

# NOTA DI LAVORO

68.2014

---

## **The Flushing Flow Cost: A Prohibitive River Restoration Alternative? The Case of the Lower Ebro River**

---

By **Carlos M. Gómez**, University of Alcalá and Madrid Institute for Advanced Studies in Water Technologies (IMDEA-Water), Spain  
**C. Dionisio Pérez-Blanco**, University of Alcalá and Madrid Institute for Advanced Studies in Water Technologies (IMDEA-Water), Spain  
**Ramon J. Batalla**, University of Lleida, Forest Science Centre of Catalonia and Catalan Institute for Water Research, Girona, Spain

# Climate Change and Sustainable Development

Series Editor: Carlo Carraro

## The Flushing Flow Cost: A Prohibitive River Restoration Alternative? The Case of the Lower Ebro River

By Carlos M. Gómez, University of Alcalá and Madrid Institute for Advanced Studies in Water Technologies (IMDEA-Water), Spain  
C. Dionisio Pérez-Blanco, University of Alcalá and Madrid Institute for Advanced Studies in Water Technologies (IMDEA-Water), Spain  
Ramon J. Batalla, University of Lleida, Forest Science Centre of Catalonia and Catalan Institute for Water Research, Girona, Spain

### Summary

Although the effectiveness of flushing floods in restoring basic environmental functions in highly engineered rivers has been extensively tested, the opportunity cost is still considered to represent an important limitation to putting these actions into practice. In this paper, we present a two-stage method for the assessment of the opportunity cost of the periodical release of flushing flows in the lower reaches of rivers with regimes that are basically controlled by series of dams equipped with hydropower generation facilities. The methodology is applied to the Lower Ebro River in Spain. The results show that the cost of the reduced power generation resulting from the implementation of flushing floods is lower than the observed willingness to pay for river restoration programmes.

**Keywords:** River Restoration, Flushing Flows, Opportunity Costs, Hydropower, Ebro River

**JEL Classification:** Q2, Q25

*Address for correspondence:*

C. Dionisio Pérez-Blanco  
Madrid Institute for Advanced Studies in Water Technologies (IMDEA-Water)  
Parque Científico Tecnológico de la Universidad de Alcalá  
28805 Alcalá de Henares, Madrid  
Spain  
Phone: +34 91 830 5962  
E-mail: [dionisio.perez@imdea.org](mailto:dionisio.perez@imdea.org)

## **The Flushing Flow Cost: A Prohibitive River Restoration Alternative? The Case of the Lower Ebro River**

Gómez, Carlos M.<sup>ab</sup>; Pérez-Blanco, C. Dionisio\*<sup>ab</sup>; Batalla, Ramon J.<sup>cde</sup>

<sup>a</sup> University of Alcalá (UAH). Plaza de la Victoria, 2. 28802 Alcalá de Henares, Madrid (Spain)

<sup>b</sup> Madrid Institute for Advanced Studies in Water Technologies (IMDEA-Water). C/ Punto Net, 4, 2º piso, Edificio ZYE. Parque Científico Tecnológico de la Universidad de Alcalá. 28805 Alcalá de Henares, Madrid (Spain)

<sup>c</sup> Department of Environment and Soil Sciences, University of Lleida, E-25198 Lleida, Catalonia, Spain

<sup>d</sup> Forest Science Centre of Catalonia, E-25280 Solsona, Catalonia, Spain

<sup>e</sup> Catalan Institute for Water Research, H2O Building, E-17003, Girona, Catalonia, Spain

\* Corresponding author. Email: [dionisio.perez@imdea.org](mailto:dionisio.perez@imdea.org); Telephone: (+34) 91 830 59 62; Fax: (+34) 91 830 59 61

### *Abstract:*

Although the effectiveness of flushing floods in restoring basic environmental functions in highly engineered rivers has been extensively tested, the opportunity cost is still considered to represent an important limitation to putting these actions into practice. In this paper, we present a two-stage method for the assessment of the opportunity cost of the periodical release of flushing flows in the lower reaches of rivers with regimes that are basically

controlled by series of dams equipped with hydropower generation facilities. The methodology is applied to the Lower Ebro River in Spain. The results show that the cost of the reduced power generation resulting from the implementation of flushing floods is lower than the observed willingness to pay for river restoration programmes.

Keywords: River restoration, Flushing Flows, Opportunity Costs, Hydropower, Ebro River

## 1. INTRODUCTION

Water is an economic asset necessary to sustaining life, the environment and the production of many valuable goods and services and should be managed accordingly. However, the prevailing paradigm considers water demand to be exogenous, and water policy, consequently, has traditionally focused on guaranteeing the supply of water services at affordable prices. As a result, during the last decades population growth and the improvement of living standards brought about by development have increased the pressures on water resources. The negative environmental effects stemming from this paradigm are especially visible in the case of the European and North American rivers, where the need to satisfy a continuously growing demand for water and river services has resulted in increased water abstractions and polluted discharges along with gravel mining, canalisation, and successive modifications in river morphologies (e.g., Furse et al., 2006; Zaqiejska and Wyzga, 2009; Batalla and Vericat, 2011).

Consequently, restoration of river ecosystems has become a priority for water management in the developed world, especially in the stressed lower reaches of its rivers (Gupta and Bravard, 2009; EC, 2000). However, restoration can only be obtained at the cost of impairing the ability of water infrastructures to provide valuable socioeconomic goods and services, such as hydropower (Bednarek and Hart, 2005; Palmieri et al., 2001; Robinson and Uehlinger, 2003). There is thus a considerable interest in learning how to balance river restoration benefits with the production of goods and services provided by water infrastructures.

As a result of this interest, significant effort in scientific research has recently been mobilised in two important directions. On one hand, considerable progress has been made in the

assessment of current ecological status and trends and in the design of effective technical alternatives to restoring some basic environmental functions of rivers. In particular, emerging research in biology and ecological engineering (e.g., Granata and Zika, 2007) shows that dams and other infrastructures that alter river systems can also be used as tools to reproduce artificially a portion of the functions performed in the past by the natural system. For instance, modifying the rules of hydropower dam operation to guarantee the periodic release of properly designed maintenance flows (namely, flushing flows) may effectively replace the role performed in the past by the natural floods characteristic of many rivers, which served to maintain the structure and functions of the river ecosystem (see Hueftle and Stevens, 2002; Vinson, 2001; Kondolf and Wilcock, 1996). On other hand, social sciences have provided methods and results for the valuation of the economic and social benefits of potential improvements in the capacity of river systems to increase the quantity and range of those environmental services that might result from a successful restoration of river systems (such as recreation opportunities, biodiversity support, health services, water security and flood control) (see, for example, Hitzhusen, 2007; Turner et al., 2003 and Gupta and Bravard, 2009). However, there is still little research on the costs of practically applying the available options to improve rivers' ecology, which makes the opportunity cost of water the missing element for the assessment of the policy options at hand.

Information on opportunity costs plays a critical role in the evaluation of river restoration alternatives for a series of reasons, including the following: i) first, this information allows us to find the most cost-effective way to improve the river environment and thus minimise the impact over marketable water services; ii) second, information on opportunity costs is essential to judging whether the associated cost is lower than the benefits expected from the improvement of the water environment (and to assess later whether the proposed measures are justified in the light of cost benefit criteria); iii) additionally, cost analysis might provide the

critical information to assessing what would, for example, be the minimum compensation demanded by water users for voluntarily adapting the use of the resource to certain new requirements; and iv) finally, information concerning opportunity costs is also crucial to knowing the real cost of harmonising the provision of water services and the improvement and protection of the water environment.

This paper aims to help bridge this information gap. The paper presents a model for the evaluation of the opportunity costs of implementing a given flushing flow programme in an area where the flow regime is basically determined by the operation of a hydropower facility. In such a situation, the requirement to release the flushing flow means that for certain precise periods of time, the outflow of water does not depend on the profit maximising criteria used by the hydropower plant (baseline scenario) but rather on an operating constraint somehow imposed by an environmental authority (counterfactual flushing-flow scenario). The opportunity cost of such measures is therefore represented by the monetary losses of the concerned commercial activity, namely, hydropower. The overall question we want to answer can be presented as determining a financial value for the minimum compensation required by a hydropower operator to voluntarily accept a predetermined programme of periodical artificial releases. The model is illustrated with an application to the Lower Ebro River.

