Erosion and fluvial sediment supply in undisturbed and cultivated basins: the case of the Desix and Maury river basins (western Mediterranean area)

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Abstract Two small neighbouring rivers basins (western Mediterranean area) were compared: the Maury and the Desix rivers which belong to the Agly River basin (1045 km^2). In this area, the climate is characterized by a marked contrast between dry and humid conditions, with the occurrence of torrential downpours during only a few days of the year. As a result, the bedload and nearly all the suspended sediment load are transported during given events. The main difference between these two catchments is the land-use patterns: viticulture and garrigue (a typical Mediterranean vegetation type) are mainly growing at the Maury basin, while forest occupies the main part of the Desix basin. As a consequence, erosion marks are clearly visible on the bare slopes of the Maury basin. This river provides an important suspended sediment load and a great part of bedload to the Agly River.

Key words bedload; erosion; fluvial dynamics; land-use; Maury and Desix rivers; Mediterranean area

INTRODUCTION

During recent years, river basins were studied using an approach which requires integrated studies based on multipurpose investigations (Snishchenko, 1992; Ludwig & Probst, 1996; Bobrovitskaya & Zubkova, 1997). It consists of understanding and linking different factors, from the local to the entire basin scale, including the fluvial dynamics (Hadley *et al.*, 1985; Ludwig & Probst, 1998; Serrat, 2003). In this paper we suggest linking different physical characteristics of two catchments, with their sediment supply at the outlet. For that, a mid spatial scale was selected, and we studied the Desix and the Maury basins, located in a Mediterranean environment. The main features of the physical patterns of these catchments have been compared (altitude, slope, drainage density, etc.). One of the main differences between both sub-basins is the land cover. The ground surface conditions of the basins may therefore affect the river sediment supply. The purpose of this study is: (a) to evaluate the influence of the viticulture on slope erosion; and (b) to identify the relationships between erosion and sediment supply. For that, the composition of bedload at the mouths of the Desix River and the Maury River has been studied, as well as their respective supply to the main river.

STUDY AREA

This comparative study is focused on the Desix and the Maury basins, which belong to the Agly basin (1045 km^2), located in the northeastern boundary of the French Pyrenees (latitude

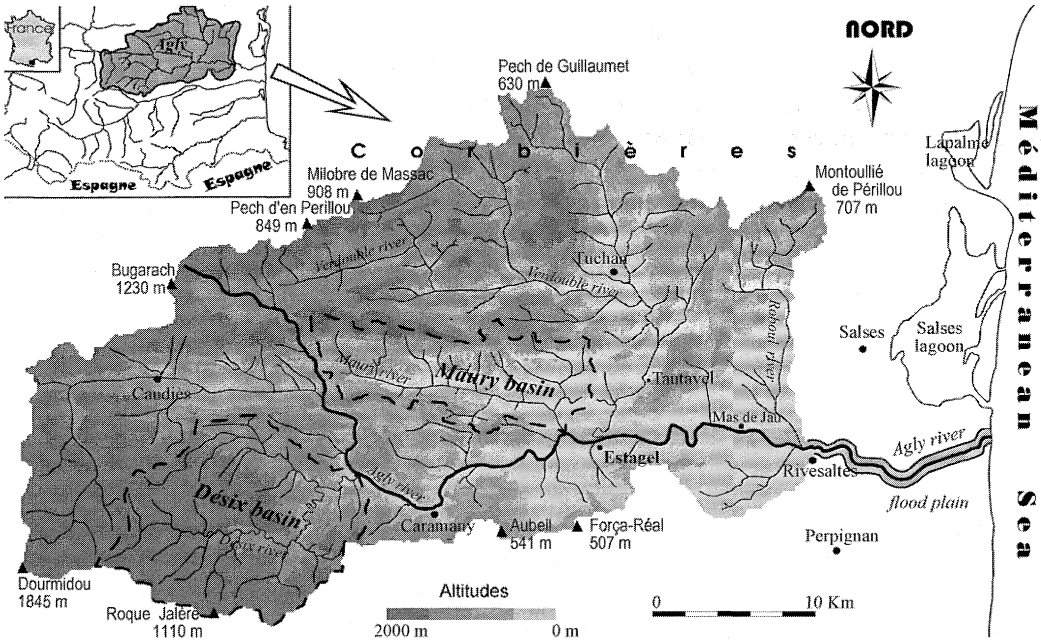

Fig. 1 Location map of the Agly basin and its sub-basins.

