Geomorphology 117 (2010) 247–260

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

# Channel changes and floodplain management in the meandering middle Ebro River, Spain

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A R T I C L E I N F O

*Article history:*
Accepted 4 January 2009
Available online 22 June 2009

*Keywords:*
Fluvial geomorphology
Channel changes
Floodplain
River management
Land management
Ebro River

A B S T R A C T

The 346 km of the middle Ebro River between Logroño and La Zaida is a free meandering channel in a wide floodplain. This reach contains a discontinuous riparian corridor, including valuable riparian forests and oxbow lakes. The Ebro has witnessed substantial changes in channel morphology, gravel bars, riparian vegetation and floodplain uses over the last 80 years. The growth in sinuosity, migrations and meander cut-offs have been frequent before 1981. Afterwards, bank protections and dykes have stabilized the channel. There has been a progressive and significant decrease of both the area covered by water and the gravel bars without plant colonization. As a result the width of the riparian corridor has been dramatically reduced for human use. The deceleration and near elimination of the free meander dynamics of the Ebro channel represent an important loss of natural heritage. Dams, land-use changes throughout the basin, and construction of flood defences that restrict the main channel have changed the river system behaviour, which urgently needs a management plan combining both improvement and risk reduction. The solution proposed is the creation of a "Fluvial Territory".



## 1. Introduction

River courses exhibit dynamic equilibrium (Chorley and Kennedy, 1971), adjusting themselves continuously in time and space to fluctuations in discharge and sediments, which results in lateral and vertical mobility (Werritty, 1997). This mobility regulates and drives ecological dynamics that guarantee the richness and diversity of natural systems (Malavoi et al., 1998). Change is therefore a natural and a vital component of a functioning river system (Brierley and Fryirs, 2005) that human activities potentially can modify.

The objectives of this paper are to assess the recent dynamics of the channel and the changes in the floodplain in the middle Ebro River, Spain over the last 80 years, to explain the causes for the progressive reduction of such dynamics, and to present feasible river channel, riparian corridor and floodplain management solutions. This paper is also a contribution from the field of fluvial geomorphology to the current scientific and technical debate on selection of land management models with reference to dynamic rivers in the Spanish plains, using the middle Ebro River as an example. A technical commission has been created by the *Confederación Hidrográfica del Ebro* (Ebro River Basin Authority) to evaluate these issues.

The middle course of the Ebro River (Fig. 1) has witnessed substantial changes in channel morphology, gravel bars, riparian vegetation and floodplain uses. Over the last two decades, the recent hydrogeomorphological dynamics in the Ebro River along with its tributaries and floodplains have been mapped and analyzed, the ecological condition of their channels and banks evaluated, flood risk situations assessed, and numerous management proposals presented to the relevant authorities. This research started on the middle course of the Ebro River (Ollero, 1992), but later also involved several of its tributaries. It accepts the free meandering reach of the Ebro River as the datum.

The changes observed (Ollero and Pellicer, 1991; Ollero, 1991, 1992, 1995; Ollero et al., 2004, 2006a; Cabezas et al., 2008) are due to anthropogenic alterations. Similar hydrological, geomorphological and ecological consequences have been assessed in other fluvial systems. Such modifications have also been studied on the tributaries of the Ebro (García-Ruiz et al., 2001; Beguería et al., 2003; Batalla, 2003; Batalla et al., 2004; Acín, 2004; Granado, 2004; Frutos et al., 2004; Ollero and Martín-Vide, 2005). Most of the cases studied dealt with transformation of braided channels into meandering ones and problems due to incision, human invasion processes on the riparian corridors, and significant reductions of the channel mobility over the last decades. A number of recent studies were on dams (Petts and Gurnell, 2005; Magilligan and Nislow, 2005; Graf, 2006), and one of the Binghampton Symposiums was on various human impacts on the fluvial system (James and Marcus, 2006; Chin, 2006; Gregory, 2006; Wohl, 2006; Simon and Rinaldi, 2006). Hooke (2006) has updated the study of human impacts on fluvial systems in the Mediterranean region, stressing that during the 20th century major changes were

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doi:10.1016/j.geomorph.2009.01.015

