EPI WATER

Evaluating Economic Policy Instruments for Sustainable Water Management in Europe

WP3 EX-POST Case studies
Lower Ebro (Spain): Voluntary agreement for river regime restoration services

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Executive Summary

Definition of the analysed EPI and purpose

This economic policy instrument (EPI) is based on the voluntary agreement that was generated by public and private incentives, to deliver a set of pulses or artificial floods designed *ad hoc* for the partial restoration of the river regime in the Lower Ebro (NE Spain) by the private operator of the three hydropower dams in that region. Apart from this voluntary agreement, since 2002 the EPI development involves a public-private partnership in order to create, disseminate and use all the information available to identify the courses of action that may contribute to improve the ecological potential of the river.

Introduction

The large dams of Mequinenza (volume: 1 530 hm^3; hydropower generation capacity: 324 MWh) and Ribarroja (218 hm^3; 262,89 MWh) built back in the 1960s significantly modified the hydrology of the Lower Ebro River. Although the river still experiences natural floods, its physical and environmental conditions have remarkably changed within the last decades.

In 2002, the hydropower company, the water authorities, and the scientific community coordinated efforts to establish and promote a voluntary agreement, which jointly considers the possibility of compensation to the hydropower utility in exchange of water delivery, producing flushing flows as a means to control and remove the excess of macrophytes (visible algae and other flora species) from the river channel. This has been performed twice a year providing a testing scenario for the increasing improvements in its design in order to enhance its effectiveness reaching removal rates.

Legislative setting and economic background

All uses and pressures in the entire river basin heavily burden the lower stretch in the Ebro River. The amount of water reaching the river mouth has decreased since 1921, where the first dam entered into operation, and is nowadays only a fraction of the natural rainfall and runoff of the river basin. As a matter of fact, the Lower Ebro sub-basin's long-term average runoff during the period 1940-2006 was 232 hm^3/yr., higher than runoff observed during the period 1980-2006 (182 hm^3/yr.). This is consistent with the values for the whole river basin. In addition, the river stream does not show the seasonal variability distinctive of the Mediterranean rivers anymore and its monthly and daily flows are closer to the minimum environmental flows prescribed by the water authority, which are steady throughout the year (10%

of the flow rate under natural regime). Apart from those minimum flows and the variations in annual rainfall, water circulating in the river-channel is basically determined by economic rather than natural factors.

That is to say that anytime any day the water flow in the Lower Ebro depends on decisions made by the hydropower utility, which tries to make the best out of its power generation capacity, and in every month total water flowing down the river depends more on the needs of the irrigation sector than on the priorities of the hydropower sector. All these factors have severely modified the river ecology in many significant ways: for example, sediment retention has increased channel incision (i.e. erosion implies net average exports of 0.18 million tons of gross sediment; this sediment deficit translates into an average incision of 30 mm a year), favoured the penetration of marine silt, reduced nutrients received by fish population in transitional waters and altered sand balances in beaches on both sides of the river delta. The habitat has been seriously modified and invasive species (such as the zebra mussel and the bullfish-siluro) take the place of endemic ones, sometimes creating serious health risks (due, for example, to summer plagues of blackfly). Furthermore, they complicate the operation of power plants (as with macrophyte blooms which impair the functioning of refrigeration devices in the Ascó nuclear plant).

The Lower Ebro is a paradigmatic case of a heavily engineered river. During the XXth century, the series of dams built in the area allowed for the consolidation of agriculture and an incipient hydropower sector, guaranteed water supply for the surrounding urban settlements and significantly reduced flood risk. All this made possible social and economic development in the region, but also worsened significantly the ecological status of the river. This poor ecological status can be explained by increasing pressures from water abstractions, gravel mining, canalization, and pollution discharges as well as by the successive modifications in the river morphology. From a policy perspective, it may be the case that actions to reduce some detrimental activities or to improve the river status can be the source of some important benefits in excess over its opportunity cost. In particular, this will be the case if the improvement in the water river ecology leads to increases in the productivity of water in its existing uses, for instance by reducing the need to treat wastewater, the cost of producing drinking water or by allowing some new uses – i.e. bathing or fishing – that were not feasible with a degraded river status. The existence of these private benefits, which come along with the ecological improvement of the river, is a necessary condition enabling the engagement of private agents in a cooperative agreement. In addition, the public sector would be able to compensate those private agents to engage in practices with the ability to contribute to the improvement of the river ecology, provided the opportunity cost of implementing those actions were higher than the benefits received.

Hydropower companies became aware of the urgent need to recover the river ecology in the early 2000s when macrophyte infestations (aquatic flora more characteristic of a lake than of a flowing river) became a problem for the operation of the nuclear plant (and also for the irrigation pumping stations and Flix hydropower plant). Costly actions were adopted in order to mechanically remove macrophytes. This problem added onto other inconveniences created by the obstruction of water intakes and filters as well as the mussel colonisation of grids.

At that time, the delivery of recurrent pulses in order to remove these plants appeared as an alternative to avoid costly adaptation to degrading physic-chemical water conditions. Of course, the direct objective of these initiatives was the partial re-naturalization of the river regime, covering a wide range of benefits from the control of invasive species to the abatement of salt intrusion in the river mouth, and the improvement of water quality along the river.

Nevertheless, the private interest of power companies claimed the attention to mainly focus on the capacity of the artificial floods to remove the macrophytes in the vicinity of the power generation facilities (which are actually located far away from the river mouth). The good news is that power companies were willing to consider water flow patterns that were not only designed to maximize financial profits within the range of prevailing regulations but also to deliver some improvements in the ecology of the river system, paving the way for a collaborative agreement and for the remarkable research effort made in the area.

Even a mild alteration in the river hydrology would imply changes in the overall amount of water delivered and in the river regime throughout time with major consequences on the value of water for power generation. Taking this into account and considering that new operation rules would mean a shift in prevailing water use rights, the EPI was designed as a reciprocated collaboration scheme. Indeed, since its early stages it involved the possibility of a side payment to the energy operators both to compensate for additional opportunity costs and for the delivery of additional ecosystem services resulting from the river restoration scheme.

Brief description of results and impacts of the proposed EPI

Since 2002 a series of controlled floods has been implemented. At the outset, this was only for experimental purposes, supported by an ambitious research program to design floods and to monitor and maximize its effectiveness; more recently as part of the Ebro River Basin management planning process. These efforts were integrated in the design of the river plan and finished with the agreement to deliver two controlled floods every year (in spring and autumn), deliberately defined to maximize macrophyte removal rates and implying the delivery of more than 30 million m^3 in 13 hours in each controlled flood.

The opportunity cost for the power utility depends on many factors and may range from a zero (or even negative) value in exceptionally wet years (where stored water is at a minimum) to severe dry years (when the value of stored water is at its maximum). Simulation results indicated that measuring the opportunity cost of every flood was expensive and bargaining upon those costs every season was also institutionally challenging. Nevertheless, enough evidence from simulation models reveals that the long-term average cost of a single flood was not significant if compared to the overall turnover derived from selling power back to the grid and was also small if compared to the existing alternatives to remove invasive macrophytes. Regarding social costs of artificial floods (of some eurocents per person living in the area), they are also negligible when related to any available figure of people's willingness to pay to restore the river ecology.

Despite the relative success of the voluntary agreement, recent evidence has shown that the effectiveness of controlled floods to restore the river is now lower than in the previous decade, even for invasive macrophytes removal. Effects are better in the immediacy of big dams and hastily decrease with only marginal changes in the river estuary. Paradoxically while the success in improving the chemical status of the river within these last ten years is a fact; this seems to have driven an increase in the potential for the proliferation of macrophytes and boosted its rate of renewal after every controlled flood. New research efforts are currently being undertaken to shed light on the limits of better-designed or more regular controlled floods. The provisional balance, according to the experts involved in the field, indicates that designed floods help in river restoration but are not sufficient to offset a number of hydromorphological changes affecting the Lower Ebro. To deliver its expected outcome artificial floods should be part of a strategy involving at least better-designed environmental flows (which are now under revision) in order to make the ecology of the river less appropriate for typical lake standing species of flora.

Conclusions and lessons learnt

The experience on voluntary agreements for the delivery of artificial floods in the Lower Ebro is a unique example of public-private partnerships for the partial re-naturalization of a heavily engineered river. The coordinating role played by the Ebro River Basin Authority, visible in the series of assessment programmes and reports and in the constitution of experts' committees, has helped building a transparent bargaining scheme supported by long-term focused research enabling a better understanding of the river ecology and contributing to a better design of restoration alternatives.

The case study also shows how the public interest in restoring water ecosystems can make use of the potential gains for water users to build a self-enforcing cooperation agreement and may serve to deeply change the reactive attitude from many private firms into a proactive one. Businesses engaging in the agreement do not only enjoy certain financial benefits but can also convert these actions into part of their corporate social responsibility strategy. Building cooperative agreements is only feasible when private interest is somehow compatible with the actual purposes of water policy, such as the recovery of some ecological potential of the river system.

Moreover, in this kind of cooperation setting, when the voluntary participation of critical water users is critical or at least of paramount importance, the emphasis can easily be placed on the design of alternatives with a better potential to contribute to the objectives of private partners (e.g. the removal of macrophytes in the closer areas of the power generation plants at the least opportunity cost in terms of power output and foregone turnover), rather than those objectives of water policy (e.g. maximizing the social benefits of river regime restoration along the whole river).

Payments for environmental services are difficult to implement in societies with advanced water regulations and institutions, especially in EU countries where water resources are not private assets and where private (use) rights can only be issued under certain conditions. Side payments for good practices are not easy to accommodate within existing regulations and will require important legal amendments besides other transaction costs. Difficulties in implementing payments for environmental services presumably reduce the scope for voluntary agreements of the kind illustrated by this example.

The effective contribution of the agreed flushing floods may depend on the previous set-up of many other measures designed to recover the ecological status of the river, such as a properly defined and effectively enforced environmental flows, which are not already in place and that cannot be expected just as the result of an agreement with water users. In fact, voluntary agreements are possible regarding particular measures that are easy to define and to observe, but the recovery of water ecosystems usually involves many different measures that may need to be coordinated.

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List of Acronyms

ACA: Catalonian Water Agency (Agéncia Catalana de l´Aigua)

AEMET: Met Office (Agencia Estatal de Meteorología)

CAT: Water Concessionary Consortium for the industries and municipalities of Tarragona (CAT, Consorci d´Aigües de Tarragona).

CHE: Confederación Hidrógrafica del Ebro (ERBA, Ebro River Basin Authority).

CLC: Corine Land Cover.

CPI: Consumers Price Index.

CTFC: Forest Sciences Center of Catalonia (Centre Tecnològic Forestal de Catalunya).

CV: Contingent Valuation.

CV-IB: Contingent Valuation with Iterative Bidding.

CV-DC: Contingent Valuation with Dichotomous Choice questioning.

ENDESA: National Electric Utility (Empresa Nacional de Electricidad S.A.).

EPI: Economic Policy Instrument

ERBA: Ebro River Basin Authority (CHE, Confederación Hidrógrafica del Ebro).

ETI: Scheme of Important Issues (previous step to a new hydrological plan) (Esquema de Temas Importantes)

FF: Flushing Flows.

GDP: Gross Domestic Product.

GHG: Greenhouse gas.

GVA: Gross Value Added.

HEP: Hydroelectric Power.

INE: National Institute of Statistics (Instituto Nacional de Estadística).

MMA: Ministry of Environment (Ministerio de Medio Ambiente).

PDF: Probability Density Function

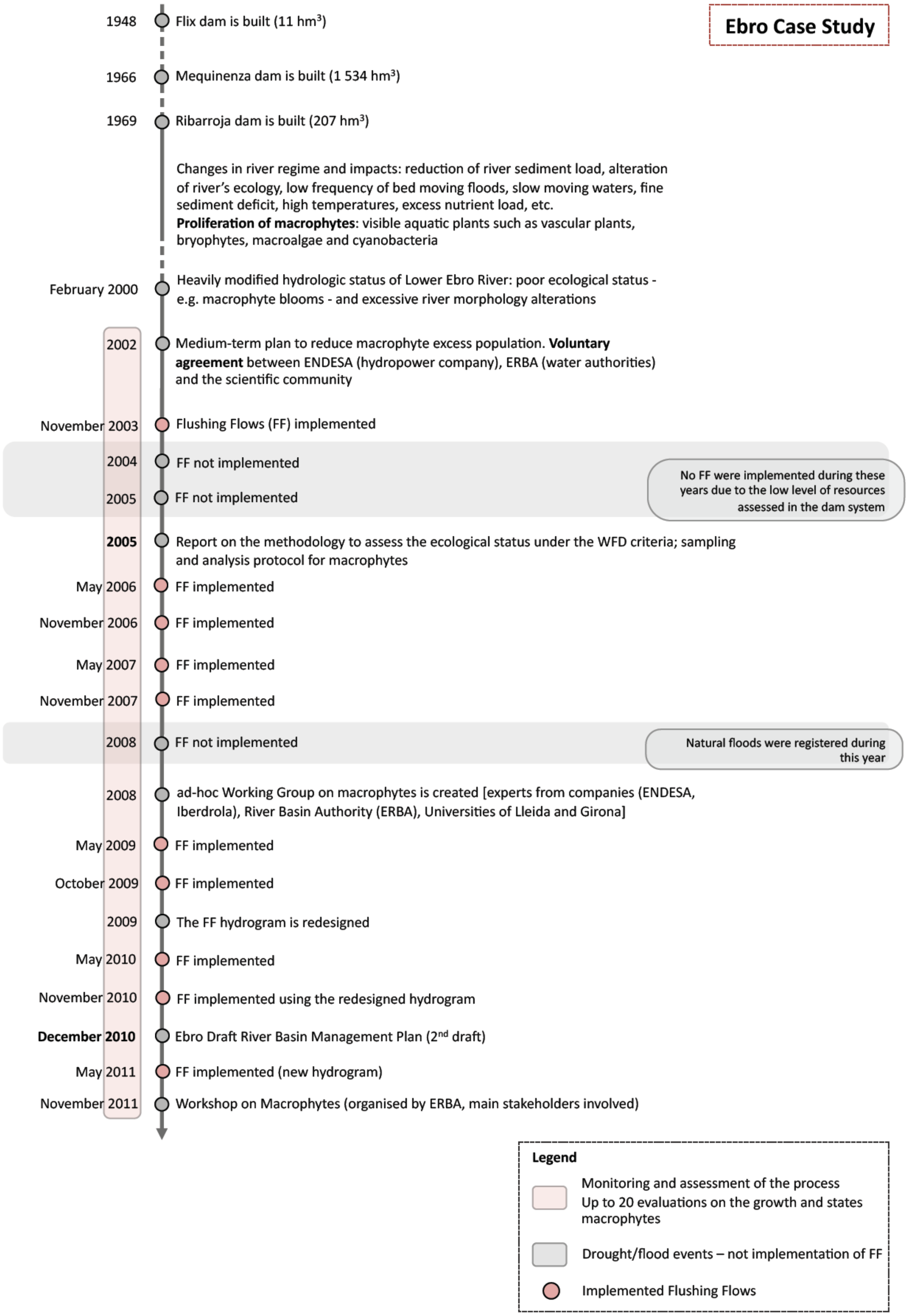
PIPDE: Comprehensive plan for the Ebro Delta protection (Plan Integral de Protección del Delta del Ebro)

RBA: River Basin Authority.