N: 42°40′/42°59′; longitude E: 2°16′/3°02′). Structural and tectonic features have a great impact on the Agly drainage network, stretched in an east–west direction (Fig. 1).

The average elevation of the Agly drainage basin is 397 m and the average slope 18.5°. The main part of this basin is underlain by compact limestone from the Jurassic and Cretaceous periods. The annual rainfall is about 700 mm for the whole basin compared to only 579 mm at Perpignan (1946–1996), which is the main regional city near the Mediterranean coast line. A major part of precipitation can occur during storm events (for example 304 mm in 6 h on 13 October 1986 at Torreilles), which cause heavy floods (MISE, 1993; Rigo & Llasat, 2003). These flash floods that only last a few hours are terrible for the population and are well-known in this region (Pardé, 1941; Serrat, 2001). While the mean annual flow of the Agly River is 6.1 $m^3 s^{-1}$ (1969–1997), floods can reach over 2000 $m^3 s^{-1}$, as occurred on 12–13 November 1999. Thus, the Mediterranean region is often affected by strong erosion processes, and fluvial dynamics depend on several basic conditions, such as basin morphology, land-use and vegetation cover.

CHARACTERISTICS OF THE MAURY AND DESIX BASINS

Morphology and hydrology

The morphology of the Agly River basin has been obtained from a Digital Elevation Model (10 m grid). The main morphological characteristics of the Agly basin and sub-basins including the Maury and Desix rivers basins are presented in Table 1. Drainage network is derived from the Digital Elevation Model. The Maury and Desix basins are characterized by

Table 1 Morphological characteristics of local river basins.

	Agly	Verdouble	Boulzane	Desix	Maury	Roboul
Basin area (km^2) - (A)	1045	317	156	143	87	66
Basin perimeter (km) - (P)	196	91	63	51	49	43
Compactness index (Ki)	1.71	1.44	1.42	1.20	1.48	1.49
Maximal altitude (m)	1845	964	1845	1542	964	707
Mean altitude (m)	397	370	739	697	241	245
Mean slope (degrees)	10.50	12.20	18.50	13.60	9.70	6.70
Relief aeration index (I_A)	4.60	2.60	2.50	2.20	4.00	2.90
Main drain lenght (km)	73.20	42.80	33.80	31.60	19.80	21.2
Drainage density	1.77	1.76	1.68	1.79	1.98	1.67

Compactness index : $Ki = P\,(2\sqrt{\pi A})^{-1}$ Relief aeration index $I_A = Alt_{max} / Alt_{mean}$

high drainage densities. The slope gradient is more important for the Desix (13.6°) than for the Maury basin (9.7°). The torrential hydrology of some rivers (the Boulzane River, the Desix River, the Maury River) can be explained by their morphological characteristics.

According to recent observations (1995–2000) mean annual water discharge at the outlet the Desix River is 1.7 $m^3\ s^{-1}$. However, maximum observed water discharges were about 250 $m^3 \cdot s^{-1}$ (e.g. on 26 September 1992 and 16 December 1996). The flood levels arise very quickly because of steep slopes and the circular configuration of the basin (Serrat & Depraetere, 1997).

Unfortunately, there is no gauging station on the Maury River. According to data (period observation 1968–1997) from neighbouring gauging stations located within basins with similar morphological characteristics, the mean annual water discharge of the Maury River may be about 1.1 $m^3\ s^{-1}$. Similar to the Desix River, flash-floods occur in the Maury basin, with maximum estimated water discharge up to 500 $m^3\ s^{-1}$ on the 12 November 1999, when a rail track near the river was completely destroyed.

Vegetation and land use

In many parts of the world, it has been shown that vegetation, land cover and agriculture practice have severe consequence on erosion and sediment delivery to the fluvial system (e.g. Johnson, 1988). In this study, in order to characterize the land cover of the two basins, remote sensing data were used (CNES Spot-Image). Spectral and reflectance analysis allow the quantification of the biomass which covers and protects the soil from erosion. The digital data result from the computation of the NDVI (Normalized Difference Vegetation Index) given by the equation:

$$NDVI = (N_{IR} - R) / (N_{IR} + R) \qquad (1)$$

where N_{IR} is near infra red (0.79–0.89 μm) and R is red (0.61–0.68 μm).

