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SHORT-TERM SEDIMENT BUDGET FOR A SMALL DRAINAGE BASIN IN A MOUNTAINOUS ABANDONED FARMING AREA

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ABSTRACT A sediment budget has been evaluated since early 1989 for a 16.65 ha drainage basin located in the Eastern Pyrenees (Spain). This small basin was selected as a representative of mountain areas on clayey bedrock prone to mass movements and gully erosion, strongly modified by past farming activity. The particulate sediment yield at the outlet is very low and derived from the stream banks and bed, while the higher amounts of sediment moved on the hillslopes do not reach the drainage system.

INTRODUCTION

Improving knowledge of the relationships between the different components of the erosion-transport-deposition drainage basin system is not only a theoretical challenge but can also represent the best way to analyze land conservation problems (Bordas & Walling, 1988).

Within the Project no. 6 of the CSIC-LUCDEME Program (Fight against desertification of the Mediterranean), a small drainage basin has been selected at Vallcebre (High Llobregat basin, Eastern Pyrenees). It was selected as representative of areas on clayey bedrock used in the past for farming but currently almost abandoned. In this area active badlands are the main source of sediment (Clotet *et al.*, 1988) but their origin and relationships with human activity are poorly understood (Gallart & Clotet, 1990).

The main concern of the study of this drainage basin is to determine the hydrological and sediment routing behavior of the old farmed areas not directly affected by extensive gully erosion, as a means of analyzing the role of human impact on hydrology and gully initiation, and to infer the long term geomorphic evolution of these areas, especially after land abandonment (Llorens & Gallart, in press).

In this paper we present the main results obtained after one year of hydrological monitoring of the more man-modified sub-basin. Mass movements are identified but not introduced into the sediment budget.

THE STUDY AREA

The total basin occupies an area of 36 ha between 1400 and 1700 m a.s.l. with a sunny aspect. The area of the central sub-basin which is the subject of this paper is 16.65 ha (Fig. 1).

The climate is submediterranean (Martin-Vide, 1985). The mean annual precipitation is about 825 mm and shows 3 rainfall peaks, in autumn, spring, and August, the last due to convective rainstorms. Snowfalls are frequent, but snow usually melts during the subsequent days. The mean annual temperature is about 10°C, with great annual and daily temperature ranges.

The bedrock is mainly a smectite rich mudstone of the non-marine upper Cretaceous

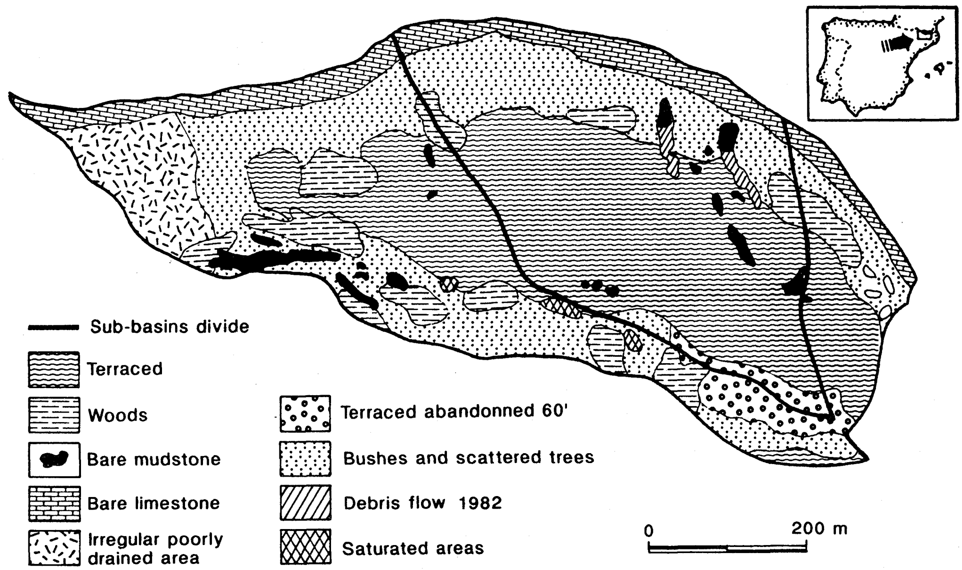

FIG. 1 Main geoecological units of the Cal Parisa Basin. The studied sub-basin is located in the cental part.