RBO: River Basin Organization

RBMP: River Basin Management Plan.

WFD: Water Framework Directive.



Ebro Case Study

1948	Flix dam is built (11 hm^3)
1966	Mequinenza dam is built (1 534 hm^3)
1969	Ribarroja dam is built (207 hm^3)
	Changes in river regime and impacts: reduction of river sediment load, alteration of river's ecology, low frequency of bed moving floods, slow moving waters, fine sediment deficit, high temperatures, excess nutrient load, etc. **Proliferation of macrophytes**: visible aquatic plants such as vascular plants, bryophytes, macroalgae and cyanobacteria
February 2000	Heavily modified hydrologic status of Lower Ebro River: poor ecological status - e.g. macrophyte blooms - and excessive river morphology alterations
2002	Medium-term plan to reduce macrophyte excess population. **Voluntary agreement** between ENDESA (hydropower company), ERBA (water authorities) and the scientific community
November 2003	Flushing Flows (FF) implemented
2004	FF not implemented
2005	FF not implemented
2005	Report on the methodology to assess the ecological status under the WFD criteria; sampling and analysis protocol for macrophytes
May 2006	FF implemented
November 2006	FF implemented
May 2007	FF implemented
November 2007	FF implemented
2008	FF not implemented
2008	ad-hoc Working Group on macrophytes is created [experts from companies (ENDESA, Iberdrola), River Basin Authority (ERBA), Universities of Lleida and Girona]
May 2009	FF implemented
October 2009	FF implemented
2009	The FF hydrogram is redesigned
May 2010	FF implemented
November 2010	FF implemented using the redesigned hydrogram
December 2010	Ebro Draft River Basin Management Plan (2^{nd} draft)
May 2011	FF implemented (new hydrogram)
November 2011	Workshop on Macrophytes (organised by ERBA, main stakeholders involved)

No FF were implemented during these years due to the low level of resources assessed in the dam system

Natural floods were registered during this year

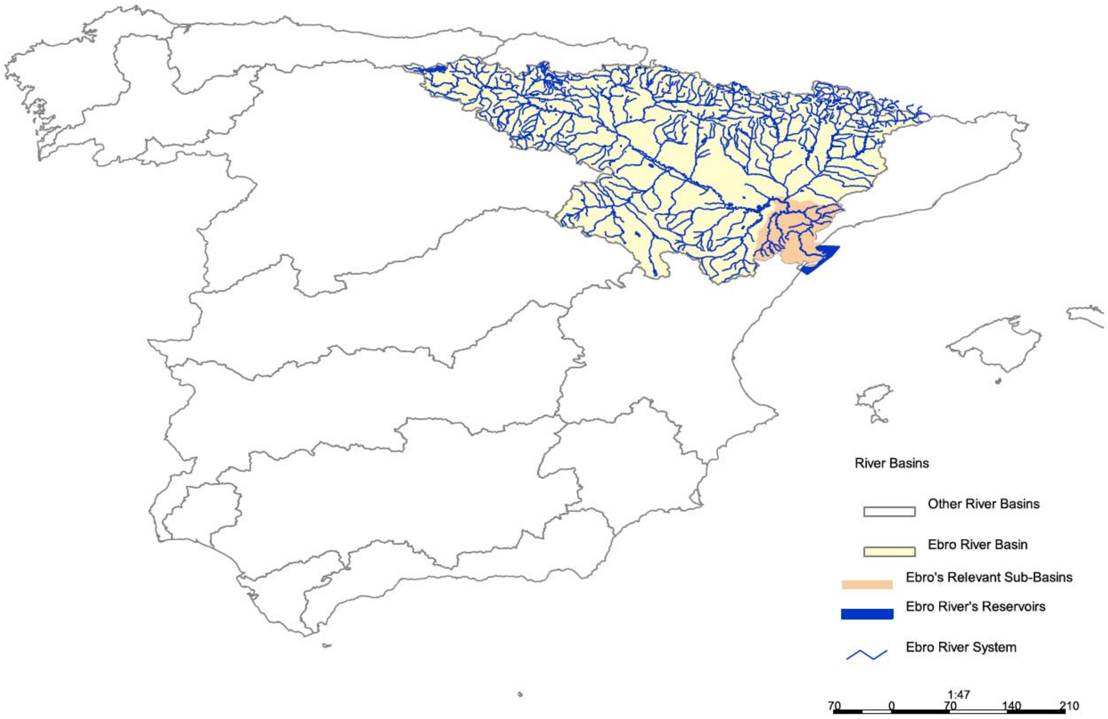
Legend

▭	Monitoring and assessment of the process Up to 20 evaluations on the growth and states macrophytes
▨	Drought/flood events – not implementation of FF
●	Implemented Flushing Flows

1. EPI Background

1.1 Rationale

The large dams of Mequinenza and Ribarroja, built back in the 1960s, heavily modified the hydrology of the Lower Ebro River (see Map 1.1). Although the river still experiences natural floods, its physical and environmental conditions have dramatically changed within the last decades.



Map 1.1 - Ebro River Basin District and relevant sub-basins

Source: Own elaboration from Ministry of the Environment, 2011

Changes in the flow regime (particularly through reduced flood magnitude) and diminished sediment supply have resulted in a series of morphological effects, including re-vegetation of formerly active areas of the river channel (Batalla et al., 2006), and local incision and riverbed armouring (Vericat et al., 2006). Since 2000, the main concern, however, has been the proliferation of macrophytes (visible algae and other organisms). Macrophyte biomass has increased downstream of the dam complex (the above-mentioned ones and a smaller one, called Flix) (Montesinos et al., 2009), causing a number of problems for a wide range of stakeholders, including irrigation pumping stations on one side, and hydropower and a nuclear power plant

(Ascó)[1] (Palau et al., 2004). There is no information on macrophyte abundance before the dam complex construction, back in the 1960s, but there is evidence that it has been also creating problems in water intakes and navigation (ERBA, 2008). Additionally, since the dams were built, in the Lower Ebro there has been a remarkable reduction of sediment inputs to the delta. This has had a major implication: for the last half a century, the ecotone has started to be dominated by the coastal dynamics, rather than the river one. Needless to say that marine intrusion through a salt wedge largely depends on the flow regime and the riverbed morphology; drought and heavy modification of the river have a role in this process.

Macrophyte colonization has taken place in formerly active channel areas, leading to the progressive and undesired stabilization of the fluvial system. The precise causes of the sudden increase in macrophyte abundance are not evident, although this happened after a 2-year intense drought that kept river under minimum flow conditions for long periods of time. Macrophytes are also seen as the main cause of a plague of black flies (*Simulium spp.*), which became a major public-health threat, especially during the summer, since they transmit diseases such as *onchocerciasis* (river blindness).

1.2 Key features of the EPI

1.2.1 EPI objectives

Following a voluntary approach between ENDESA, the power company, and the Ebro River Basin Authority (ERBA), a compensation payment to the hydropower utility was initially discussed in exchange for water delivery in two annual controlled water floods (flushing flows), in spring and autumn. Although co-ordination (within a larger consortium with academic experts on floods and sediment flows) started in 2002, design floods were implemented from 2003 on, with the exception of 2004 and 2005 (dry years), and also 2008 and spring of 2009 (natural floods).

Experimental flushing flow releases designed by Batalla and Vericat (2009), have been undertaken with the main aim of controlling macrophyte biomass growth downstream from the above-mentioned dam complex.

1.2.2 EPI design

The design of these artificial floods was based on the sediment entrainment method (Kondolf and Wilcock, 1996), that is mobilizing an active layer equal the maximum root depth of algae, and has been continually informed by sediment attributes and macrophyte removal at representative sites along the river channel. The economic

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[1] For instance, a power cut at Ascó II (one of the reactors of the a downstream nuclear power station), distorted measures at Ascó and Tortosa hydrographical gauging stations (ERBA, 2010).

instrument is not the design of an experimental flood but rather the voluntary agreement to generate (or merge) incentives for a win-win situation.

It is important to note that the design of flushing flows is constrained by a number of factors such as the operation of the hydropower dam system (water storage and power output), water availability in the second reservoir (Ribarroja, from where the flushing flows are released), and the risk of flood in riparian human settlements (Batalla et al., 2008). The latter may have demanded measures to take account of negative externalities of these design floods, but this is still under verification in this case study. Higher demand of electricity in winter limits the opportunity to flushing flows, and this explains the time sequence of these artificial floods.

What is assessed in this case study is the voluntary agreement (that is, the set of economic incentives to design these experimental floods to abate macrophyte proliferation).

1.2.3 Monitoring and enforcement

In 2008, a working group on macrophytes in the Ebro river basin was created (ERBA, 2009). The group consists of experts from the involved companies and universities working to control macrophyte development in the Lower Ebro, through the use of remote sensing techniques, and a quantitative and qualitative monitoring approach in different moments of the year. In addition, this task force has developed a biological study on abiotic requirements of those organisms and a literature survey of other relevant scientific pieces of work. ENDESA's Sustainability Report (Endesa, 2011), records design, monitoring, and implementation studies in the period 2005-2010.

1.2.4 Impact assessments

A number of research projects have been carried out since 2001 (initially by University of Lleida and CTFC; ulteriorly with contributions from the economic analysis viewpoint from experts from the University of Alcalá)[2]. Data obtained were used to review and redesign threshold discharges for flushing flows.

Outcomes of these projects can be synthesised as follows:

- Flushing flows are overall an effective way of removing macrophytes (although maybe insufficient to control their development) and are far from being incompatible with hydropower production. As a matter of fact they can actually create positive impacts for energy generation and water pumping for

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[2] During 2002-2010, 20 assessments were carried out on macrophyte growth and status (just before or after every controlled water flow implementation) in the Lower Ebro River (from the Flix dam tot he Ebro mouth) (URS, 2010, p. 79).

irrigation by decreasing the clogging of water intakes (critical, for instance, for the cooling of the two nuclear reactors at Ascó).

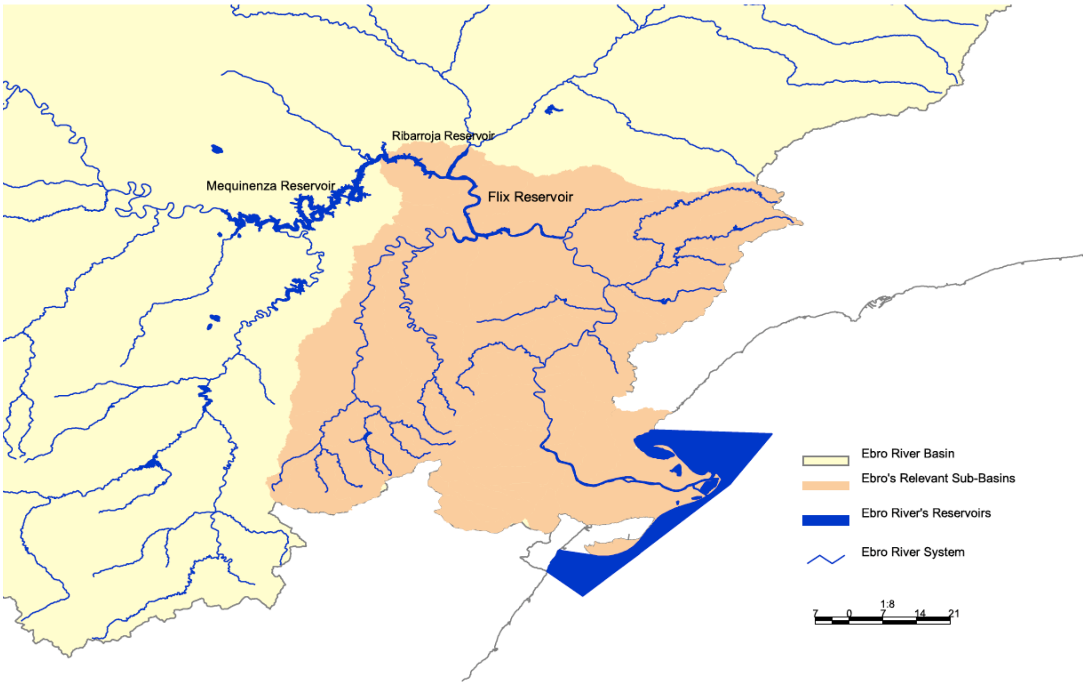
- Socio-economic benefits from the restoration of the natural river regime stem from pest prevention cost savings, significant improvements in the efficient use of water, maintenance of water infrastructures, risk abatement, and natural river habitat enhancement (both in-flow and riparian). In addition, opportunity costs of flushing flows consist of production losses in the economic uses of water derived towards river restoration (specifically in hydropower generation). The balance between opportunity costs and environmental benefits determines the economic feasibility of these experimental floods, which need to be regularly re-assessed and re-designed.