These data have been completed by a supervised classification. This involved identifying a set of sample locations that have been visited in the field. The land cover mapped in the field was then compared with the one mapped in the image at the same location. To simplify, we considered that the signature analysis produced three groups of vegetation: a set of conifer forest and beech grove; the olm oak forest; and the garrigue and the vineyards.

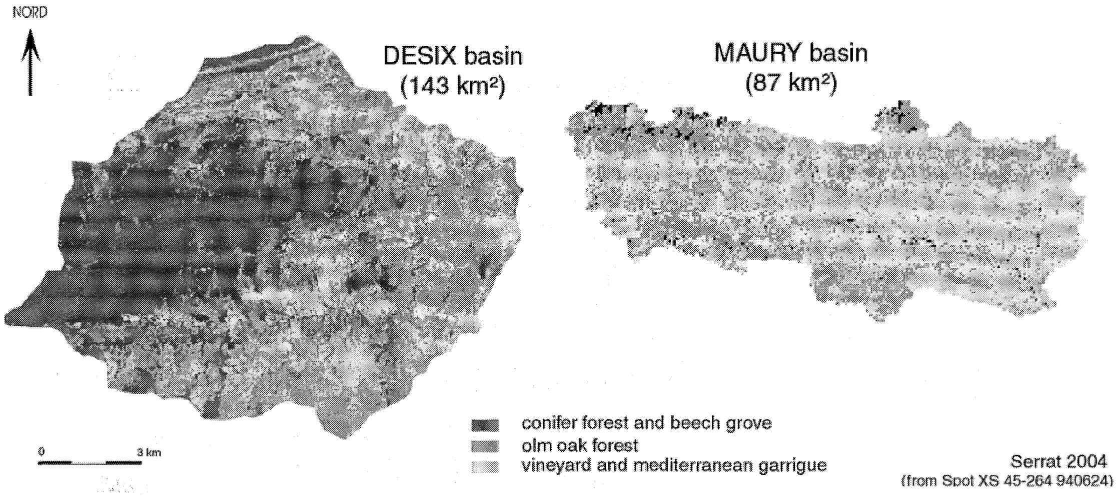

Fig. 2 Land cover maps of the Desix and the Maury basins from remote sensing data (CNES-Spot-image).

Table 2 Land cover of the studied basins (Desix and Maury).

Basin	Conifers, beech grove	Olm oak forest	Garrigue, vineyard
Desix	58.9 km^2 (41.2%)	60.8 km^2 (42.5%)	23.2 km^2 (16.3%)
Maury	1.6 km^2 (1.8%)	27.9 km^2 (32.1%)	57.5 km^2 (66.1%)

These three groups make up three different heights of vegetation and as many types of protection against the intensive rainfalls which occur between September and February at Mediterranean region. Height and density of vegetation play an important role in the processes of interception of the drops and their high fall velocity.

The Maury basin area is mainly covered by vineyards and garrigue. A main part of the Desix basin is covered by different forests (Fig. 2, Table 2). A striking feature is the opposition for the third group (garrigue, vineyards) between the Maury and Desix basins. So, what are the consequences on erosion and sediment supply?

IMPACTS OF LAND USE: EROSION, SUSPENDED SEDIMENT AND BEDLOAD

We investigated erosion, suspended sediment and bedload, using different approaches in order to study their relations with the land cover.

Slope erosion

In the Desix basin, forests occupy a greater area and ensure an efficient protection of the ground against heavy rainfall. Except for vineyards in the bottom valley sides, there are only few erosion marks.

Fig. 3 Gully erosion in the vineyard of the Maury basin.

On the other hand, overland flow and rill erosion were frequently observed in the Maury basin. Gullies of 0.5 m depth have been often observed on many parcels of vineyard (Fig. 3) This has been observed, in relation to specific conditions, in other areas of the world (Mura *et al.*, 1988). Studies of these processes allow an understanding of why the suspended matter is so important at the outlet of the Maury River.

Suspended sediments

Sediment concentrations of the Desix River are 0.3–0.9 g l^{-1}. Up to now, sediment fluxes are not available because of an insufficient number of samples and too short a period of flow observation.

During floods events of the Maury River, high concentrations were measured (2.1–4.8 g·l^{-1}). At the confluence with the Agly River, the colour of the Maury River water was very brown and this high density of the flow did not allow mixing with the main river water (Fig. 4). For the entire Agly basin the mean total suspended sediment is 107 t $year^{-1}$ for the period 1968–1997 (Serrat, 2003). The X-ray analysis of clay minerals reveals for the Maury River >10% illite and 52% of quartz, which means a strong degree of erosion. However, these values are low for the Desix and Agly rivers downstream (Table 3).

