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Suspended sediment load at the lowermost Ebro River (Catalonia, Spain)

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ABSTRACT

Several attempts to estimate the suspended load and the sediment deficit caused by the reservoirs have been carried out in the lower Ebro River. However, existing data are scarce, scattered along time and space, and obtained under different hydrological conditions and methods. This study estimate the presently suspended sediment load of the lowermost Ebro River, using field data collected during three consecutive years at different verticals of a cross-section and covering a large range of discharges. In addition, the daily suspended load for the last 30 years has been reconstructed and validated. The suspended load for the period 2007–2010 has been estimated at 84,000 t/y (±9800 t) while 99,500 t/y (±18,000 t) accounted for 1981–2010 period. Approximately, 80% of the total suspended load (period 2007–2010) has been transferred as inorganic load. A significant seasonal variability in the total (organic and inorganic) suspended load is observed. Therefore, two distinct cycling phases in the suspended load production and transfer has been inferred: an initial phase in which the sediment was prepared into the basin followed by a second phase in which most of the load was transferred downstream. These two phases are governed by the relative temporal location of the natural floods and the river regulation from the reservoirs. Nowadays, less than 1% of suspended load is transferred compared to pre-dams construction. The current levels of suspended load are very low and not enough to supply the material needed to maintain the delta elevation and avoid coastal retreat. The sustainability of the lower Ebro River and its delta could only be guaranteed by the implementation of a new reservoir management concept with the allocation of an appropriate liquid and solid flow regime.

1. Introduction

Under natural conditions, rivers tend to maintain their morphology in a dynamic equilibrium where the amount of sediment exported in a section is similar to that comes from upstream (Williams and Wolman, 1984). From this point of view, the sediment transport in a basin is continuous, being ultimately responsible for the balance between the fluvial and marine processes in delta and coastal areas. However, the transfer of sediment transported from the mainland towards the sea has been severely modified by human activities, mainly as water demand has been growing and fresh water has becoming an increasingly scarce resource. As a consequence, dam construction has been strongly developed.

The construction of dams and reservoir projects produces a number of social benefits. But, in producing these benefits, dams also alter the natural balance of sediment flow in rivers by impounding sediment within and upstream of the reservoir and discharging clean water downstream (Morris and Fan, 2000). For instance, more than 40% of the global river discharge is intercepted by at least 42,000 large reservoirs (≥0.5 km^3 maximum reservoir storage capacity) (Morris and Fan, 2000); and nearly 600 km^3 of reservoir storage is being lost through sedimentation at an annual rate of 1% of the storage volume capacity (the equivalent to ~30 km^3/y) (White, 2001). In its turn, the sediment storage in reservoirs is reducing land–ocean sediment transfer by about 10 Gt/y, equivalent to a reduction of between 33 and 40% of the presently land–ocean sediment flux (Walling, 2006). In consequence, the sediment exported to the sea is drastically reduced. For instance, in the Mediterranean basin, the potential sediment discharged into the sea has dropped over 50% since 1950 (Poulos and Collins, 2002). This reduction, mainly associated with the retention of sediment in reservoirs, leads the disruption of the sediment transport continuity. A clear example is the case of the Colorado River where the

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suspended sediment load severely decreased from 159 × 10^6 t/y to 0.1 × 10^6 t/y after the Hoover dam construction (Meade and Parker, 1985). Under these conditions, the morphological system is dramatically altered and the balance between fluvial sediment input and coastal erosion is altered.

In recent years, the recovery of water and sediment fluxes through an improvement of river and reservoir management is a topic of increasing concern (Rovira et al., 2014). Environmental flows need to incorporate specific requirements for sediment transport in order to avoid the loss of geomorphic functionality of rivers and coastal areas (Ibánez and Prat, 2003). However, sediment data are often scarce, scattered in time and space and obtained under different methods: such is the case of the lower Ebro River.