2. Characterisation of the case study area (or relevant river basin district)

2.1 Environmental characterization

2.1.1 Land use

The study site is located downstream the Mequinenza-Ribarroja-Flix dam system (see Map 2.1) and corresponds to the so-called "veguería" (somehow equivalent to a county) of Tierras del Ebro, which is located in the most southern part of Catalonia and adjoins other Spanish regions (NUTS-2) such as Comunidad Valenciana and Aragón. Tierras del Ebro stretches along 3 340.87 km^2 (52% of the area in the province of Tarragona and 10% of that of the region of Catalonia), and is made up of the districts of Ribera de Ebro (827.3 km^2), Bajo Ebro (1 034.8 km^2), Montsià (735.37 km^2) and Tierra Alta (743.4 km^2). Its corresponding sub-basin is Lower Ebro (*Bajo Ebro*), which covers a similar area of 3 869 km^2.



Map 2.1 - Dam system in the Lower Ebro

Source: Own elaboration from Ministry of the Environment, 2011

Land use in Tierras del Bajo Ebro is mainly agricultural (see Map 2.2), an activity which covers 64.32% of its total area and has showed a significant decrease within the last decades. Irrigated land in the study site was estimated to be 665.18 km^2 in 2006 and shows no remarkable increase since 2000 (652.11 km^2) (ERBA, 2011), although this estimation widely varies along with the methodology applied[3].

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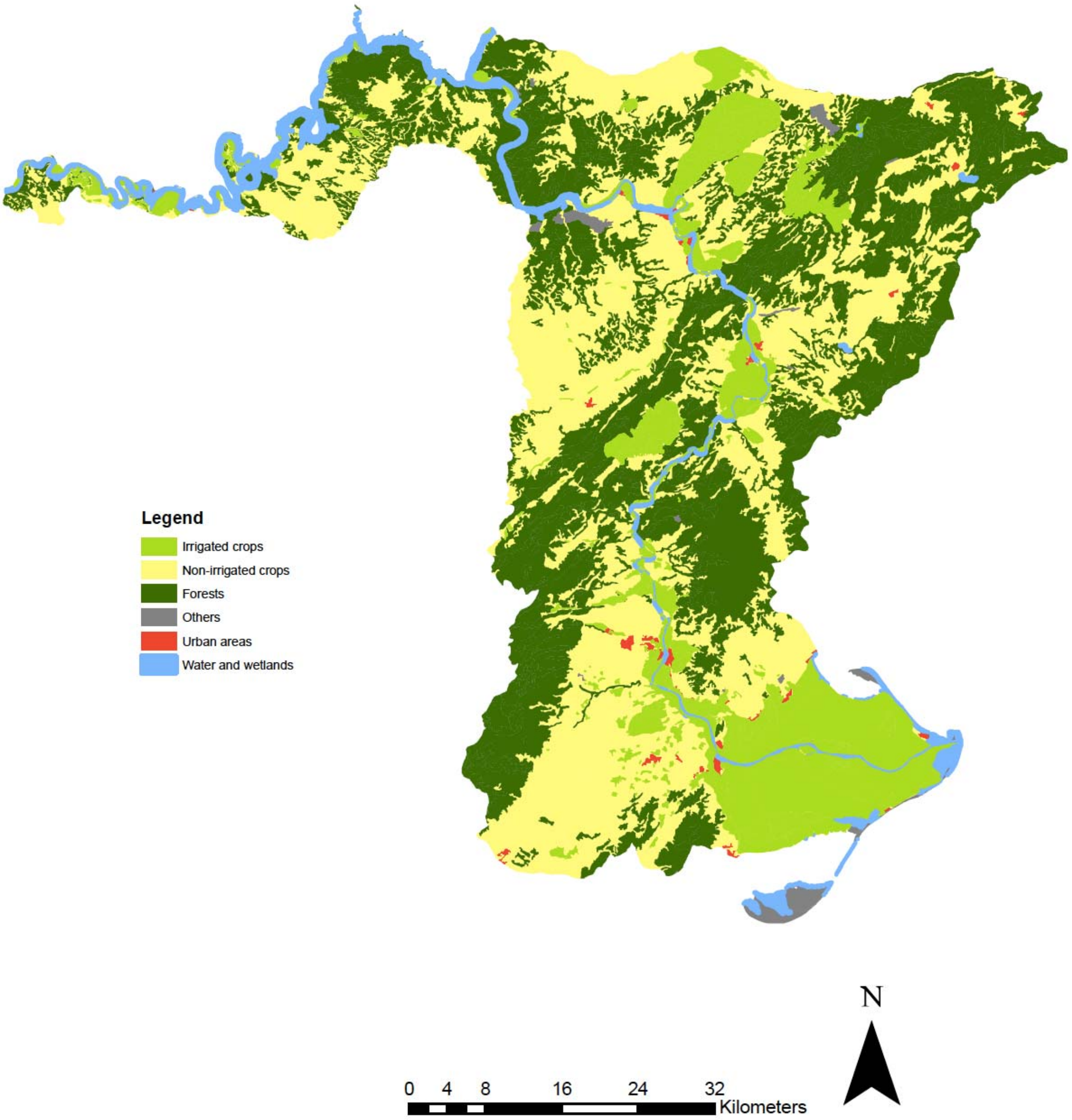
[3] Geo-referenced data on irrigated surface estimated in 1997 1 213 km^2 of irrigated surface in the Bajo Ebro. However, this amount dropped to 652.11 km^2 in 2000 (665.18 km^2 in 2006) (ERBA, 2011). Other methodologies have estimated irrigated area in the Ebro to be 822.66 km^2 in 2007 (ERBA, 2008).



Map 2.2 - Land use in the study site (2006)

Sources: Own elaboration from Ministry of Public Works, 2011 and Ebro River Basin Authority (ERBA), 2011

2.1.2 Description of the hydrology

Long-term rainfall pattern in Tierras del Ebro varies along its territory. Northwestern areas closer to the municipalities of Ribarroja and Pobla de Massaluca show average annual rainfall values lower than 400 mm, which progressively increase to 600 mm as one moves towards the coast. Rainfall values are higher in close mountains and natural parks (850 mm) (Generalitat de Cataluña, 2011). On the other hand, rainfall in the Ebro's delta ranges between 500 and 600 mm.

Rainfall variability in the region can be very high. For example, in the municipality of Tortosa (in the mouth of the Ebro), where average rainfall for the period 1921-2010 was 540.89 mm (lower than that of the basin's average of 645.46 mm); the standard deviation was 174.71 mm (as compared to that of the Ebro River Basin of 90.27 mm) (AEMET, 2011).

Additionally long-term rainfall patterns in the Ebro show a decrease in the average annual rainfall since the 1980s (MARM, 2011a), although no significant results can be inferred (ERBA, 2008). However, decreasing rainfall patterns are predicted for both the Lower Ebro and the whole basin in the incoming years (MARM, 2011b), which would support the rainfall reduction trend. This trend can already be found in the above-mentioned municipality of Tortosa (the largest of Tierras del Ebro, with 218.45 km^2) (see Annex I).

The Lower Ebro sub-basin's long-term average runoff during the period 1940-2006 was 232 hm^3/yr., higher than runoff observed during the period 1980-2006 (182 hm^3/yr.). This implies a decrease in the river runoff along the last century and is consistent with the values for the whole river basin; this phenomenon is a consequence of forest surface expansion and increasing pressures upriver of the dam system (ERBA, 2007). The combined effect of all these pressures has reduced water flows and flow variability downstream as compared to those values that would be found under a natural regime scenario. This has resulted in an increased exposure to drought events and poorer water quality, although this trend has been reverted during the last years of the XXth century as a result of water treatment improvement.

Available water resources in the study site are stored in the dam system, which provides water for irrigation, urban supply, hydropower, nuclear power station cooling, industry and recreational activities. The system controls water flows in the estuary as well, as it is the last regulating infrastructure before the Ebro's inlet. The system is made up of three dams: Mequinenza (with a volume of 1 530 hm^3), Ribarroja (218 hm^3), and Flix (5 hm^3), which are granted to the private company ENDESA S.A. (shared in 92% by the Italian company ENEL Energy Europe S.L.).[4] [5]

2.1.3 Analysis of pressures and impacts

The Lower Ebro irrigation district demands 1 203.06 hm^3/yr. of water for consumptive uses, 14.43% of total water demand in the Ebro River Basin (ERBA, 2008). These resources are mainly diverted from surface waters (1 179 hm^3/yr.,

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[4] Water stored in the system is the key variable to decide on water allocation amongst different uses, including river regime restoration. Water stock data series for the dam system are available since 1968, when the whole system started operating.

[5] The Ebro River Basin is extensively regulated, with over 190 dams impounding *circa* 60% of the basin mean anual runoff. Reservoirs are mainly located in the central and the upper reaches of the tributaries. Most of the reservoir capacity (67%) was built between 1950 and 1975.

97.24% of total demand), while groundwater sources have a marginal weight (33.48 hm^3/yr., 2.76% of total demand).

Main pressures on water resources stem from the irrigation canals of the right bank of Ebro River, the water transfer to the Water Concessionary Consortium for the industries and municipalities of Tarragona (CAT), and the nuclear power station of Ascó (operated by ENDESA and Iberdrola, which demands about 1 250 hm^3/yr.; ERBA, 2008). Consumptive water demand in the Lower Ebro is mainly linked to agriculture, which demands 1 087.5 hm^3/yr. (89.64% of total consumptive demand). Urban supply means 1.26% (15.4 hm^3/yr.) and industrial supply 2.79% (33.95 hm^3/yr.), excluding the water transfer to Tarragona, which requests 6.28% (76.27 hm^3/yr.) of total resources for industries and municipalities in that province.

Therefore, there are two main pressures that can be highlighted. The first one concerns the increasing water demand for population and industrial uses from the water transfer to the CAT, which shows significant peaks during summer due to tourism and conflicts with agricultural uses.

The second one is specifically related to this case study and refers to the river morphology and dynamics alteration, which is an outcome of the building of the large dams of Mequinenza and Ribarroja, back in the 1960s. Most important changes include the reduction of flood frequency and magnitude, which are the energy source for keeping an active river channel morphology; the reduction of the river's sediment load, which implies the erosion of the coarser fractions in the channel; and the alteration of the river's ecology, as a compound effect of impoundment, low frequency of bed moving floods, slow moving waters, fine sediment deficit, high temperatures, and excess nutrient load (Batalla et al., 2006; Vericat and Batalla, 2006; Vericat et al., 2006; Batalla and Vericat, 2009;). Although the river still experiences natural floods and the impact of regulation is much smaller than that found in commensurable large rivers such as the Sacramento and the San Joaquin in California (Kondolf and Batalla, 2005), and even in some of its main tributaries (Ollero, 2009), the river's physical and environmental conditions have remarkably changed in the last decades.

2.2 Economic characterization

Tierras del Ebro had a population of 191 568 inhabitants in 2008 distributed along 52 municipalities. Its large surface (3 340.87 km^2) combined with its low population, made a density of 58 inhabitants/km^2, much lower than the Spanish average of 92 inhabitants/km^2.

Population distribution within Tierras del Ebro was and still is heterogeneous, with the lowest density ratios in the southern districts of Tierra Alta and Ribera del Ebro and the highest ones in the northern districts of Bajo Ebro and Montsià. In spite of its low-density ratio, average population growth in Tierras del Ebro during the period

1996-2010 (1.61%) has been higher than the Spanish average, especially in the largest urban poles of the region (Generalitat de Cataluña, 2011; INE, 2011).

Tierra del Ebro is a relevant agricultural area and this is reflected in the share of the primary sector over its total GDP (9.3%). Indeed, agriculture represents an even larger share in Tierra Alta, where it generates 16% of total GDP. Agriculture generates 7% of total employment in the study site (Generalitat de Cataluña, op. cit.). Main crops in Tierra del Ebro are olive trees and hazel. In the northern part, vineyard is intensively farmed, whereas in the southern side horticulture prevails. In the estuary of the Ebro most common crops are citrus fruits and rice. Non-irrigated crops are concentrated in the plains (ibid.) (see Map 2.2).

Industry and energy represent 33% of total GDP and 18% of total employment, showing a comparatively high specialization (the share of this sector in the region of Catalonia is 22%). However, the spatial distribution of this sector is highly heterogeneous, mainly concentrated in Ribera del Ebro (60% of local GDP) and Montsià (27%). In the former most important activities are related to the management of the nuclear power station of Ascó and the chemical industry plant of Erquimia (Flix) (ibid.).

The service sector generates 48% of GDP in Tierras del Ebro and 59% of total employment, a comparatively lower amount than that of Catalonia (68%), resulting from high industrial and agricultural bias (ibid.).

Given the specificities of the case study (mainly focused on river morphology attributes), no significant impact will be expected in the assessment for most economic activities. The river regime restoration mainly affects the energy sector, and specifically hydropower generation in the Mequinenza-Ribarroja-Flix system. All dams in the system have hydropower generation devices, with capacity ranging from 324 MWh (Mequinenza) to 42.5 MWh (Flix) (Ministry of the Environment, 2011).

3. Assessment Criteria

3.1 Environmental outcomes

3.1.1 Drivers of water use

As it has been showed, the Lower Ebro sub-basin is a traditional agricultural area. Still today agriculture continues being a significant activity for income generation (9.3% of local GDP) and employment in the area (8%, as compared to the average value of 1.2% in the region of Catalonia). Indeed, agricultural surface is the main land use in the region (64.3% of total surface in 2006), with a significant and growing share of irrigated areas mainly in the delta and the banks of the Ebro River (about 30% of agricultural land in 2006, showing a positive trend, contrary to that of rainfed crops).

