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Trade-offs between Water Allocations and Environmental Flows: A Hydro-economic Analysis in the Ebro Basin

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Abstract

Addressing a more sustainable management of water resources involves new policies that require improved knowledge on water allocations and benefits from the economic and environmental uses of water. However, environmental uses have been mostly disregarded in traditional water management, and just recently the maintenance of environmental water flows is being considered as a key issue in water policies. The aim of this study is to analyze the spatial and sectoral allocation of water resources in the Ebro Basin (Spain), in order to inform the debate on the environmental flow in the Ebro mouth. The study analyzes in detail the irrigation districts using most of the water resources, and the environmental flow proposals for the river mouth. A hydro-economic model is developed to analyze the effects of different water allocation mechanisms under combinations of water availability and environmental flow scenarios. This is an important tool to explore the tradeoffs and political economy aspects from water reallocation. Results show that the petition of raising the environmental flow at the Ebro mouth during droughts by the downstream state (Cataluña) would be very costly for all irrigation districts in the basin. One alternative for the downstream state to gain the support of the rest of states for raising the environmental flow would be to compensate the losses of irrigation districts in upstream states.

Keyworks: Environmental flow · Drought · Water policy · Hydro-economic modeling · Ebro Basin

JEL Codes: Q25, Q54, D78, C61.

1. Introduction

Pressures on water resources have been mounting worldwide creating a widespread degradation of water resources in basins around the world. Global water extractions have climbed six fold during the last century (WWC 2000; Biemans et al. 2011). The scale of the global growing water scarcity indicates that water mismanagement is quite common, and that sustainable management of basins is a complex and difficult task. The upcoming water governance problem would be especially acute in arid and semiarid regions, where the combined effects of human-induced permanent water scarcity and climate change-induced water scarcity and droughts portend unprecedented levels of water resources degradation in the absence of remediating water reforms (WWAP 2006; Albiac 2017). Climate change is expected to become a major challenge for sustainable agricultural production, especially difficult to harness because global food demand will almost double by 2050 driven by the growth of world population and income (Alexandratos and Bruisma 2012). Water resources projections using coupled global hydrological and crop models indicate that crop losses from severe climate change impacts could be in the range of 20-30% by the end of the century (Elliot et al. 2014), with further losses occurring from water scarcity in some regions forcing the conversion of irrigated to rainfed cropland.

Most policies implemented to address water scarcity in water stressed basins frequently fail because the common pool characteristic of water resources are not taken into account and also because environmental externalities are ignored (Booker et al. 2012). The management of water resources requires collective action processes since pure competitive markets cannot account for the common pool and public good characteristics of water. Additionally, collective action is needed to account for the externalities linked to the use of water resources, such as, ecosystem damages or depletion of groundwater systems (Rausser et al. 2011). Lastly, the sustainable management of water requires accurate information on the economic and environmental costs and benefits of water allocations among sectors and spatial locations. Traditionally, environmental externalities have been not included in water management. But the severe degradation of basins across the world in recent decades is calling for implementing measures that specifically protect ecosystems. An example is the case of Europe, where water legislation emphasizes the objective of good ecological status for all water bodies by improving water quality. However, water allocation among sectors, locations and the environment is hardly addressed, despite the fact that this is the key issue in basins with acute water scarcity in Southern Europe.

Environmental flows sustain water dependent ecosystems, which provide many ecosystem goods and services to human societies. The water cycle of hydrological processes underlies the biodiversity, functionality and health of aquatic ecosystems. The alteration of environmental flows is the consequence of irrigation, urbanization and industrial activities that require growing streamflow diversions through reservoirs, water transfers and groundwater extraction schemes. There is a severe biodiversity decline of aquatic ecosystems that exceeds by far the decline of terrestrial and marine ecosystems (Arthington 2012).

The choice of ecosystems to be preserved determines the regime of the required environmental flows, implying a trade-off among water allocations for human and for environmental uses (Acreman 2016). The experience about this trade-off in basins around the world suggest that human uses have much higher priority over environmental uses, especially in arid and semi-arid regions. Furthermore, for maintaining healthy ecosystems not just environmental flows are required but also the maintenance of the natural seasonal flow patterns after human water withdrawals (Acreman et al. 2009). Water allocation in basins could be improved by considering both the economic and the environmental benefits provided by the different water allocation choices.

Hydro-economic modeling is a suitable methodology to analyze the economic and environmental impacts of different water allocation mechanisms between sectors and users, including water allocation for environmental purposes. This methodology is an advanced approach to support the design of policies at basin scale. This is because hydro-economic models integrate the spatially distributed water sources, water storage and conveyance infrastructures, water-based economic activities, and water-dependent ecosystems into a unified framework. The advantage of this approach is the formulation of interrelationships among hydrologic, economic, institutional and environmental components for a comprehensive assessment of the tradeoffs among water policy choices (Booker et al. 2005; Harou et al. 2009; Kahil et al. 2015).

This paper aims to highlight the importance of considering both the environmental flow requirements and economic impacts when designing policies to allocate water resources in a water-scarce river basin. To meet this objective, we have developed a hydro-economic model of the Ebro basin of Spain, which integrates major water uses, sources, and infrastructure in the basin. This model has been used to analyze three different water allocation policies: upstream priority, proportional sharing, and water markets. These allocation policies can be implemented to maintain different environmental flow proposals under various water availability scenarios. An important contribution of the study relative to prior literature is to provide information on the socio-economic impacts sustained by human water uses, when ecosystems are protected by establishing different levels of environmental flows under various water scarcity conditions. The results highlight that the establishment of environmental flow requirements in water-scarce river basins is a key issue involving both human wellbeing and protection of water dependent ecosystems. However, the success of water allocation policies require the implementation of economically efficient and socially acceptable measures. The Ebro basin is an illustrative case for exploring the political tradeoffs when water is reallocated to the environment, and results could entail important lessons for other basin in arid and semiarid regions.

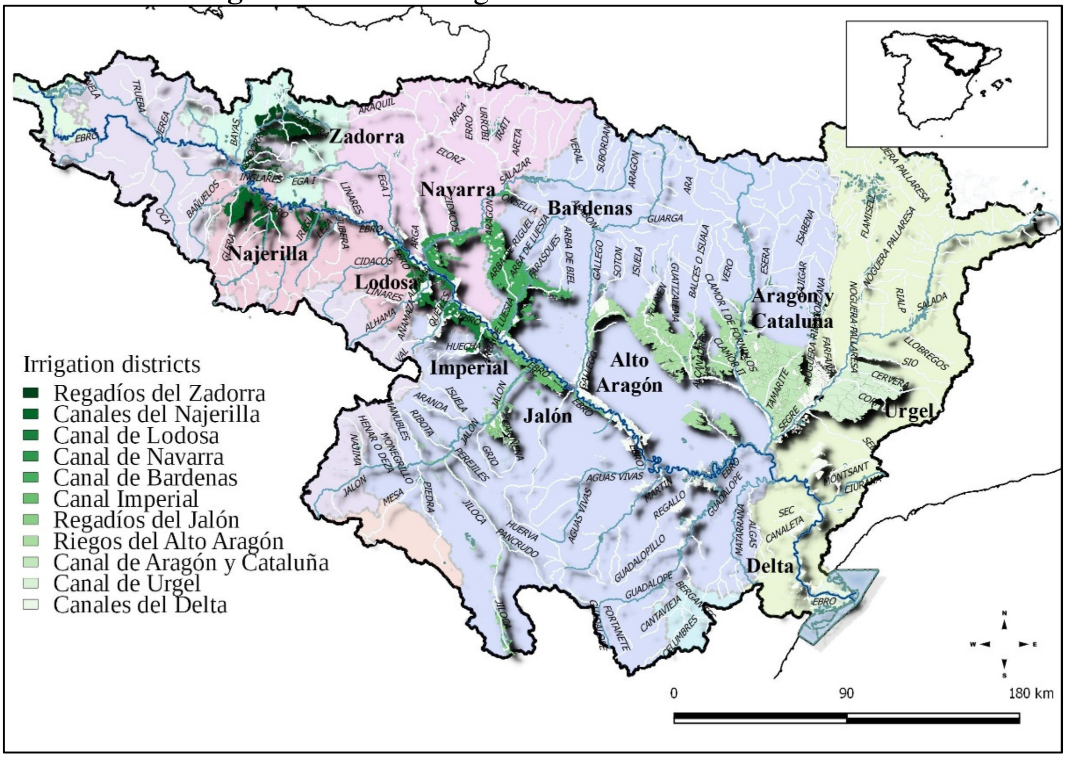
The paper is organized as follows. First, we briefly summarize the main issues with water management in the Ebro basin in section 2. Section 3 presents the development of the hydro-economic model of the Ebro basin. Section 4 describes the model application and the main results of the hydro-economic analysis. Finally, section 5 concludes with the summary and policy implications.

2. The Ebro River Basin

The Ebro basin is located in Northeastern Spain covering 85,000 km^2 and sustaining the economic activities of 3.2 million inhabitants (Figure 1). Available renewable water resources amount to 14,600 Mm^3 per year, and water withdrawals are 8,460 Mm^3 divided between 8,110 Mm^3 of surface diversions and 350 Mm^3 of groundwater extractions (CHE 2015). Water withdrawals for agriculture are around 7,680 Mm^3 covering 700,000 ha of irrigated crops. Withdrawals by water companies supplying urban centers are 630 Mm^3, and direct withdrawals by industries are 150 Mm^3. There are also non-consumptive withdrawals for the cooling of thermoelectric power plants (3,100 Mm^3) and for hydropower production (38,000 Mm^3). Water for agriculture represents 90% of the water demand and the main irrigated crops are alfalfa, corn, barley, wheat, rice and fruit trees.

The management of water is made by the Ebro Basin Authority (Confederación Hidrográfica del Ebro). The water authority is in charge of elaborating the Ebro River Plan setting the medium term management strategies, where the objectives are to feed

Fig. 1 Ebro Basin irrigation districts and river tributaries



Source: CHE (2017)

water demand, contribute to regional development, and protect ecosystems in the basin. Ecosystems protection is implemented by establishing minimum environmental flows in selected river reaches.

