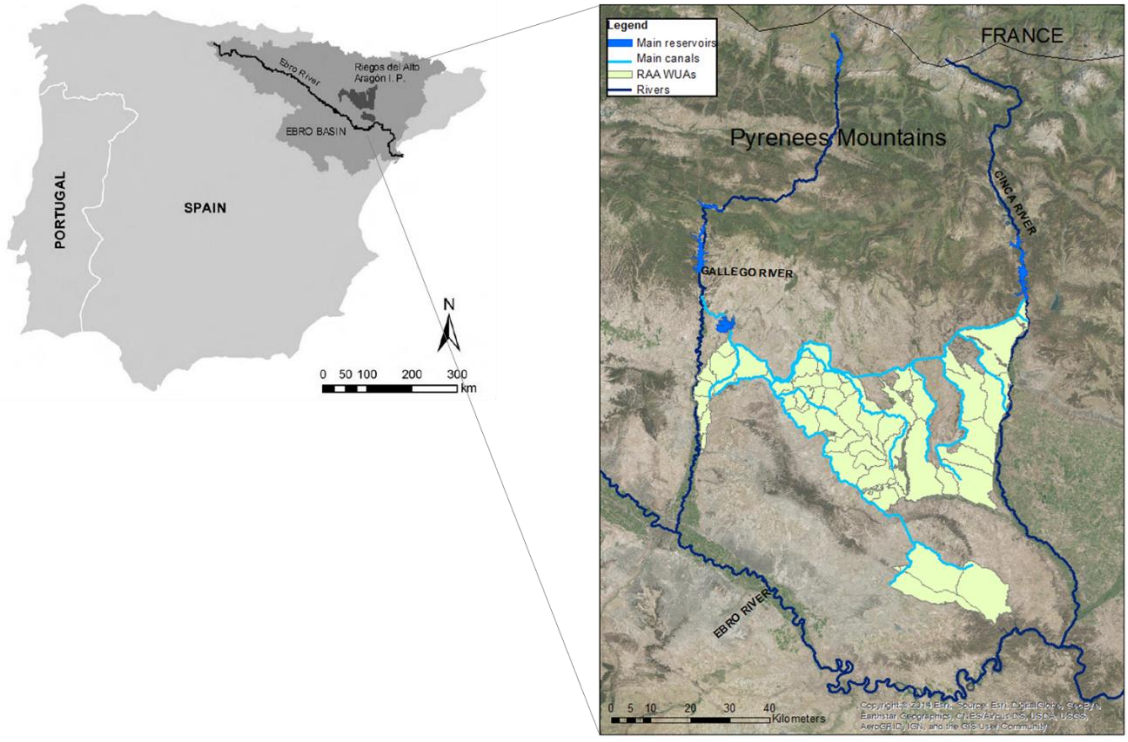
Appendix 1

Figure A1.1 Location of RAA irrigation project



Sources: Esri (2014, https://www.arcgis.com), Gobierno de Aragon (https://idearagon.aragon.es/portal/), and General Association of Riegos del Alto Aragon (GCRAA).

Table A1.1 Univariate sample test of total reservoir water entries (October to September)

Years	Total availability (hm^3)	Change (vs. 1971-2003 series)	T statistic[§]	Difference (vs. sum of water use rights)
1971-2003	1,640			
2004	1,915	+17%	-3.5***	+26%
2005	685	-60%	12.11***	-55%
2006	1,186	-28%	5.74***	-22%
2007	1,673	+2%	-0.42	+10%

* p<0.1; ** p<0.05; *** p<0.01

n=37

[§]: tests based on time series distribution (1971-2003)