## **2. THE LOWER EBRO RIVER: RIVER DIAGNOSIS AND THE NEED OF FLUSHING FLOWS**

The Lower Ebro River is located in the northeast of Spain and comprises the area located between the Mequinenza-Ribarroja-Flix Dam Complex (hereafter MRFDC) and the outlet of the river to the Mediterranean Sea (see Figure 1). Water demand from agriculture is significant (1.200 hm<sup>3</sup>/yr, i.e., 90% of the total water demand), and runoff has been reduced by more

than 20% as a result of increasing pressures from upstream and long-term changes in the land use (i.e., afforestation). However, water is still relatively abundant, and droughts are rare (ERBA, 2007). The main environmental concern in the area is related to the impoverished ecological status that resulted from the alteration of the river's hydrology and, subsequently, the channel morphology after the construction of the MRFDC (see Table 1).

The large Mequinenza and Ribarroja dams built in the 1960s substantially modified the flow regime of the lower Ebro. Among other hydrological components, flood magnitude and frequency have been altered. Of special interest for the river's ecological functioning is the reduction of 25%, on average, of the relatively frequent floods (i.e., those between 2 and 25 years of return period) (Batalla et al., 2004). Although the river still experiences natural floods, and the impact of regulation is much smaller than that found in comparable large rivers, such as, for instance, the Sacramento and the San Joaquin Rivers in California (Kondolf and Batalla, 2005), the river's physical and environmental conditions have changed notably in the last decades, as has been reported in a series of research papers (e.g., Batalla et al., 2006; Vericat and Batalla, 2006; Vericat et al., 2006; Batalla and Vericat, 2009). The main dam induced changes can be summarised as follows:

- Reduction of flood frequency and magnitude; floods provide the energy for keeping an active river channel morphology, and this reduction has led to the loss of formerly sedimentary active areas, the encroachment of riparian vegetation and the narrowing of the channel.
- Reduction of the river's sediment load, which implies the erosion of the gravelly fractions in the channel with no replacement from upstream and simultaneous riverbed armouring during small frequent floods and during high flow periods.
- Alteration of the river's ecology, as a compound effect of impoundment, exemplified by the low frequency of bed moving floods, slow moving waters, deficit of fine



sediment, high temperatures and excess nutrient load. These combined alterations create a new functioning in the river ecosystem with consequences regarding the river's ability to provide key environmental services.

[Insert Figure 1 about here]

[Insert Table 1 about here]

This new set of environmental conditions, together with similar changes in the upstream main tributaries, appears in the basis for the uncontrolled proliferation of macrophytes in the Lower Ebro River channel (e.g., Goes, 2002; Palau et al., 2004). Macrophytes threaten river infrastructures, increasing the operating cost, reducing the productivity of power-generating plants and water-pumping devices and reducing the ability of the river to provide navigation and recreation services. Competition for space and resources resulting from the stabilisation of dense macrophyte stands also affects the biology of the river ecosystem in many different ways. Macrophyte stands limit the access to microhabitats that are important for the growth and survival of juvenile fish, and the decomposition of growing organic matter depletes the water of its oxygen. Macrophytes communities also enhance flow resistance, thus exacerbating the reduction in flow velocity and trapping an important portion of fine sediment load (Batalla and Vericat, 2009).

Within this context, a considerable body of research has been devoted to the design and implementation of flushing flows as a means to improve the ecological status of the Lower Ebro River. These efforts started in 2002 when the previously mentioned problems were exacerbated after the succession of two notably dry years. That situation created the conditions for an effective cooperation between the hydropower company, the water

authorities and the scientific community. With the exception of two dry years in 2004 and 2005, flushing flows have been regularly performed twice a year (in autumn and spring) providing a testing scenario for the increasing improvements in its design to enhance its effectiveness, reaching macrophytes removal rates as high as 95% in areas close to the dam (Batalla and Vericat, 2009). Despite the need to limit peak floods to avoid damages to riverine villages, flushing flows in the lower Ebro are now a tested means to enhance the biological productivity of the physical habitat, to entrain and transport sediments to restore the dynamism 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.

Figure 2 presents the standard hydrograph of the flushing flow implemented in the lower Ebro since 2002 (for an extensive analysis of the flushing flow design and field monitoring, as well as a critical discussion on its effectiveness as a river restoration tool, see Batalla and Vericat, 2009).

[Insert Figure 2 about here]

### **3. MATERIAL AND METHODS**

The opportunity cost of guaranteeing artificial flood flows in modified river reaches, where the flow regime is basically determined by the operation of hydropower facilities, can be defined as the reduction of the value of the energy produced resulting from the new environmental constraints. The assessment of this opportunity cost requires knowing how the power company makes profit maximising decisions and how it would react to a change in the

operating constraints imposed by the river basin authority. To solve this problem, we present a methodology in two stages as follows: i) first, we present a theoretical general model that allows the calculation of the opportunity cost of flushing flows based on the previously stated characteristics; ii) second, we calibrate the general model to our particular case study in the Lower Ebro River.

### *3.1. The Basic Opportunity Cost Evaluation Model*

From the company's perspective, the dam and its associated power production facility are capital assets. At any given time, the operating company decides on the flow of energy to be produced. This decision is based upon a number of variables, such as the technical characteristics of the plant, the current operating rules, the expected evolution of the amount of water stored in the reservoir and the current and the expected energy prices. From a private business perspective, these decisions aim at maximising the value of the expected flow of benefits along the entire life span of the dam (eventually over an infinite horizon). As the electricity produced cannot be stored for its future selling, this circumstance implies making two kinds of decisions simultaneously. The first decision involves choosing how much water to use every day ( $x_t$ ), and the second involves choosing how to distribute the electricity produced throughout the day ( $x_{tk}$ ). Both kinds of decisions aim at maximising the flow of financial revenues. In what follows, we analyse each one of these key production decisions:

*The first kind of decision* (1) involving the amount of water released every day can be represented by the following dynamic optimisation programme. For simplicity, we assume a zero discount rate:

$$\max_{x_t} \sum_{t=0}^{\infty} E[\Pi_t(x_t)] \quad [1]$$

$$z_{(t+1)} = z_t + y_t - x_t \quad [2]$$

$$\underline{z}_t \leq z_t \leq \bar{z}_t \quad [3]$$

$$\underline{x}_t \leq x_t \leq \bar{x}_t \quad , \quad [4]$$

where the decision variable  $x_t$  represents the flow of water used for power generation on day  $t$ ; the function  $\Pi_t(x_t)$  represents the daily financial revenue at the moment  $t$ , which (see below for details) is assumed to increase at a decreasing rate with the amount of water used to produce energy. The upper case  $E$  underlines the fact that companies' decisions are based on imperfect information concerning the future values of critical variables, such as the level of the reservoir and future energy prices (i.e., nature and market uncertainty imply that the objective function is in fact the expected financial value of the energy produced; thus, the model avoids the problem of most optimisation models that assume that companies have "perfect hydrological foresight", which leads to unrealistic results). The state variable  $z_t$  measures the amount of water stored in the reservoir on day  $t$ ; its dynamics are represented by the transition function [2], where the state of the system on the following day depends, first, on its state the previous day, second, on the exogenous net inflow of water ( $y_t$ ) obtained from the river basin net of the evaporation and the abstractions taken from the reservoir for other uses out of the control of the company and, finally, on the decision made by the company on day  $t$ ,  $x_t$ .

Constraint [3] shows the boundaries of the state variable  $z_t$  on any day. The left term of this constraint shows the minimum level of water stored ( $\underline{z}_t \leq z_t$ ). This lower bound is the value determined by the technical requirements of the infrastructure or by the institutional

requirement to guarantee a minimum water availability for other present and future uses. Thus, the lower limit may vary in different seasons or months (depending, for example, on seasonal crops requirements). The right term of the constraint [3] shows the upper bound of the amount of water stored ( $z_t \leq \bar{z}_t$ ), which also may depend on different factors, such as the reservoir's storage capacity or the flood limit to avoid the flooding of downstream riverine villages (which may also vary during the year according to flood risk perceptions).

Constraint [4] shows the boundaries of the daily decision variable,  $x_t$ . The lower bound ( $\underline{x}_t \leq x_t$ ) may come either from a minimum environmental flow, from the requirement to deliver given amounts of water to other water uses downstream or, alternatively, from any water authority requirement to release a certain amount of water at the date  $t$  (for example, for an artificial flood). In a similar way, the relevant upper limit ( $x_t \leq \bar{x}_t$ ) is the higher value among the quantity of water resulting from the hydropower generation plant maximum capacity. Provided that the plant is not always functioning at its full capacity, none of the above-mentioned constraints is binding, and the company is able to distribute the energy produced among the different days of the year in order to maximise its revenue<sup>1</sup>.