The distinctive characteristic of this institutional approach is the key role played by stakeholders. Water stakeholders are inside the water authority and include water users, public administrations, and environmental groups. These stakeholders' representatives are in all governing and participation bodies at basin scale, and they run the watershed boards at local scale.

An important issue in the Ebro basin in recent decades is the conflict between the upstream states and the downstream state (Cataluña) because of the minimum environmental flow at the Ebro mouth. The Ebro and the Duero rivers are the only rivers in Spain with substantial minimum environmental flows at the river mouth, which are around 20% of natural stream flows compared with minimum flows around 0.1-4% in the rest of the basins.

Despite this significant minimum environmental flow threshold in the Ebro, Cataluña is asking for a steep increase in minimum environmental flow in normal years from the current 3,000 up to around 8,000-9,000 Mm^3/year, increasing the share over natural streamflow from 20% up to 50-65%. These extraordinary claims by the downstream

Cataluña state are opposed by all upstream states in the basin, since their water related economic activities would be seriously threatened.

The aim of this paper is to analyze the socio-economic impacts and costs of this large expansion in the Ebro basin environmental flows. Additionally, different alternative policies to distribute the costs among users and states along the basin are examined.

3. The hydro-economic model of the Ebro basin

A hydro-economic model of the Ebro basin is developed to analyze the current water allocation by sector and spatial location in the basin. The model integrates the hydrology, the economic activities, and the environmental flows of the basin. The hydrological component is a node-link network of supply nodes such as rivers and dams, and demand nodes such as irrigation districts, urban centers, and environmental flows. The regional economic component includes the irrigation activities and the urban and industrial activities, where a detailed farm-level optimization module represents irrigation districts, and urban centers maximize the social surplus derived from the supply and demand of urban water. The environmental use of water is represented by minimum environmental flow constraints, given the lack of information on the response of environmental benefits to the allocation of environmental flows (Momblanch et al. 2016). The full hydro-economic model framework showing the interactions among the model components is depicted in figure SM2.1 (Online Supplementary Material).

3.1. Reduced form hydrological component

The reduced form hydrological component is built with information from the Ebro basin authority (CHE 2007; 2015), using data on stream flows and water allocations during normal climatic conditions. The hydrological component represents water flows among supply and demand nodes, using the basic hydrological concepts of mass balance and continuity of river flows (Figure SM1 in Online Supplementary Material). The hydrological component is used to estimate the volume of available water for economic activities after fulfilling the restrictions on environmental flows. The mathematical formulation is the following:

$$W_{out_d} = W_{in_d} - W_{loss_d} - Div_d^{IR} - Div_d^{URB} \quad (1)$$

$$W_{in_{d+1}} = W_{out_d} + r_d^{IR} \cdot (Div_d^{IR}) + r_d^{URB} \cdot (Div_d^{URB}) + RO_{d+1} \quad (2)$$

$$W_{out_d} \geq E_d^{min} \quad (3)$$

where equation (1) is the mass balance equation, where water outflow W_{out_d} from a river reach d, is equal to water inflow W_{in_d} minus the loss of water W_{loss_d}, and minus the diversions for irrigation (Div_d^{IR}) and urban and industrial uses (Div_d^{IR}). Equation (2) is the continuity equation of river flow that indicates the water inflow to the next river reach $W_{in_{d+1}}$ is the sum of outflow from upstream river reach W_{out_d}, return flows from the upstream irrigation districts $[r_d^{IR} \cdot (Div_d^{IR})]$, return flows from urban centers $[r_d^{URB} \cdot (Div_d^{URB})]$, and runoff entering that river reach from tributaries RO_{d+1}. Equation (3) states that the water outflow W_{out_d} from a river reach d must be greater or equal to the minimum environmental flow requirements E_d^{min} in that river reach.

The calibration of the hydrologic component is made by adjusting the model parameters to reproduce the observed streamflows under baseline conditions. This calibration procedure involves introducing slack variables that represent unmeasured sources or uses of water, in order to balance supply and demand at each node. Headwater inflows, gauged streamflows and canal releases in the basin have been obtained from the Ebro Basin Authority and the Ministry of Agriculture for the period 2000-2014 (CHE 2009; CEDEX 2016). The water available in the system is 14,600 Mm^3, and the water allocated to irrigation districts and urban centers depends on the allocation rules of the Ebro Basin Authority.

3.2. Economic component

The economic component includes optimization models for each irrigation district, and an optimization procedure of social surplus for the provision of water to each urban center. The optimization model of agricultural activities represents the crop production of the main irrigation districts in the basin (Figure 1). This model maximizes the private benefits of farmers from crop production activities for each irrigation district, subject to various technical and resource constraints. For simplicity, it is assumed that yield functions are linear and decreasing, and input and output prices are constant. The problem formulation is the following:

$$Max(B_k^{IR}) = \sum_{ij} C'_{ijk} X_{ijk} \quad (4)$$

subject to

$$\sum_i X_{ijk} \leq Tland_{kj};\ j = surface, sprinkle, drip \quad (5)$$

$$\sum_{ij} W_{ijk} X_{ijk} \leq Twater_k \quad (6)$$

$$\sum_{ij} L_{ijk} X_{ijk} \leq Tlabor_k \quad (7)$$

$$X_{ijk} \geq 0 \quad (8)$$

where B_k^{IR} is private benefit in irrigation district k, and $C_{ijk}^{'}$ is net income per hectare of crop i under irrigation technology j. The decision variable in the problem is X_{ijk}, the area of crop i under irrigation technology j. Equation (5) is the land constraint representing the land $Tland_{kj}$ available in irrigation district k equipped with irrigation technology j. The water equation (6) represents the water available T_{water_k} in the irrigation district k, where W_{ijk} is gross water requirement per hectare of crop i under technology j. The water constraint level is the connecting variable between the optimization model of irrigation districts and the hydrological component. The labor constraint (7) represents labor available $Tlabor_k$ in irrigation district k, where L_{ijk} is the labor requirement per hectare of crop i under irrigation technology j. The irrigation systems for field crops are surface and sprinkle irrigation, and for fruit trees and vegetables are surface and drip irrigation.

The net income per hectare C'_{ijk} is the difference between revenue and costs, and is defined by the following equation:

$$C'_{ijk} = P_i Y_{ijk} - CP_i \qquad (9)$$

where P_i is price of crop i, Y_{ijk} is yield of crop i under technology j in district k, and CP_i are the production costs of crop i. The model includes the Ricardian rent principle of decreasing yields when additional land enters production. The yield function is linear and decreasing in the area of crop i under technology j as follows:

$$\mathrm{Y_{ijk}} = \beta_{0_{\mathrm{ijk}}} + \beta_{\mathrm{1ijk}} \mathrm{X_{ijk}} \qquad (10)$$

The optimization model is calibrated with the positive mathematical programming (PMP) method, using the procedure of Dagnino and Ward (2012). This procedure involves the estimation of the parameters of the linear yield function [Equation (10)], based on the first order conditions for profit maximization. The data on yields, prices, crop water requirements, production costs, availability of water, land and labor, together with the information on biophysical parameters, have been obtained from statistical databases and previous studies (MARM 2010; MAGRAMA 2015; INE 2009; DGA 2009; GC 2009; GN 2009).

In urban use, the procedure is to maximize the economic surplus, adding the consumer and producer surpluses from the main urban centers in the basin. The optimization problem is the following:

$$Max\ B_u^{URB} = (a_{du}Q_{du} - ½\, b_{du}Q_{du}^2 - a_{su}Q_{su} - ½\, b_{su}Q_{su}^2) \qquad (11)$$

subject to

$$Q_{du} - Q_{su} \leq 0 \qquad (12)$$

$$Q_{du};\ Q_{su} \geq 0 \qquad (13)$$

where B_u^{URB} is the consumer and producer surplus of urban center u. Variables Q_{su} and Q_{du} are water supply and demand in urban center u. Parameters a_{du} and b_{du} are intercept and slope of the inverse demand function, and parameters a_{su} and b_{su} are the intercept and slope of the supply function. Equation (12) states that water supply must be greater of equal than demand. Water supply Q_{su} is the variable connecting the urban model with the hydrologic component. Water demand parameters for urban centers are based on the studies by Arbués et al. (2004) and Arbués et al. (2010).

