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Monitoring Water and Sediment Yield In Mediterranean Mountainous Watersheds: Preliminary Results

J. Rius, R. Batalla and R.M. Poch*

ABSTRACT

Water availability is one of the main objectives in the management of water resources in Mediterranean areas. Urban development and the European Union policy have led, in rural areas, to the abandonment of agricultural land since the fifties, which has brought about an increase of forestland.

In order to assess the influence of watershed characteristics and management on water resources of a large pre-Pyrenean reservoir, three nested basins (2.6 km^2, 65.2 km^2 and 222.5 km^2) are being monitored for water and sediment budgets. Mainland use is forest (*Pinus sylvestris*) and the management system is mostly selective cuttings. Monitoring scheme consists of continuous recording of discharge in the three basins, and sampling of water and suspended sediment in the two smaller ones. Rainfall is measured by means a series of rain gauges distributed in the watersheds. Besides, subsurface water flow along selected slopes of the smallest watershed is estimated by continuous recording of water content through a network of reflectometers and tensiometers. The working hypothesis is that, being subsurface flow the main source of water for rivers in subhumid environments, forest canopy ensures a more constant water supply than agricultural lands, in spite of larger water consumption by evapotranspiration. In this sense, forest management would not affect the water availability as long as the physical characteristics of the soils would be preserved.

The use of these results for watershed and reservoir management and modeling needs the definition of land units within the watershed, where transfer functions for the physical properties of the soils at different scales can be applied in order to take into account soil variability. Furthermore, variable sediment sources, especially erosion processes in the hillslopes and sediment transport in the channel network, are investigated in order to build up an integrated sediment budget for the whole area.

INTRODUCTION

Evaluation of the water resources is essential for land use planning in semiarid areas, as the Ebro valley in NE Spain. Water is supplied through large reservoirs fed with waters draining the Pyrenean mountain range. Land use in this area has evolved during the last half century from a mosaic pattern of pastures, crops and forest to an increase of forest and range areas due to depopulation and urban development. This trend has been reinforced by the European Union policy of setting aside agricultural land. Some effects of these changes in the soil and water resources are well known, as the increase of interception losses, better water quality or increase of infiltration capacity. Nevertheless, the existing quantitative data for the whole region, representative of subhumid Mediterranean watersheds is scarce and does not allow one to draw definitive conclusions.

With the aim to assess these aspects of water resources in mountainous Mediterranean drainage basins, an investigation was set in the Odèn-Port del Comte Ranges in the Pyrenees, namely the Ribera Salada watershed (Fig 1), where effects of logging on runoff and erosion are being analyzed in an area of *Pinus uncinata* and *Pinus sylvestris*. Forest is managed through selective cuttings, but the exploitation degree is not very intense and the average density of the canopy is rather high. Two aspects will be particularly analyzed: 1) the relation between main hydrological fluxes (soil moisture, rainfall-runoff relation, river response) at several temporal scales, from individual events up to annual water budget), as basis for the quantitative evaluation of water resources and, 2) the relation between discharge, sediment transport and sediment yield, as important variables for the assessment of water quality.

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MATERIAL AND METHODS

Catchment characteristics

The substrate of the catchment consists of massive conglomerates and calcareous sandstones merging to calcareous siltstones to the south. The relief is tabular, with slopes often higher than 20%. The whole watershed has a south aspect and its altitude interval is comprised between 660 m and 2383 m asl. Soils are shallow, calcareous and stony. They are classified as Lithic and Typic Ustorthents and Udorthents, depending on the soil moisture regime and the presence of a lithic contact (SSS 1999). The annual rainfall ranges from 600 mm to 1200 mm in the highest points.