*The second kind of decision* (2) consists of choosing the hourly production of electricity in a particular day. This decision can be represented by the following daily revenue maximisation problem:

$$\max_{x_t} \Pi_t = \sum_{k=1}^{24} p_{tk} \alpha x_{tk} \quad [5]$$

---

<sup>1</sup> In fact, the key role played by hydropower in the stabilization of the electricity supply system implies the presence of spare capacity ready to be used to turbine water at peak demand hours. In the last ten years, hydroelectricity in Spain used less than 20% of its installed power production capital (Gómez, 2009).

$$\underline{x}_k \leq x_k \leq \overline{x}_k \quad [6]$$

$$\sum_{k=1}^{24} x_{tk} = x_t \quad [7]$$

The objective function in this case,  $\pi_t$ , represents the daily financial revenue. This revenue depends on the following: i) the decision variable ( $x_{tk}$ ), showing the quantity of water used for power generation per hour ( $k$ ), ii) the corresponding prices, ( $p_{tk}$ ), which are assumed to vary in a predictable way for every day ( $t$ ) depending on the season, the day of the week, weather conditions and other factors that are known in advance by the company, and iii) an input-output technical parameter ( $\alpha$ ) measuring the quantity of water required to produce one unit of electricity. Under these conditions, the company finds the optimal distribution of the energy produced during the day (producing at a maximum capacity at peak price and minimising the energy delivered to the market when electricity demand is at its lowest). The variable and fixed costs of producing hydroelectricity can be considered negligible; accordingly, variations in the revenue function reflect changes in financial returns. The decision variable ( $x_{tk}$ ) is subject to the same upper and lower bounds as in the first problem, but the relevant time units are now hours instead of days (as in [6]).

Provided that there is detailed data on both the hourly market price of electricity and all of the relevant constraints on the decision variable  $x$ , obtaining a closed solution for decision problem (2) becomes straightforward. The solution of this problem for the range of all of the likely values of the daily decision  $x_t$  is the financial revenue function  $\pi_t = F(x_t)$ . This maximum daily revenue function is concave and non-decreasing and varies on different days along the year according to random and seasonal changes in electricity demand and supply.

Problems (1) and (2) are closely linked. On one hand, the overall quantity of water delivered in the solution of problem (2) must equal the optimal decision of the first problem for the

corresponding day (as in constraint [7]). On other hand and most importantly, the optimal solution of problem (2) is nested in the definition of problem (1). In other words, the maximum revenue as a function of the decision variable ( $x_t$ ) becomes the main argument, and its expected value in the future is the objective function of problem (1). Thus, when deciding how much water to use every day, companies know how this water can be delivered at any time to obtain the maximum revenue in the electricity market.

### *3.2. Calibration of the model*

The maximum daily revenue function above is an important step in the calibration of daily production decisions as represented in problem (1). Nevertheless, finding the analytical solution to problem (1) is not an easy task given its dynamic nature, the wide time span that needs to be considered and the uncertainty associated with natural water inflows and energy markets. A theoretical solution will require assuming either perfect hydrological foresight or accepting strong assumptions about the company's risk attitude. Instead of finding the analytical solution of problem 1, we have the option of deducing its solution from the decisions that companies have taken in the past under a given set of conditions.

In this paper, we use detailed data on the decisions taken by the company in the past (on different days, under different decision constraints, and in different states of the river system) to obtain econometrically the company's underlying decision function of using water and producing energy every day. This function (problem 1) and the maximum daily revenue function (problem 2) provide the representation of the optimal behaviour of the company in the baseline scenario. These two functions and the information set of observed decisions and

constraints are all that we need to represent the company's behaviour and assess the opportunity cost of imposing the delivery of a flushing flow.

The information used in this work comes first from the daily data on the level of water stored in the three reservoirs and their hourly outflow of water provided by the Hydrological Information Automatic System (SAIH) of the Ebro River Basin Authority (ERBA, 2012a). We have taken data from September 1997 to October 2008 to cover an 11-year period, which is long enough to encompass several hydrological cycles during which regulations over water use have been relatively stable, as defined in the River Basin Management Plan (ERBA, 2012b). Secondly, the River Basin Authority has also provided an entire set of data on the relevant constraints with which the company must comply. These data include the following: the minimum flows, set at  $100 \text{ m}^3 \text{ s}^{-1}$ ; the amount of water that was required to be supplied by the reservoir system for other uses different from power generation in any given month; and the monthly changing minimum level of water stored in the MRFDC determined by the water authorities to guarantee water supply at any time. Finally, the hourly price of electricity was obtained from the Spanish Electricity Market Operator (SEMO, 2013), and the quantity of electricity produced by the hydropower company at any moment was deduced from the outflow of water and the technical characteristics of the power plants in each reservoir (we assume a standard 0.8 energy conversion efficiency). In this way, we have observations of all of the parameters and for all of the state and decision variables implied in the optimisation problems (1) and (2) for a total sequence of 4,017 days. This sample provides both the data required for calibrating the base model and the scenario to assess the opportunity cost of the flushing flow programme.

The *first stage* in calibrating the model deals with optimisation problem 2. The daily financial returns are a maximum argument function of the following: the amount of water used for power generation, the set of hourly prices of the day, the minimum flow set by water



authorities and the maximum production capacity of the plant. Figure 3 shows the daily financial return function obtained from using hourly prices and the production capacity and the minimum flows for three selected months: i) December, when water demand and the average price are that their highest, ii) March, when prices are the lowest, and iii) January, when the price is close to the yearly average. As can be observed, the financial return function increases at a decreasing rate with the amount of water. Once the minimum flow is satisfied, the decreasing marginal productivity of the water input is caused by the fact that at lower production levels, the energy is produced at peak price time; any increase in water use implies selling the energy at a decreasing price. Daily income is also bounded by the maximum capacity of the plant.

[Insert Figure 3 about here]

Once the optimal financial returns are determined, this information is introduced in the intertemporal decision problem (1) to obtain the optimal decision profile of how much water to use any day, considering the transition equation [2] and the technical and policy constraints of the baseline scenario. The ability of the operating company to obtain rents from market price variations is one of the key elements that are affected by the requirement to adjust water delivery to a pre-designed flushing flow scenario.

The *second stage* of model calibration deals with optimisation problem 1, which is associated with the decision on the daily outflow of water. Obtaining an explicit functional form of the optimal daily decision profile  $x_t$  is not feasible given the amount of parameters involved and the stochastic nature of the problem. Nevertheless, the number and the details of the available data in the sample allow for an empirical approximation of this optimal value

function with econometric techniques; this circumstance allows revealing the functional form that better explains the observed behaviour of the company. We thus expect the decision variable ( $x_t$ ) to be an increasing function of the amount of water stored (represented by the state variable  $z_t$ ) and the water inflow received from the basin on the previous days,  $y_t$ . As this relationship is not linear, we use a maximum likelihood estimation method to obtain the better fitting function among the Box Cox power transformation family of functions. In addition, as restrictions over the minimum level of the stored water and the other uses of water that are different from electricity production vary from month to month, we also used dummy variables for every month of the year. The empirical model is then as follows:

$$x_t(\mu) = \alpha_1 z_t(\lambda) + \alpha_2 y_T(\eta) + \beta_i \quad [8]$$

where  $\lambda$ ,  $\mu$  and  $\eta$  are the box cox transformation parameters:

$$x(\mu) = \frac{x^\mu - 1}{\mu} \quad z(\lambda) = \frac{z^\lambda - 1}{\lambda} \quad y(\eta) = \frac{y^\eta - 1}{\eta}, \quad [9]$$

and the coefficients  $\beta_i$  ( $i = 1, \dots, 12$ ) represent the fixed effect parameters for any months that are included in the model as dummy variables. The variable  $y_T$  measures the overall net inflow from the upstream river basin and helps to include variations explained by dry or wet years.

[Insert Table 2 about here]

This function of the private decision on how much water to deliver on any day, along with the maximum revenue function determining how to distribute this water during the day to produce energy, allows the calibration of the model for the complete sequence of the >4000

days of the sample. Table 2 shows the econometric results. Transformation parameters  $\mu$  and  $\eta$  were not found to be significantly different from 1; therefore, the associated variables  $x_t$  and  $z_t$  enter linearly in the equation. The maximum likelihood value of the nonlinear transformation parameter ( $\lambda$ ) was determined at 0.35. All of the remaining coefficients are significant at a 1% level. Apart from maximum likelihood criteria, the final equation fulfils Wald's and Lagrange's multiplier tests for the optimisation of the econometric estimation. The size and detail of the sample seem to be important factors behind the robust and efficient econometric estimation of the daily decision variable.

This baseline scenario and the associated optimisation functions are the basis by which to assess the impact of flushing flows over the quantity and value of the energy produced.

#### 4. RESULTS

Flushing flows are implemented through the imposition of particular constraints over the operating rules of the hydropower plant. This circumstance implies the obligation of firms to deviate from the optimal decision profile (baseline scenario) with a negative impact over expected financial profits. The revenue variation, or the opportunity cost, is moreover the net result of two different effects of opposite sign. The first effect is the immediate revenue increase, as controlled floods require the delivery of an amount of water that exceeds the quantity that the company would have chosen otherwise. The second effect is the decreased revenue resulting from the reduction in the stock of water available after the flood<sup>2</sup> during the

---

<sup>2</sup> Under extreme events, the implementation of flushing flows may lead to additional opportunity costs.