Bedload

A petrographic study of bedload was initiated for evaluating the respective sediment input of each tributary to the main river. Nine sites were investigated in order to study the

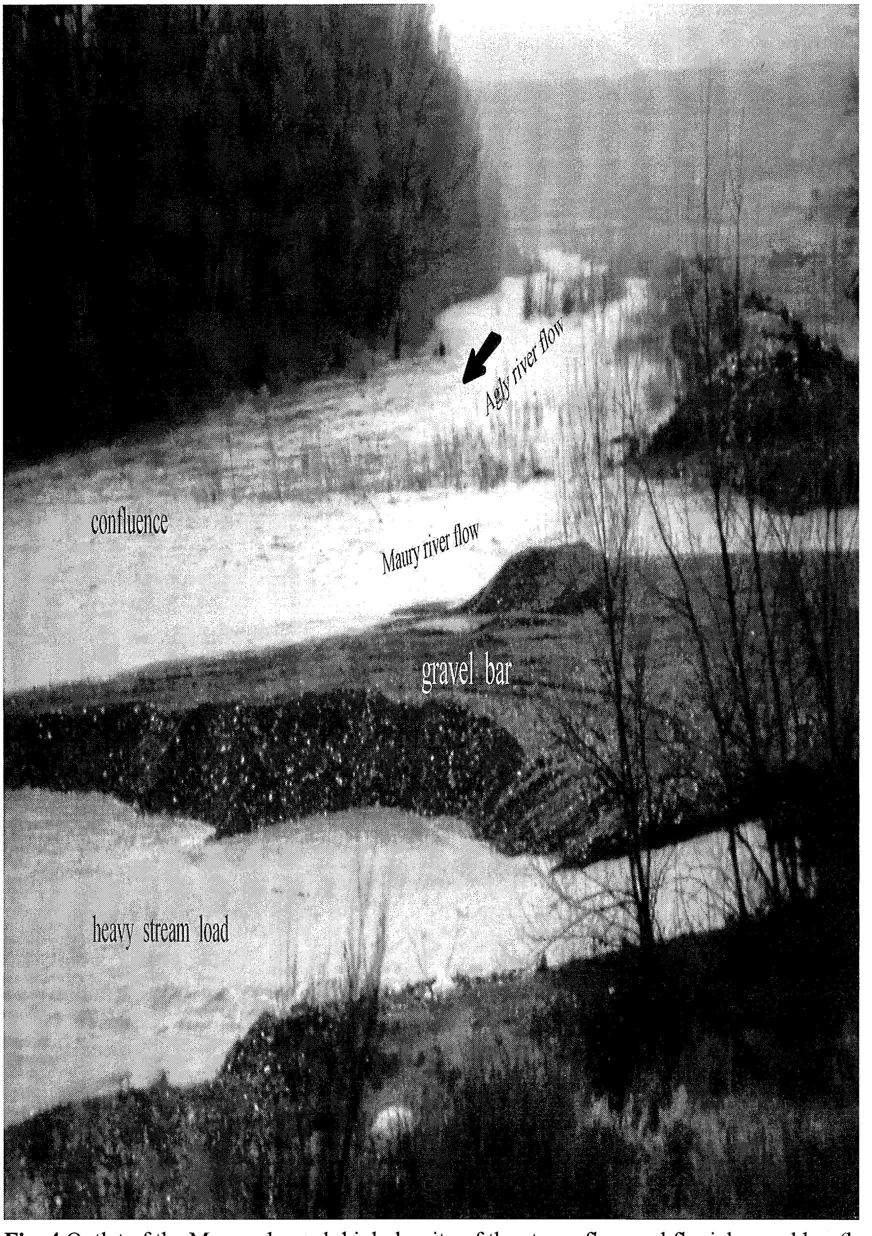

Fig. 4 Outlet of the Maury channel: high density of the streamflow and fluvial gravel bar (bed transport) carried during floods in December 1996.

Table 3 X-ray analysis of suspended sediments (clay minerals in %).