*J. Rius, R. Batalla, and R.M. Poch, Centre Tecnològic Forestal de Catalunya, Universitat de Lleida, Dept. Environment and Soil Sciences, UdL, Av. Rovira Roure 177, 25198 Lleida, Spain. *Corresponding author: Rbatalla@macs.udl.es

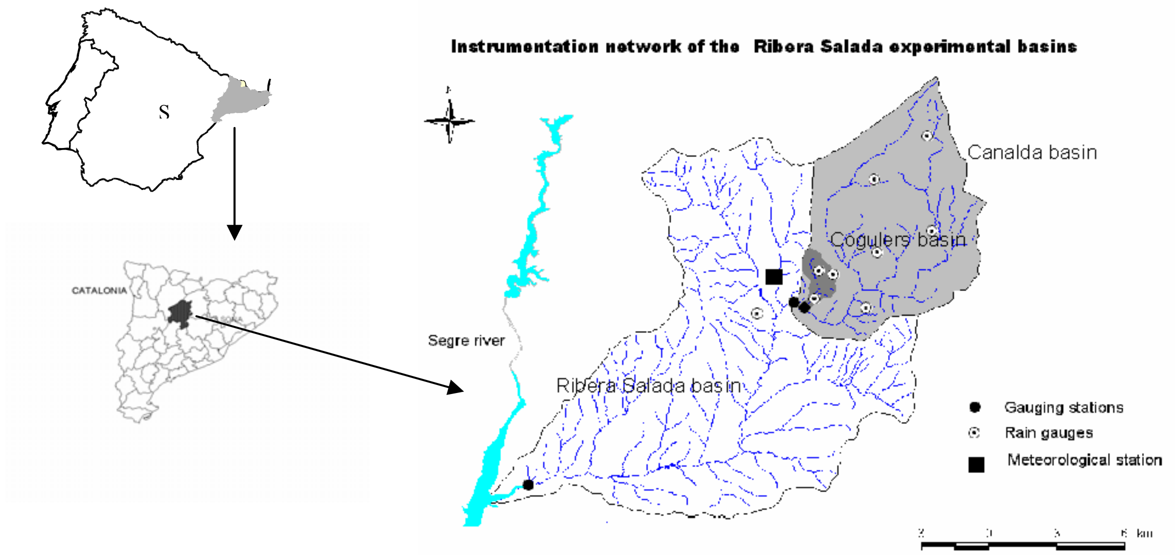

Figure 1. Location and design of the experimental watersheds.

Table 1. Monitoring and sampling instruments

	Nested catchments		
Instrumentation	*Cogulers* (2.6 km^2)	*Canalda* (65.2 km^2)	*Ribera Salada* (222 km^2)
Meteorological station			1
Rain-gauges	3	8 (5+3)	9 (1+5+3)
Hydrometric station (weir)	1		
Hydrometric station (river bed)		1	1
Water level sensors	1	1	1
Water temperature sensors	1	1	
Reflectometers	8		
Tensiometers	4		
Air temperature sensors	1	1	4 (1+1+2)
Water and sediment samplers	1	1	
Bedload traps			6

Research design

Research design involves monitoring and experimentation in representative basins. From the scientific point of view, a working scheme of three nested basins (2.6 km^2, 65.2 km^2 and 222.5 km^2) is being used as basis for hydrological modeling (Fig 1).

Research is being carried out by means of a progressive instrumentation of the catchment. Applied activities of interest for the Rialb reservoir (water yield and silting), in the Segre river basin are also taken into account.

Field instrumentation and experimentation is composed by the following elements, which are summarized in Table 1:

a) Hydrological fluxes
- Precipitation: Network of 9 pluviographs
- Interception and through fall: Interception plot under *Pinus nigra* with 16 pluviometers and 5 stem rings to measure through fall and stem flow.
- Soil moisture and soil water flow: Network of reflectometers and tensiometers in two locations: one under forest and one under pasture, with a continuous monitoring.
- Infiltration: Measured with a tension infiltrometer in selected soil units.
- Evapotransporation: Meteorological station with records allowing the calculation of ET with the Penman method.
- River discharge: Four river sections with continuous monitoring of water discharge.

b) Fluvial dynamics
- Riverbed micro and macro morphology: Control sections along the river for geometric section monitoring.
- Sediment transport: Sampling of suspended sediment in three river sections. Automatic sampling of bedload in downstream river sections.