For example, when the amount of water stored in the reservoirs is below or at its lowest or minimum

days or weeks required for the reservoir to come back to its baseline level. Once this convergence is complete, not only will the amount of water stored be back to normal but the company's decisions and revenues will also be the same as in the baseline scenario. The absorption period, or the time during which water stocks, flows and profits diverge from the baseline, is a measure of the time required by the system to absorb the shock produced by the flood.

The cost of the flushing flow can be reduced by a careful selection of the right moment at which to start delivering the water for the subsequent hours. Although the company cannot decide upon the day and the quantity of water to deliver during the artificial flood, it can choose the right hour at which to start the flood. This decision allows minimising the foregone revenues, as expected energy prices vary in a predictable way during the day. Figure 4 shows the market value of the energy obtained during the flood for the autumn and spring seasons according to the flushing flow hydrograph shown in Figure 2.

[Insert Figure 4 about here]

The correct selection of the time to start delivering the water might explain differences as high as 40% of the maximum revenue. A wrong timing can therefore increase the opportunity cost in as much as EUR 160,000 per flood. In what follows, we assume that the delivery of water

---

acceptable level, flushing flows would imply a reduction of the water supplied for crops or any other uses. In any case, despite being technically feasible, the River Basin Authority clearly establishes a series of priorities under extreme events that rule out the possibility of implementing flushing flows (ERBA, 2007).

always starts at a time that maximises the value of the energy produced during the flushing flow (thus minimizing the opportunity cost of the flushing flow).

Provided that the artificial flood is feasible (which occurs when water level is above a minimum critical level) and its starting point has been chosen to minimise its impact over the value of the electricity produced, we are now ready to analyse the opportunity cost of flushing flows. Figure 5 presents the overall opportunity cost for the days in the sample when the flood is feasible in autumn (Fig. 5a) and spring (Fig. 5b). The revenue variation is measured on the left axis. The figure is complemented with data over the amount of water stored in the upstream reservoir on the day of the flood, which is measured on the right axis.

As expected, the flushing flow cost varies with the varying conditions of the system, and the expected revenue variation is negative. This expected revenue variation amounts to EUR -76,000 and EUR -33,000 for the autumn and spring floods, respectively (a total opportunity cost of 99,000 EUR/year). In the same way, the absorption time varies from a few days to several months with an average value of 82 days and a standard deviation of 50<sup>3</sup>.

---

<sup>3</sup> Companies' decisions in our model are based on expectations over the water inflow that the reservoir might receive in the future. These expectations might or might not be fulfilled, and the consequence of this circumstance is that the opportunity cost may actually differ from its expected value (depending basically on rainfall on the days following the flood) and can even be negative. Given the timing of the different effects and, particularly, the fact that the increase in revenue occurs at the start of the flood, while the cost is different along the absorption time, the succession of wet days can shorten the absorption time, and when the reservoir recovers rapidly enough, it can even avoid a negative opportunity cost. This outcome is observed on the days when the revenue variation of the flood is negative (see Figure 5).

[Insert Figure 5 about here]

## 5. FINAL REMARKS

Flushing flows are an effective means to achieve a successful river restoration (Hueftle and Stevens, 2002; Vinson, 2001; Kondolf and Wilcock, 1996). While the benefits and technical effectiveness of this alternative are widely known, the cost it might impose over the economic uses of water is still considered an important reason against the feasibility of implementing the periodical release of artificial floods. In this paper, we present a planning-level methodology for the assessment of such opportunity costs in heavily modified downstream areas where flushing flows affect the operational rules of hydropower facilities. We show how the model can be calibrated with a combination of a deterministic maximum revenue function for the hourly delivery of water and an econometrically obtained decision function for the daily amount of water delivered. The model enables us to analyse the impact of imposing a new operation rule over a hydropower company's optimal decisions. This rule consists in the obligation to release water during certain periods of time in accordance with an artificial flood purposely designed to restore the basic functions of a river ecosystem. As the technical design, feasibility and opportunity cost of flushing flows heavily depend on the intrinsic conditions of river ecosystems, we used the detailed time information about the stocks and flows of water in the Lower Ebro River to calibrate and simulate the model for all of the days in spring and autumn in the sample when an artificial flood is feasible.

Implementing flushing flows on a regular basis will result in a reduction in the asset value of the involved hydropower facilities, as they will have to operate under more stringent institutional rules. The studied case shows that hydropower facilities in the lower Ebro can provide the artificial flows required for the restoration of the river channel at a cost that is equivalent to a small fraction of the overall revenue obtained during the year and by only accepting a marginal change in the quantity of energy delivered to the market. The expected cost of two floods per year (approximately EUR 100,000) is equivalent to only 0.16% of the average yearly revenue and is only a fraction of the average revenue obtained every day by the company (which amounts to EUR 250,000 in the sample days).

Provided that flushing flows are implemented with sound economic criteria, their opportunity cost is small when compared to the people's willingness to pay (WTP) to secure the benefits of river restoration programmes. Original estimations in areas that resemble our policy context show that WTP ranges from EUR 5.3 to EUR 63.6 per person per year (Loomis et al., 2000, Meyerhoff and Dehnhardt, 2007, Berrens et al., 1998, Brown and Duffield, 1995, Colby, 1993, González-Cabán and Loomis, 1997). Depending on the size of the population benefited by the programme, the opportunity cost can range from EUR 1 (if we consider the million people living in the Lower Ebro River) to EUR 0.1 per person per year (if we consider the ten million people living in the entire Ebro Basin). As a result, in spite of the variability in the flushing flow opportunity cost attributable to the uncertain behaviour of flows and stocks of water in Mediterranean rivers, this cost is expected to be between 5 and over 630 times lower than the benefits associated with the river restoration programmes, as measured by individual's WTP.

The cost of guaranteeing the periodical release of flushing floods by changing the operation 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 water recycling and desalination) to have the additional stock of water available for these

purposes in the reservoirs. Each artificial flood requires the delivery of approximately 36 million cubic metres over sixteen hours; considering the opportunity cost mentioned above (of EUR 76,000 and EUR 33,000 for the autumn and the spring floods, respectively), we can conclude that the cost per cubic metre delivered is lower than EUR 0.002 for the autumn flood and less than half of that quantity for the spring flood. Experience shows that there are few alternatives to obtaining such a large amount of water at a lower cost from other economic uses.

The results obtained suggest that the real policy challenge consists in finding the institutional agreement to implement the flushing flood programme and agreeing on the potential financial compensations to deal with the incentive problem that must be overcome for this purpose. The considerable distance between the opportunity cost and the societal benefits provides sufficient room for private operators and the government to conduct a successful bargaining and thus agree on the voluntary compliance of a soundly designed programme of water releases to restore the critical functions of the water ecosystem. The cooperation between power generation companies and water authorities is also a positive signal, showing that flushing flows for river restoration purposes can be compatible with private corporate interests. These efforts are now considered to be the pioneering phase of a comprehensive restoration programme of the whole river's ecosystem and a key piece of the River Basin Management Plan that is being elaborated for the implementation of the WFD.



## **Acknowledgments**

This research has been undertaken under the auspices of a sequence of research projects funded by the Spanish Ministry of Education and Science (REN2001-0840-C02-01/HID, CGL2005-06989-C02-02/HID, CGL2006-11679-C02-01/HID and CGL2009-0977) as well as European Community's Seventh Framework Programme Project EPI-WATER ("Evaluating Economic Policy Instrument for Sustainable Water Management in Europe", grant agreement nº 265213). Special thanks are due to Endesa Generación S.A. and the Ebro Water Authorities for providing hydrological data and useful insights into the functioning of the Ebro dams system. We thank Alvaro Tena for drawing Figure 1.

## References

Batalla, R.J., C.M. Gómez, and G.M. Kondolf (2004), Reservoir-induced hydrological changes in the Ebro River basin (Northeastern Spain), *Journal of Hydrology*, 290, 117-136.

Batalla, R.J., D. Vericat, and T.I. Martinez (2006), River-channel changes downstream from dams in the Lower Ebro River, *Zeitschrift für Geomorphologie (Suppl. B.)*, 143, 1-14.

Batalla, R.J. and D. Vericat (2009), Hydrological and Sediment Transport Dynamics of Flushing Flows: Implications for Management in Large Mediterranean Rivers, *River Research and Applications*, 25, 297-314.

Bednarek, A. and D. Hart (2005), Modifying Dam Operations to Restore Rivers: Ecological Responses to Tennessee River Dam Mitigation, *Ecological Applications*, 15(3), 997-1008.