Main income generating activity in the region is the tertiary sector, which generates 48% of local GDP and 59% of total employment. This sector, although still having a comparatively lower importance than in the surrounding areas, has experienced a sharp growth in the last years as a consequence of tourism development in the coastal areas.

Manufacturing sectors and energy represent 33% of total GDP due to the presence of Erquimia chemical industry since the very end of the 19th century and Ascó and Vandellós nuclear plants since the 1970s; these activities have a large environmental impact and were located there due to the marginalization and low population density of the area (Generalitat de Cataluña, 2011).

Population loss has been the dominant trend during most of the 20th century, although it has been reverted and during the last decade population showed a significant growth, higher than in most areas of the country. Despite this growth, population does not pose a relevant threat to the quantitative or qualitative status of the river in this area (ERBA, 2008).

The construction of the large dam system, which was finished in the 1960s, critically altered the hydrology of the river and has been a major determinant of water dynamics in the area since the end of the 1990s (URS, 2010). This system, privately managed, is therefore assumed to follow common optimization rules. The company decides at any point in time on the energy flow to be converted, taking account of given technical specifications of the plant, current operating rules (minimum water flow in the river) and the expected evolution of the amount of water stored in the reservoir and of energy price projections. From a private business perspective these decisions aim at maximizing the value of the expected flow of benefits along the entire life span of the reservoir (eventually over an infinite horizon). As the electricity produced cannot be stored for its future selling, the profit-maximizing company can be assumed to simultaneously make two kinds of decisions: on one side, choosing how much water to use every day; on the other, choosing how to distribute the daily water used along the day.

As a result of the implementation of this EPI, the hydropower company had to face another constraint when deciding on the daily amount and distribution of water. Since then, the company has to free a specified amount of water in certain days and at certain hours, which may increase its financial revenue that day as well as diminishing water stocks that otherwise could have been used in price-peak hours.

3.1.2 Demand for water services

Total water demand for consumptive uses in the Lower Ebro sub-basin is 1 203 hm^3/yr, which are mainly taken from surface resources (1 179 hm^3/yr). The most relevant consumptive use is agriculture (1087.5 hm^3/yr), followed by the water transfer to Tarragona (CAT) (76.27 hm^3/yr). Urban water demand plays a minor role (49.35 hm^3/yr) (see previous section). Ascó nuclear power station annually demands about 1 250 hm^3 for cooling. This demand has not been modified as a consequence of the EPI studied (ERBA, 2008).

In this case study the most important water economic use is hydropower generation. The Mequinenza, Ribarroja and Flix dams in the system have a capacity of 324 000, 262 800 and 42 500 Kw/h, respectively, which demand 6.2, 11.19 and 37.91 m^3/s when working at full capacity (Ministry of the Environment, 2011). The rest of the time water flow is reduced to the minimum legal requirements (10% of average annual runoff under natural regime), with exceptions such as flow peaks (ERBA, 2007) and since 2002 the implementation of flushing flows.

3.1.3 Pressures on water resources

The Ebro River Basin does not show the structural quantitative problems distinctive of many Mediterranean and Central and Southern Spanish river basins, although the hydrology in the very last years has been modified and shows a trend towards rainfall and runoff decline (as above); in fact, the reduction in long-term average annual runoff from the period 1940-2006 to the period 1980-2006 is 21.55% (ERBA, 2007).

This pattern is also observed in the Lower Ebro, which has a significant rainfall and runoff variability that makes the area especially vulnerable to extreme events, as compared to the rest of the basin (AEMET, 2011). This situation has already generated conflicts between water users, mainly between irrigators and the users of the water transfer to the CAT (water supply for population and industrial uses). The transfer shows significant peaks during the summer and decreases water availability for agriculture.

As a result, droughts have increased their frequency although they are still moderate. The following table (see Table 3-1) shows drought thresholds in the Lower Ebro, which are measured according to the water stock in the Mequinenza dam. These thresholds were approved in the *Ebro Drought Contingency Plan* (ERBA, 2007) and establish the limits from which certain measures and restrictions in water use are applied: under pre-alert levels, some studies are developed and awareness-raising campaigns are implemented; under alert levels, water for irrigation is reduced by 10% and drought infrastructures are activated; and under an emergency, urban water supply can be restricted and irrigation stopped.

Table 3-1 - Emergency, alert and pre-alert levels under the new drought contingency plan, Lower Ebro (water stock in the Mequinenza dam, hm^3)

	Oct	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Pre-alert	1054.2	1085.2	1201.3	1266.3	1275.5	1302.8	1379.4	1387.6	1340.8	1185.7	1088	1055.5
Alert	713.7	732.3	801.9	840.9	846.4	862.8	908.8	913.7	885.6	792.6	734	714.5
Emergency	458.3	467.6	502.4	521.9	524.6	532.8	555.8	558.3	544.2	497.7	468.4	458.7

Source: ERBA, 2007

The chart below (Figure 3-1) shows monthly water stock in the Mequinenza dam since 1970, when the dam system was already working at its full capacity. The Lower Ebro would have been under emergency only twice since then (these thresholds only apply since 2007), although alert junctures have been common, especially during the last decade.

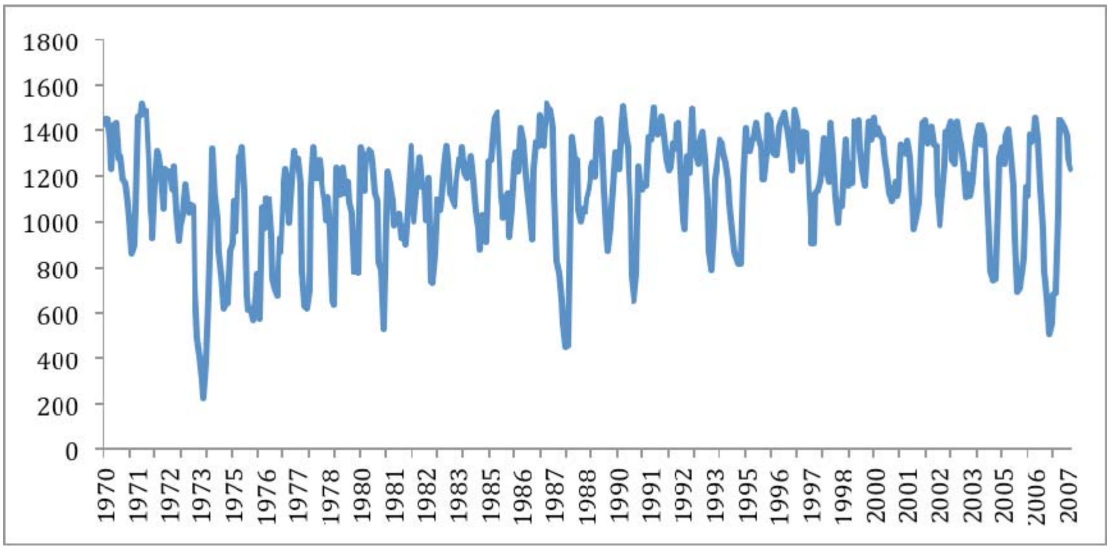

Figure 3-1 - Average monthly stock (hm³) in the Mequinenza dam, 1970-2007

Source: Own elaboration from Ministry of Environment, 2011

Qualitative and quantitative status of the aquifers in Lower Ebro is good, which results from a low abstraction rate that in the Lower Ebro accounts to less than 35 hm^3/yr. (ERBA, 2008).

Most significant pressures are on the qualitative side, mainly from the alteration in the river morphology and dynamics as a result of the construction of the large dams of Mequinenza and Ribarroja back in the 1960s. Amongst other hydrological components, flood magnitude and frequency were altered.

It has been shown that dams and other water infrastructures, which alter river systems, can also be used as tools to artificially reproduce some of the functions performed in the past by the natural system (Granata and Zika, 2007). Channel maintenance flows together with sediment injections downstream can effectively restore the sediment balance altered by a reservoir (Buer, 1994; Kondolf, 1997). Similarly, modifying hydropower dam operational rules to guarantee the recurring release of properly designed flushing flows may effectively replace the role performed in the past by the natural floods typical of many Mediterranean rivers, which served to maintain the structure and functions of the river ecosystem (Hueftle and Stevens, 2002; Vinson, 2001; Kondolf and Wilcock, 1996). Since the implementation of flushing floods there has been an improvement in the ecological status of the river stretches close to the dam.

Another relevant qualitative problem in the area stems from the Erquimia industry located in Flix, which dumped for years over 700 000 m^3 of waste materials including mercury and other heavy metals that were accumulated in the Flix dam. There is a project running to remove these pollutants (Generalitat de Cataluña, 2011).

3.1.4 Ecological status of water resources

The increasing water demand in the last decades through the combined action of agriculture, manufacturing industries, and population demand and the reduction in water supply as a result of new rainfall patterns have reduced runoff in the river as compared to what would be normal under a natural regime scenario. Additionally, the construction of the Mequinenza-Ribarroja-Flix dam system and the constant ecological flows in use (10% of the flow rate under natural regime) have flattened the river hydrograph in its lower stretch.

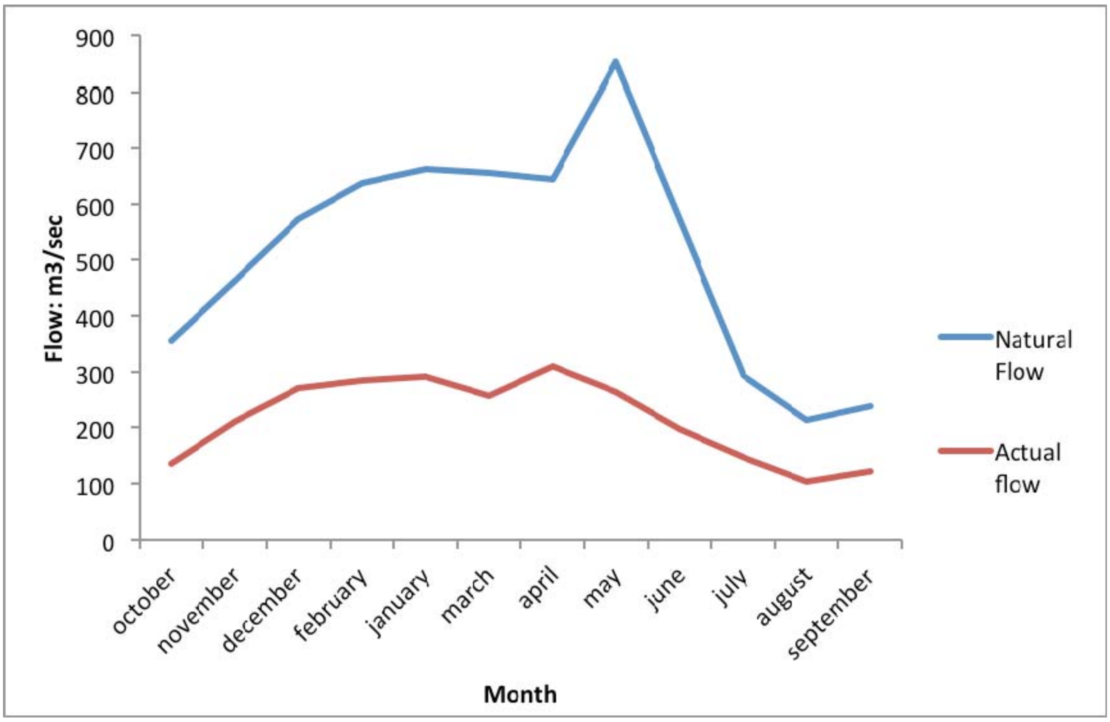

Figure 3-2 - Runoff under different flow regimes, 1940-2006, Ebro at Flix

Source: Own elaboration from Ministry of Environment, 2011

The result has been a reduction of flood frequency and magnitude, which are the energy source for keeping an active river channel morphology; the reduction of the river's sediment load, which implies the erosion of the coarser fractions in the channel; and the alteration of the river's ecology, as a compound effect of impoundment, low frequency of bed moving floods, slow moving waters, fine sediment deficit, high temperatures and excess nutrient load (Batalla et al., 2006; Vericat and Batalla, 2006; Vericat et al., 2006; Batalla and Vericat, 2009).

The implementation of the EPI in the Lower Ebro started in 2002 after two dry years (corresponding to one of the most remarkable mycrophyte bloom ever, URS, 2010, p. 77), which created the necessary context to begin co-operation between the hydropower company, water authorities and the scientific community. Since then and with the exception of the years 2004, 2005, 2008 and spring of 2009, flushing flows have been regularly performed twice a year (at the end of spring and autumn) and have resulted in macrophyte[6] removal rates as high as 95% in areas close to the dam (Batalla and Vericat, 2009).

The efficiency of flushing flows in macrophytes removal depends on the amount of macrophytes; natural flow variability and macrophyte life cycle. For example, removal rates are considerably higher during autumn than during spring, when macrophytes are growing and stalks are stronger (according to the macrophytes life cycle, macrophytes mass reaches its peak in summer) (URS, 2010).

Artificial floods have proved themselves a useful means to maintain the river ecosystem, with the highest macrophyte concentration after years where flushing flows were not implemented (ERBA, 2010). However, removal rates have been reduced both in intensity and extension since 2002, demonstrating that flushing flows with its present design are not enough to keep macrophytes under control in the long term. Alternative systems such as new designs of artificial floods and the use of mechanical tools are being considered to avoid macrophytes proliferation in the long term (URS, 2010).

On the other hand, flushing flows are also tested means to enhance biological productivity of the physical habitat, to entrain and transport sediments for the restoration of the river channel, to remove pollution loads and improve the water quality, to control salt intrusion and to supply sediments to the delta and the transition waters (ecotones) (Batalla and Vericat, 2009).

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[6] Aquatic plants growing in near water. They are beneficial to lakes where they are considered as eco-indicators, but growing on heavily modified rivers where its presence is an evidence of degradation, rather than good ecological status.