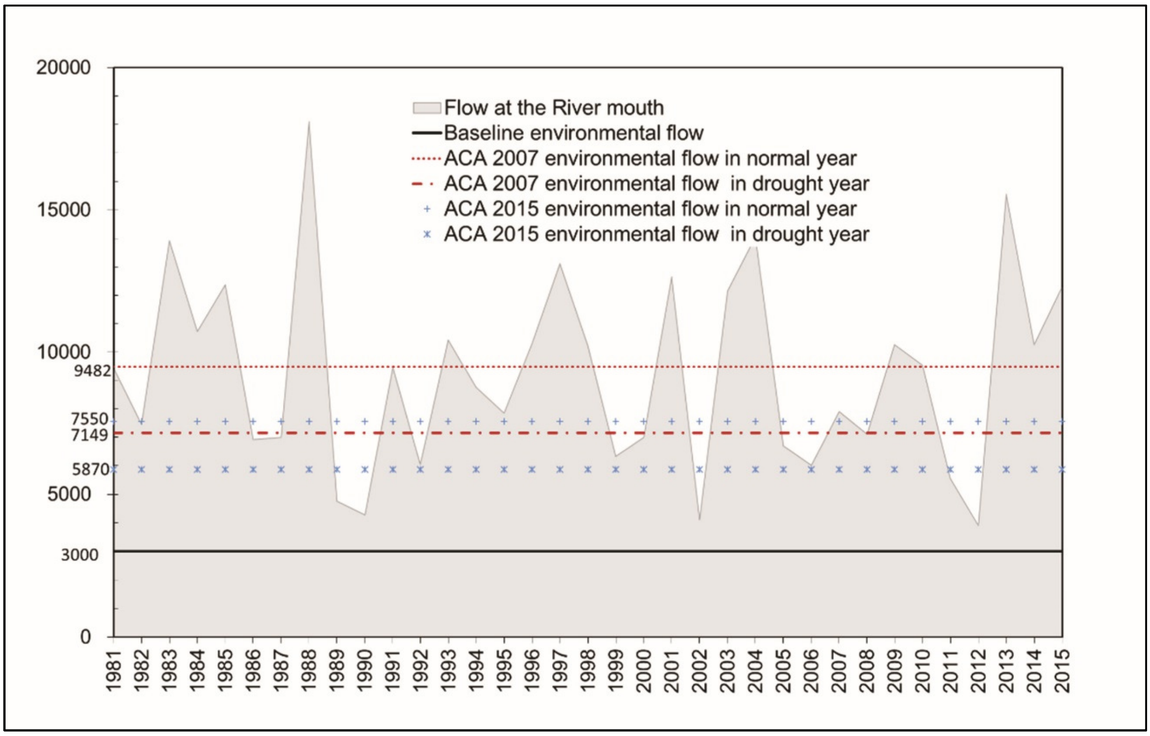
3.3. Environmental component

Wetlands provide a diverse range of goods and services to society including food production, groundwater recharge, nutrients cycle, carbon capture, species habitat or recreation. Environmental benefits from ecosystems services can be represented by modeling the ecological response of these ecosystems and using available studies on the economic value of the different good and services they provide. However, to the best of our knowledge, the representation of environmental benefits in hydro-economic models is still quite limited. Some studies have included the water consumption of ecosystems in hydro-economic models (Ahmadi et al. 2012; Connor et al. 2013), but the insufficient knowledge on the ecosystems response to water and the lack of information on the economic benefits of ecosystems, prevents the inclusion of ecosystems in hydro-economic modeling. When the ecological response functions to water and the economic valuation studies are not available, a useful alternative is to represent the environmental uses of water by minimum environmental flow requirements (Jenkins and Lund 2000; Girard et al. 2015). This is the approach taken in this study for the environmental component.

In the Ebro basin, the Water Plan establishes different environmental flows for the different river reaches in the basin. The most important environmental flow is in fact the one established for the Ebro mouth, because it affects the 'Delta del Ebro' which is the main ecosystems in the basin, and also all upstream water uses in the basin including ecosystems.

To analyze the impact of the environmental flow at the mouth, a constraint of minimum mouth flow is added into our model. This constraint changes in the different scenarios that combine water availability in the basin and environmental flows at the mouth. The comparison of results is used to analyze the impacts on the whole basin of

Fig. 2 Ebro River flow and minimum environmental flow at the mouth (Mm^3)



Source: CHE (2016)

the different environmental flows at the river mouth, and to assess the implications for stakeholders of alternative water allocation policies.

In this study, the baseline environmental flow is the current level established in the Ebro Water Plan of 2015 setting a minimum flow of 3,000 Mm^3/year. Two other environmental flow levels are the two lobbied by the Agencia Catalana del Agua in 2007 [ACA (2007)] and in 2015 [ACA (2015)]. The ACA is the water agency in Cataluña, which is the downstream state in the Ebro basin. The ACA (2007) calls for a minimum flow of 9,482 Mm^3 in normal years and 7,149 Mm^3 during drought years. The ACA (2015) calls for a minimum flow of 7,550 Mm^3 in normal years and 5,870 Mm^3 in drought years (Figure 2). Each of these three environmental flow proposals (Water Plan, ACA 2007 and ACA 2015) is analyzed under two different water availability scenarios corresponding to normal and drought years. Finally, we analyze the alternative water allocation policies under water scarcity that could satisfy the three environmental flow proposals. The allocation policies considered are proportional shares, water markets, and priority of upstream regions. Figure 2 shows the historical Ebro river flows at the mouth, together with the environmental flow proposals.

It is important to mention that the proposal of the minimum environmental flow made by the Cataluña water agency in 2007 is incompatible with the hydrologic conditions of the Ebro basin. This is because the 9,482 Mm^3 minimum flow proposal in normal years is above 9.000 Mm^3, which is the average flow observed during the last thirty years. Such proposal will shut down a significant share of economic activities in all regions in the basin.

3.4. Policy analysis and environmental flows

The model optimizes the total basin benefits subject to the hydrological, technical and environmental constraints in every water sector and by spatial location. The optimization problem is given by the expression:

$$Max \sum_l B_l \quad \forall \, l = k, u \qquad (13)$$

subject to the constraints of equations (1)-(3), (5)-(8) and (11)-(12), where B_l are the benefits of each demand node l. The demand nodes in the hydro-economic model are the irrigation districts, urban centers and environmental flows, and the supply nodes are the rivers and dams. The regional economic component includes the irrigation districts and the urban centers in the basin (Figure SM1 in Online Supplementary Material).

The hydro-economic model of the Ebro basin is used to analyze the impacts of the different levels of environmental flow at the river mouth. Additionally, we have included three water availability scenarios, of normal, moderate and severe drought conditions, to simulate the economic impacts from imposing different environmental flows under diverse hydroclimatic conditions. The inflows to the system under normal climate conditions are set at 14,600 Mm^3, which are the mean inflows for the period 2000-2014. These inflows are very close to the average inflow 14,700 Mm^3/year for the 1981-2006 period (CHE 2015). Under moderate and severe drought conditions, the basin inflows are reduced by 30% and 40% with respect to normal climate conditions, respectively. Three environmental flow scenarios are simulated following the environmental restrictions established by the Ebro Basin Plan and the two proposals of ACA (2007) and ACA (2015) being requested by the Cataluña state (see figure 2). The Basin Plan establishes an environmental flow of 3,000 Mm^3 at the mouth for normal and drought years, and this is the baseline scenario. In the case of droughts, the basin authority reduces water allocations proportionally for all irrigation uses in the basin, in order to satisfy the urban uses which have highest priority and the environmental flow constraint of 3,000 Mm^3.

Three water allocation policies are considered to analyze the ACA (2007) and ACA (2015) proposals of environmental flow when there is water scarcity because of drought: proportional share (which is the current allocation mechanism), water markets, and priority of water use by upstream regions. These alternative allocation policies result in very different benefit outcomes for stakeholders in downstream and upstream states. Since the downstream state (Cataluña) is asking for the huge increase of environmental flow in the mouth that is opposed by upstream states, the reasonable solution is that the bulk of the costs has to be borne by the downstream state. This solution correspond to the policy of upstream priority.

4. Results and policy implications

4.1. Baseline scenario of environmental flow and proportional allocation policy

The results of the water allocations and benefits under the baseline scenario of environmental flow (3,000 Mm^3) are presented in Table 1, showing the allocation of irrigation water by crop and irrigation technology. For normal climate conditions, the irrigation area is 528,000 ha divided between field crops (399,000 ha), fruit trees (104,000 ha), and vegetables (25.000 ha). By irrigation technology, 280,000 ha are under surface irrigation, 170,000 ha under sprinkle, and 78,000 ha under drip. The total water diversions are 5,400 Mm^3. Employment is 31,500 annual work units, and the net income generated is 635 million Euros.

As indicated, the main crops in the basin are field crops (75%), fruit trees (20%), and vegetables (5%), where Canal de Lodosa, Riegos del Jalón, Zadorra, Rioja and Canal de Navarra districts specialize in highly profitable vegetables and fruit trees. Riegos del Alto Aragón and Canal de Bardenas districts specialize in less profitable field crops. Other districts specializing in fruit trees are Canal de Aragón y Cataluña, Canal de Lodosa, Canal de Urgel and Riegos del Jalón.

During drought periods, the Basin Authority reduces the water allocated to irrigation districts proportionally, while allocation to urban centers is maintained. The provision of water to urban centers has priority over any other use, including environmental flows. The urban use of water is maintained in all scenarios and the social surplus from urban use is almost 1,900 million Euros. Under moderate drought, water allocation to irrigation is reduced by 30%, down to 3,780 Mm^3. The effects of this reduction are smaller irrigated area (349,000 ha), net income (484 million €), and labor (26,100 AWU). The environmental flow at the river mouth is 5,710 Mm^3, well above the minimum environmental flow established at 3,000 Mm^3. Under a more extreme drought scenario, water allocation to irrigation is reduced by 40%, down to 3,530 Mm^3, with further

Table 1 Outcomes from current and ACA 2015 flow scenarios with moderate drought

	Normal year	Moderate drought			
Environmental flow	**3000**	**3000**	**5870 (ACA 2015)**		
Policy	**Baseline**	**Proportional**	**Proportional**	**Market**	**Priority**
Irrigated area (1.000 ha)	528	349	327	343	331
Cereals	399	235	215	227	219
Vegetables	25	21	20	21	21
Fruit trees	104	93	92	95	92
Labor (1.000 AWU)	31.5	26.1	25.5	26.1	25.4
Water use (Mm^3)	5,802	4,181	3,908	3,692	3,841
Agriculture water diversions	5,400	3,779	3,506	3,292	3,439
Urban water demand	402	402	402	402	402
Flow at the river mouth	8,890	5,710	5,870	5,870	5,870
Benefits (10^6 €)	2,492	2,341	2,321	2,337	2,325
Irrigation benefits	635	484	464	480	468
Urban benefits	1,857	1,857	1,857	1,857	1,857
Price of water (€/m^3)	0.04	0.09	0.16	0.15	0.15

reductions in irrigated area (304,000 ha), net income (444 million €), and labor (24,700 AWU). The production of field crops falls by half, because of their low profitability and high water requirements. The environmental flow at the river mouth is 4,650 Mm^3, which is also above the current minimum flow.

The results under moderate and severe drought scenarios show that in both cases the current 3,000 Mm^3 level of environmental flow are fulfilled. The proportional share policy distributes water shortages among all irrigation districts in the basin, and the drought costs are between 150-190 million Euro per year. These results suggest that the current water allocation regime in the Ebro basin is able to balance the economic activities with the environmental flow requirements of ecosystems, and this balance is maintained under different levels of water availability.