Berrens R., A.K. Bohara, H. Jenkins-Smith, C. Silva, P. Ganderton and D. Brookshire (1998), A joint investigation of public support and public values: Case of instream flows in New Mexico, *Ecological Economics*, 27, 189-203.

Brown, T. and J. Duffield (1995), Testing part-whole valuation effects in contingent valuation of instream flow protection, *Water Resources Research*, 31, 2341-2351.

Colby, B. (1993), *Benefits, Costs and Water Acquisition Strategies: Economic Considerations in Instream Flow Protection*, in: *Instream Flow Protection in the West*. L. MacDonnell and T. Rice (eds). 6.1-6.32. Boulder: Natural Resources. Law Center, University of Colorado.

European Commission (EC) (2000), Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, *Official Journal of The European Communities*, L(327)}, 22/12/2000, 1-73.

Ebro River Basin Authority (ERBA) (2007), Plan Especial de Actuación en Situaciones de Alerta y Eventual Sequía. Zaragoza.

Ebro River Basin Authority (ERBA) (2012a), Hydrological Information Automatic System. <http://195.55.247.237/saihebro/index.php>. Last accessed 03/04/2013.

Ebro River Basin Authority (ERBA) (2012b), Ebro River Basin Management Plan (DRAFT). <http://www.chebro.es/contenido.visualizar.do?idContenido=14093&idMenu=3048>. Last accessed 03/04/2013.

Furse, M., D. Hering, K. Braben, L. Buffagni and F. Verdonchat (2006), *The Ecological Status of European Rivers: Evaluation and Intercalibration of Assessment Methods*. Springer.

Goes, B.J.M. (2002), Effects of river regulation on aquatic macrophyte growth and floods in the Hadejia-NguruWetlands and flow in the Yobe River, northern Nigeria; implications for future water management, *River Research and Applications*, 18(1), 81-95.

Gómez, C.M. (2009), La Eficiencia en la Asignación del Agua en España: principios básicos y hechos estilizados, *Información Comercial Española*, 847, 23-39.

González-Cabán, A. and J. B. Loomis (1997), Economic Benefits of Maintaining Ecological Integrity of Rio Mameyes in Puerto Rico, *Ecological Economics*, 21(1), 63-75.

Granata, T.C. and U. Zika (2007), The role of biology and ecological engineering in watershed and river restoration. *Economic Valuation of River Systems*, Ed. F. Hitzhusen. Edward Elgar.

Gupta, A. and Bravard, J.P (2009), Introduction to management of large European rivers, *Geomorphology*, forthcoming.

Hitzhusen, F.(2007), *Economic Valuation of River Systems*, Edward Elgar.

Hueftle, S.J. and L.E. Stevens (2002), Experimental Flood Effects on the Limnology of Lake Powell Reservoir; implications for future water management, *Ecological Applications*, 11, 644-656.

Kondolf, G.M. and P.R. Wilcock (1996), The flushing flow problem: defining and evaluating objectives, *Water Resources Research*, 32(8), 2589-2599.

Kondolf, G.M. and R.J. Batalla (2005), *Hydrological Effects of Dams and Water Diversions on Rivers of Mediterranean-Climate Regions: Examples from California*, in Catchment Dynamics and River Processes. Mediterranean and Other Climate Regions. Garcia, C and Batalla, R.J. (eds). 197-212. Elsevier.

Loomis, J., P. Kent, L. Strange, K. Fausch and A. Covich (2000), Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey, *Ecological Economics*, 33, 103-117.

Meyerhoff, J. and A. Dehnhardt (2007), The European Water Framework Directive and economic valuation of wetlands: the restoration of floodplains along the River Elbe, *European Environment*, 17(1), 18-36.

Palau, A., R.J. Batalla, E. Rosico, A. Meseguer and D. Vericat (2004), *Management of water level and design of flushing floods for environmental river maintenance downstream of the Riba-roja reservoir (Lower Ebro River, NE Spain)*, in HYDRO 2004: A New Era for Hydropower. Porto-Portugal.

Palmieri, A. and F. Shah, and A. Dinar (2001), Economics of Reservoir Sedimentation and Sustainable Management of Dams, *Journal of Environmental Management*, 61, 149-163.

Robinson, C.T. and U. Uehlinger(2003), Using Artificial Floods for Restoring River Integrity, *Aquatic Sciences*, 65, 181-182.

Spanish Electricity Market Operator (SEMO) (2013), *Red Eléctrica Española* Database [http://www.ree.es/sistema\\_electrico/informeSEE.asp](http://www.ree.es/sistema_electrico/informeSEE.asp). Last accessed 03/04/2013.

Turner, R.K., S. Georgiou, R. Brouwer, I.J. Bateman and I.J. Langford (2003), Towards and integrated environmental assessment for wetland and catchment management, *The Geographical Journal*, 169(2), 99-116.

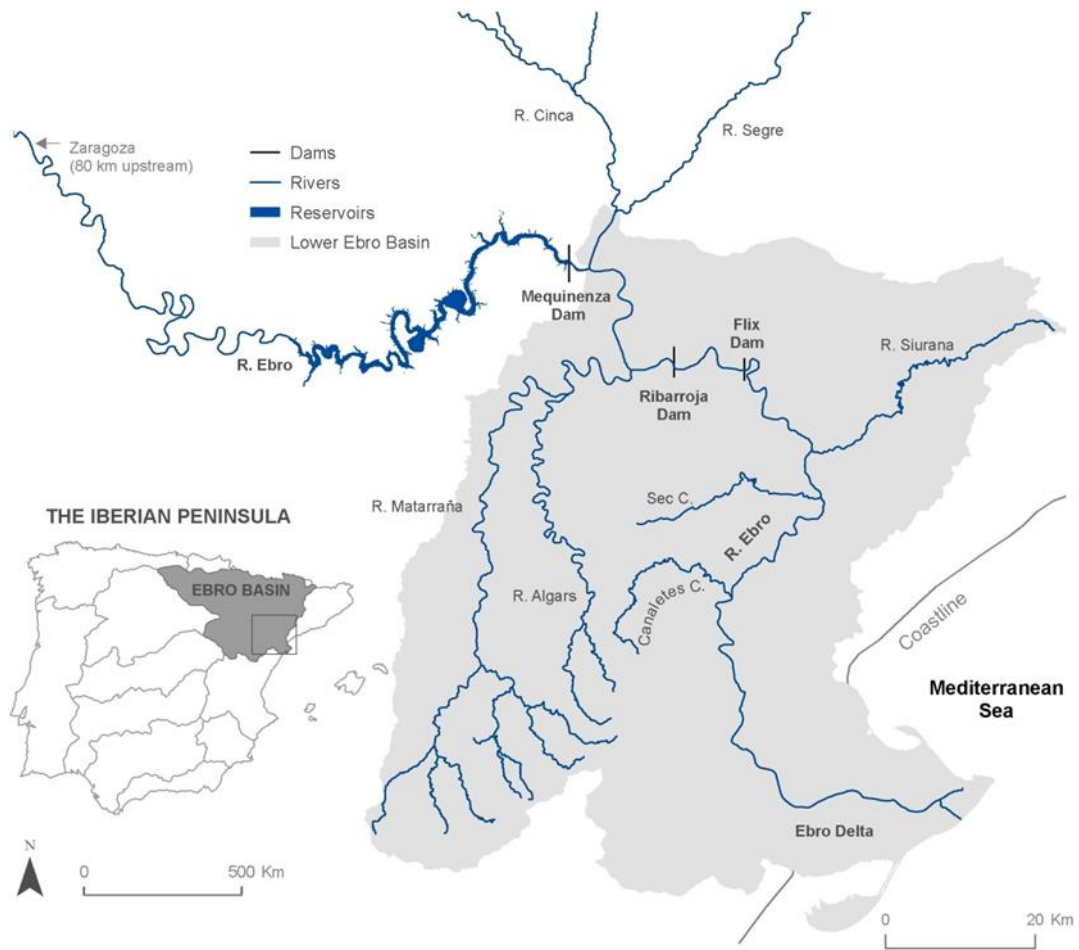
Vericat, D. and R.J. Batalla (2006), Sediment transport in a large impounded river: the lower Ebro, NE Iberian Peninsula, *Geomorphology*, 79, 72-92.

Vericat, D. and R.J. Batalla, and C. García (2006), Breakup and reestablishment of the armour layer in a highly regulated large gravel-bed river: the lower Ebro, *Geomorphology*, 76, 122-136.

Vinson, M.R.(2001), Long term Dynamics of Invertebrate Assemblage Downstream From a Large Dam, *Ecological Applications*, 6, 140-151.