3.2 Economic Assessment Criteria

3.2.1 Economic efficiency

The implementation of flushing flows has contributed to improve the ecological status of the river at a reasonable cost, especially if compared to the costs of removing macrophytes using exclusively labour and physical capital (i.e. mechanical prune). Flushing flows reduce financial revenue of the hydropower company, but different environmental valuation studies (Loomis et al., 2000; Magat et al., 2010) show that expected welfare gains by society as a whole are significantly higher, which allows for the payment of compensation.

The co-operation between power generation companies and water authorities is also a positive signal showing that flushing flows for river restoration purposes (public interest) can be compatible with private corporate concerns and incentives.

Restoring the ability of river ecosystems to provide basic ecological services and functions (which is indeed an efficiency goal, in the sense that it potentially increases social welfare) has therefore become a priority for water management (Gupta and Bravard, 2009).These objectives can only be obtained at the cost of impairing the ability of water infrastructures to provide valuable socioeconomic goods and services, as hydropower, sufficient water supply, flood control and amenities (Bednarek and Hart, 2005; Palmieri et al., 2001; Robinson and Uehlinger, 2003). This explains the increasing interest in learning how to balance river rehabilitation benefits with the provision of goods and services by water infrastructures.

3.2.2 Costs

Under the actual scheme flushing flows, implemented twice a year, have an estimated cost of EUR 100 000 per year (own elaboration), compared to the estimate daily revenue of the company of EUR 250 000 (thus, losses mean only 0.16% of the average yearly revenue) (*ibid.*). Losses are a consequence of the change in electricity output during the flood and the absorption period and the regulation of the production timing during the flushing flows, which prevents the company from adapting the production to those moments of the day when energy prices are at their highest value. The artificial floods require 36 million cubic meters along 16 hours, which implies a cost of EUR 76 000 in the autumn flood and EUR 33 000 in the spring flood. On average, it can be shown that the cost per cubic meter delivered is around EUR 0.002 for the autumn flood and half of that for the spring one. The different cost is explained by higher energy prices during autumn than in spring.

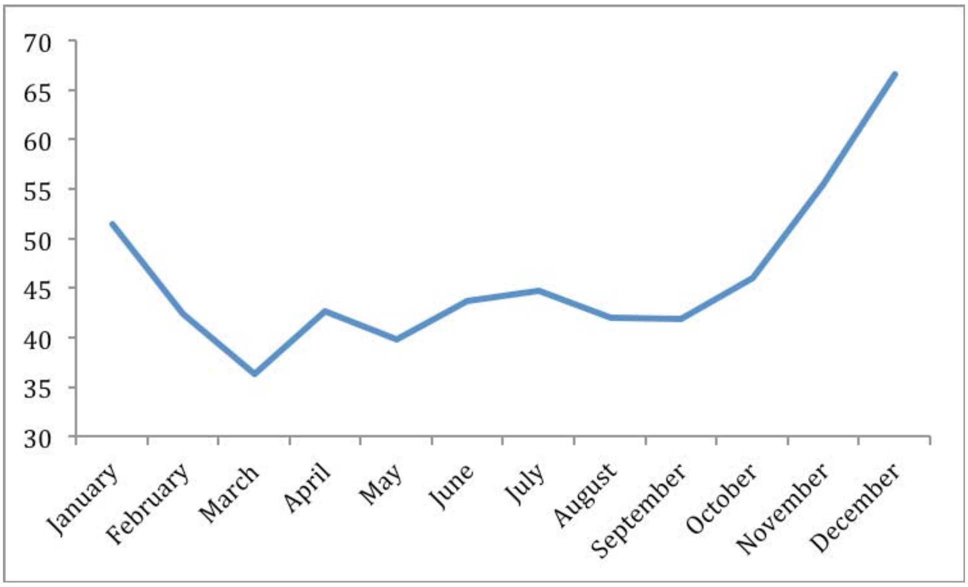

Figure 3-3 - Hydropower energy price (2007)
Source: Own elaboration from Comisión Nacional de la Energía, 2011

It is important to underline that prices from an estimated model (Gómez, 2010) are average values, so that actual costs can be lower or higher than expected, as hydropower generation is a very volatile market with daily price variations as large as 64%. The value displayed of EUR 100 000 is the long-term annual average.

In the case of the Lower Ebro the expected reduction in the energy output is only the equivalent to 0.06% of the hydroelectricity produced by the system in an average year. Thus, the implementation of the river restoration program does not seem to be in contradiction with the potential role of hydropower as a clean energy source and might not imply an increase in greenhouse gas (GHG) emissions. Within this context, the water conservation policy is not in contradiction with any global warming control objectives.

Foregone hydropower output as a consequence of the flushing flood program represents an even smaller fraction of the overall production of the system. The cost of guaranteeing the periodical release of flushing floods by changing the operational rules of hydropower facilities also seems to be lower than any other alternative of obtaining water from other sources (such as saving water in agriculture and domestic consumption or from water recycling, desalination and so forth) in order to have the additional stock of water available for these purposes in the reservoirs.

Under this EPI, public institutions cover financial costs faced by the hydropower company. The public sector therefore provides a response to the public demand for a better river ecological status. Therefore, cost recovery has to be assessed according to the willingness to pay expressed or inferred from the behaviour of economic agents.

3.2.3 Cost effectiveness

Public expenditure not based on actual social willingness to pay (WTP) can be justified on the basis of the precautionary principle in cases when the expenditure is aimed towards avoiding irreversible effects on natural assets (Bishop, 1978). On the other hand, when this expenditure maintains or increases the supply of goods and services over population needs over safe minimum standards for habitat preservation, expenditure is not justified without social profitability or positive cost-effectiveness (Norton, 1987). For this case study, river alteration is actually relatively low and there is no irreversibility; hence, social profitability is also required.

Financial costs of this policy were estimated at EUR 100 000 in the previous section. For the measurement of benefits, several methodologies can be applied, such as contingent valuation, travel costs, hedonic prices, and choice experiments (environmental valuation) or multicriteria analysis, although their cost (time, money) would be too high for our purpose here and there still would be doubts about the convenience to use these valuation techniques in such a case study. Nevertheless, there exist a number of environmental valuation studies on river restoration in highly modified rivers, which can give us a range of the expected willingness to pay for river restoration programs such as the one herewith assessed, following a *sui generis* meta-analysis procedure which is adequate for the purposes of this *ex-post* assessment.

Table 3-2 - WTP *for different river restoration programs*

Author(s)	Method1	Location	Valuation	WTP (USD 2008)
Magat et al., 2000	CV - IB	Colorado and North Carolina, USA	All aquatic species	114-377
Loomis et al., 2000	CV - IB	Platte River, Colorado, USA	Ecosystem services	252
Desvousges et al., 1983	CV - DC	Unspecific	Recreation	111-220
Loomis, 1998	CV	Mono Lake, California	Recreation and use value	156
Colby, 1993	CV	Western, USA	Minimum instream flow	40-80
Berrens et al., 1998	CV	New Mexico, USA	Minimum instream flow	73
Loomis, 1996	CV	Elwha River, Washington, USA	Dam Removal	59
González and Loomis, 1996	CV	Mamayes River, Puerto Rico	Minimum instream flow	27
Matthews et al., 1999	CV - IB	Minnesota, USA	Quality improvement	15-22
Johnston et al., 2005	Meta-analysis	USA	81 Studies of WTP for Water Quality Changes	11
Brown and Duffield, 1995	CV	Minnesota, USA	Minimum instream flow	6.7

Source: Own elaboration from different sources

Notes: (1) CV: Contingent Valuation; CV-IB: Contingent Valuation with Iterative Bidding; CV-DC: Contingent Valuation with Dichotomous Choice questioning.

According to these studies, WTP ranges from 11 USD/year per person to 377 USD/year per person. Even from a narrow perspective and considering that ecosystem services were to be paid for only by the local population of 191 568 inhabitants (which is not necessarily the case), the average cost would be only 0.52 €/year/person, which is considerably lower than the total WTP estimated by all the studies. On the contrary, should river restoration measures be paid by the million people living in areas close to the Ebro River, the cost would fall to 0.1 €/year per person; 0.01 €/year per person if taking the whole river basin as a reference (10 million inhabitants).

Provided flushing flows are implemented by using sound economic criteria their opportunity cost is lower even in one or two orders of magnitude than people's willingness to pay to secure the benefits of river restoration programs. In spite of the variability in the flushing flood opportunity cost, due to the uncertain behaviour of water flows and stocks in Mediterranean rivers, this cost is lower than the benefits associated to the river restoration programs as measured by individual's willingness to pay. Depending on the size of the program beneficiaries, the opportunity cost can vary within the above-mentioned range, whereas the willingness to secure the benefits of river restoration programs can be as high as USD 21 per person-month as reported for example by Loomis et al. (2000) or Meyerhoff and Dehnhardt (2007). This information might be considered sufficient to judge that the agreement would be compatible with a cost-benefit decision rule, and no specific valuation exercise is required.

3.2.4 Risk reduction

The assessed EPI contributes to improve the water quality of the river, although risk in water supply is exogenous to the implementation of these ecosystem services in the lower stretches of the Ebro River. See below for an analysis implementing a stochastic methodology in the Lower Ebro sub-basin.

Since the implementation of the EPI, the stock of the Mequinenza dam has been in alert levels in several occasions (2004, 2005 and 2006-2007). Droughts can significantly increase the costs of the EPI implementation. When water availability is lower, production loss is located in the hours with highest prices. As price variability is high (See *Figure* 3-3), revenue variability is also high and thus compensation for the losses faced by the energy utility should be higher. On the other hand, in years of relative abundance of water resources, production lost by the company by the implementation of the EPI will have a lower value than expected (100 000 €/year), and thus compensation should consequently be adjusted.

The Lower Ebro sub-basin spreads downstream Mequinenza. The drought index for this sub-basin is obtained from the amount of water stored in this dam (ERBA, 2007), which in turn depends on current (runoff) and accumulated rainfall (stock). It is possible to estimate the probability of having a certain stock at a certain time as well as to estimate its short-term evolution by adjusting a Probability Density Function (PDF) for stock and rainfall. Following the literature (McWorther et al., 1966; Martin et al., 2001; Gómez-Iglesias et al., 2002) we have adjusted a Weibull PDF for the stock and a Gamma PDF for the rainfall values.

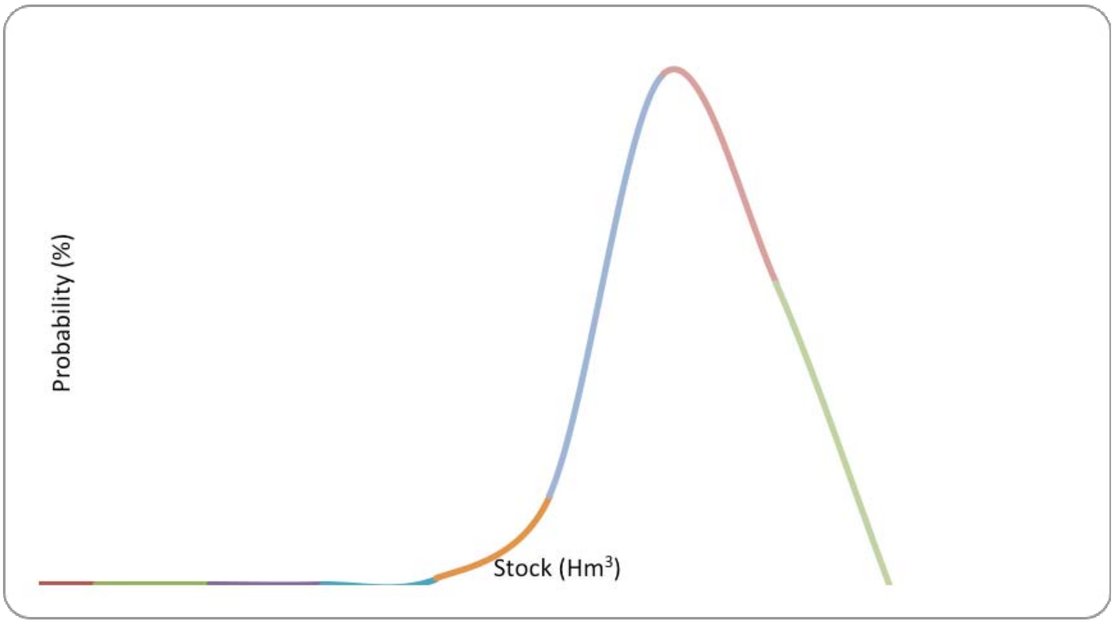

Figure 3-4 - Stock Probability Density Function, Mequinenza dam (hm³) (1941-2011)
Source: Own elaboration from Ministry of Environment, 2011

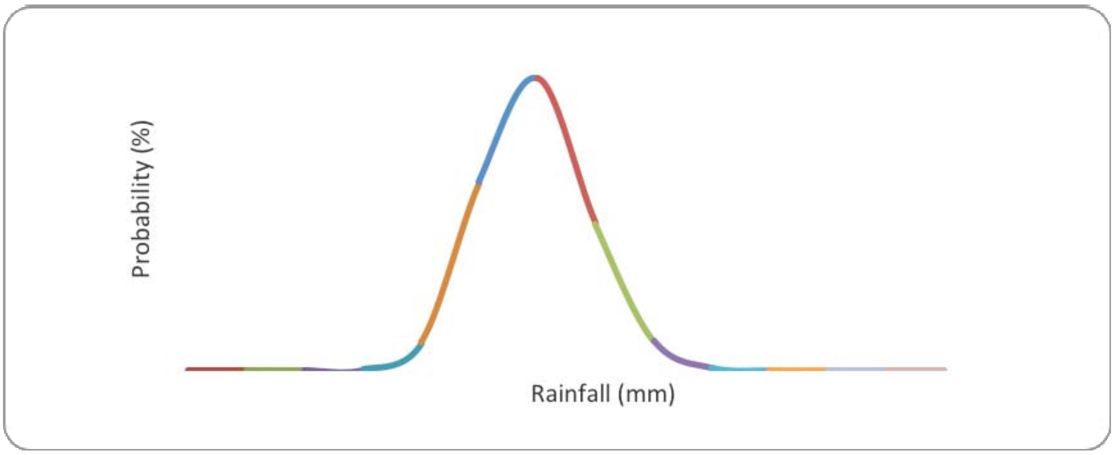

Figure 3-5 - Rainfall Probability Density Function, Ebro River Basin (mm) (1941-2011)
Source: Own elaboration from AEMET, 2011

Probability of emergency is low, although alert is a likely event according to historical data.