4.2. Environmental flow proposals ACA (2015) and ACA (2007) under different allocation policies

Under normal climate conditions, the environmental flow proposals are 9,480 Mm^3 by ACA (2007) and 7,550 Mm^3 by ACA (2015). These large increases over current minimum environmental flows (3,000 Mm^3) imply that more than half of the basin inflows have to be reserved for mouth streamflows in normal years. The ACA (2007) environmental flow is slightly above the 9,000 Mm^3 average flow in the river, so it would be almost feasible in normal years. The ACA (2015) environmental flow is below the average flow, so it is fully feasible in normal years. The ACA environmental flow scenarios are simulated only under moderate or severe drought, because in normal years environmental flows are above the requested thresholds.

Table 2 Outcomes from current and ACA 2015 flow scenarios with severe drought

	Normal year	Severe drought			
Environmental flow	**3000**	**3000**	**5870 (ACA 2015)**		
Policy	**Baseline**	**Proportional**	**Proportional**	**Market**	**Priority**
Irrigated area (1.000 ha)	528	304	139	153	141
Cereals	399	195	64	57	81
Vegetables	25	19	12	16	14
Fruit trees	104	90	63	80	46
Labor (1.000 AWU)	31,5	24.7	16.1	19.8	12.5
Water use (Mm^3)	5,802	3,635	1,704	1,413	1,491
Agriculture water diversions	5,400	3,533	1,302	1,211	1,089
Urban water demand	402	402	402	402	402
Flow at the river mouth	8,890	4,650	5,870	5,870	5,870
Benefits (10^6 €)	2,492	2,301	2,112	2,159	2,194
Irrigation benefits	635	444	255	302	237
Urban benefits	1,857	1,857	1,857	1,857	1,857
Price of water (€/m^3)	0.04	0.14	0.43	0.32	0.75

The problem with the ACA claims appears clearly during drought years, because the flow at the mouth is only 5,710 Mm^3 under moderate drought and 4,650 Mm^3 under severe drought. Both ACA drought minimum flow requirements of 7,150 Mm^3 in ACA (2007) and 5,870 Mm^3 in ACA (2015) cannot be fulfilled even under moderate drought without curtailing the basin economic activities in order to reallocate water into the Ebro mouth. Since urban use has the highest priority, the shortfall during droughts to comply with the ACA claims requires the cutback of irrigation activities in the basin.

Three alternative water allocation policies are considered during droughts for water reallocation from irrigation into the Ebro streamflow in order to satisfy the ACA claims in the Ebro mouth: proportional sharing, water market, and priority of water use by upstream regions. The proportional sharing policy is the current policy enforced by the Ebro Water Authority during droughts. When there is water scarcity, water allocations in every basin location are reduced proportionally to the shortfall. The water market policy would allow water transfers between willing buyers and sellers, leading to private benefit gains. The policy of priority of water use by upstream regions is the following: if the downstream state (Cataluña) wants to increase the environmental flow at the mouth above 3,000 Mm^3 during periods of drought, the required water has to come first from curtailing downstream use of irrigation in the Cataluña region.

4.2.1 Water allocation policies under the ACA (2015) proposal and droughts

Proportional sharing: irrigation allocations are fixed shares of the available water in the basin, and they fall under drought scenarios. To satisfy the ACA environmental flow of

5,870 Mm^3 at the mouth during drought, the proportional sharing involves reducing irrigation water to 3,506 Mm^3 in moderate drought (-35% of baseline) and to 1,302 Mm^3 in severe drought (-76%) (Tables 1 and 2). The irrigated area falls sharply, mostly affecting low profitable field crops and less efficient surface irrigation technologies. Benefit losses of farmers are also strong from 171 million Euros in moderate drought (-27% of baseline) to 380 million Euro in severe drought (-60%).The losses sustained by farmers are evenly distributed among all irrigation districts in the basin.

Water market: the irrigation districts receive their allocation share, and then water trading between districts maximize their joint benefits. Irrigation water use is reduced to 3,292 Mm^3 under moderate drought (-39% of baseline) and to 1,211 Mm^3 under severe drought (-77%). The irrigated area with the water market policy is above the area cultivated with the proportional sharing policy. Benefit losses range between 155 million Euros in moderate drought (-25% of baseline) and 333 million in severe drought (-52%). Farmers would prefer water markets over proportional sharing allocation because of higher benefits with markets. The irrigation districts specializing in fruit trees and vegetables experience lower losses than districts specializing in field crops.

Priority of upstream regions: Cataluña is the downstream state asking for a steep increase in the environmental flow at the Ebro mouth. This policy places the burden of the water reallocation on the region requesting the reallocation of water from economic activities to the environmental, rather than on the upstream regions. The reallocation effort is made first by the irrigation districts located in the downstream region, and then any additional reallocation to meet the environmental flow at the mouth is made by the upstream regions. Under moderate drought, irrigation water in the basin falls to 3,439 Mm^3 (-36% of baseline), and the burden of the water reallocation is supported by the downstream region. In this region, the reduction of irrigation water with respect to the baseline is 45%, 30% because of the drought and 15% to cover the 5,870 Mm^3 environmental flow requirements. The reduction in upstream regions is 30% to cover the drought shortfall.

Under severe drought, the use of irrigation water at basin level is 1,089 Mm^3 feeding 103,000 ha of crop activities. All irrigation water in Catalonia is reallocated to the environmental flow of the Ebro mouth, while in upstream irrigation districts the use of water falls by 65% with respect to the baseline, compared to 76 percent under the proportional sharing policy. There is a full loss of benefits in Cataluña amounting to 167 million Euros with respect to the baseline. In the upstream regions the benefit loss is 233

Table 3 Upstream and downstream benefits under flow scenarios by climate (10^6 €)

Environmental flow/Policy	Climate					
	Moderate drought			Severe drought		
	Region			Region		
	Upstream	Downstream	Basin	Upstream	Downstream	Basin
Baseline (3,000 Mm^3)						
Proportional	357	127	484	328	116	444
ACA 2015 (5,870 Mm^3)						
Proportional	342	122	464	185	70	255
Market	359	121	480	229	73	302
Upstream priority	357	111	468	237	0	237
ACA 2007 (7,150 Mm^3)						
Proportional	202	75	277	Unfeasible[a]	Unfeasible	Unfeasible
Market	245	79	324	Unfeasible	Unfeasible	Unfeasible
Upstream priority	258	0	258	Unfeasible	Unfeasible	Unfeasible

a: "Unfeasible" indicates that there is no solution under severe drought because the environmental flow can not be reached even by cutting off all irrigation in the basin.

million Euro. This loss is 50% of the baseline compared to 60% loss under the proportional sharing policy. The policy of priority of upstream regions during severe droughts is extremely costly to Cataluña for the 5,870 Mm^3 environmental flow requirement, but it is also very costly for upstream regions which are against raising the requirement. If Cataluña wants to raise the environmental flow from 3,000 Mm^3 up to 5,870 Mm^3 during severe drought years, the rest of regions could ask Cataluña for compensation of their losses. This compensation would amount to 91 million Euros, which is the benefit difference in upstream regions under severe drought between having the 3,000 Mm^3 threshold (328 million €) and having the 5,870 Mm^3 threshold (237 million €) (Table 3). Then under upstream priority and compensation to upstream states, the total costs for Cataluña of raising the environmental threshold would be 207 million Euros, the sum of the loss of 116 million from the upstream priority policy, plus the 91 million of compensation to upstream farmers.

4.2.2 Water allocation policies under the ACA (2007) proposal and droughts

Under moderate drought, the ACA (2007) claim of increasing environmental flow from 3,000 up to 7,150 Mm^3 cuts the farmers benefits by more than half with respect to a normal year for the three allocation policies, falling from 635 to between 260 and 320 million Euros (Table SM2.3 in Online Supplementary Material). By expanding the environmental flow from the current 3,000 to 7,150 Mm^3 during drought, the percentage of farmers losses doubles to more than 50% under any allocation policy.

Under severe drought, the ACA (2007) environmental flow claim is unfeasible, which means that the 7,150 Mm^3 of environmental flow can not be achieved even by cutting all irrigation use in the basin.

These results indicate that the ACA (2007) proposal of environmental flow under drought is untenable. This is not only because this flow level is impossible to achieve under severe drought, but also because under moderate drought the massive losses to farmers would make this flow claim politically unfeasible.