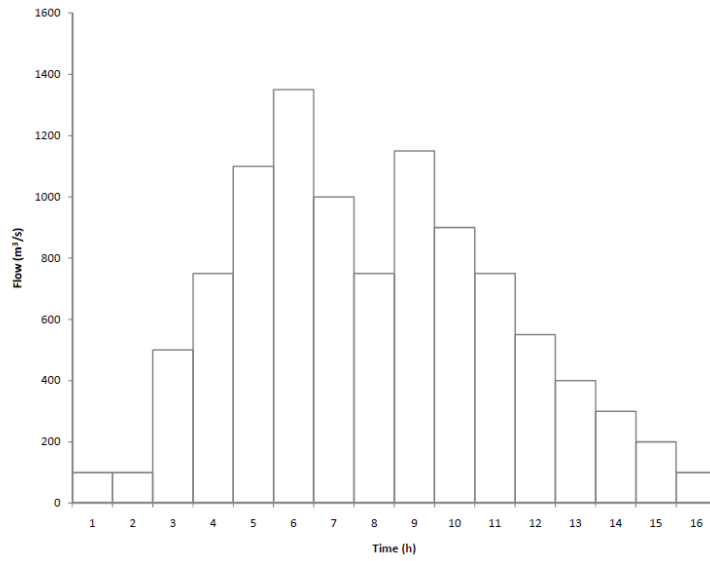
Zawiejska, J. and B. Wyzga (20010), Twentieth-century channel change on the Dunajec River, southern Poland: Patterns, causes and controls, *Geomorphology*, 117, 234–246.

Figure 1. Location of the River Ebro Basin in the Iberian Peninsula and detail of the Lower Ebro River.



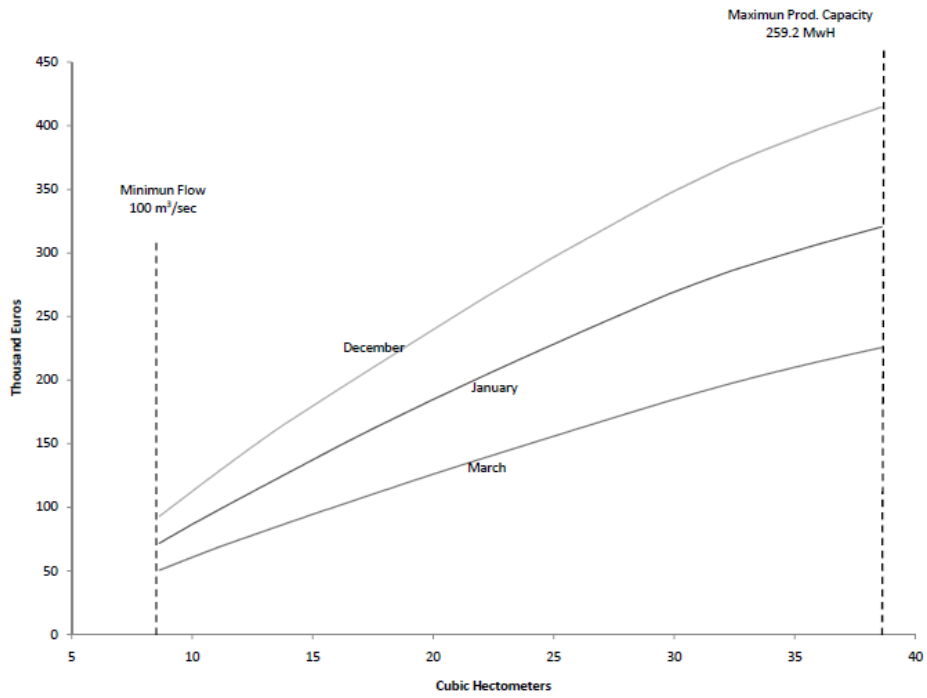
Source: Own elaboration from ERBA, 2012a.

Figure 2. Standard hydrograph of the flushing flow implemented in the Lower Ebro River since 2002.



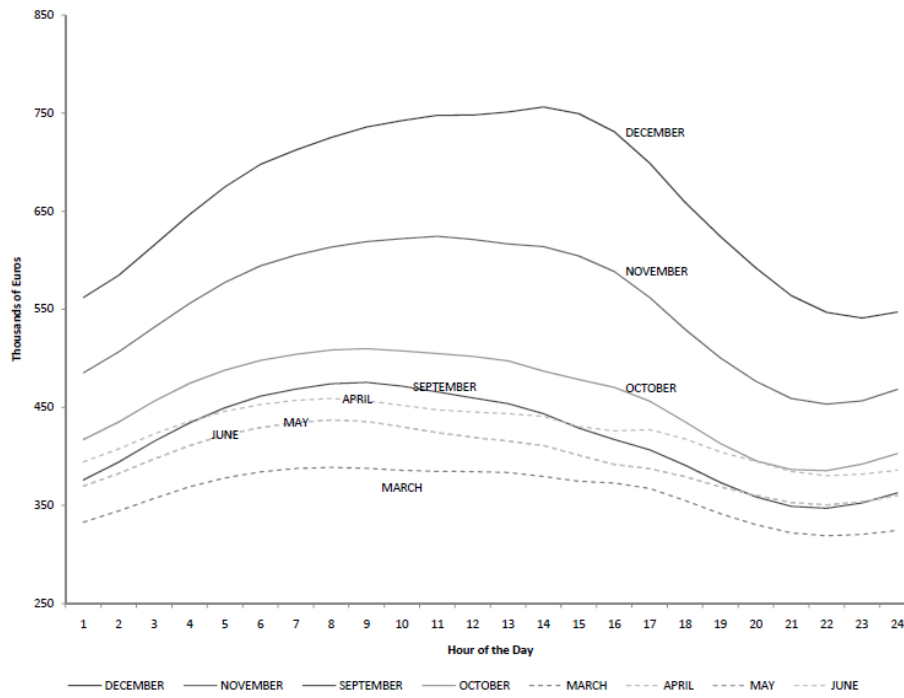
Source: Own elaboration.

Figure 3. The optimal daily revenue function in the upstream Mequinenza Power Plant.



Source: Own elaboration.

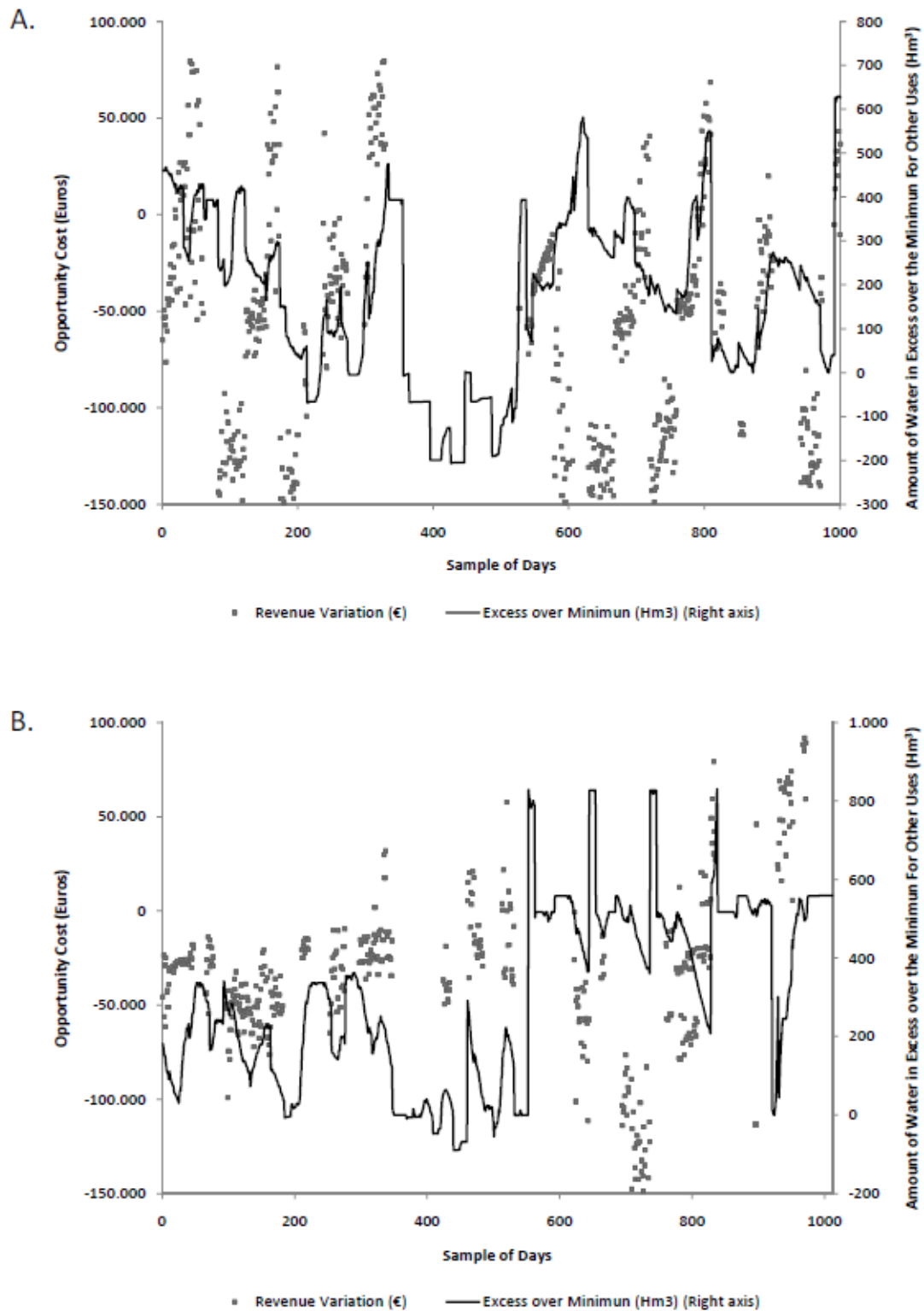
Figure 4. The optimal timing of the flushing flow in the Lower Ebro River.



