# EROSION PROCESSES AT THE GULLY SCALE: OBSERVATIONS, QUANTIFICATION AND INTERPRETATION OF FIELD DATA FROM THE DRAIX LABORATORY

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## 1. Introduction

In the Southern French Alps, the black marls formation covers a large area and is highly susceptible to weathering and erosion. It has a badlands topography and is subject to high solid transport, bringing high sediment yield downstream and silting up reservoirs. Many studies have been carried out in southern Europe and North Africa evaluating sediment yield from this type of basin. However, most of these studies provide information on the average annual rate and only a few studies focus on the sediment response to a specific rainfall event (Canton et al., 2001). Scale is important in the study of erosion processes and quantification of sediment production (de Vente and Poesen, 2005). This paper focuses on erosion at the slope and gully spatial scale and at the event temporal scale.

## 2. Material and Methods

Since 1983, the Cemagref has been monitoring a group of four small basins, with a surface area ranging from 1330 m? to 1.08 km?, in order to study the processes and factors that influence the production, storage and transfer of water and sediments in marly basins and their network. The smallest, called Roubine (1330 m?), is well adapted to the study of erosion processes at the slope and gully scale (Fig. 1). The vegetation cover is limited and gathered at the top of the basin, the hydrographic network is simple and allows for no or very little intermediate sediment storage.

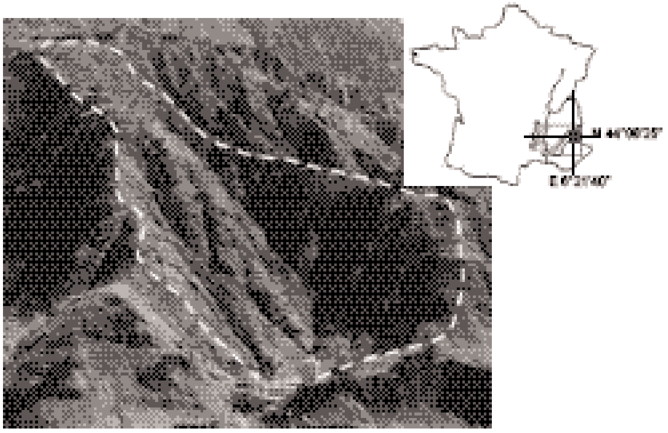

**Fig. 1.** View and location of the study site.

The basin faces west, the altitude ranges from 848 to 885 m, with very steep slopes (40–45°). The substratum is Callovo-Oxfordian marls with dips facing north at 40°. As a consequence, most of the marl surfaces are perpendicular to the bedding and steep, which is the most favourable situation for infiltration, weathering and erosion (Mathys et al., 2005).

A rainfall recorder measures the precipitation close to the gully with 0.2-mm accuracy. The gauging control section is a V-shaped weir equipped with two level-recorders (one floating device and one numerical ruler). A sediment trap upstream of the gauging station retains the coarse material. The measurement of the deposited material, with a bucket for low volumes and a topographic method for larger deposits, gives the global amount of transported bed-load material. Downstream of the sediment trap grid, an automatic sampler takes samples during floods with a program recording both the water level and the time lag between two samples.

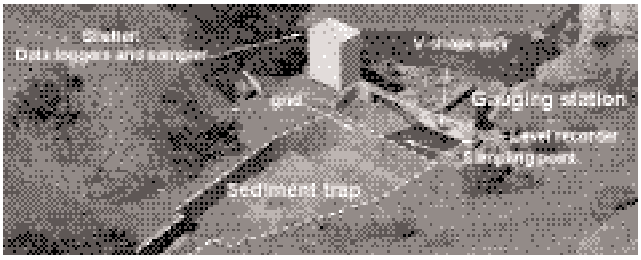

**Fig. 2.** Measurement device at the outlet of the basin.

Other measurements were conducted occasionally or for shorter monitoring periods:

- soil temperature for different soil depths and aspects,
- properties of the weathered layer such as vertical profile and grain size distribution, and
- water content, bulk density, and grain size distribution of the deposits in the sediment trap.

For the 1985–2003 period, 1016 rainfall events (over 5 mm of total rainfall or over 30 mm $h^{-1}$ in 1 min) were registered, 472 produced runoff at the outlet and 373 yielded measurable erosion. A total of 288 sediment trap measurements are available: 196 for a single event and 92 corresponding to two to nine successive rainfall events. Two hundred and five floods were sampled for suspended sediment.