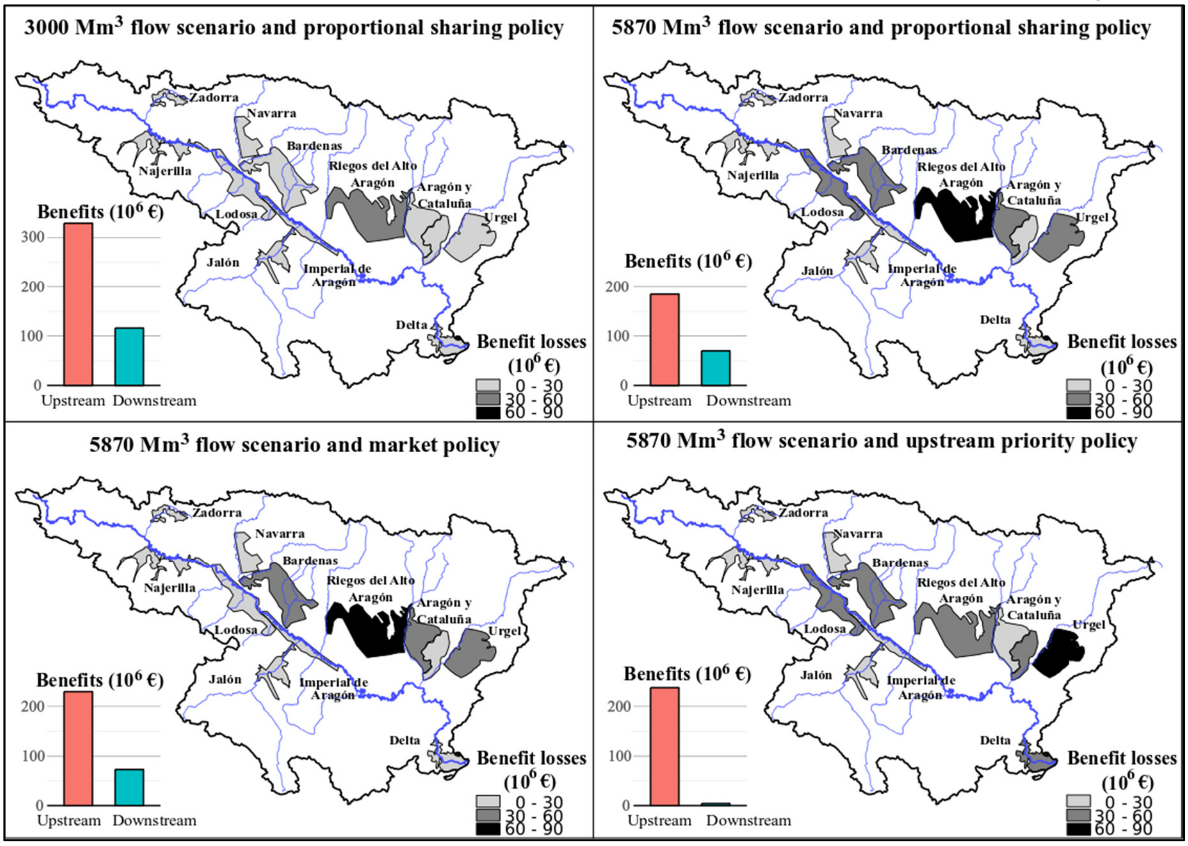
Table 3 summarizes the results, by showing the benefits to upstream and downstream regions from the three water allocation policies under the environmental flow scenarios and climate conditions. Implementing the ACA (2015) proposal and the policy of upstream priority under moderate drought will maintain the benefits of upstream regions in relation to the baseline at 357 million Euros, but under severe drought the benefits of upstream regions fall by 91 million Euros with respect to the baseline. Implementing the ACA (2007) proposal and the policy of upstream priority under moderate drought will reduce the benefits of upstream regions by 99 million Euros, and this environmental flow proposal is unfeasible under severe drought.

Considering both the ACA (2015) and ACA (2007) proposals, the main outcomes from the three allocation policies are the following: i) raising the environmental flow of the Ebro mouth escalates the losses of benefits during droughts, and the losses become untenable in severe drought; ii) the water market policy is an alternative policy that could achieve higher benefits under both the moderate and severe droughts; iii) the bulk of the negative impact of raising the environmental flow requirements under droughts is supported by the farmers of field crops; and iv) the proportional sharing policy distributes the benefit losses evenly among all basin regions, achieving higher total basin benefits compared to the upstream priority policy. However, the upstream regions could obtain higher benefits with the upstream priority policy than with the proportional sharing policy (Figure 3).

5. Conclusions

There is a growing concern in societies across the world regarding the escalating water scarcity in basins located in arid and semi-arid regions. Expanding human water demands are resulting in severe ecosystem degradation but also on serious threats to human activities. These emerging social demands call for securing minimum environmental

Fig. 3 Benefits for current (3,000) and ACA 2015 (5,870) scenarios, under severe drought (10^6 €)[a]



a: Benefit losses are calculated with respect to the baseline (normal year).

flows for water-dependent ecosystems, which further increase the competition for already scarce water in basins exacerbated during drought periods.

This study contributes to the debate on water allocation in the Ebro basin of Spain. The paper analyzes the current disputes among states and the different basin stakeholders over the environmental flow at the Ebro mouth. We have developed a hydro-economic model of the Ebro basin which integrates various hydrological, economic and environmental components and includes the main irrigation districts and urban centers in the basin. The model is used to analyze three scenarios of environmental flow at the river mouth under normal and drought climate conditions. The environmental flow scenarios are the current flow of 3,000 Mm^3 established in the Ebro Water Plan, and the ACA 2007 and 2015 proposals of the downstream state (Cataluña) of raising the minimum environmental flow at the Ebro mouth between two and three times. Additionally, three allocation policies (upstream priority, proportional sharing, and water markets) have been simulated to analyze the different ways of sharing the costs imposed by raising the current environmental flow. The allocation policies are implemented in order to comply with the environmental flows proposals under different water stress scenarios.

Results show that under the current environmental flow requirement of 3,000 Mm^3, drought events already generate important losses of benefits to farmers. The adaptation of irrigation districts to drought consists in modifying both the crop pattern and the relative share of irrigation systems, concentrating production in the more profitable crops. The adjustment to water scarcity reduces the production of field crops cultivated in surface irrigation systems. The capability of response to drought conditions is higher in areas with profitable crops under advanced irrigation systems. The current minimum environmental flow requirement at the river mouth does not restrict the economic activities in the basin under any climate condition, and this flow level also facilitates a more flexible water management in the future.

Accepting the claims of Cataluña and raising the minimum environmental flow by two or three times at the Ebro mouth increase significantly the benefit losses sustained by farmers during droughts. These losses depend on the water allocation policy chosen. The policies considered are proportional sharing, water market, and priority of upstream regions. The comparison between these policies during droughts shows that the water market policy is a feasible alternative that achieves higher economic benefits in the basin. The policy of proportional sharing generates higher benefits than the policy of priority of upstream regions, and it is also more equitable by distributing the drought losses evenly among regions in the basin. This is because this policy favors the irrigation districts with low profitable crops and less advanced irrigation systems. The policy of upstream priority places the burden of adjusting to drought over the downstream region of Cataluña.

The reason behind the policy of upstream priority is that the downstream state of Cataluña is asking for a steep increase of the current environment flow requirement between two and three times, and upstream states will sustain heavy losses and are not willing to accept this proposal. The policy of upstream priority shifts therefore the costs of reaching the higher environmental flow towards the downstream region requesting it first, rather than spreading the costs evenly among all regions in the basin. So, the reallocation effort is made first by the irrigation districts downstream, and then any additional reallocation to meet the environmental flow threshold is made by the upstream regions. Our results indicate that the proposal by Cataluña of expanding environmental flows is very costly to farmers in other states of the basin. This negative impact could be reduced somehow by the policy of upstream priority, but benefit losses remain in some cases. One possibility to gain the support of these regions is by providing payments from the Cataluña downstream state to the upstream states to compensate for any remaining losses they could sustain because of the increase of environmental flow at the Ebro mouth.

Policy tradeoffs and other political economy aspects for a more sustainable management have been examined in the Ebro basin. This is an illustrative case for exploring the political viability of reallocating water to the environment, which may entail important lessons for other basin in arid and semiarid regions.

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Supplementary Material

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1. Irrigation districts and urban centers in the Ebro Basin

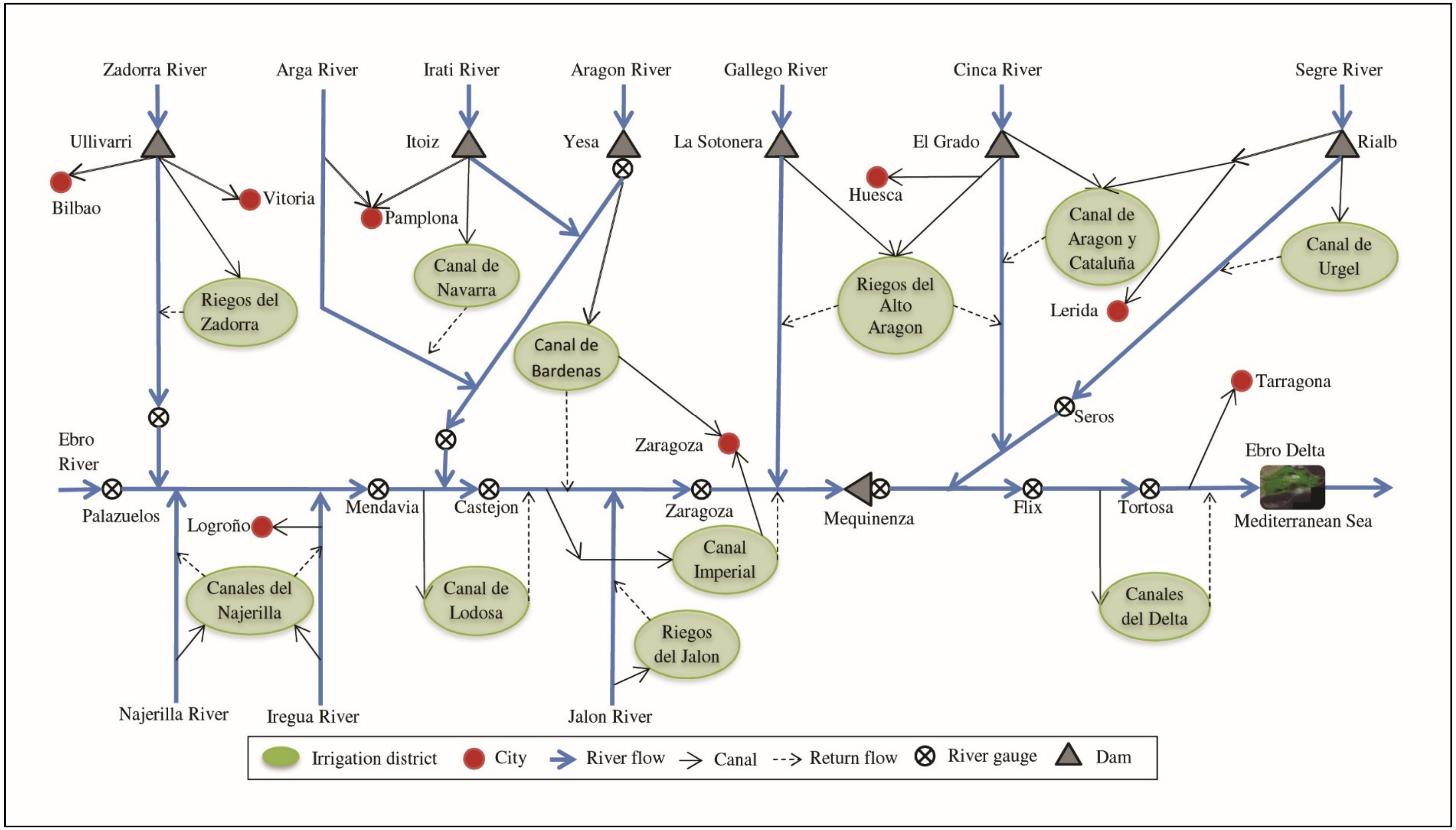
2. Modelling framework, Ebro basin network, and Outcomes from current and ACA 2007 flow scenarios with moderate drought

3. Disaggregated results by irrigation district

1. Irrigation districts and urban centers and the Ebro Basin network

The irrigation districts considered are shown in figure SM1 (upstream to downstream): Regadíos del Zadorra (ZA), Canales del Najerilla (CN), Canal de Lodosa (LO), Canal de Navarra (NA), Canal de Bárdenas (BA), Canal Imperial (IM), Regadíos del Jalón (JA), Riegos del Alto Aragón (RA), Canal de Aragón y Cataluña in Aragón (AA), Canal de Aragón y Cataluña in Cataluña (AC), Canal de Urgel (UR) y Canales del Delta (DE). The model of urban use includes the main towns of Vitoria, Logroño, Pamplona, Zaragoza, Huesca y Lérida, and the inter-basin water transfers to Bilbao and Tarragona.