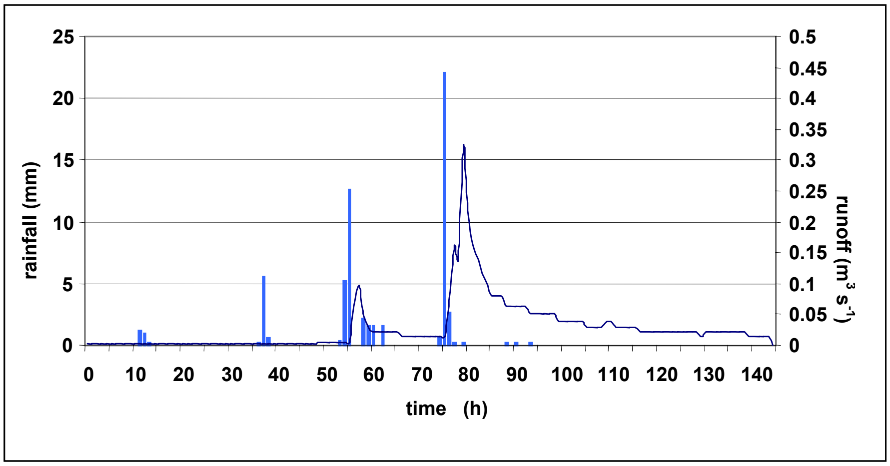

Figure 2. Hydrograph of the 22-27 Sept 98 – flood in the Cogulers gauging station.

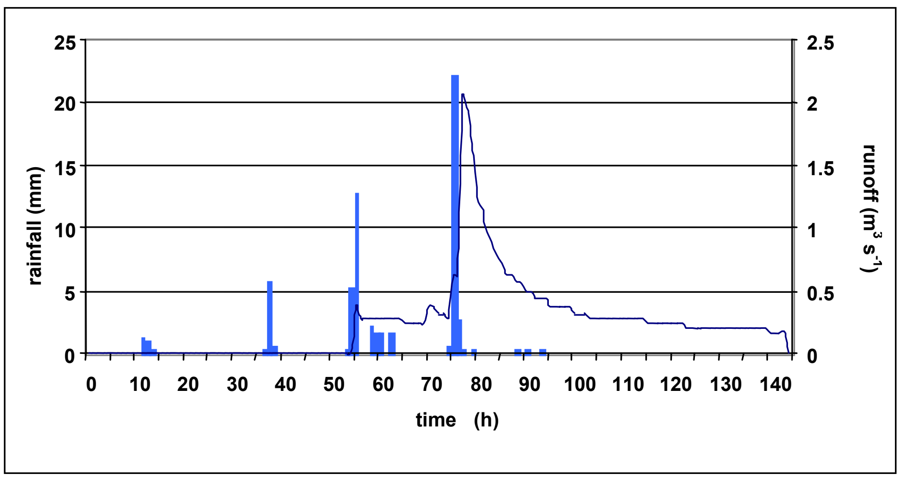

Figure 3. Hydrograph of the 22-27 Sept 98 – flood in the Canalda gauging station.