Since the 1960s, the sediment transport of the lower Ebro River is being altered by the reservoirs of Mequinensa and Riba-roja. As a result, the lower Ebro River and its delta are facing a severe sediment deficit leading to a progressive change of the river channel morphology and sediment transport dynamics (Guillén and Palanques, 1992; Tena et al., 2012), a degradation of the fluvio-deltaic system (Ibáñez et al., 2012a), and a dramatic reduction of fluvial sediment inputs to the delta (Jiménez and Sánchez-Arcilla, 1993). In the long-term, a significant elevation loss of the delta plain due to subsidence and sea level rise is expected, with the prediction that 45% of the emerged delta will be under mean sea level at the end of this century (Ibáñez et al., 2010). In light of this situation, a new water and sediment plan is being developed to achieve sustainable management of the Ebro River and its delta (Rovira and Ibáñez, 2007). This requires the estimation of the past and currently suspended load transferred at the lowermost reaches of the Ebro in order to evaluate the sediment deficit and the required restoration from the reservoirs. However, the existing sediment data are not continuous in space and time and were obtained under different hydrological conditions and methods (Table 1). For example, Roura et al. (2008) collected the samples by means of one automatic sampler placed at the exit of the Riba-roja reservoir. Vericat and Batalla (2006) took the samples by means of a depth-integrating US D-74 sampler in a single column in Móra d'Ebre (located 22 km downstream of the reservoirs). Tena et al. (2012) used water samples obtained during 6 years in Móra d'Ebre by means of a US D-74 sampler to calibrate and complement the turbidity data recorded in a section 16 km upstream of Móra d'Ebre. Négrel et al. (2007) used water samples collected on a monthly basis by the Confederación Hidrográfica del Ebro (CHE) in Tortosa (69 km downstream of the reservoirs); and Guillén and Palanques (1992) obtained water samples in Amposta (in the estuarine zone; 84 km downstream) by means of a water pump. Consequently, comparison is not always reliable.

The suspended load of the lowermost Ebro River has been computed by means of a new set of field sediment samples in order to: 1) evaluate the current suspended load just upstream of the delta (estuary); 2) understand the present organic and inorganic suspended load dynamics and, 3) reconstruct the daily suspended load concentration (SLC) over the last 30 years (from 1981 to 2010). Compared to previous studies, this is the first time that organic and inorganic matters are differentiated. In addition, the physical interpretation of the rating curves between organic and inorganic suspended load and discharge has been performed. Rating curves have been constructed by means of samples collected across the whole river channel section, and the model validated by using existing previous data. This takes into account the spatial variability of the SLC across-section for the computation of the sediment transport, allowing determination of the suspended load from 1981 to the present.

2. Study area

The Ebro river basin (85,530 km^2) is located in the northeast Iberian Peninsula (Fig. 1). It covers the south-facing slopes of the Cantabrian Range and the Pyrenees (in the northern part of the basin), and the north-facing slopes of the Iberian Massif in its southern part. The basin can be divided into four main climatic areas (Batalla et al., 2004): the Atlantic headwaters, with average annual precipitation of about 900 mm, the west-central Pyrenees (about 950 mm), the eastern Pyrenees (about 800 mm), and the southern Mediterranean zone (about 500 mm). Consequently, precipitation varies greatly across the basin due to its topographic and climatologic diversity. Although precipitation shows some degree of variability between years and regions, there is no statistical evidence that rainfall has decreased during the 20th century in any of the regions of the Ebro basin (García, 2000). Mean annual discharge for the period 1913–2010 in Tortosa, located 40 km upstream of the river mouth, is 425 m^3/s giving an average annual water yield of 13,403 hm^3. Runoff varies substantially from year to year, but there has been a significant decrease in discharge along the last century due to increasing water uses in the basin and the river regulation from reservoirs (Gallart and Llorens, 2004).

Nowadays, the impoundment capacity of the approximately 200 dams scattered around the Ebro basin is equivalent to 57% of the mean annual water yield (Batalla et al., 2004). This is a much higher rate of impoundment than that typically encountered in more humid regions and for catchments of similar size (i.e. 5–18% in the river Rhine, Elbe and Wesser; Vericat and Batalla, 2005). Virtually all dams were built during the twentieth

Table 1
Results of the main studies on suspended load carried out in the lower Ebro River after the construction of the Mequinensa-Riba-Roja dam system.

Source	Site	Study period	No samples	Q[a] (m^3/s)	RSLC[b] (mg/l)	MSLC[c] (mg/l)	MSLY[d] (10^{-3} t/y)
Roura et al. (2008)	Riba-Roja	1997–1999	254	180–2100	2–1251	19	370
Vericat and Batalla (2006)	Móra d'Ebre	2002–2004	269	460–2440	3–550	32	270
Tena et al. (2011)	Móra d'Ebre	1998–2008 (2002–2008[e])	452	127–2160	1–240	9	92
Tena et al. (2012)	Xerta	1998–2008	100	53–2479	1.6–274	13	115
Muñoz (1990)	Tortosa	1986–1987	19	50–675	7–25	13	130
Négrel et al. (2007)	Tortosa	1987–2004	274	53–1140	1–107	9	99
Present study	Tortosa	1981–2010	448	98–2025	2–104	13	99
		(2007–2010[f])					84
Guillén and Palanques (1992)	Amposta	1988–1990	No data[g]	110–675	10–21	15	120

[a] Q = Range of sampled discharges.
[b] RSLC = Range of recorded suspended load concentrations (mg/l).
[c] MSLC = Mean suspended load concentration.
[d] MSLY = Mean annual suspended load yield.
[e] Sampling period.
[f] Sampling period.
[g] During the 2 year study period only 7 field campaigns were carried out.

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