Garumnian facies. These sediments are silty owing to the presence of abundant micrite and microesparite (about 62% of $CaCO_3$), and their aggregates show a marked slaking behavior in contrast to the high stability of the aggregates from the soils they produce (Solé *et al.*, in press).

This sub-basin shows evidence of severe geoecological disturbances that were produced by agricultural modifications in the past: About 80% of the sub-basin is currently covered by dense grass and used for cattle and sheep stockbreeding; the remainder corresponds to marginal areas for agricultural use and is covered by bushes (*Buxus sempervirens, Genista scorpio, Juniperus communis*) and some small areas of woodland and dispersed trees mostly of *Pinus sylvestris*. This vegetation replaced the old woodland composed mainly of *Quercus pubescens*.

The topography is terraced in most of the sub-basin and this modification introduced a marked change in water circulation, that induced phreatic water to discharge along the inner edge of the terraces, where soils are thinner, and caused the formation of saturated areas. In order to prevent this surface saturation, a network of man-made drainage ditches was constructed, increasing the total network length.

The instrumentation network for the sub-basin, set up in June 1989, consists of: four rain recorders, a meteorological station, and a hydrometric and sampling station based on a steel H flume (see Llorens & Gallart, in press).

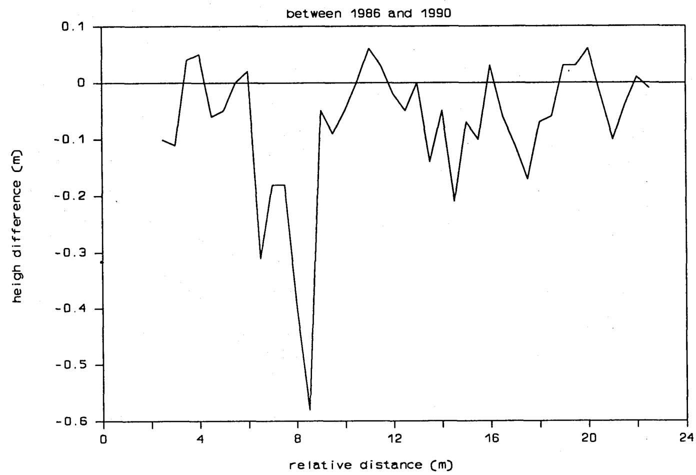

FIG. 2 Height differences between cross profiles surveyed in May 1986 and Ocotber 1990 through a landslide scar. Note the active linear erosion.

GEOMORPHIC PROCESSES AND SEDIMENT SOURCES

The general form of the basin is a concave hillslope dominated by a vertical cliff cut in lacustrine limestones which evolves by small rock falls. At the foot of the cliff, there is a very steep (30°) rectilinear hillslope, cut in the mudrock and covered by thin soils which were slightly terraced for agricultural use.Two shallow landslides (mudflows) occurred in this area during the extreme event of November 1982 (see Gallart & Clotet, 1988). The same event produced a shallow movement of the entire hillslope, evidenced by a series of cracks which follow the trend of the contour lines. Both mudflow scars show a tendency towards linear erosion rather than rim retreat (Fig. 2), and the microtopography is therefore changing from a sloping plane to a small gullied badland. It should be noted that all the sediment produced from these scars is deposited on grassed terraces after being transported less than 100 m.

TABLE 1 Erosion rates and sediment production from bare mudrock areas and landslide scars.

	Area (ha)	Erosion Rate (mm $year^{-1}$)	Sediment Movement (t $year^{-1}$)
Bare Areas	0.14	9.0	18.9
Landslide scars	0.09	33.0	41.6

The right divide of the basin lies on a clay formation with limestone debris and boulders, which constitutes a tongue left by an older (presumably Holocene) mass movement. There are several small gullies in this area, but most of the sediment is deposited in flat areas which seem to be produced by subsequent small mass movements.