Fig. SM1 Network of the Ebro River Basin



2. Modelling framework, and Outcomes from current and ACA 2007 flow scenarios with moderate drought

Fig. SM2.1 Modelling framework

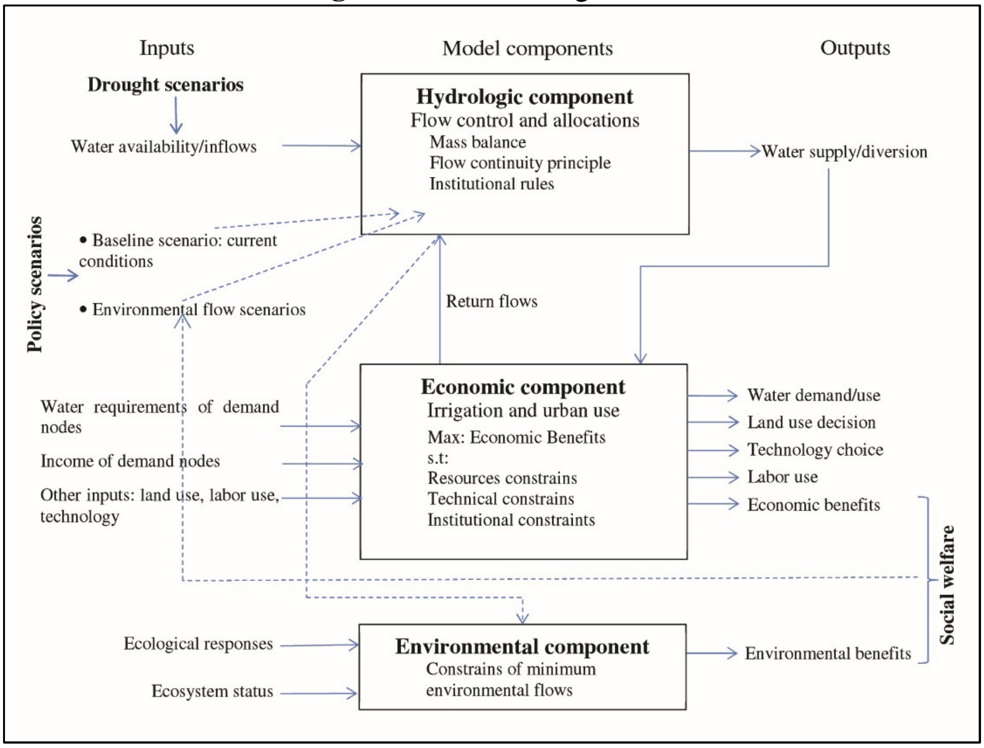


Table SM2.1 Outcomes from current and ACA 2007 flow scenarios with moderate drought

	Normal year	Moderate drought			
Environmental flow	**3000**	**3000**	**7150 (ACA 2007)**		
Policy	**Baseline**	**Proportional**	**Proportional**	**Market**	**Priority**
Irrigated area (1.000 ha)	528	349	154	172	158
Cereals	399	235	74	72	94
Vegetables	25	21	13	17	15
Fruit trees	104	93	67	83	49
Labor (1.000 AWU)	31.5	26.1	17.4	20.6	13.4
Water use (Mm^3)	5,802	4,181	1,872	1,784	1,653
Agriculture water diversions	5,400	3,779	1,470	1,382	1,251
Urban water demand	402	402	402	402	402
Flow at the river mouth	8,890	5,710	7,150	7,150	7,150
Benefits (10^6 €)	2,492	2,341	2,134	2,181	2,115
Irrigation benefits	635	484	277	324	258
Urban benefits	1,857	1,857	1,857	1,857	1,857
Price of water (€/m^3)	0.04	0.09	0.38	0.29	0.71

3. Disaggregated results by irrigation district

Table SM3.1.1 Land use and labor under climate conditions an environmental flow scenario (1.000 ha y 1.000 AWU)

Climate	Normal												
Irrigation districts and basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario													
Irrigated área	6	22	56	23	78	27	21	110	49	34	72	31	528
Cereals	2	7	25	18	73	24	8	106	40	20	56	21	399
Vegetables	1	5	8	3	3	2	0	1	0	0	1	1	25
Fruit trees	3	10	22	2	2	2	13	3	9	14	15	9	104
Sprinkler	0	4	8	10	16	5	3	62	33	16	12	0	170
Drip	1	5	15	4	2	2	10	3	7	12	7	9	78
Surface	5	12	33	9	59	20	7	46	9	6	53	21	280
Labor	0.3	1.5	8.0	1.2	1.7	1.0	2.3	2.3	2.5	3.2	4.3	3.2	31.5
ACA 2015 environmental flow scenario proportional sharing													
Irrigated area	6	22	56	23	78	27	21	110	49	34	72	31	528
Cereals	2	7	25	18	73	24	8	106	40	20	56	21	399
Vegetables	1	5	8	3	3	2	0	1	0	0	1	1	25
Fruit trees	3	10	22	2	2	2	13	3	9	14	15	9	104
Sprinkler	0	4	8	10	16	5	3	62	33	16	12	0	170
Drip	1	5	15	4	2	2	10	3	7	12	7	9	78
Surface	5	12	33	9	59	20	7	46	9	6	53	21	280
Labor	0.3	1.5	8.0	1.2	1.7	1.0	2.3	2.3	2.5	3.2	4.3	3.2	31.5
ACA 2015 environmental flow scenario market													
Irrigated area	6	22	56	23	78	27	21	110	49	34	72	31	528
Cereals	2	7	25	18	73	24	8	106	40	20	56	21	399
Vegetables	1	5	8	3	3	2	0	1	0	0	1	1	25
Fruit trees	3	10	22	2	2	2	13	3	9	14	15	9	104
Sprinkler	0	4	8	10	16	5	3	62	33	16	12	0	170
Drip	1	5	15	4	2	2	10	3	7	12	7	9	78
Surface	5	12	33	9	59	20	7	46	9	6	53	21	280
Labor	0.3	1.5	8.0	1.2	1.7	1.0	2.3	2.3	2.5	3.2	4.3	3.2	31.5
ACA 2015 environmental flow scenario upstream priority													
Irrigated area	6	22	56	23	78	27	21	110	49	34	72	31	528
Cereals	2	7	25	18	73	24	8	106	40	20	56	21	399
Vegetables	1	5	8	3	3	2	0	1	0	0	1	1	25
Fruit trees	3	10	22	2	2	2	13	3	9	14	15	9	104
Sprinkler	0	4	8	10	16	5	3	62	33	16	12	0	170
Drip	1	5	15	4	2	2	10	3	7	12	7	9	78
Surface	5	12	33	9	59	20	7	46	9	6	53	21	280
Labor	0.3	1.5	8.0	1.2	1.7	1.0	2.3	2.3	2.5	3.2	4.3	3.2	31.5

Climate	Moderate drought												
Irrigation districts and basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario													
Irrigated área	4	13	39	15	51	17	14	74	32	22	46	21	349
Cereals	1	1	11	10	47	14	3	70	23	10	31	12	235
Vegetables	1	3	7	3	2	1	0	1	0	0	1	1	21
Fruit trees	3	9	20	2	2	2	11	3	8	12	13	8	93
Sprinkler	0	1	4	6	13	4	2	44	19	8	8	0	109
Drip	1	5	14	4	2	2	9	2	7	10	6	8	71
Surface	3	8	20	5	36	11	4	27	6	3	32	13	168
Labor	0.3	1.2	7.1	1.0	1.2	0.8	2.0	1.6	2.1	2.7	3.6	2.8	26.1
ACA 2015 environmental flow scenario proportional sharing													
Irrigated area	4	12	37	14	48	16	13	70	30	21	43	20	327
Cereals	1	1	10	9	44	13	2	66	21	8	29	11	215
Vegetables	1	3	7	3	2	1	0	1	0	0	1	1	20
Fruit trees	3	9	20	2	2	2	11	3	8	12	13	8	92
Sprinkler	0	1	4	6	12	3	1	42	18	7	8	0	102
Drip	1	5	14	4	2	2	9	2	7	10	6	8	70
Surface	3	7	19	4	33	10	3	27	5	3	29	12	154
Labor	0.3	1.1	7.0	0.9	1.1	0.8	1.9	1.5	2.0	2.7	3.5	2.7	25.5
ACA 2015 environmental flow scenario market													
Irrigated area	5	16	45	16	38	18	17	70	34	25	46	13	343
Cereals	1	3	16	12	34	15	5	66	25	12	32	4	227
Vegetables	1	4	8	3	2	1	0	1	0	0	1	1	21
Fruit trees	3	9	21	2	2	2	12	3	8	13	13	8	95
Sprinkler	0	2	5	7	10	4	2	41	20	10	8	0	109
Drip	1	5	14	4	2	2	9	2	7	11	6	8	71
Surface	3	10	25	6	26	13	6	27	6	4	32	5	163
Labor	0.3	1.3	7.4	1.0	1.0	0.8	2.1	1.5	2.1	2.8	3.5	2.4	26.1
ACA 2015 environmental flow scenario upstream priority													
Irrigated area	4	13	39	15	51	17	14	74	32	18	37	18	331
Cereals	1	1	11	10	47	14	3	70	23	6	24	9	219
Vegetables	1	3	7	3	2	1	0	1	0	0	1	1	21
Fruit trees	3	9	20	2	2	2	11	3	8	12	13	8	92
Sprinkler	0	1	4	6	13	4	2	44	19	5	7	0	105
Drip	1	5	14	4	2	2	9	2	7	10	6	8	70
Surface	3	8	20	5	36	11	4	27	6	3	24	10	156
Labor	0.3	1.2	7.1	1.0	1.2	0.8	2.0	1.6	2.1	2.5	3.6	2.6	25.4