Source: *Own elaboration.*



Figure 5. . The opportunity cost of a flushing flood in the Lower Ebro. (A) Autumn, (B) Spring.



Source: Own elaboration.

Table 1. Characteristics of the Mequinenza-Ribarroja-Flix Dam System

<b>Reservoir</b>	<b>Mequinenza</b>	<b>Ribarroja</b>	<b>Flix</b>
Storage Capacity (hm <sup>3</sup> )	1530	218	5
Licensed Flow (m <sup>3</sup> /s)	760	940	400
Installed Capacity (Kw/h)	324	262.8	42.5
Height (metres)	74	41	12.1
Efficiency	0.8	0.8	0.8
Input Output Ratio (m <sup>3</sup> /Kwh)	6.2	11.19	37.91

Source: ERBA, 2012a.

Table 2. Box Cox Estimation of the Daily Outflow of Water

Variable	Coefficient	Standard error	Significance
Water stored (hm <sup>3</sup> )*	0.0009339	0.0368078	99%
Lag Water stored (hm <sup>3</sup> )	0.1480627	0.00718118	99%
Water inflow (hm <sup>3</sup> /day)	0.48437	8.13874E-05	99%
October	-12.4484	1.34145119	99%
November	-11.278	1.34805527	99%
December	-10.647	1.3814159	99%
January	-8.71131	1.39861698	99%
February	-9.53085	1.40190417	99%
March	-8.7341	1.41103021	99%
April	-10.3591	1.44114208	99%
May	-10.9435	1.47712765	99%
June	-13.4476	1.48860571	99%
July	-12.3389	1.44571131	99%
August	-12.4329	1.37090634	99%
September	-12.8491	1.32810979	99%
$\lambda$	0.383011	0.00718118	99%
Wald test	34.07		
Elasticity of water stored	1.14593		
Elasticity of water inflow	0.79495		
Elasticity of lag water inflow	0.35503		

\* Variables transformed by  $\lambda$

Source: Own elaboration.

## NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

### Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

<http://www.feem.it/getpage.aspx?id=73&sez=Publications&padre=20&tab=1>  
[http://papers.ssrn.com/sol3/JELJOUR\\_Results.cfm?form\\_name=journalbrowse&journal\\_id=266659](http://papers.ssrn.com/sol3/JELJOUR_Results.cfm?form_name=journalbrowse&journal_id=266659)  
<http://ideas.repec.org/s/fem/femwpa.html>  
<http://www.econis.eu/LNG=EN/FAM?PPN=505954494>  
<http://ageconsearch.umn.edu/handle/35978>  
<http://www.bepress.com/feem/>

### NOTE DI LAVORO PUBLISHED IN 2014

CCSD	1.2014	Erin Baker, Valentina Bosetti, Karen E. Jenni and Elena Claire Ricci: <a href="#">Facing the Experts: Survey Mode and Expert Elicitation</a>
ERM	2.2014	Simone Tagliapietra: <a href="#">Turkey as a Regional Natural Gas Hub: Myth or Reality? An Analysis of the Regional Gas Market Outlook, beyond the Mainstream Rhetoric</a>
ERM	3.2014	Eva Schmid and Brigitte Knopf: <a href="#">Quantifying the Long-Term Economic Benefits of European Electricity System Integration</a>
CCSD	4.2014	Gabriele Standardi, Francesco Bosello and Fabio Eboli: <a href="#">A Sub-national CGE Model for Italy</a>
CCSD	5.2014	Kai Lessmann, Ulrike Kornek, Valentina Bosetti, Rob Dellink, Johannes Emmerling, Johan Eyckmans, Miyuki Nagashima, Hans-Peter Weikard and Zili Yang: <a href="#">The Stability and Effectiveness of Climate Coalitions: A Comparative Analysis of Multiple Integrated Assessment Models</a>
CCSD	6.2014	Sergio Currarini, Carmen Marchiori and Alessandro Tavoni: <a href="#">Network Economics and the Environment: Insights and Perspectives</a>
CCSD	7.2014	Matthew Ranson and Robert N. Stavins: <a href="#">Linkage of Greenhouse Gas Emissions Trading Systems: Learning from Experience</a>
CCSD	8.2013	Efthymia Kyriakopoulou and Anastasios Xepapadeas: <a href="#">Spatial Policies and Land Use Patterns: Optimal and Market Allocations</a>
CCSD	9.2013	Can Wang, Jie Lin, Wenjia Cai and ZhongXiang Zhang: <a href="#">Policies and Practices of Low Carbon City Development in China</a>
ES	10.2014	Nicola Genovese and Maria Grazia La Spada: <a href="#">Trust as a Key Variable of Sustainable Development and Public Happiness: A Historical and Theoretical Example Regarding the Creation of Money</a>
ERM	11.2014	Ujjayant Chakravorty, Martino Pelli and Beyza Ural Marchand: <a href="#">Does the Quality of Electricity Matter? Evidence from Rural India</a>
ES	12.2014	Roberto Antonietti: <a href="#">From Outsourcing to Productivity, Passing Through Training: Microeconomic Evidence from Italy</a>
CCSD	13.2014	Jussi Lintunen and Jussi Uusivuori: <a href="#">On The Economics of Forest Carbon: Renewable and Carbon Neutral But Not Emission Free</a>
CCSD	14.2014	Brigitte Knopf, Bjørn Bakken, Samuel Carrara, Amit Kanudia, Ilkka Keppo, Tiina Koljonen, Silvana Mima, Eva Schmid and Detlef van Vuuren: <a href="#">Transforming the European Energy System: Member States' Prospects Within the EU Framework</a>
CCSD	15.2014	Brigitte Knopf, Yen-Heng Henry Chen, Enrica De Cian, Hannah Förster, Amit Kanudia, Ioanna Karkatsouli, Ilkka Keppo, Tiina Koljonen, Katja Schumacher and Detlef van Vuuren: <a href="#">Beyond 2020 - Strategies and Costs for Transforming the European Energy System</a>
CCSD	16.2014	Anna Alberini, Markus Bareit and Massimo Filippini: <a href="#">Does the Swiss Car Market Reward Fuel Efficient Cars? Evidence from Hedonic Pricing Regressions, a Regression Discontinuity Design, and Matching</a>
ES	17.2014	Cristina Bernini and Maria Francesca Cracolici: <a href="#">Is Participation in Tourism Market an Opportunity for Everyone? Some Evidence from Italy</a>
ERM	18.2014	Wei Jin and ZhongXiang Zhang: <a href="#">Explaining the Slow Pace of Energy Technological Innovation: Why Market Conditions Matter?</a>
CCSD	19.2014	Salvador Barrios and J. Nicolás Ibañez: <a href="#">Time is of the Essence: Adaptation of Tourism Demand to Climate Change in Europe</a>
CCSD	20.2014	Salvador Barrios and J. Nicolás Ibañez Rivas: <a href="#">Climate Amenities and Adaptation to Climate Change: A Hedonic-Travel Cost Approach for Europe</a>
ERM	21.2014	Andrea Bastianin, Marzio Galeotti and Matteo Manera: <a href="#">Forecasting the Oil-gasoline Price Relationship: Should We Care about the Rockets and the Feathers?</a>
ES	22.2014	Marco Di Cintio and Emanuele Grassi: <a href="#">Wage Incentive Profiles in Dual Labor Markets</a>
CCSD	23.2014	Luca Di Corato and Sebastian Hess: <a href="#">Farmland Investments in Africa: What's the Deal?</a>
CCSD	24.2014	Olivier Beaumais, Anne Briand, Katrin Millock and Céline Nauges: <a href="#">What are Households Willing to Pay for Better Tap Water Quality? A Cross-Country Valuation Study</a>
CCSD	25.2014	Gabriele Standardi, Federico Perali and Luca Pieroni: <a href="#">World Tariff Liberalization in Agriculture: An Assessment Following a Global CGE Trade Model for EU15 Regions</a>
ERM	26.2014	Marie-Laure Nauleau: <a href="#">Free-Riding on Tax Credits for Home Insulation in France: an Econometric Assessment Using Panel Data</a>