The main part of the basin is a gentler (18-8°) hillslope, strongly modified by terracing. This unit shows great variability in soil thickness: there are areas where the clay bedrock outcrops on the inner part of terraces or on tracks, and areas with clayey deposits up to 3 m deep (shown by geoelectrical survey). The general topography suggests that the terraces were superimposed on a former irregular landscape produced by a system of mass movements, probably Pleistocene. This unit looks very stable, with only few small slumps in the terrace banks or failures of their stone walls. The network of ditches shows some discontinuous linear erosion forms.

Gross erosion rates

As stated above, significant sediment transfer only occurs in bare mudrock areas, which are almost devoid of vegetation and where the material shows a marked tendency to slake in the presence of water. A preliminary assessment of sediment movement from these small bare areas has been obtained by applying erosion rates measured in neighboring badland areas on the same bedrock (Clotet et al., 1988); while the sediment produced from the two landslide scars has been estimated from the data obtained in the repeated cross profiles (Fig. 2 and Table 1).

HYDROLOGICAL AND SEDIMENT TRANSPORT RESPONSE

The hydrological monitoring station is located in a reach selected to measure high discharges, but which is free of baseflow. Stream discharges less than $1\ l\ s^{-1}$ infiltrate and are monitored in a neighboring spring.

Table 2 shows that for a period of 12 months, from July 1989 to June 1990, the annual storm runoff was only 10.3% of annual precipitation, and that 89% of this runoff was produced during three events by only 34% of the annual precipitation.

This behavior confirms the preliminary analysis of the sub-basin response (Llorens & Gallart, in press). The hydrological response is strongly regulated by the soil moisture conditions prior to precipitation, storm runoff at the outlet being generated by precipitation on saturated areas. Under dry conditions, precipitation events up to 55 mm do not produce runoff. For example, during the months of July-August 1989 a total precipitation of 166.2 mm (18.1% of the annual precipitation) produced only 0.96 mm of runoff (1.0% of annual runoff). On the other hand, under wet conditions, the sub-basin exhibits much higher runoff coefficients. For example, during the month of November 1989 a total precipitation of 105.2 mm (11.4% of the total) produced 22.9 mm of runoff (24.2% of the total) and during the months of May-June 1990 a total precipitation of 309.4 mm (33.6% of the total) produced 62.3 mm of runoff (65.7% of the total). The main features of this behavior are being analyzed with a simulation model based on a daily water balance and an empirical relationship between water storage and the runoff coefficient (Llorens & Gallart, 1990).

It also is evident that summer storms produce Hortonian runoff from areas of bare bedrock, but this storm runoff does not reach the basin outlet because the water infiltrates when it reaches the terraced area.

TABLE 2 Hydrological response of the sub-basin (storm runoff).

Year	Month	Total Precip. (mm)	Total Runoff (mm)	Event (days)	Precip. (mm)	Runoff (mm)	Prop. of Months Precip. (%)	Runoff (%)
1989	JUL	63.5	0.2					
	AUG	102.7	0.7					
	SEP	64.5	0.7					
	OCT	43.8	0.2					
	NOV	105.2	22.9	16-22	95.8	22.7	91.1	99.0
	DEC	85.6	1.3					
1990	JAN	22.8	0.0					
	FEB	0.7	0.0					
	MAR	25.2	0.0					
	APR	97.1	6.4					
	MAY	182.5	41.4	20-28	134.6	41.2	73.8	99.4
	JUN	126.9	20.9	10-17	78.7	20.5	62.0	98.3
	TOTAL	920.5	94.9		309.1	84.4	33.6	89.0

TABLE 3 Mean chemical characteristics of surface and subsurface water.