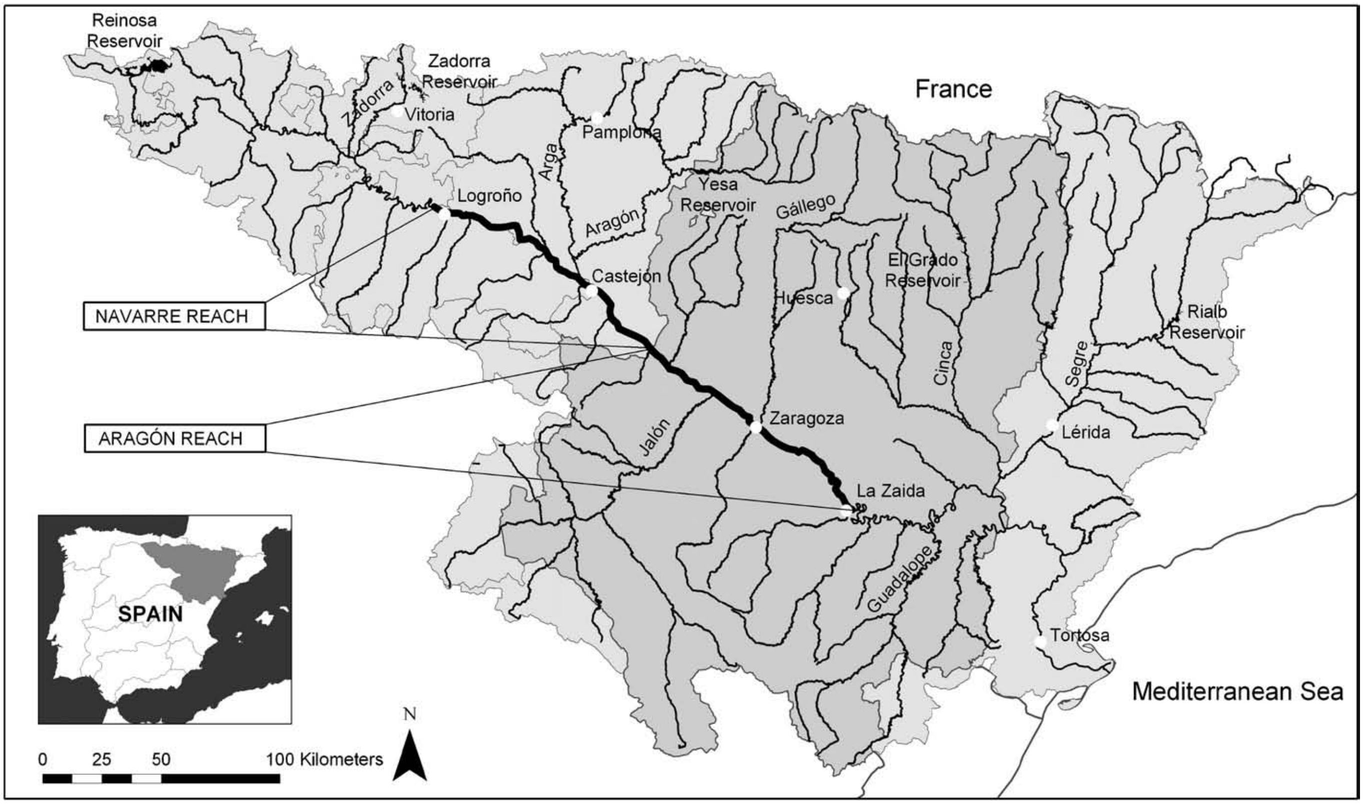


**Fig. 1.** The Ebro River Basin and the free meandering reach.

made directly through channelization, dam construction, and gravel extraction.

## 2. The meandering middle Ebro River

The Ebro is the largest Mediterranean river of the Iberian Peninsula, with a basin of 85,000 $km^2$ and a channel length of 930 km (Fig. 1). In the middle reach it has a 739 $km^2$ floodplain, the most extensive one in the Iberian Peninsula. This floodplain is frequently flooded with significant economic damage. The *Confederación Hidrográfica del Ebro,* created in 1926, is the oldest basin agency in Europe and has been in the forefront of water management in Spain. It has a dense network of gauging stations and a flood alert system, the SAIH (Automatic System of Hydrological Information).

Between Logroño and La Zaida, passing through lands of La Rioja, Navarre and Aragón, the Ebro River meanders for 346.5 km (Fig. 1). It is the longest reach of this nature in the Peninsula, and an example of a dynamic channel. The mean width of its floodplain is 3.2 km, reaching to a maximum of 6 km. Mean sinuosity index is 1.505, increasing to 1.608 in the Aragonese reach. The average channel slope is 0.67 m/km and the average width of the meander belt is 812 m.

The river, the relict gallery forests and the irrigating cultivation lands constitute a green strip of land in strong contrast with the arid surroundings (rainfall 300–400 mm/year). Striking differences occur between the riverbanks. The convex banks are mostly made of thick sediment of easily flooded point bars. Not all the bars are tilled and thus riparian vegetation still exist in places. In comparison, the concave banks, 2 to 3 m above the stream and composed of fine materials deposited by floods, have a sparse vegetation cover, are tilled up to the edge, and have to be protected from erosion. The floodplain, made up of overbank deposits as vertical accretion of fine materials, shows old abandoned meander channels of a historically active river.

Although the riparian corridor of the free meandering Ebro River has narrowed over the last several decades, it is an area of great environmental importance with the riparian vegetation covering 2720 ha. Almost the entire area has been declared a Site of Community Importance for the conservation of natural habitats (European Commission, 2006), and in some of the reaches it has more protected sites with stricter nature conservation designations.

Before entering the Community of Aragón and but after receiving the discharges of the Aragón and Arga Rivers, the Ebro reaches a mean discharge at Castejón gauging station of 230.7 $m^3$/s, or 9.16 l/s/$km^2$. Below Castejón and above Zaragoza, the Ebro does not receive significant inflow, while substantial volumes are diverted for irrigation. As a result, the mean annual discharge of 216.5 $m^3$/s (5.35 l/s/$km^2$) is lower in Zaragoza than that of Castejón.

The hydrological regime has a maximum in February, a minimum in August, and an asymmetry in the upward and downward curves with a prolongation of the high water level in spring and the low water level in autumn. The rainfall of Atlantic affects the headwaters of the Ebro and significant winter discharges and a higher frequency of floods arrive from the western Pyrenees. Although an interannual irregularity occurs on the Ebro River, it is less than that of most Mediterranean rivers. The decreasing trend of the discharge since the 1960s at the Zaragoza gauging station (Fig. 2) is notable (Frutos et al., 2004).

Low water levels occur in the Ebro from the end of June until the first fortnight of October. Before 1960, low flows were of long-duration, and always occurred in summer. During the 1940s there was an average of 114 days of discharge of less than 30 $m^3$/s. The hydrological year 1948–49 stands out with 148 days (Fig. 3) below 30 $m^3$/s. From the year 1960 on, due to the regulation of big dams and coincidence of some years with high rainfall, the low water levels have become uncommon, practically disappearing between 1970 and 1985. From that date on, some droughts have won the battle of the regulation capacity in the basin, and lengthy and serious low water levels have occurred. Although these are mainly recorded in summer, the extreme low water may appear also during spring and autumn (Frutos et al., 2004).