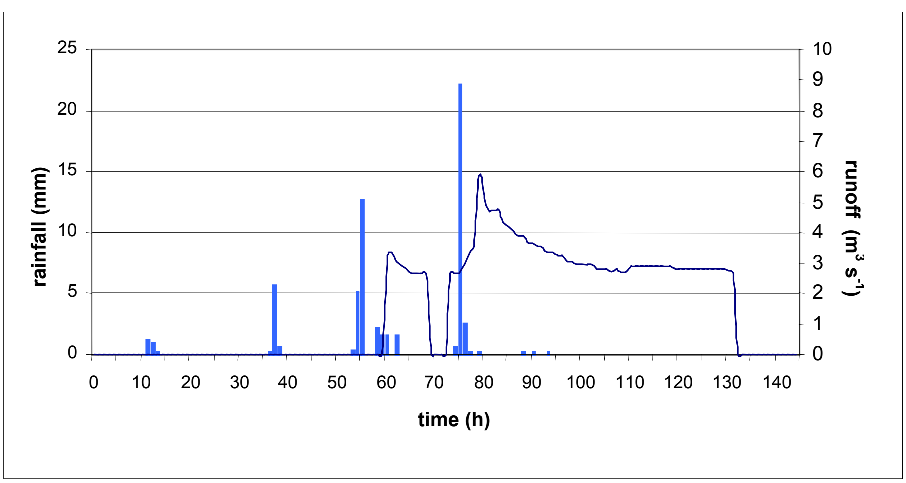

Figure 4. Hydrograph of the 22-27 Sept 98 – flood in the Altés gauging station.

Monitoring design allows to analyze the basin response in relation to forest and watershed management, as runoff mechanisms under different land uses, sediment yield depending on the type and size of the watersheds, assessment of the fluvial sediment budget, or location of sediment sources.

PRELIMINARY RESULTS

Hydrological fluxes

The analysis of the hydrographs of the smallest watershed during two years show very low runoff coefficients, around 10% of the total rainfall. They are due to the predominance of forest in the watershed and to the nature of the parent material, mainly fissured limestone.

Multiple regression analyses show a good relation between runoff coefficient and the variables peak flow and lag time (r^2 = 0.91), but almost no relation with antecedent moisture content or accumulated rainfall. Therefore, the most effective rainfall events as far as runoff generation is concerned, are those causing hydrographs with highest peak flows and not those with only high-accumulated rainfall (Poch et al., 2000).

Soil moisture content under the monitored forest is high, ranging from 20 to 194 mm for a depth of 30 mm. The temporal variation of soil moisture content shows that it is controlled by the rainfall regime, with peaks in autumn and spring. During the monitored period, more than 67% of the days the control section exceeds field capacity. Given the high infiltration capacity of these soils, around 80 mm h^{-1}, saturation is the main responsible for runoff generation in this land unit (Poch et al., 2000).

Figures 2, 3, and 4 show the flood hydrographs for the 22 to 27 Sept '98 floods. It is remarkable the short lag times of the two smaller watersheds, which in the case of Canalda, with a surface of 65 km^2, is about 2 hours. Contrastingly, peak flows are laminated very soon, at a rate of 1/3, routing from Cogulers (Qp/area ≈1/9) to Canalda (Qp/area ≈ 1/30) and Ribera Salada (Qp/area ≈ 1/37).

The analyses of the evolution of the moisture status and soil matric potential of the slopes (Figs 5 and 6) show that subsurface flow occurs mostly as short duration pulses of unsaturated flux during the flows, since the values of matric potential decrease very fast after rainfall episodes. Rainfall thresholds of 5 mm are enough to produce a hillslope response. Thus, the water supply to the rivers from the soils of forested slopes as subsurface flow would be very effective in the sense of a fast response for short duration rainfall events (Peters et al., 1995).

Sediment transport

Figures 7 and 8 show the evolution of suspended sediment load during the flood of 27-sept 98, after a drought period, in the two smaller watersheds. In the smallest one (Cogulers) sediment is quickly mobilized, which causes an advance of the sediment peak in comparison to the flow peak. Although this is a common fact in small watersheds (Emmett 1970, Walling 1974), the observed peak sediment concentrations, over 200 mg l^{-1}, are remarkable. In the intermediate watershed (Canalda) both peaks proceed simultaneously and a quasi-linear hysteresis is observed during the flood, suggesting the existence of important sediment stocks, uniformly distributed over the watershed (Batalla and Sala, 1994). The sediment concentrations also reach high values, over 1000 mg l^{-1}, due to the previous drought, which prevented the sediment to be exported.