	Surface water	Subsurface water
Specific Conductance ($\mu S\ cm^{-1}$)	407.6	639.5
pH	8.0	7.4
Na^+ ($mg\ l^{-1}$)	3.8	7.6
K^+ ($mg\ l^{-1}$)	0.8	1.3
Ca^{2+} ($mg\ l^{-1}$)	80.1	125.2
Mg^{2+} ($mg\ l^{-1}$)	2.1	3.4
HCO_3^- ($mg\ l^{-1}$)	202.5	301.9
Cl^- ($mg\ l^{-1}$)	1.5	5.1
SO_4^{2-} ($mg\ l^{-1}$)	26.0	71.9

Water Chemistry

The chemistry of surface and subsurface water is mainly dominated by calcium bicarbonate, HCO_3^- represents between 60 and 70% and Ca^{2+} about 25% of the total dissolved solids. This high concentration of calcium bicarbonate produces frequent calcite precipitation mainly in subsurface water, but also in stream water, where calcite precipitates are frequently found in water samples collected by the automatic sampler.

Table 3 shows that subsurface water is richer in SO_4^{2-}, Cl^- and Na^{2+} than surface water. The main reason for this difference is that these are mobile ions that come from the soil solution and the weathering front, and a longer residence period, therefore, produces higher concentrations. On the other hand, concentrations of HCO_3^- and Ca^{2+} are limited by calcite solubility.

TABLE 4 The main hydrological and sediment transport events.

Event	Total Precip. (mm)	Total Runoff (mm)	Runoff Coeff. (%)	Q_{max} (l s^{-1})	TDS (kg)	TSS (kg)	TBL (kg)
16-22.11.89	94.2	22.8	24.0	152.5	1017.6	1.8	?
22-28.05.90	134.6	41.2	30.6	282.4	1443.0	6.8	14.5
22-23	71.0	15.1	21.3	282.4	512.0	3.7	
23-25	12.3	7.8	63.4	65.4	211.0	2.1	
25-26	12.4	3.8	30.6	66.8	152.0	0.3	
26-27	12.9	9.0	69.8	117.4	330.0	0.4	
27-28	9.7	4.8	49.5	54.3	206.0	0.3	
10-17.06.90	78.7	20.5	26.0	191.0	1098.0	1.5	6.0
Total	307.5	84.6			3559.2	10.1	>20.5

Events The hydrological and material transport characteristics of the main events within the study period are shown in Table 4. This table demonstrates that the pattern of solids export from this sub-basin is strongly governed by dissolved solids transport. On average, dissolved solids export (TDS) is 500 times greater than that of suspended one (TSS) and 150 times greater than that of bedload (TBL). The dissolved solids export by base flow (at the spring near the outlet), estimated for this period, is of the same magnitude as that associated with storm runoff.

The event of 22 to 28 May 1990, with 5 discharge peaks (see Table 4 and Figs. 3, 4 and 5) has been selected as representative of the recorded events, which typically show several discharge peaks.

A continuous record of dissolved solids concentrations has been derived from 5-minute electrical conductivity readings and a conductivity-TDS concentration rating curve. Dissolved solids concentrations show a slight negative relationship with discharges (Fig. 4), but minimum values are always higher than 180 mg l^{-1}, and the clockwise hysteresis loops may reflect the rapid dissolution of fine-grained calcite precipitates.

Suspended sediment data were obtained by filtering stream water samples taken by both a stage sampler and an automatic time-programmed sampler, triggered by a level sensor. Suspended sediment concentrations are much lower than previously expected, and the rapid exhaustion behavior observed on Fig. 5 suggests that most of the material comes from the drainage network itself. This interpretation is consistent with the strong relation observed between bedload (TBL) and suspended sediment load (TSS) in Table 4.