Climate	Severe drought												
Irrigation districts and basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario													
Irrigated área	4	11	35	13	44	14	12	65	28	19	40	19	304
Cereals	1	1	8	8	40	11	1	61	19	7	27	10	195
Vegetables	1	2	7	3	2	1	0	1	0	0	1	1	19
Fruit trees	3	8	19	2	2	2	11	3	8	12	13	8	90
Sprinkler	0	0	4	5	12	3	1	40	16	5	7	0	95
Drip	1	4	14	4	2	2	9	2	7	10	6	8	69
Surface	3	6	17	4	30	9	3	23	5	3	27	11	140
Labor	0.2	1.1	6.8	0.9	1.1	0.8	1.8	1.4	2.0	2.6	3.4	2.7	24.7
ACA 2015 environmental flow scenario proportional sharing													
Irrigated area	2	5	16	6	21	6	4	30	12	8	17	11	139
Cereals	0	0	0	2	17	3	0	27	5	0	6	2	64
Vegetables	0	0	5	2	2	1	0	1	0	0	0	1	12
Fruit trees	2	5	11	2	2	2	4	3	7	8	11	8	63
Sprinkler	0	0	0	2	8	1	0	20	5	0	3	0	38
Drip	1	3	10	3	2	2	4	2	6	7	5	8	52
Surface	1	2	7	1	11	3	0	9	2	1	9	3	49
Labor	0.2	0.4	4.3	0.7	0.7	0.6	0.6	0.7	1.5	1.6	2.5	2.3	16.1
ACA 2015 environmental flow scenario market													
Irrigated area	3	11	30	9	7	6	12	22	15	14	17	7	153
Cereals	0	0	5	5	5	4	2	20	7	3	7	0	57
Vegetables	1	2	7	2	1	1	0	1	0	0	0	1	16
Fruit trees	2	8	18	2	1	1	11	2	7	11	10	6	80
Sprinkler	0	0	2	3	2	1	1	13	6	2	2	0	33
Drip	1	4	13	3	2	1	8	2	6	9	5	6	60
Surface	2	6	15	3	3	3	3	8	3	2	10	0	60
Labor	0.2	1.0	6.5	0.8	0.4	0.6	1.8	0.6	1.6	2.2	2.4	1.7	19.8
ACA 2015 environmental flow scenario upstream priority													
Irrigated area	3	7	23	8	28	8	7	41	17	0	0	0	141
Cereals	0	0	1	4	24	5	0	37	9	0	0	0	81
Vegetables	0	1	6	2	2	1	0	1	0	0	0	0	14
Fruit trees	2	6	16	2	2	2	7	3	8	0	0	0	46
Sprinkler	0	0	1	3	9	2	0	27	8	0	0	0	49
Drip	1	3	12	3	2	2	6	2	6	0	0	0	38
Surface	2	3	10	2	16	4	1	12	3	0	0	0	54
Labor	0.2	0.6	5.8	0.8	0.8	0.6	1.1	0.9	1.7	0.0	0.0	0.0	12.5

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Table SM3.1.2 Land use and labor under climate conditions an environmental flow scenario (1.000 ha y 1.000 AWU)

Climate	Normal													Moderate drought													Severe drought												
Irrigation districts and basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario																																							
Irrigated area	6	22	56	23	78	27	21	110	49	34	72	31	528	4	13	39	15	51	17	14	74	32	22	46	21	349	4	11	35	13	44	14	12	65	28	19	40	19	304
Cereals	2	7	25	18	73	24	8	106	40	20	56	21	399	1	1	11	10	47	14	3	70	23	10	31	12	235	1	1	8	8	40	11	1	61	19	7	27	10	195
Vegetables	1	5	8	3	3	2	0	1	0	0	1	1	25	1	3	7	3	2	1	0	1	0	0	1	1	21	1	2	7	3	2	1	0	1	0	0	1	1	19
Fruit trees	3	10	22	2	2	2	13	3	9	14	15	9	104	3	9	20	2	2	2	11	3	8	12	13	8	93	3	8	19	2	2	2	11	3	8	12	13	8	90
Sprinkler	0	4	8	10	16	5	3	62	33	16	12	0	170	0	1	4	6	13	4	2	44	19	8	8	0	109	0	0	4	5	12	3	1	40	16	5	7	0	95
Drip	1	5	15	4	2	2	10	3	7	12	7	9	78	1	5	14	4	2	2	9	2	7	10	6	8	71	1	4	14	4	2	2	9	2	7	10	6	8	69
Surface	5	12	33	9	59	20	7	46	9	6	53	21	280	3	8	20	5	36	11	4	27	6	3	32	13	168	3	6	17	4	30	9	3	23	5	3	27	11	140
Labor	0.3	1.5	8.0	1.2	1.7	1.0	2.3	2.3	2.5	3.2	4.3	3.2	31.5	0.3	1.2	7.1	1.0	1.2	0.8	2.0	1.6	2.1	2.7	3.6	2.8	26.1	0.2	1.1	6.8	0.9	1.1	0.8	1.8	1.4	2.0	2.6	3.4	2.7	24.7
ACA 2007 environmental flow scenario proportional sharing																																							
Irrigated area	5	18	48	20	66	23	18	94	42	29	60	26	449	2	5	18	7	23	7	5	34	14	9	20	11	154													
Cereals	2	4	19	14	62	19	5	90	33	15	46	17	326	0	0	0	3	19	4	0	30	6	0	8	3	74													
Vegetables	1	4	8	3	3	2	0	1	0	0	1	1	23	0	0	5	2	2	1	0	1	0	0	1	1	13													
Fruit trees	3	9	21	2	2	2	12	3	9	13	14	9	99	2	5	13	2	2	2	5	3	7	9	11	8	67													
Sprinkler	0	3	6	8	15	5	2	54	27	13	10	0	143	0	0	0	2	8	2	0	22	6	0	3	0	43													
Drip	1	5	15	4	2	2	10	3	7	11	7	9	75	1	3	11	3	2	2	4	2	6	8	5	8	55													
Surface	4	10	27	7	49	16	6	38	8	5	44	18	231	1	3	8	1	12	3	1	9	2	1	11	4	56													
Labor	0.3	1.3	7.6	1.1	1.5	0.9	2.1	2.0	2.3	3.0	4.0	3.0	29.2	0.2	0.5	1.9	0.7	0.7	0.6	0.8	0.8	1.6	1.9	2.6	2.3	17.4													
ACA 2007 environmental flow scenario market																																							
Irrigated area	6	20	51	21	61	24	19	95	43	30	61	24	454	3	11	32	10	10	7	13	27	16	15	21	7	172													
Cereals	2	6	22	15	57	20	7	90	34	17	47	15	331	0	1	6	6	7	5	2	24	9	4	9	0	72													
Vegetables	1	4	9	3	2	2	0	1	0	0	1	1	24	1	2	7	2	2	1	0	1	0	0	1	1	17													
Fruit trees	3	10	22	2	2	2	12	3	9	13	14	9	100	2	8	19	2	1	2	11	3	7	11	11	6	83													
Sprinkler	0	3	7	9	14	5	3	54	28	17	10	0	146	0	0	3	3	3	2	1	15	7	3	3	0	41													
Drip	1	5	15	4	2	2	10	3	7	11	7	9	75	1	4	13	3	2	2	8	2	6	9	5	6	62													
Surface	4	11	30	8	45	17	7	38	8	5	45	15	233	2	7	16	3	5	4	3	9	3	2	13	0	69													
Labor	0.3	1.4	7.8	1.1	1.4	0.9	2.2	2.0	2.4	3.1	4.0	2.9	29.4	0.2	1.1	6.6	0.8	0.5	0.6	1.8	0.7	1.6	2.3	2.6	1.8	20.6													
ACA 2007 environmental flow scenario upstream priority																																							
Irrigated area	6	22	56	23	78	27	21	110	49	17	35	17	461	3	8	25	9	31	9	8	46	19	0	0	0	158													
Cereals	2	7	25	18	73	24	8	106	40	6	22	9	338	0	0	2	5	27	7	0	42	11	0	0	0	94													
Vegetables	1	5	8	3	3	2	0	1	0	0	1	1	25	1	1	6	2	2	1	0	1	0	0	0	0	15													
Fruit trees	3	10	22	2	2	2	13	3	9	12	13	8	98	2	6	17	2	2	2	8	3	8	0	0	0	49													
Sprinkler	0	4	8	10	16	5	3	62	33	5	7	0	153	0	0	1	3	10	2	0	30	9	0	0	0	56													
Drip	1	5	15	4	2	2	10	3	7	10	6	8	75	1	4	13	3	2	2	7	2	6	0	0	0	40													
Surface	5	12	33	9	59	20	7	46	9	3	23	9	234	2	4	11	2	19	5	1	14	3	0	0	0	63													
Labor	0.3	1.5	8.0	1.2	1.7	1.0	2.3	2.3	2.5	2.5	3.2	2.6	29.1	0.2	0.7	6.1	0.8	0.8	0.6	1.3	1.0	1.7	0.0	0.0	0.0	13.4													

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Table SM3.2.1 Agricultural and urban water use under climate conditions and environmental flow scenarios (Mm^3)