3.3 Distributional Effects and Social Equity

Since the EPI assessed is a voluntary agreement between the energy company generating hydropower and the ERBA on behalf of the public interest, equity issues at stake are not especially remarkable. No distributional consequences can be directly associated to the introduction of this EPI. As a matter of fact, a financial compensation (due to profit loss for the hydropower company), which was part of the negotiations between the energy company and the river authorities, was not actually paid after all; incentives for an agreement were clear even in its absence, which is a very insightful lesson from this EPI: the critical part is the scheme of incentives (both for the power generating companies and the river basin authority) rather than whatever monetary compensation.

In addition, no significant deprivation of water uses or other equity concerns were at stake. We see the potential for some conflict of uses in the Lower Ebro, however, although nothing has been raised so far as part of the analysis and the key stakeholder consultation developed for this case study (essentially with academics responsible for flood design and ERBA representatives, in a basin which is renowned for its public participation processes in Spanish basins).

It is important to note that restoration programs (the restoration of natural river regimes compatible with private hydropower generation) may imply a reduction in the water flow to be turbined (or the operational rules involved in such a procedure). Batalla and Vericat (2009) insist that flushing flows are far from being incompatible with HEP production and can actually create positive impacts by decreasing of clogging of water intakes in the downstream nuclear power plants and irrigation pumping stations, therefore inducing positive externalities (for other stakeholders). Yet, flushing flows designed for the Lower Ebro have been partially insufficient to avoid clogging, and complementary actions such as mechanical extraction of macrophytes has been in place, at least in areas upstream the intakes.

A significant public health risk, linked to a plague of black flies due to macrophyte accumulation is to be taken into account, though. Black flies nourish by feeding on the blood of mammals, including humans. In several stretches of the Lower Ebro there has been evidence of black fly plagues, which actually became a common nuisance for the local population and visitors. The public-health threat is due to the fact that black flies spread several diseases (although the incidence is especially higher in Africa and South America). Intense feeding is said to cause a fever, with headache, nausea, high temperature, swollen lymph nodes, and aching joints, besides some sort of allergic reactions (Gratz, 2006). Unfortunately, this public health risk is not very well documented, which in turn provides an idea of its mild incidence and prevalence.

> As a matter of fact, it seems more a question of annoyance, because of the bites of black flies. There are records that in 2010, 4 500 people were seen in primary health care centres, which implied a cost of *circa* EUR 45 000. This adds to around EUR 300 000 allocated by the Regional Government to the prevention and minimization of effects linked to black flies.

3.4 Institutions

To provide a clear idea of the institutional background in which the assessed EPI was implemented, it must be first said that the Ebro river basin is not any basin but one that has been the stage of a very controversial episode of water planning in Spain.

The 2001 proposal for an inter-basin water transfer from the Ebro river basin was designed to solve severe degradation of South-eastern Jucar, Segura and Sur basins, by transferring 820 hm^3 from the Ebro to areas 750 km away, as well as sending 180 km northwards an additional volume of 200 hm^3 to Barcelona. The main (formal) argument against the transfer was that supply-side approaches to water management were obsolete and water demand policies were rather needed. Albiac et al. (2006) analysed both the costs of alternatives and the response of demand to water prices, pointing out that the Spanish water authority had ignored both critical aspects in those days. Advocates of the Ebro inter-basin transfer argued that it would contribute to spatial social cohesion, via the creation of wealth in SE Spain.

The Ebro inter-basin transfer proposal was cancelled after a different Government took office in 2004. The legal amendment (11/2005, June 22nd) was passed in 2005, after very intense public debate and participation. Official reasons for the transfer cancellation were: the overestimation of benefits and the underestimation of costs, the inadequate explanation and analysis of pricing issues, the wrong estimation of the price-elasticity of demand, threats to ecological flow conservation in the Ebro, the ecological threat of invasive species expansion, lacking analysis of energy provisions, lack of rigour in the estimation of surplus water to be transferred, and the subsequent opposition of the European Commission authorities, which would have conditioned the project funding.

This political background, though, does not explain that much about the context in which this EPI was implemented, which was at an intra-basin level. It mainly shows that this basin has been under recent public scrutiny and, at the same time, that there are relevant issues at stake regarding the conservation of the Ebro's estuary (i.e. the biophysical flows of ecosystem services), and the proliferation of invasive species.

Main institutions involved are the ERBA (Ebro River Basin Authority, CHE), which was the first river basin organization in the world (1926), ENDESA (Italian privately owned energy company) and the University of Lleida, responsible for flushing flow design. *Ad hoc* institutional arrangements (such as working and consultation groups) have been established, as above, which has consolidated a fluid relationship between these main stakeholders.

Water planning is well known for having a very long tradition in Spain. To some extent, it could be argued that water planning in Spain was much more a logical need than just an outcome of political will across the past century. One may find references to water policy (more as an idealized expression of agricultural policy or even of the economic development policy of the country), back in 1902 (when the first National Plan on Water Works was passed). The 1879 Water Act had already made a significant contribution to water management and the definition of the public domain, but it was not until the early years of the 19th century that water policy acquired a different status.

During those years, Spain was going through a very incipient stage of water resource exploitation; one based upon the simple idea of taking water from natural sources to where it is actually demanded. Water policy within that context was very much a question of building canals that, stemming from a small dam for water withdrawal. Water policy was thus equivalent to fostering irrigation. As a result of that conception, the National Plan on Water Works (1933), did include a significant number of water regulation infrastructures and even a first version of the Tagus (Central Spain) – Segura (SE Spain) inter-basin water transfer, but always aiming at developing specific areas for irrigation.

Intersectoral conflicts and a higher complexity of water challenges required a more integrated approach, based upon watershed as a management unit. This resulted in an increase of water regulation works, with very preliminary concepts of economic efficiency (making the most out of available water), both from a static (meeting current needs) and dynamic perspective (as an interannual guarantee, to meet future needs). At this level, not only surface and groundwater resources had to be connected from a management and analytical perspective or multiple-use projects needed to be deployed; rational criteria were also to be designed (and implemented) to obtain efficient and sustainable solutions to water conflicts. Since this could not easily be done without river basin, *ad hoc* institutional arrangements and specific incentives for stakeholders, including a clear perception not just of welfare gains (efficiency) but also of distributional improvements (equity).

The 1985 Water Act was definitely a landmark in Spanish water planning evolution, since river basin plans were a binding requirement in that legal body.

3.5 Policy Implementability

Adverse effects on channel geomorphology such as armouring and incision would have persisted if non–appropriate decisions regarding frequency and magnitude of flushing flows would have been made disregarding the driving controls of the natural flood regime (Vericat and Batalla, 2009). Gravel injection to minimize incision during floods should be considered to ameliorate this problem. Likewise, possible aggradation in reaches where flow competences is lower should also be examined. As a matter of fact, there is a clear need for the co-ordination of different water policy goals regarding the river restoration and also sectoral interests at stake if considering this restoration program as a whole, and not just in terms of algae removal. The co-ordination level of significant stakeholders is remarkable so far, at least since the creation of the working group in 2008. The Ebro River Basin Authority has a long tradition of public participation and accountability, ranking high in the *Transparency International* index. Its ability to engage stakeholders proved as a catalyst for the success of this EPI.

In the Ebro River Basin Management Plan 2010-2015 a specific Action Plan to tackle macrophyte massive growth was included. A significant bias towards algae removal (and not other river restoration measures) has been observed within the past few years, and therefore we have placed much emphasis in analysing implementability concerns in this regard, since the public good variables at stake might have been fading.

As in other countries, water in Spain belongs to the public domain (art. 2 TRLA, RDL 1/01, July 20th) and is subject to state planning (art. 3 TRLA). State functions are in turn subject to policy principles, including, *inter alia*, the economy of water (art. 14.1 TRLA). River basin organizations (RBOs) are responsible for the administration, management and control of water resources, the preparation of water plans, the operation of common works, and the preparation, construction and exploitation of water projects (art. 23, TRLA). All these legal provisions generically frame the voluntary agreement assessed in this document, but have not posed implementability challenges from a policy perspective, since they are linked to the overall integrated water management approach and have not been an obstacle, rather the opposite, to the EPI implementation. The fact that macrophyte removal became a spur for the agreement does not necessarily show a bias towards the interest of the hydropower company but rather a practical means to find common ground for such a cooperation agreement.

Furthermore, this EPI is consistent with efforts within the WFD implementation process regarding HMWB, although technically the Lower Ebro is not a HMWB but a significantly modified water body. It shows that water uses can also provide important benefits downstream and on the catchment. This EPI, in fact, provides evidence in an area, which has not been sufficiently developed in the literature, providing information on the current and potential future contribution of the hydropower sector not to renewable energy targets or greenhouse gas emission abatement, but rather to the regeneration of the river regime.

Renewable energy policy objectives are definitely a driver for hydropower development. When that energy development happens in already significantly modified water bodies, the impact is especially intense. Hydropower generation is unavoidably related to hydromorphological alterations, which primarily include: impoundment and diversion of the watercourse associated with disruption of the aquatic habitat, alteration of the upstream migration of fish and invertebrates, disruption of the downstream migration of fish (not to mention problems linked to raking systems and mechanical installations of the plants), and other effects due to storage effects, retention of the bed load, hydro-peaking and so on.

3.6 Transaction Costs

No specific definition of transactions costs has been identified in the literature review for this case study. However, we are aware that there were significant monitoring costs of the agreement, mostly based upon research projects, which, in most cases, were funded through competitive research programmes at a national level (National Plan of R&D) (See Table 3-3).

In the summer of 2002, Endesa, together with the Hydrologic Risk Group of the University of Lleida, prepared a medium-term action plan aimed at reducing, at significant rates, the macrophyte population in the river (Palau et al., 2004). Macrophyte removal was not the main objective, indeed, or at least it was not so from a public perspective; yet, as above, it proved to be the catalyst for agreement and reconciliation of public good concerns (river restoration) and private interests. The design and implementation of the EPI actively involved the participation of key water users (including the hydropower generation companies themselves), local water authorities and river scientists. Endesa (2011; 2009; 2008; 2007; and 2006) provides corporate information on the monitoring process. A task force was actually created in 2008, which has been working since then in the design of flushing flows and monitoring activities.

The fundamental idea of transaction costs linked to this EPI is that they consist both of the costs of arranging the agreement *ex ante* and monitoring and enforcing it *ex post*. It should be clear (and this is a good example) that transaction costs are not to be avoided (they are indeed critical to the success of this EPI) but rather to be minimized. *Table 3.3.* shows some of the most relevant research projects that have been developed regarding the aims of this EPI, directly coupled to and part of monitoring activities. All these research efforts are the main transaction costs of this EPI.

Table 3-3 - Research projects linked to the EPI implementation (relevant examples)

Research Project and Reference	*Details (Funding body, period and amount granted – current Euros)*
Flushing flows	
Controlled flows: A methodology for analysing its economic costs and social benefis downstream from reservoirs [CGL2009-09770]	• Ministry of Science and Technology • 2001-2004
A methodology for controlled flood design: application to the Lower Ebro River resevoirs [CICYT REN2001-0840-C02-01/HID]	• Ministry of Science and Technology (Spain). • 2001-2005 • EUR 47 101.8
Design and analysis of flushing flows in the Lower Ebro as hydrologic and sedimentary balancing tool [CICYT CGL2005-06989-C02-02/HID]	• Ministry of Science and Technology • 2005 • EUR 3 570
Effects of water quality improvement and flow regime induced changes on biologic communities located in the Lower Ebro River [CGL2006-0148]	• Ministry of Science and Technology • 2006 (agreement) • EUR 135 520
A methodology for the economic analysis of regeneration measures in heavily modified rivers [CGL2005-06989-C02-01]	• Ministry of Science and Technology • 2006-2009 • EUR 44 528
Development of a Cascade Flushing Flow Programme –SIMEC- based on the analysis and modelling of physical processes and economic parameters of the river basins draining into the Ribarroja Reservoir [CGL2009-09770]	• Ministry of Science and Innovation • 2009-2012 • EUR 146 652
Macrophytes	
Multi-spectral flight for macrophyte detection in the Lower Ebro [173/08-SNS]	• ERBA (Ebro River Basin Authority) • 2008 (agreement) • EUR 28 500
Macrophyte control: Lower Ebro dams management improvement [215/09-SNS]	• ERBA (Ebro River Basin Authority) • 2009-2010 • EUR 68 200
Remote Sensing and GIS techniques for monitoring macrophyte populations in the Lower Ebro [106/10-SNS]	• ERBA (Ebro River Basin Authority) • 2010 (agreement) • EUR 4 673.2
Monitoring submerged macrophyte dynamics in the Lower Ebro –Flix dam to the Ebro mouth stretch [169/11-SNS]	• ERBA (Ebro River Basin Authority) • 2011 (agreement) • EUR 65 023.68

Source: Own elaboration on the basis of funding bodies' databases and records

3.7 Uncertainty

3.7.1 Environmental objectives

The objective of the EPI was to promote a voluntary agreement to reconcile public and private interests regarding temporal natural river regime restoration in the Lower Ebro for macrophytes removal. The EPI started in 2002 and has no clear deadline stated (it is still functional), although it can alsop be regarded as the basis for a further and comprehensive river restoration project. The reference against which the performance of the EPI is assessed is the quality of the river prior to the implementation of the policy every year (see *Annex II*).