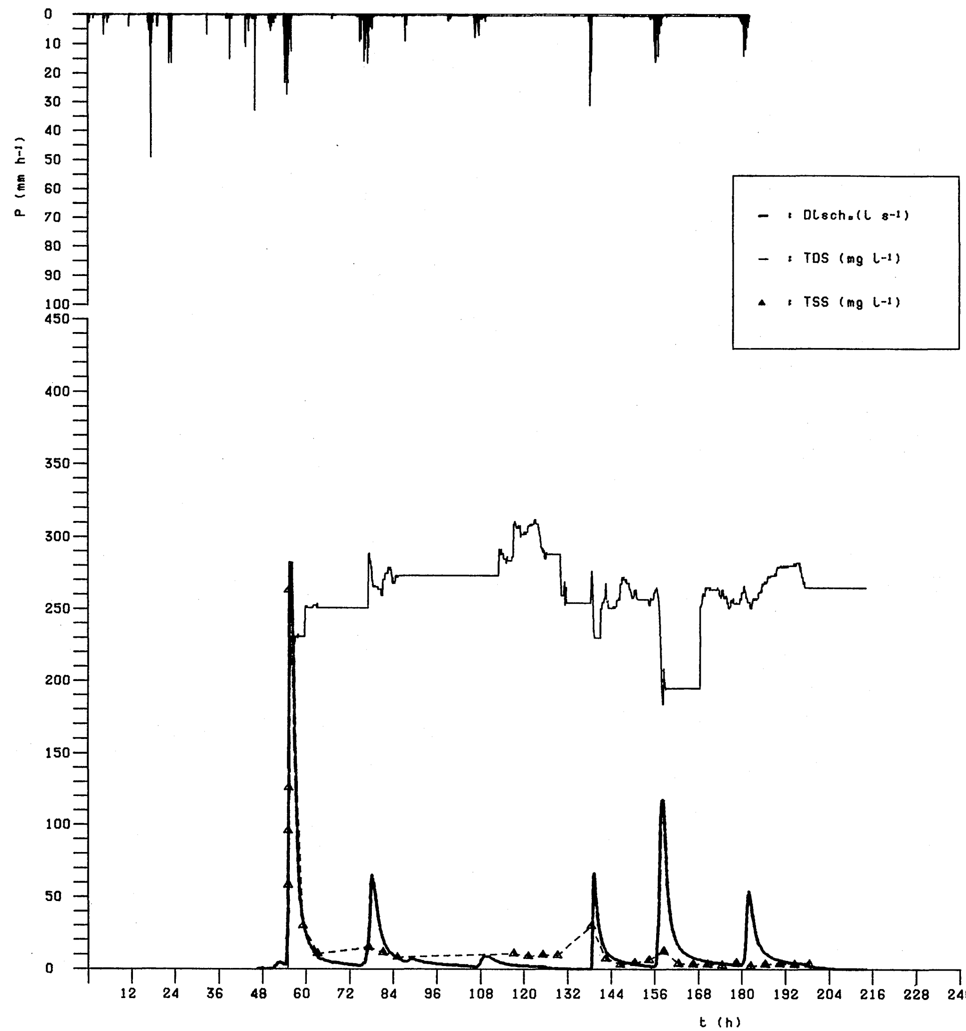

FIG. 3 Rainfall and water and solid discharges during the event of 22 to 28 May 1990.

DISCUSSION AND CONCLUSIONS

The particulate sediment yield from this basin (about 0.18 t km^{-2} $year^{-1}$) is very low, and more characteristic of very stable forested areas than those affected by human activities and prone to gully erosion and landslides. This reflects the very low erosion rates associated with the grassed terraces, and the marked sediment conveyance discontinuities within the basin. Clay flocculation due to the high Ca^{2+} content of the water, as observed in grain-size analysis, seems to be one of the reasons for this discontinuity. On the other hand, erosion