Basin	Smectite	Illite	Kaolinite	Chlorite	Quartz	Feldspar	Carbonates	Total
Desix	6.3	3.8	2.4	1.2	35.2	21.5	29.6	100
Maury	0.2	10.4	0.2	0.3	52.1	0.7	36.1	100
Agly downstream	1.5	9.9	0.7	0.8	26.6	2.0	58.5	100

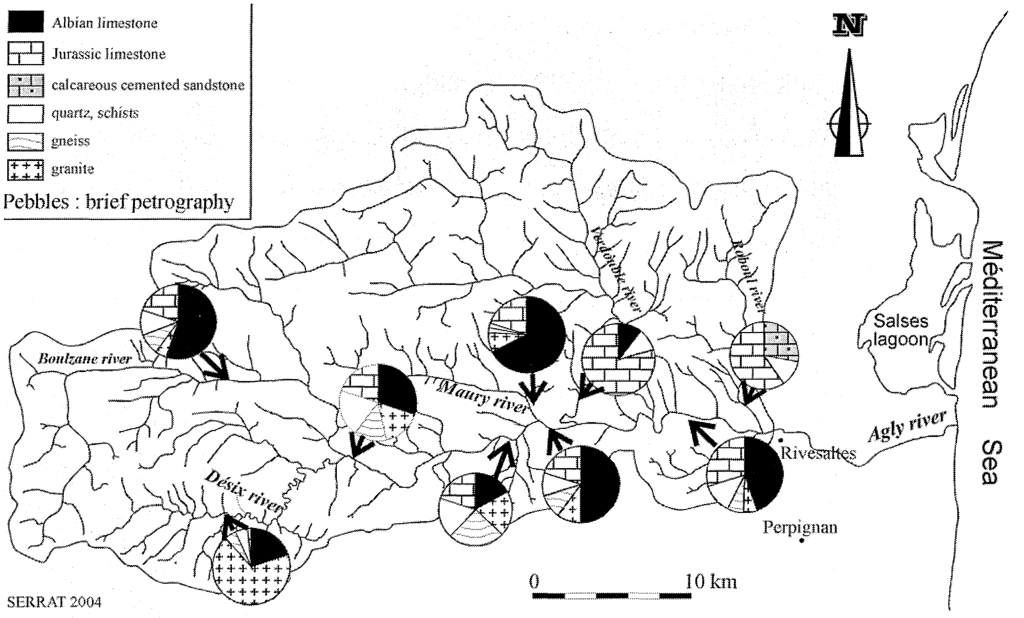

Fig. 5 Petrography of gravel and pebbles along the Agly River and its tributaries.

percentages of rock types. The best tracer is Albian limestone, pebbles of which are well represented in the Maury riverbed and downstream in the Agly River. It is possible to conclude that an important part of bedload enters from the Maury basin (Fig. 5). For the entire Agly basin, bedload is 1000 t year^{-1}, obtained by bathymetric measurements from 1991 to 1999 in a small retention dam near Rivesaltes (Serrat, 1999). By taking this result and using numerical values of repartition of pebble petrography shown in Fig. 5, we solved a system of four equations. The bedload of the Maury River was estimated: 300 t year^{-1}, including 210 t year^{-1} of Albian limestone. As a confirmation of this result, after the high flood of December 1996, we find a new bar of coarse sand and gravel at the outlet of this basin, with a volume of 1100 m^3 (Fig. 4). If we considered the results of Reid & Dunne (1996) and also observed suspended sediments downstream in the Agly River (Serrat, 1999), the expected percentage of bedload in total load is only 2%. The Maury basin provides about 15 000 t year^{-1} (172 t km^2 year^{-1}), which represents about 15% of the sediment supply of the entire Agly.

CONCLUSION

Although further studies should be done, this work is a first step towards understanding the erosion processes involved in the Agly basin. Erosion is significantly greater on unprotected soils of the Maury basin than on the forested soils of the Desix basin. In the Maury basin, thin soils contribute to low infiltration capacities, and during periods of heavy rain, overland flow has been frequently observed. Mineral tracers such as carbonates for suspended sediment, and Albian rocks for bedload, confirm the importance of sediment supply provided by the small Maury basin (87 km^2). The anthropogenic factors are dominant. The Desix basin, which has a greater area (143 km^2), higher mean altitude and more steep slopes, provides less sediment load. Further studies should be undertaken: small runoff-erosion plots will be used to assess soil loss in undisturbed forest conditions and in vineyards. As a general rule, viticulture leads to important soil loss (e.g. Loughran *et al.*, 2000). In the south of France, intensive viticulture, which originates from the mid 19th century, is perhaps unsustainable under long-term clean-till management practices.

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