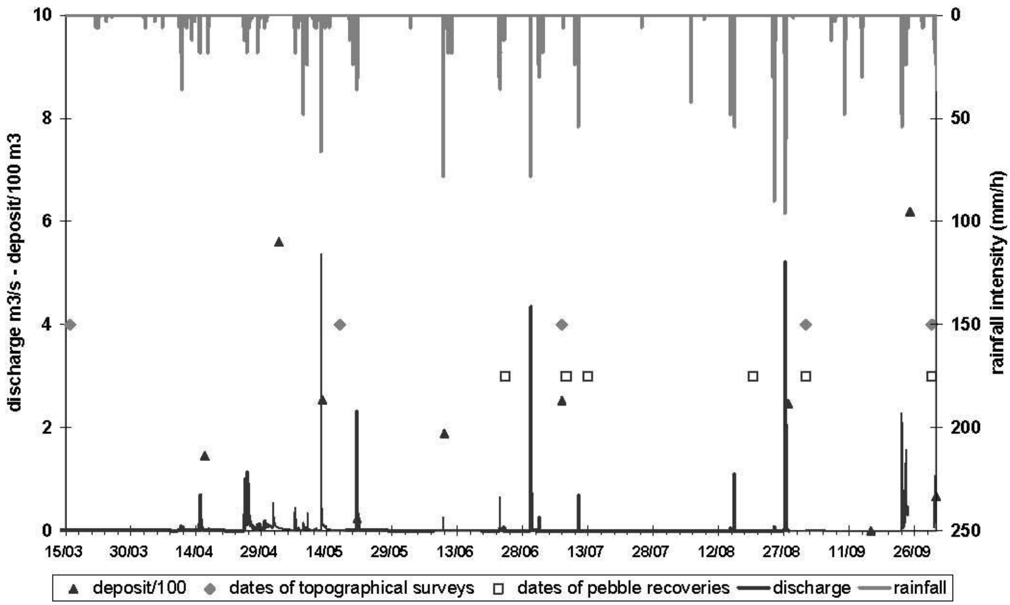

Fig 2: Flood sequences and measurements of spring and summer 1993

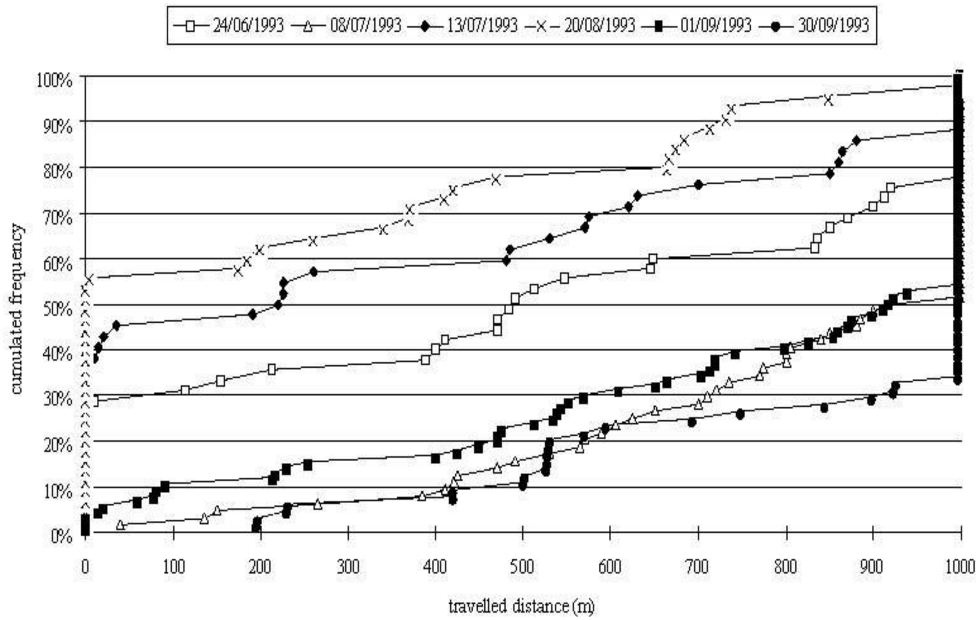

Fig 3: Travel distance of individual pebbles

Topographical surveys of the main channel

Table 1 summarizes the results of the five surveys for the nine sections of the channel and for the total deposits in the sediment trap during the same periods. These results make it possible to analyze the erosion–deposition–scouring processes:

During the first period, five flood events brought a great amount of sediment downstream, principally from the slopes, and scoured some material in the main channel. From 17/5 to 7/7, the flood sequence, including a major event of 4.5 m^3/s, yielded moderate volume in the sediment trap but increased considerably the stock in the reaches. The flash floods occurring in summer (three events, one of which was over 5 m^3/s) transported a limited volume in the trap and eroded a part of the previous deposits in lower streams of the channel. New deposits from the slopes or from secondary gullies increased the volume deposited in the upper section. A single, long-lasting event in September removed a great amount of sediment in these stocks all along the channel. These results are consistent with the recoveries of the pebbles described above. They are confirmed by the series of photographs taken in the main channel during all the experiments, as shown in Fig. 4: this BF8 section was full of sediment on September 1st and completely emptied down to the bedrock on September 30th.

Table 1: volume variations in the sediment trap and in the reaches

period	deposit in the sediment trap	total variation in the main stream	yield from slopes and upper channels	Total rainfall of the period	variation in the reaches (m^3)									
					reach n°	BF1	BF2	BF3	BF4	BF5	BF6	BF7	BF8	BF9
					length (m)	100	74	57	46	179	108	149	116	113
	m^3	m^3	m^3	mm	distance from upstream (m)	942	842	768	711	665	486	378	229	113
16/03 - 17/05	960	-136	824	278.9		-10	6	-14	-12	-32	-32	-33	-1	-7
17/05 - 07/07	465	671	1136	125.5		32	6	205	195	42	100	12	6	74
07/07 - 01/09	250	-52	198	93.9		0	-7	-104	-14	58	-112	43	46	37
01/09 - 30/09	620	-371	249	155.0		-18	-18	16	-14	-57	-54	-84	-56	-86

1/09: Deposits in the Laval channel

30/09: Bedrock outcrop after a long flood

Fig. 4: Deposition and scouring processes in a reach

CONCLUSION

This study revealed the importance of the temporary deposits in the channels in explaining the non-linearity of the basin's erosion response to a rainfall event. The season of occurrence also appears to be very important, with a tendency for the main reach to deposition in spring and early summer and to erosion at the end of summer and autumn. On the annual scale, these phenomena often cancel each other out, which explains that annual sediment yield is relatively well correlated with annual rainfall (Richard and Mathys, 1999), while it is not on the event scale. However, it is necessary to complete field surveys by observation on sediment stocks in the secondary network of the basin and on the slopes. This work is now being carried out by several teams at the Draix experimental site.

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