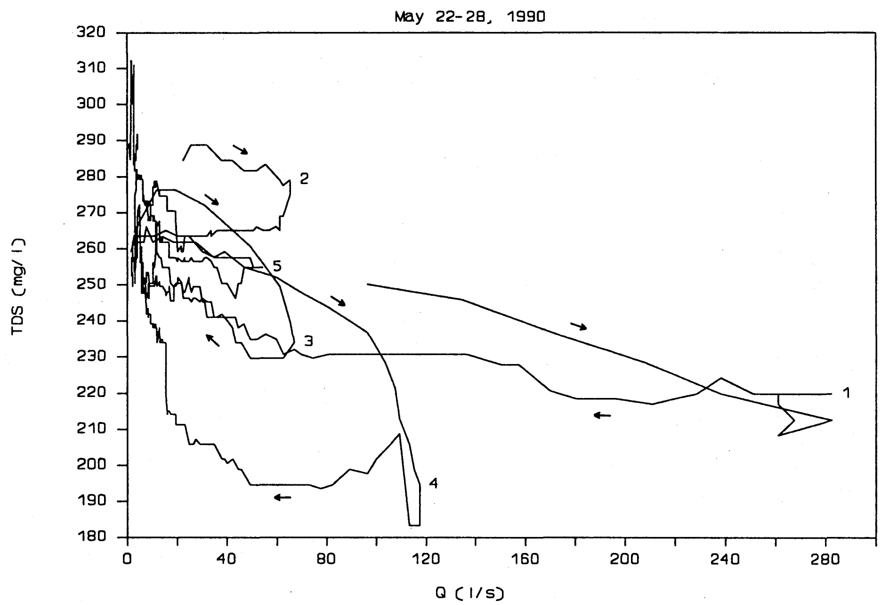

FIG. 4 Hysteresis loops of dissolved solids concentrations obtained from continuous electrical conductivity readings. Figures on the graph identify the order of the peaks.

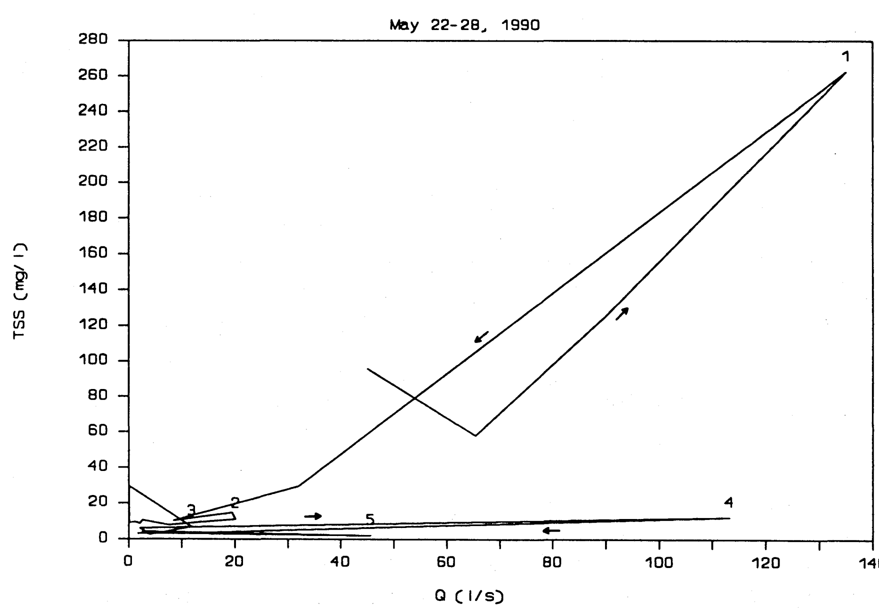

FIG.5 Suspended solids hysteresis loops obtained from stage and automatic water samplers. Figures on the graph identify the order of the peaks. Note the marked exhaustion effect.

from bare mudrock areas and landslide scars, even if not apparent at the basin outlet, is quite significant and suggests that badland areas could develop in the future. This behavior is the result of the intricate environmental conditions, and, in particular, the old land conservation practices and the change from agricultural to grazing use.

Nevertheless, these conditions are far from equilibrium:

(a) land use change towards abandonment has promoted dense grasses, bushes and forest, but the artificial drainage net and terrace walls need maintenance. Terrace failures do not seem to induce a significant environmental deterioration, but the peakedness of the hydrological response suggests that a reorganization of the drainage net could result in extensive gully erosion.

(b) in the longer term, erosion without sediment export represents a change in landform. As stated above, gullies seem to develop in landslide scars, and also increasing hillslope steepness (by erosion) and soil thickness (by deposition) contribute to landslides, which represents a major geomorphic process in this area.

Finally, it should be noted that the low sediment yields reported here are only representative of small well preserved areas. Larger areas may have active badlands or streams with unstable eroded banks which supply large amounts of sediment (Clotet & Gallart, 1986).

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