Keeping in mind the evolution to a higher proportion of forestland in the last decades in the watershed, the sediment supply from slopes to river water is very low. The concentration of suspended sediment is rarely surpassing 0.002 kg m^{-3}. Regarding bedload, the surface material has diameters between 30 and 60 mm, while the subsurface materials range from 8 and 22 mm in size. Transport rates are often higher than 2 kg m^{-1} s^{-1} (submerged weight during full bank flows). Measured values are below model predictions (Alisedo et al., 2000), which points to a lower availability of sediments in the river. This can be due to the armoring caused by winnowing of fines and sand during flood recessions and to a lower frequency and magnitude of the flows caused by land use changes in the watershed.

The amount of exported sediment as bedload from the whole watershed is around 2000 Mg $year^{-1}$, lower than the values recorded for similar areas in Catalonia.

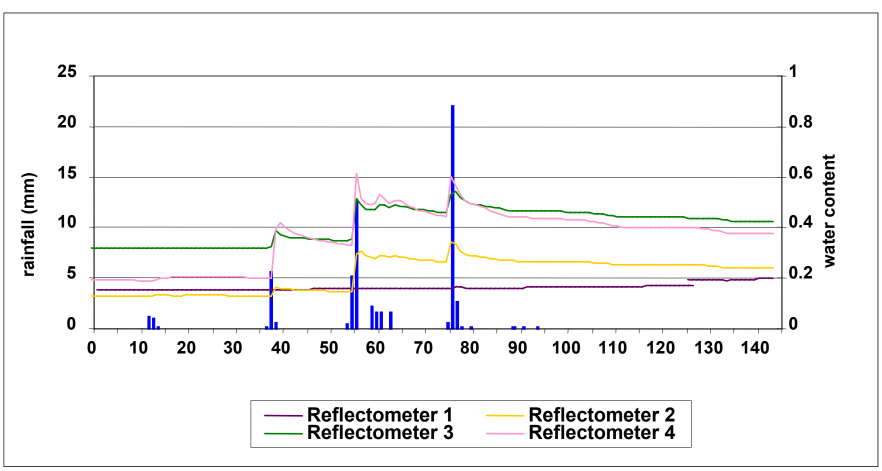

Figure 5. Evolution of the volumetric water content for the 22-27 Sept 98 rainfall event along the monitored slope in Cogulers.

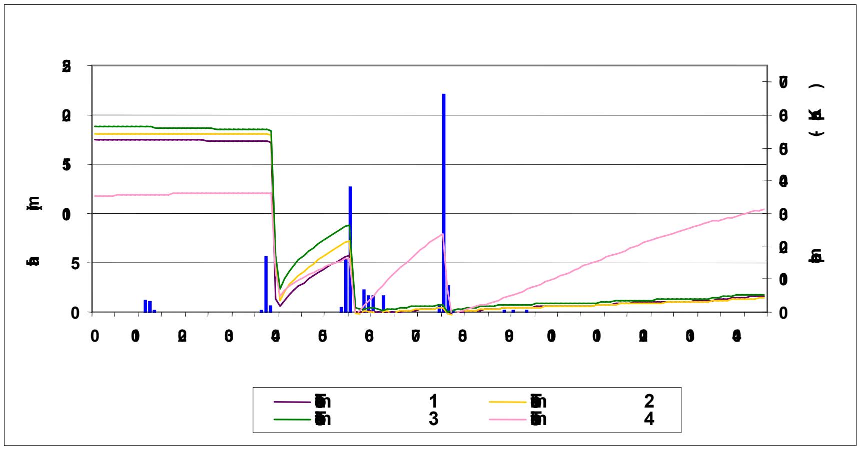

Figure 6. Evolution of the matric potential for the 22-27 Sept 98 rainfall event along the monitored slope in Cogulers.