Climate	Normal													Moderate drought													Severe drought												
Irrigation districts and basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline																																							
Agriculture water diversions	53	124	331	156	792	202	123	998	366	243	791	1,203	5,382	37	85	229	109	554	162	85	698	255	168	550	847	3,779	32	72	195	94	475	139	72	598	218	143	470	725	3,233
Flow at the river mouth													8,890													5,710													4,650
Urban water demand													402													402													402
ACA 2015 environmental flow scenario and proportional sharing policy																																							
Agriculture water diversions	44	104	277	131	665	170	103	838	307	203	664	1,008	5,382	34	78	212	101	514	150	78	648	237	156	510	786	3,506	12	24	72	39	198	57	22	249	89	53	189	298	1,302
Flow at the river mouth													8,890													5,870													5,870
Urban water demand													402													402													402
ACA 2015 environmental flow scenario and market policy																																							
Agriculture water diversions	46	139	300	139	618	176	113	840	319	216	674	895	5,382	39	104	277	122	400	400	109	658	270	191	546	403	3,292	22	68	162	64	64	61	72	175	105	96	190	131	1,211
Flow at the river mouth													8,890													5,870													5,870
Urban water demand													402													402													402
ACA 2015 environmental flow scenario and upstream priority policy																																							
Agriculture water diversions	53	124	331	157	792	202	123	998	366	116	383	587	5,382	37	85	229	109	554	162	85	698	255	131	430	664	3,439	18	38	109	57	277	80	37	349	126	0	0	0	1,089
Flow at the river mouth													8,890													5,870													5,870
Urban water demand													402													402													402

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Table SM3.2.2 Agricultural and urban water use under climate conditions and environmental flow scenarios (Mm3)

Climate	Normal													Moderate drought													Severe drought												
Irrigation districts and basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline																																							
Agriculture water diversions	53	124	331	156	792	202	123	998	366	243	791	1,203	5,382	37	85	229	109	554	162	85	698	255	168	550	847	3,779	32	72	195	94	475	139	72	598	218	143	470	725	3,233
Flow at the river mouth													8,890													5,710													4,650
Urban water demand													402													402													402
ACA 2007 environmental flow scenario and proportional sharing policy																																							
Agriculture water diversions	44	104	277	131	665	170	103	838	307	203	664	1,008	4,514	14	29	83	43	221	64	26	279	100	62	214	335	1,470													
Flow at the river mouth													9,480													7,150													
Urban water demanda													402													402													
ACA 2007 environmental flow scenario and market policy																																							
Agriculture water diversions	46	139	300	139	618	176	113	840	319	216	674	895	4,446	23	74	174	72	91	73	76	209	118	104	229	139	1,382													
Flow at the river mouth													9,480													7,150													
Urban water demand													402													402													
ACA 2007 environmental flow scenario and upstream priority policy																																							
Agriculture water diversions	53	124	331	157	792	202	123	998	366	116	383	587	4,233	21	45	127	62	316	92	44	399	145	0	0	0	1,251													
Flow at the river mouth													9,480													7,150													
Urban water demand													402													402													

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Table SM3.3.1 Irrigation benefits and price of irrigation water under climate conditions and environmental flow scenarios (10^6 € y €/m^3)

Climate	Normal													Moderate drought													Severe drought												
	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario																																							
Benefit	15	44	96	30	64	30	37	97	54	47	88	32	635	12	36	80	23	47	21	31	68	39	36	67	24	484	12	34	75	21	42	19	29	61	36	33	61	22	444
Price of water	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.18	0.16	0.11	0.09	0.05	0.09	0.11	0.06	0.08	0.09	0.07	0.04	0.09	0.44	0.23	0.14	0.12	0.07	0.12	0.15	0.08	0.11	0.12	0.10	0.05	0.14
ACA 2015 environmental flow scenario and proportional sharing policy																																							
Benefit	15	44	96	30	64	30	37	97	54	47	88	32	635	12	35	78	22	44	20	30	64	38	35	64	23	464	7	16	47	14	25	10	12	32	22	19	36	15	255
Price of water	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.17	0.26	0.17	0.16	0.10	0.15	0.18	0.11	0.14	0.16	0.13	0.09	0.15	0.64	1.05	0.61	0.30	0.17	0.28	0.82	0.20	0.26	0.41	0.25	0.13	0.43
ACA 2015 environmental flow scenario and market policy																																							
Benefit	15	44	96	30	64	30	37	97	54	47	88	32	635	13	39	85	24	37	22	34	64	40	38	66	17	480	10	33	70	17	13	11	28	24	24	27	35	11	302
Price of water	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.18	0.18	0.14	0.14	0.16	0.16	0.13	0.14	0.14	0.14	0.15	0.12	0.15	0.41	0.41	0.30	0.30	0.34	0.34	0.26	0.29	0.29	0.29	0.32	0.25	0.32
ACA 2015 environmental flow scenario upstream priority policy																																							
Benefit	15	44	96	30	64	30	37	97	54	47	88	32	635	12	36	80	23	47	21	31	68	39	32	58	21	468	9	23	60	16	30	13	18	41	27	0	0	0	237
Price of water	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.16	0.22	0.16	0.14	0.10	0.14	0.16	0.11	0.13	0.18	0.15	0.10	0.15	0.45	0.68	0.35	0.26	0.15	0.23	0.56	0.17	0.21	1.97	1.97	1.94	0.75

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Table SM3.3.2 Irrigation benefits and price of irrigation water under climate conditions and environmental flow scenarios (10^6 € y €/m^3)

Climate	Normal												
	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario													
Benefit	15	44	96	30	64	30	37	97	54	47	88	32	635
Price of water	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
ACA 2007 environmental flow scenario and proportional sharing policy													
Benefit	14	41	89	27	56	26	35	84	47	42	80	28	568
Price of water	0.10	0.13	0.10	0.09	0.07	0.09	0.10	0.07	0.08	0.09	0.08	0.06	0.09
ACA 2007 environmental flow scenario and market policy													
Benefit	14	42	92	28	53	27	36	84	48	43	81	26	574
Price of water	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.07	0.08	0.08	0.09	0.07	0.09
ACA 2007 environmental flow scenario upstream priority policy													
Benefit	15	44	96	30	64	30	37	97	53	32	57	21	574
Price of water	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.20	0.17	0.11	0.07

Climate	Moderate drought												
	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario													
Benefit	12	36	80	23	47	21	31	68	39	36	67	24	484
Price of water	0.18	0.16	0.11	0.09	0.05	0.09	0.11	0.06	0.08	0.09	0.07	0.04	0.09
ACA 2007 environmental flow scenario and proportional sharing policy													
Benefit	8	18	51	14	27	11	14	35	24	22	38	16	277
Price of water	0.58	0.92	0.50	0.29	0.17	0.26	0.73	0.19	0.24	0.35	0.24	0.13	0.38
ACA 2007 environmental flow scenario and market policy													
Benefit	11	34	72	18	16	12	29	28	26	28	39	11	324
Price of water	0.37	0.37	0.28	0.28	0.31	0.31	0.24	0.26	0.26	0.26	0.29	0.23	0.29
ACA 2007 environmental flow scenario upstream priority policy													
Benefit	10	25	64	17	33	14	21	45	29	0	0	0	258
Price of water	0.35	0.58	0.31	0.24	0.14	0.22	0.44	0.16	0.20	1.97	1.97	1.94	0.71

Climate	Severe drought												
	ZA	CN	LO	NA	BA	IM	JA	RA	AA	AC	UR	DE	Basin
Baseline environmental flow scenario													
Benefit	12	34	75	21	42	19	29	61	36	33	61	22	444
Price of water	0.44	0.23	0.14	0.12	0.07	0.12	0.15	0.08	0.11	0.12	0.10	0.05	0.14
ACA 2007 environmental flow scenario and proportional sharing policy													
Benefit													
Price of water													
ACA 2007 environmental flow scenario and market policy													
Benefit													
Price of water													
ACA 2007 environmental flow scenario upstream priority policy													
Benefit													
Price of water													

ZA: Regadios del Zadorra; CN: Canales del Najerilla; LO: Canal de Lodosa; NA: Canal de Navarra; BA: Canal de Bardenas; IM: Canal Imperial; JA: Regadios del Jalon; RA: Riegos del Alto Aragon; AA: Canal de Aragon y Cataluña in Aragon; AC: Canal de Aragon y Cataluña in Cataluña; UR: Canal de Urgel; DE: Canales del Delta.

Table SM3.4.1 Benefits under climate conditions and Baseline and ACA 2007 environmental flow scenarios (10^6 €)

Climate	Normal			Moderate drought			Severe drought		
	Agriculture	*Urban*	*Total*	*Agriculture*	*Urban*	*Total*	*Agriculture*	*Urban*	*Total*
Baseline environmental flow scenario									
Benefits	635	1,857	2,492	484	1,857	2,341	444	1,857	2,301
ACA 2007 environmental flow scenario and proportional sharing policy									
Benefits	568	1,857	2,425	277	1,857	2,134			
ACA 2007 environmental flow scenario and market policy									
Benefits	574	1,857	2,431	324	1,857	2,181			
ACA 2007 environmental flow scenario and upstream priority policy									
Benefits	573	1,857	2,430	258	1,857	2,115			

Table SM3.4.2 Benefits under climate conditions and Baseline and ACA 2015 environmental flow scenarios (10^6 €)

Climate	Normal			Moderate drought			Severe drought		
	Agriculture	*Urban*	*Total*	*Agriculture*	*Urban*	*Total*	*Agriculture*	*Urban*	*Total*
Baseline environmental flow scenario									
Benefits	635	1,857	2,492	484	1,857	2,341	444	1,857	2,301
ACA 2015 environmental flow scenario and proportional sharing policy									
Benefits	635	1,857	2,492	464	1,857	2,321	255	1,857	2,112
ACA 2015 environmental flow scenario and market policy									
Benefits	635	1,857	2,492	480	1,857	2,337	302	1,857	2,159
ACA 2015 environmental flow scenario and upstream priority policy									
Benefits	635	1,857	2,492	468	1,857	2,325	237	1,857	2,194