3.7.2 Performance of policy instruments

The indicators considered to assess the performance of the EPI mostly come from scientific works and are based on sound methodologies, although they are not official and thus can be subject to some kind of bias (see *Annex II*).

The river quantitative state is taken from official data and thus it is the indicator with the lowest bias. The methodology is sound and widespread and based on the largest possible sample coming from different stations along the lower stretch of the Ebro River.

The environmental benefits are estimated following a *sui generis* benefit transfer methodology (not a stric one), and thus are the result of different valuation techniques in relevant basins (further data from the EU would help). All the measurements are based on field experiments following reliable methods widely accepted in the scientific community; this and the large number of studies reviewed guarantee a good fit.

Financial costs are estimated following a methodology developed along a series of research projects in the river basin. The model has been published in scientific journals and provides a good fit.

Macrophyte removal rates are highly precise and are based on the best available practice consisting on taking small samples along the river. The additional indicators of the ecological status (biological productivity of the physical habitat; sediment transport; pollution loads removal; water quality; salt intrusion; sediments in the delta and the transition waters -ecotones) of the river are obtained according to different methodologies and are well correlated.

Finally, the methodology for risk assessment is based on modelled data with accepted methods and a good correlation.

4. Conclusions

4.1 Lessons learned

The experience on voluntary agreements for the delivery of artificial floods in the Lower Ebro is a unique example of public-private partnerships for the partial re-naturalization of a heavily modified river in the world. It has helped building a transparent bargaining scheme supported by long-term focused research enabling a better understanding of the river ecology and contributing to a better design of restoration alternatives.

The case study also shows how the public interest in restoring water ecosystems can make use of the potential gains for water users to build a self-enforcing cooperation agreement and may serve to deeply change the reactive attitude from many private firms into a proactive one. Businesses engaging in the agreement do not only enjoy certain financial benefits but can also convert these actions into part of their corporate social responsibility strategy. Building cooperative agreements is only feasible when private interest is somehow compatible with the actual purposes of water policy, such as the recovery of some ecological potential of the river system.

Moreover, in this kind of cooperation setting, when the voluntary participation of critical water users is critical or at least of paramount importance, the emphasis can easily be placed on the design of alternatives with a better potential to contribute to the objectives of private partners (e.g. the removal of macrophytes in the closer areas of the power generation plants at the least opportunity cost in terms of power output and foregone turnover), rather than those objectives of water policy (e.g. maximizing the social benefits of river regime restoration along the whole river).

4.2 Enabling / Disabling Factors

Payments for environmental services are difficult to implement in societies with advanced water regulations and institutions, especially in EU countries where water resources are not private assets and where private (use) rights can only be issued under certain conditions. Side payments for good practices are not easy to accommodate within existing regulations and will require important legal amendments besides other transaction costs. Difficulties in implementing payments for environmental services presumably reduce the scope for voluntary agreements of the kind illustrated by this example.

The effective contribution of the agreed flushing floods may depend on the previous set-up of many other measures designed to recover the ecological potential of the river, such as a properly defined and effectively enforced environmental flows, which are not already in place and that cannot be expected just as the result of an agreement with water users. In fact, voluntary agreements are possible regarding particular measures that are easy to define and to observe, but the recovery of water ecosystems usually involves many different measures that may need to be coordinated.

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7. Annex I: Additional information for sections 1 and 2

Table 7-1 - Use and Land Use Change 1990, 2000, 2006, Ebro River Basin

Land use/Year	**1990**	**2000**	**2006**	**Land use change 1990-2006 (%)**
Agriculture	47.23%	47.48%	47.41%	-0.86%
Forests	50.30%	49.86%	49.65%	-2.53%
Urban areas	0.45%	0.57%	0.73%	60.14%
Water and wetlands	0.58%	0.61%	0.62%	4.99%
Others	1.43%	1.47%	1.58%	8.67%
Total	**100.00%**	**100.00%**	**100.00%**	**-**

Source: Own elaboration from Corine Land Cover 1990, 2000 and 2006 (Ministry of Public Works, 2011)

Table 7-2 - Land Use and Land Use Change 1990, 2000, 2006, Lower Ebro

Land use/Year	**1990**	**2000**	**2006**	**Land use change 1990-2006 (%)**
Agriculture	71.04%	65.00%	64.32%	-9.46%
Forests	25.97%	31.65%	32.00%	23.22%
Urban areas	0.5%	0.62%	0.68%	36.00%
Water and wetlands	2%	2%	2 %	0.00%
Others	0.55%	0.72%	1.01%	83.64%
Total	**100.00%**	**100.00%**	**100.00%**	**-**

Source: Own elaboration from Corine Land Cover 1990, 2000 and 2006 (Ministry of Public Works, 2011)

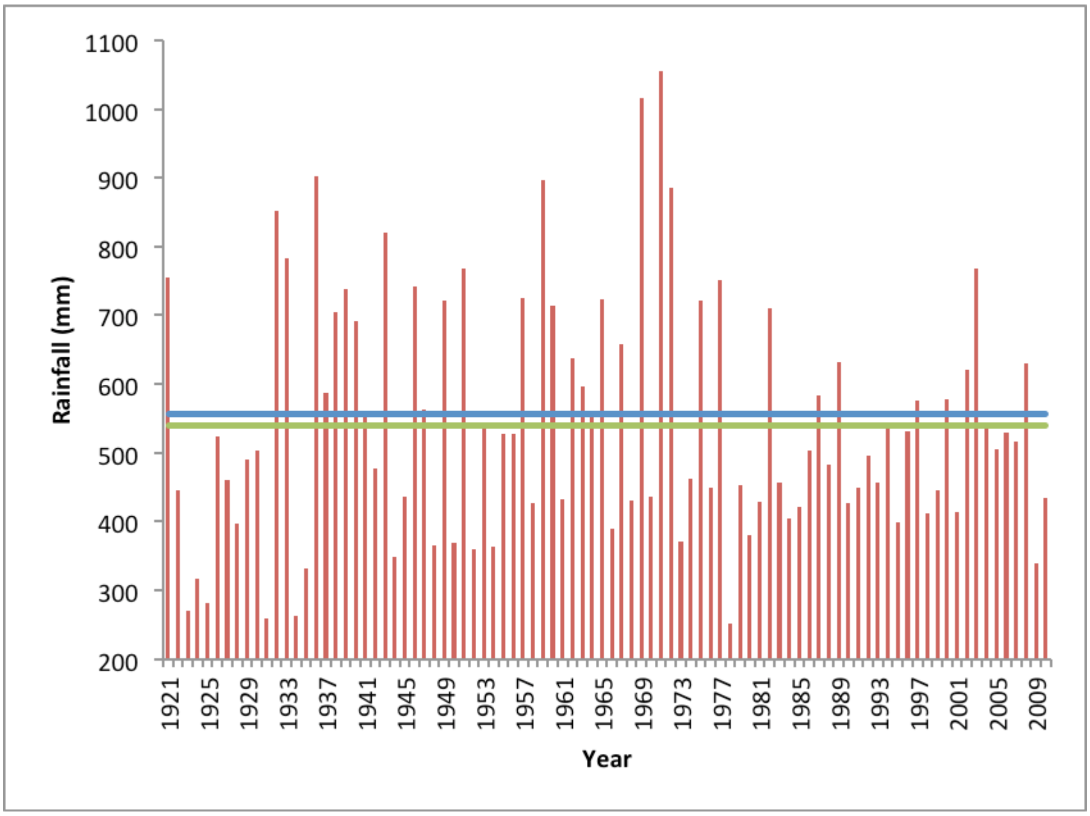


Figure 7-1 - Rainfall (mm) in Tortosa, Lower Ebro

Source: Own elaboration from Agencia Española de Meteorología (AEMET), 2011

Table 7-3 - Average long term runoff, 1940-2006, Lower Ebro

Exploitation board	Average runoff 1940-2006	Average runoff 1980-2006
Bajo Ebro	232	182
Total Ebro RBD	16 195	13 869

Source: Ebro River Basin Authority, 2008

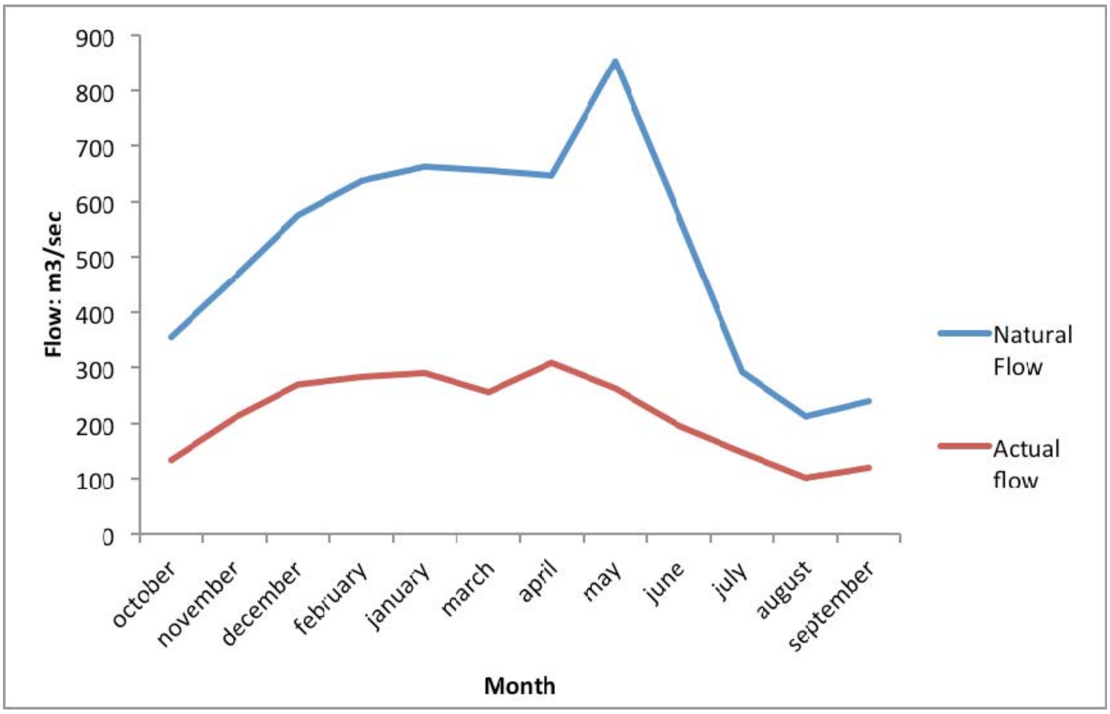


Figure 7-2 - Runoff under different flow regimes, 1940-2006, Lower Ebro at Flix

Source: Own elaboration from Ministry of Environment, 2011

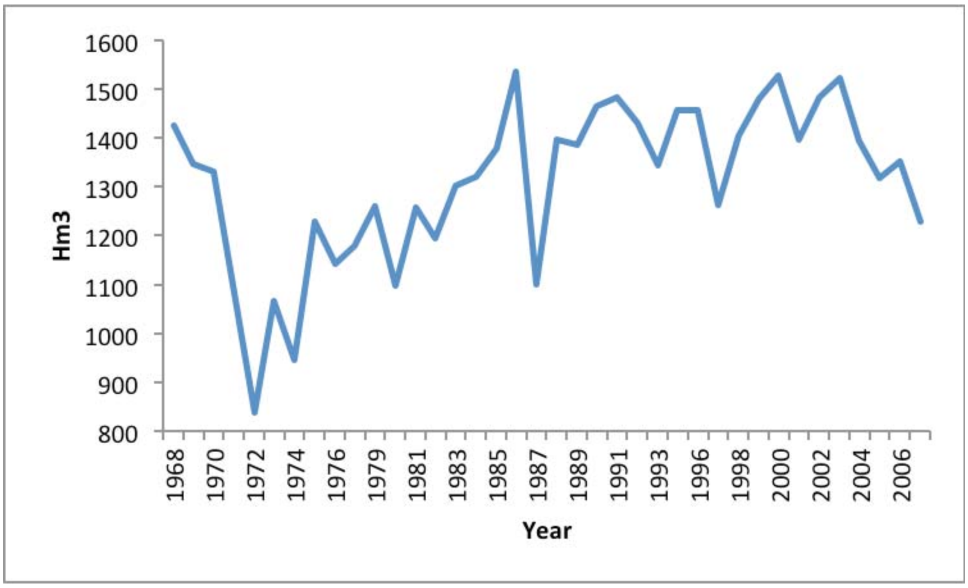


Figure 7-3 - Average annual stock (hm3) in the Mequinenza-Ribarroja-Flix dam system, 1968-2008