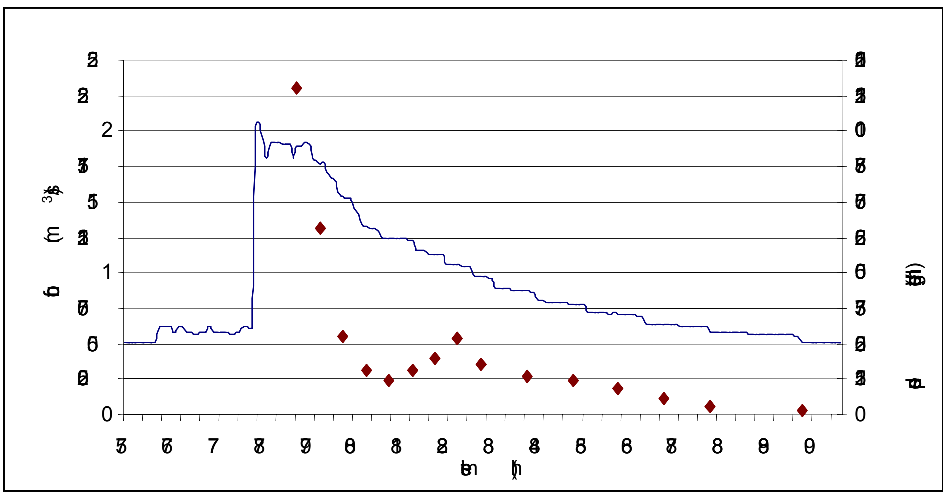

Figure 7. Hydrograph and sedimentograph for the 27 Sept 98 flood in Canalda (line: runoff; point: sediment).

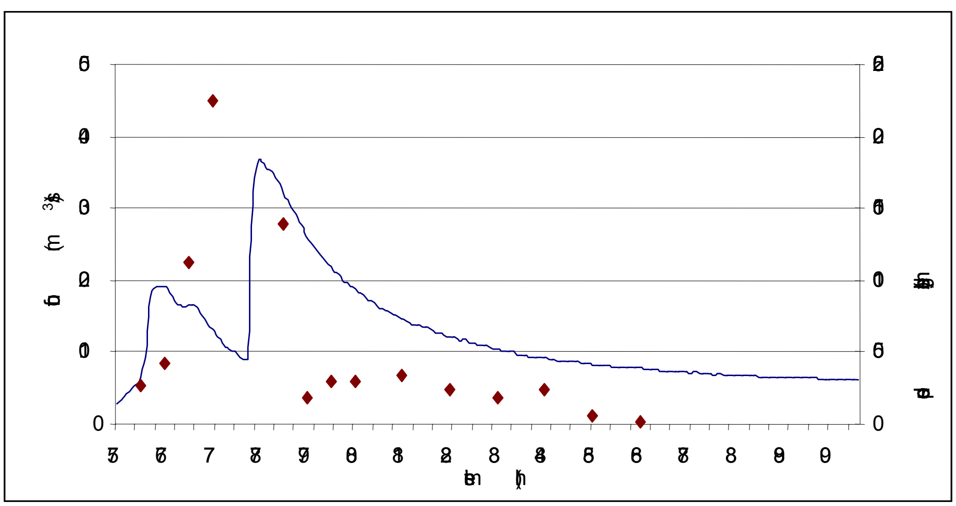

Figure 8. Hydrograph and sedimentograph for the 27 Sept 98 flood in Cogulers (line: runoff; point: sediment).

CONCLUSIONS

Water and sediment monitoring of nested catchments from slopes to small-scale station gauges allow a comprehensive understanding of the functioning of hydrological systems, which can be used for management purposes and river and reservoir regulation.

Forested watersheds, as water-supplying areas to reservoirs in Mediterranean climate areas have to be assessed from their potential to supply good quality water in adequate quantities. In the watershed that is being monitored preliminary analyses suggest: a) the importance of undisturbed forest soils to ensure the entrance of water in the system and b) the need for controlling non-point sediment sources through forest management practices.

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