CCSD	27.2014	Hannah Förster, Katja Schumacher, Enrica De Cian, Michael Hübler, Ilkka Keppo, Silvana Mima and Ronald D. Sands: <a href="#">European Energy Efficiency and Decarbonization Strategies Beyond 2030 – A Sectoral Multi-model Decomposition</a>
CCSD	28.2014	Katherine Calvin, Shonali Pachauri, Enrica De Cian and Ioanna Mouratiadou: <a href="#">The Effect of African Growth on Future Global Energy, Emissions, and Regional Development</a>
CCSD	29.2014	Aleh Cherp, Jessica Jewell, Vadim Vinichenko, Nico Bauer and Enrica De Cian: <a href="#">Global Energy Security under Different Climate Policies, GDP Growth Rates and Fossil Resource Availabilities</a>
CCSD	30.2014	Enrica De Cian, Ilkka Keppo, Johannes Bollen, Samuel Carrara, Hannah Förster, Michael Hübler, Amit Kanudia, Sergey Paltsev, Ronald Sands and Katja Schumacher: <a href="#">European-Led Climate Policy Versus Global Mitigation Action. Implications on Trade, Technology, and Energy</a>
ERM	31.2014	Simone Tagliapietra: <a href="#">Iran after the (Potential) Nuclear Deal: What's Next for the Country's Natural Gas Market?</a>
CCSD	32.2014	Mads Greker, Michael Hoel and Knut Einar Rosendahl: <a href="#">Does a Renewable Fuel Standard for Biofuels Reduce Climate Costs?</a>
CCSD	33.2014	Edilio Valentini and Paolo Vitale: <a href="#">Optimal Climate Policy for a Pessimistic Social Planner</a>
ES	34.2014	Cristina Cattaneo: <a href="#">Which Factors Explain the Rising Ethnic Heterogeneity in Italy? An Empirical Analysis at Province Level</a>
CCSD	35.2014	Yasunori Ouchida and Daisaku Goto: <a href="#">Environmental Research Joint Ventures and Time-Consistent Emission Tax</a>
CCSD	36.2014	Jaime de Melo and Mariana Vijil: <a href="#">Barriers to Trade in Environmental Goods and Environmental Services: How Important Are They? How Much Progress at Reducing Them?</a>
CCSD	37.2014	Ryo Horii and Masako Ikefuji: <a href="#">Environment and Growth</a>
CCSD	38.2014	Francesco Bosello, Lorenza Campagnolo, Fabio Eboli and Ramiro Parrado: <a href="#">Energy from Waste: Generation Potential and Mitigation Opportunity</a>
ERM	39.2014	Lion Hirth, Falko Ueckerdt and Ottmar Edenhofer: <a href="#">Why Wind Is Not Coal: On the Economics of Electricity</a>
CCSD	40.2014	Weij Jin and ZhongXiang Zhang: <a href="#">On the Mechanism of International Technology Diffusion for Energy Productivity Growth</a>
CCSD	41.2014	Abeer El-Sayed and Santiago J. Rubio: <a href="#">Sharing R&amp;D Investments in Cleaner Technologies to Mitigate Climate Change</a>
CCSD	42.2014	Davide Antonioli, Simone Borghesi and Massimiliano Mazzanti: <a href="#">Are Regional Systems Greening the Economy? the Role of Environmental Innovations and Agglomeration Forces</a>
ERM	43.2014	Donatella Baiardi, Matteo Manera and Mario Menegatti: <a href="#">The Effects of Environmental Risk on Consumption: an Empirical Analysis on the Mediterranean Countries</a>
CCSD	44.2014	Elena Claire Ricci, Valentina Bosetti, Erin Baker and Karen E. Jenni: <a href="#">From Expert Elicitations to Integrated Assessment: Future Prospects of Carbon Capture Technologies</a>
CCSD	45.2014	Kenan Huremovic: <a href="#">Rent Seeking and Power Hierarchies: A Noncooperative Model of Network Formation with Antagonistic Links</a>
CCSD	46.2014	Matthew O. Jackson and Stephen Nei: <a href="#">Networks of Military Alliances, Wars, and International Trade</a>
CCSD	47.2014	Péter Csóka and P. Jean-Jacques Herings: <a href="#">Risk Allocation under Liquidity Constraints</a>
CCSD	48.2014	Ahmet Alkan and Alparslan Tuncay: <a href="#">Pairing Games and Markets</a>
CCSD	49.2014	Sanjeev Goyal, Stephanie Rosenkranz, Utz Weitzel and Vincent Buskens: <a href="#">Individual Search and Social Networks</a>
CCSD	50.2014	Manuel Förster, Ana Mauleon and Vincent J. Vannetelbosch: <a href="#">Trust and Manipulation in Social Networks</a>
CCSD	51.2014	Berno Buechel, Tim Hellmann and Stefan Köllner: <a href="#">Opinion Dynamics and Wisdom under Conformity</a>
CCSD	52.2014	Sofia Priazhkina and Frank Page: <a href="#">Formation of Bargaining Networks Via Link Sharing</a>
ES	53.2014	Thomas Longden and Greg Kannard: <a href="#">Rugby League in Australia between 2001 and 2012: an Analysis of Home Advantage and Salary Cap Violations</a>
ES	54.2014	Cristina Cattaneo, Carlo V. Fiorio and Giovanni Peri: <a href="#">What Happens to the Careers of European Workers when Immigrants "Take their jobs"?</a>
CCSD	55.2014	Francesca Sanna-Randaccio, Roberta Sestini and Ornella Tarola: <a href="#">Unilateral Climate Policy and Foreign Direct Investment with Firm and Country Heterogeneity</a>
ES	56.2014	Cristina Cattaneo, Carlo V. Fiorio and Giovanni Peri: <a href="#">Immigration and Careers of European Workers: Effects and the Role of Policies</a>
CCSD	57.2014	Carlos Dionisio Pérez Blanco and Carlos Mario Gómez Gómez: <a href="#">Drought Management Plans and Water Availability in Agriculture. A Risk Assessment Model for a Southern European Basin</a>
CCSD	58.2014	Baptiste Perrissin Fabert, Etienne Espagne, Antonin Pottier and Patrice Dumas: <a href="#">The Comparative Impact of Integrated Assessment Models' Structures on Optimal Mitigation Policies</a>
CCSD	59.2014	Stuart McDonald and Joanna Poyago-Theotoky: <a href="#">Green Technology and Optimal Emissions Taxation</a>
CCSD	60.2014	ZhongXiang Zhang: <a href="#">Programs, Prices and Policies Towards Energy Conservation and Environmental Quality in China</a>
CCSD	61.2014	Carlo Drago, Livia Amidani Aliberti and Davide Carbonai: <a href="#">Measuring Gender Differences in Information Sharing Using Network Analysis: the Case of the Austrian Interlocking Directorship Network in 2009</a>
CCSD	62.2014	Carlos Dionisio Pérez Blanco and Carlos Mario Gómez Gómez: <a href="#">An Integrated Risk Assessment Model for the Implementation of Drought Insurance Markets in Spain</a>
CCSD	63.2014	Y. Hossein Farzin and Ronald Wendner: <a href="#">The Time Path of the Saving Rate: Hyperbolic Discounting and Short-Term Planning</a>
CCSD	64.2014	Jessica F. Green, Thomas Sterner and Gernot Wagner: <a href="#">The Politics of Market Linkage: Linking Domestic Climate Policies with International Political Economy</a>
CCSD	65.2014	Luca Di Corato, Cesare Dosi and Michele Moretto: <a href="#">Bidding for Conservation Contracts</a>

- CCSD 66.2014 Achim Voß and Jörg Lingers: [What's the Damage? Environmental Regulation with Policy-Motivated Bureaucrats](#)
- CCSD 67.2014 Carolyn Fischer, Richard G. Newell and Louis Preonas: [Environmental and Technology Policy Options in the Electricity Sector: Interactions and Outcomes](#)
- CCSD 68.2014 Carlos M. Gómez, C. Dionisio Pérez-Blanco and Ramon J. Batalla: [The Flushing Flow Cost: A Prohibitive River Restoration Alternative? The Case of the Lower Ebro River](#)