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Tradeoffs in river restoration: Flushing flows vs. hydropower generation in the Lower Ebro River, Spain

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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 a 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.

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 visible for instance 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; Zawiejska and Wyzga, 2010; Batalla and Vericat, 2009).

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, 2010; EC, 2000). However, restoration is often 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. 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). Social sciences have also 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

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recreation opportunities, biodiversity support, health services, water security and flood control) (see, for example, Hitzhusen, 2007; Turner et al., 2003 and Gupta and Bravard, 2010; CSIRO, 2012). 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: to find the most cost-effective way to improve the river environment and thus minimise the impact over marketable water services, to judge 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), to provide the critical information to assess 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 to know 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 driven 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 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 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, Spain.

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 Fig. 1). Water demand from agriculture is significant (1.200 million cubic meters/year, 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 land use (i.e., afforestation). However, flows are 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 particular interest for the river's ecological functioning is the 25% reduction, on average, of the relatively frequent floods (i.e., those with a return interval between 2 and 25 years) (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 (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 maintaining 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 gravel 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.

This new set of environmental conditions, together with similar changes in the upstream main tributaries, appears to explain the uncontrolled proliferation of macrophytes[1] in the Lower Ebro River channel (e.g., Goes, 2002; Palau et al., 2004). Macrophytes threaten river infrastructures, increasing operating costs, 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 following two notably dry years. These drought conditions encouraged cooperation between the hydropower operator, 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). These flushing flows have provided opportunity to the design of such flows to increase their effectiveness, and macrophytes removal rates as high as 95% have been achieved in areas close to the dam (Batalla and Vericat, 2009). Despite the need to limit peak floods to avoid damage 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 estuary.

Fig. 2 presents the standard hydrograph of the flushing flow implemented in the Lower Ebro since 2002 (for an extensive anal-

[1] Macrophytes are visible algae and other flora species that are rooted in shallow waters with vegetative parts emerging above the water surface. In lakes, macrophytes provide cover for fish and substrate for aquatic invertebrates, produce oxygen, and act as food for some fish and wildlife, therefore being a symptom of a good environmental status. However, in a river their proliferation occurs when water is stagnated and denotes a poor environmental status, having negative effects over the ecosystem and economic activities.