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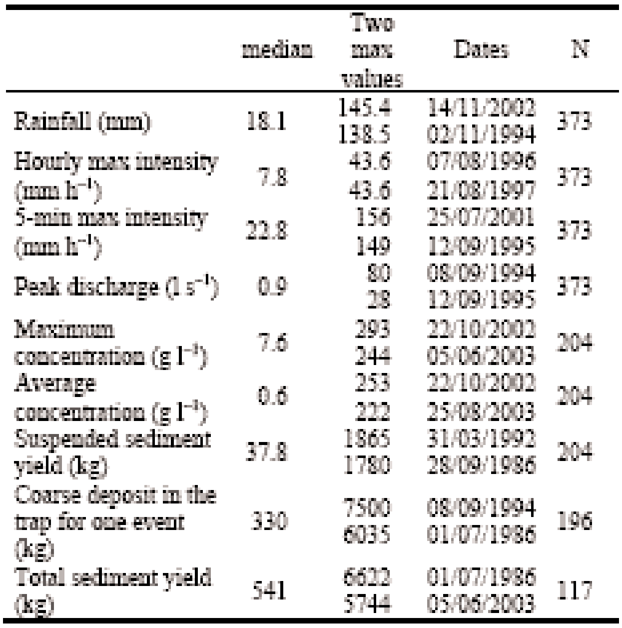
## 3. Results and discussion

Table 1 summarizes various features of the rainfall-runoff-sediment yield data (N is the size of the data set). The large difference between the medians and the maxima highlight the role of the major events in the sediment yield. For the 19 years of the study period, the 19 highest values represent 33% of the total production of the period.

**Table 1.** Range of values for the main features of the events studied.



| | median | Two max values | Dates | N |
|---|---|---|---|---|
| Rainfall (mm) | 18.1 | 145.4<br>138.5 | 14/11/2002<br>02/11/1994 | 373 |
| Hourly max intensity (mm h$^{-1}$) | 7.8 | 43.6<br>43.6 | 07/08/1996<br>21/08/1997 | 373 |
| 5-min max intensity (mm h$^{-1}$) | 22.8 | 156<br>149 | 25/07/2001<br>12/09/1995 | 373 |
| Peak discharge (l s$^{-1}$) | 0.9 | 80<br>28 | 08/09/1994<br>12/09/1995 | 373 |
| Maximum concentration (g l$^{-1}$) | 7.6 | 293<br>244 | 22/10/2002<br>05/06/2003 | 204 |
| Average concentration (g l$^{-1}$) | 0.6 | 253<br>222 | 22/10/2002<br>25/08/2003 | 204 |
| Suspended sediment yield (kg) | 37.8 | 1865<br>1780 | 31/03/1992<br>28/09/1986 | 204 |
| Coarse deposit in the trap for one event (kg) | 330 | 7500<br>6035 | 08/09/1994<br>01/07/1986 | 196 |
| Total sediment yield (kg) | 541 | 6622<br>5744 | 01/07/1986<br>05/06/2003 | 117 |

### 3.1. Suspended sediment yield

For the data of all the events, there was no relation between sediment concentration and flow discharge, but for one event, as commonly described, hysteresis curves were observed (Alexandrov et al., 2003; Soler et al., 2006). Three types of curve were found: clockwise (type 1), anti-clockwise (type 2) and figure-eight shaped or complex (type 3). These three types were found for all the levels of sediment production, but the high concentrated floods were mainly type 2. The seasonal pattern shows that spring floods were mainly type 1 and June–October (except September) floods were mainly type 2. The rainfall intensity and the peak discharge were the main factors explaining sediment concentration, whereas the depth of the intense fraction rainfall and the runoff volume of the 5 min of maximum discharge explain the total yield.

### 3.2. Coarse sediment yield

The average amount of sediment deposited in the trap per year is 9 m$^3$ or 10 kg y$^{-1}$ m$^{-2}$ (bulk density 1.5 Mg m$^{-3}$). Many events with high rainfall depth produced low or no deposit, whereas a moderate rainfall amount could yield a huge amount of coarse sediment. For the trap volumes corresponding to a single event, the deposited volume was correlated with the peak discharge (R = 0.7), but several low discharges yielded high amounts of deposit and most of the corresponding events were in spring.

### 3.3. Total sediment yield

The total sediment yield was related to both the peak discharge of the event and the amount of intense rain (threshold, 15 mm h$^{-1}$), but in some cases these variables considerably underpredicted the erosion (Fig. 3). This occurred mainly in spring when the weathered mantle was very thick because of freez–thaw processes in winter and debris accumulation in the gully bottom. The ratio of suspended sediment in the total yield was 15% on average and 20% in cumulated amount, but reached 50% for a few events. The most productive months were July–September due to the number and high yield of storms, followed by May and March with rarer productive events.

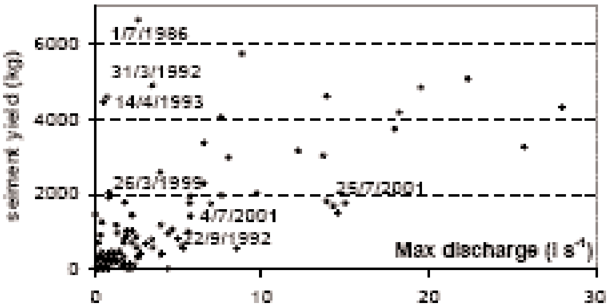


**Fig. 3.** Sediment yield–discharge relationship.

The analysis conducted on 19 years of rainfall-runoff-erosion data and field observations allows us to propose an erosion production model at the gully scale in marly badlands catchments. A seasonal pattern was observed with the renewal of the weathered mantle in winter, substantial displacement of material with spring events, high production of numerous and intense summer storms, and a decrease in sediment availability in autumn. The detailed succession of the different successive processes within a storm needs to be investigated further.

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