Source: Own elaboration from Ministry of Environment, 2011

Table 7-4 - Main crops and area in Tierras del Ebro

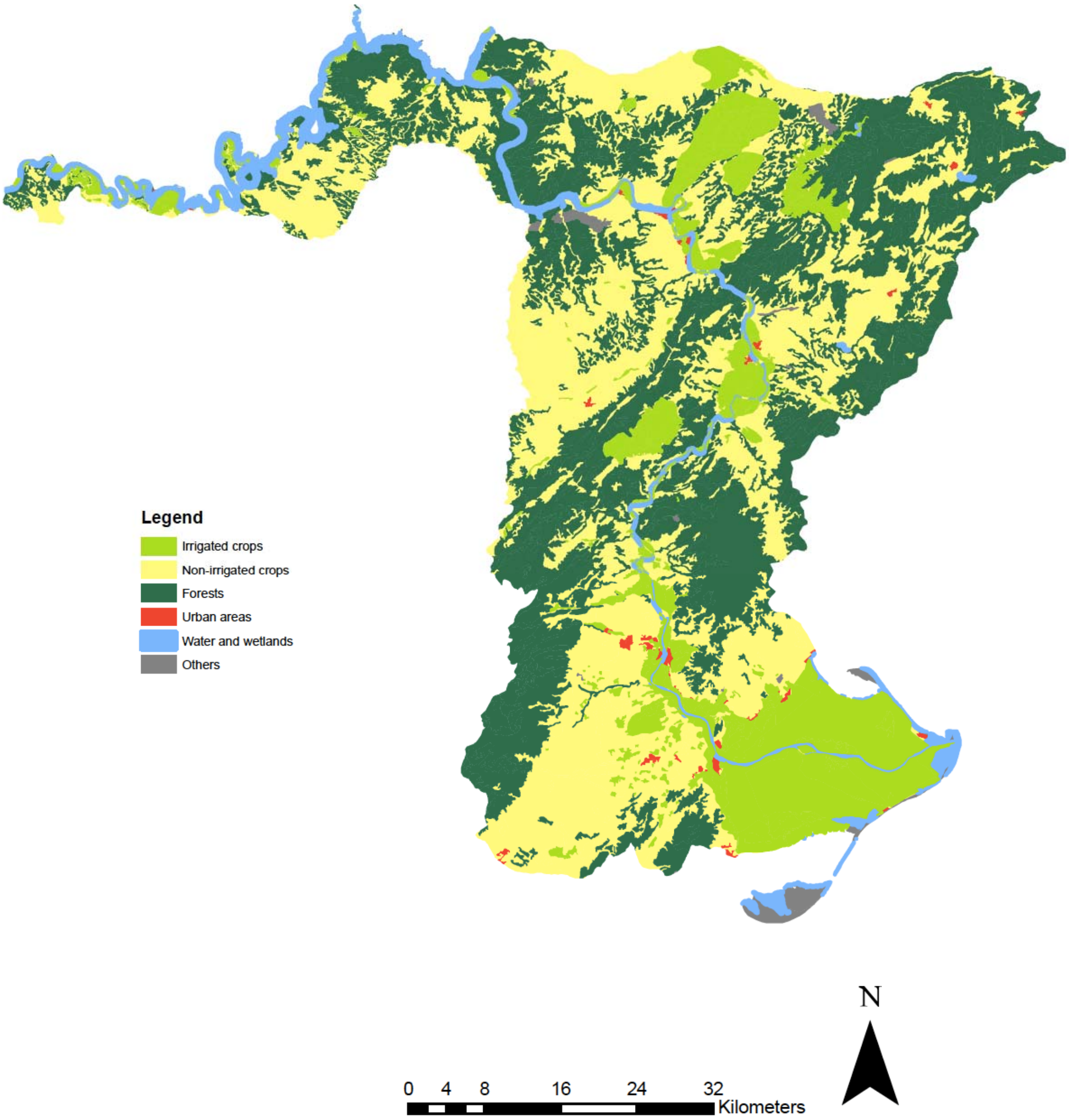
Crop	Area (ha)
Herbaceous extensive irrigation crops	4 124.43
Herbaceous extensive non irrigated crops	1 385.98
Rice	22 602.09
Tall fruit trees, mostly non irrigated: olive tree, almond tree, carob tree	90 427.96
Fruit trees, mostly irrigated: apple tree, peach tree, pear tree	6 555.17
Citrus trees	9 332.98
Vineyard	17 338.53
Hazel tree	949.02

Source: Generalitat de Cataluña, 2011

Table 7-5- Characteristics of the Mequinenza, Ribarroja and Flix reservoirs

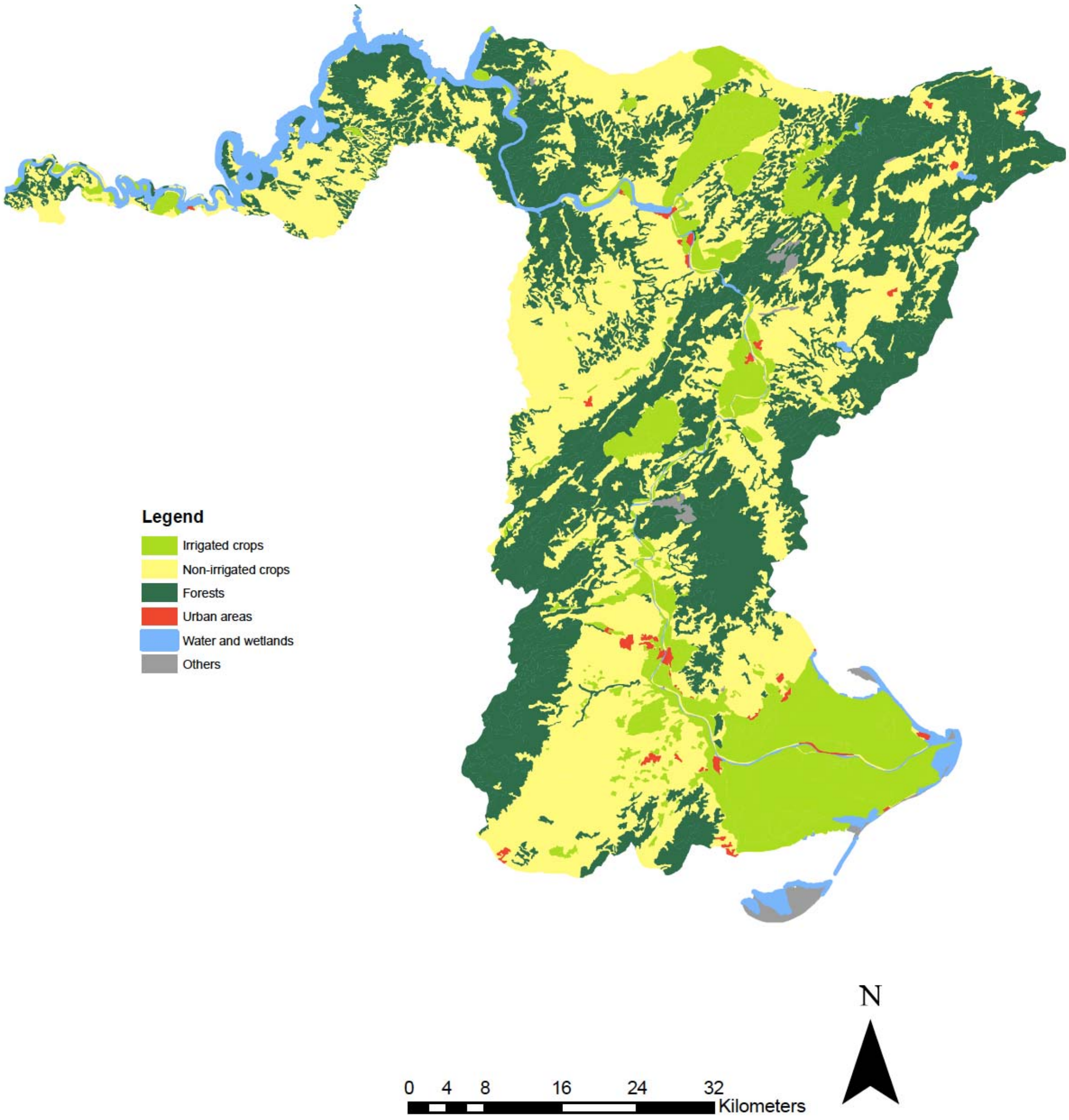
Dam/Attribute	Mequinenza	Ribarroja	Flix
River	Ebro	Ebro	Ebro
Municipality	Mequinenza	Riba-Roja D'Ebre	Flix
Volume (hm^3)	1 530	218	5
Construction	1 964	1 968	1 948
Flow conceded (m^3/s)	760	940	400
Maximum capacity (Kwh)	324 000	262 800	42 500
Height	74	41	12.1
Efficiency	0.8	0.8	0.8
m^3/kWh	6.2	11.19	37.91

Source: Ministry of Environment, 2011



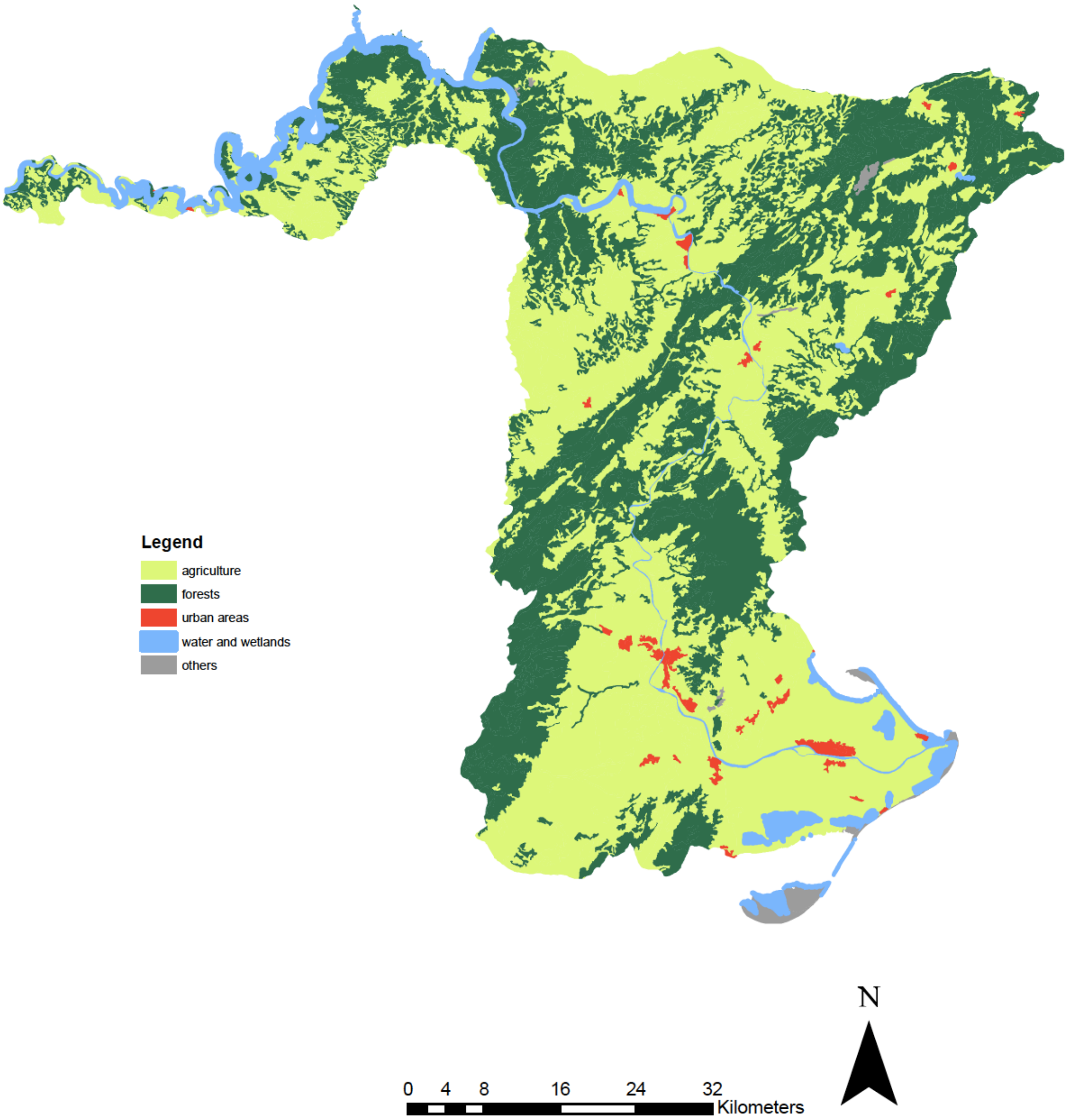
Map 7.1 - Land use in the Lower Ebro, 2006

Sources: Own elaboration from Corine Land Cover 1990, 2000 and 2006 (Ministry of Public Works, 2011) and Ebro River Basin Authority (CHE), 2011



Map 7.2 - Land use in the Lower Ebro, 2000

Sources: Own elaboration from Corine Land Cover 1990, 2000 and 2006 (Ministry of Public Works, 2011) and Ebro River Basin Authority (CHE), 2011



Map 7.3 - Land use in the Lower Ebro, 1990

Sources: Own elaboration from Corine Land Cover 1990, 2000 and 2006 (Ministry of Public Works, 2011) and Ebro River Basin Authority (CHE), 2011

8. Annex II: Pedigree analysis

Table 8-1 - Pedigree table, environmental objectives

	Policy target[1]	Policy deadline[2]	Reference[3]
Improve water quality at an affordable cost	Reduction of macrophytes	Intended as a pilot study for a further and comprehensive river restoration project	Qualitative status prior to the implementation
Pedigree	2	2	2

Source: Own elaboration

Notes: (1) Policy target: [1] quantifiable and clearly stated, [2] measurable in principle, qualitative levels of achievements (e.g. weak, substantial), [3] vague and hardly quantifiable; (2) Policy deadline: [1] clearly stated, [2] stated in qualitative terms (short, medium, long term), [3] no statement; (3) Reference: [1] clearly stated in quantitative terms and with specific reference, [2] not stated.

Table 8-2 - Pedigree table, performance of policy instruments

	River quantitative state	Environmental Benefits	Financial costs	Ecological status - macrophytes	Ecological status - others	Risk assessment
EPI: Improve water quality at an affordable cost	Runoff, Rainfall	WTP: Benefit transfer from several environmental valuations	Have to be less than WTP	Macrophytes removal rate	Qualitative assessment	Probability of drought events
Proxy[1]	4	2	3	3	2	2
Empirical[2]	4	3	2	3	3	2
Method[3]	4	3	3	4	2	3

Source: Own elaboration

Notes: (1)Proxy: 4, exact measure; 3, Good fit or measure; 2, well correlated; 1, weak correlation; 0, not clearly related; (2) Empirical: 4, Large sample, direct measurements; 3, small sample, direct measurements; 2, modeled/derived data; 1, educated guesses/rule of thumb estimate; 0, crude speculation; (3) Method: 4, Best available practice; 3, reliable method commonly accepted; 2, acceptable method, limited consensus on reliability; 1; preliminary methods, unknown reliability; 0, no discernible rigor.

9. Annex III: Contributors to the report/ Acknowledgments

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