Table A1.2 List, measurements and sources of variables

CONDITIONS	DEFINITION	SOURCE	ANALYSIS	
			HCA	QCA
Outcome				
Drought adaptation	Difference between irrigation performance index in 2005 minus in 2004 (see Box A 1.2 for details on index)	DGA CGRAA		X
Biophysical conditions				
Irrigable area*	Irrigated area (hectares) in the irrigation system	DGA CGRAA	X	
Summer crops	Percentage of area in an irrigation system that is planted with summer crops (higher water demand)	DGA CGRAA	X	
Technological conditions				
Piped canals	Percentage of the irrigable area in a system that relies on tubed conveyance systems	Survey	X	
Sprinkler	Percentage of the irrigable area in a system that uses sprinkler irrigation technology	Survey	X	
Technology heterogeneity	Fractionalization index based on "Sprinkler" variable	Survey	X	
Social and political conditions				
Age of WUA*	Year that the irrigation association was constituted	CGRAA	X	
Retired farmers	Percentage of irrigable area in a system that is cultivated by retired farmers (>65 year old)	DGA CGRAA	X	
Average farm size*	Average farm size	CGRAA	X	
Political overlap	Does at least 90% of the irrigation system fall within the boundaries of a single municipality?	DGA CGRAA	X	
Political heterogeneity	Fractionalization index based on "Political overlap" variable	DGA CGRAA	X	
Institutional conditions				
Rent	Percentage of irrigable area in a system that is cultivated by a renter (of that land)	Survey	X	
Property heterogeneity	Fractionalization index based on "Rental" variable	Survey	X	
Demand irrigation	Does the association use a demand (metered system) or a request (water is requested and then guard or farmers allocate it) allocation system?	Survey	X	
Guard	Does the association have a field guard?	Survey	X	
Adaptation institutions				
Monitoring (generic adaptation)	Did the WUA reinforced monitoring during the 2005 drought?	Survey		X
Participation (generic adaptation)	Percentage of farmers who assisted, on average, to the assemblies celebrated in 2005 (drought year), as measured by the hectares represented	Survey		X
Transfers (specific adaptation)	Number of hectares benefited by water transfers (this option is only available during droughts as part of the quota system: only farmers with cultivated land in more than one irrigation system have that option)	GCRAA		X

Note: DGA: Government of Aragon; GCRAA: General Association of Riegos del Alto Aragon.

* We used the LN transformation of these variables to avoid scale effects in continuous variables

Table A1.3 Descriptive statistics of variables

	Mean	St. Dev.	Min.	Max.
Outcome	-23.9	13.9	-49.8	7.5
Biophysical conditions				
Soil WHC (% of total has)	47.6	26.6	0	97
Irrigable area (has)	2,432	1,871	249	9,309
Summer crops (% of total has)	75.2	10.5	43.3	90.5
Technological conditions				
Sprinkler (% of has)	22.9	33.3	0	100
Piped canals (% of total has)	39.5	49.5	0	100
Technology heterogeneity (index)	0.19	0.21	0	0.89
Socio-political conditions				
Age of WUA (years)	40	19.7	7	80
Retired farmers (% of total has)	22.7	8.6	5.5	38.9
Average farm size (has)	17.5	6.9	5.9	33.4
Political overlap (% of total has)	52.6	50.6	0	100
Political heterogeneity (index)	0.24	0.23	0	0.70
Institutional conditions				
Rent (% of land)	40.3	13.4	17.1	90
Property heterogeneity (index)	0.45	0.07	0.19	0.5
Demand irrigation (% of total has)	15.7	37	0	100
Guard (1,0)	0.79	0.41	0	1
Monitoring (1,0)*	0.29	0.46	0	1
Participation (% of total has)*	30.2	21.9	3	100
Transfers (% of total has)*	3.1	2.3	0	7.8

*During droughts (i.e., 2005 drought). Raw data (i.e.,before the QCA calibration).

Box A1.1 Survey questions delivered to representatives of WUAs and used in this study

¿Could you indicate which soils dominate in the irrigable land with full irrigation rights of your irrigation system in percentage?*

«Sasos»	%
«Suelos Fuertes»	%
Saline soils	%

Which conveyance infrastructure dominates in your irrigation system in % of the area irrigated?

Unpaved ditches	%
Paved ditches	%
Flumes (elevated ditches)	%
Pipes	%

Which irrigation infrastructure dominates in your irrigation system in % of the area irrigated?

Flood irrigation	%
Sprinkler irrigation	%
Drip irrigation	%

Which land tenure regime dominates in your irrigation system in % of the area irrigated?

Cultivated by owners	%
Rented	%
Sharecropping	%
Other	%

Which water allocation system/s is/are used in your irrigation system % of the area irrigated?

Turn	%
Command/requests	%
Demand (metered)	%

Does your WUA count on a patrolling guard or someone under the control of the management board who carries that task?

____ Yes
____ No

Did the guard reinforce patrolling during the 2005 drought?

____ Yes
____ No

Which percentage of the irrigable land did the people who attended the assembly meetings represent in 2005?.*Please check the meeting minutes of the meetingif necessary to double-check the numbers.*

	Month of the meeting	Number of attendants	Percentage of land represented
2005	→_____	_____	_____%
	→_____	_____	_____%
	→_____	_____	_____%
	→_____	_____	_____%

Note: The original questions were in Spanish

*"Sasos" is the colloquial name used in the area for Xerosol Calcic soils, which tend to have low available water holding capacity (AWHC) and high infiltration. "Suelos Fuertes" correspond to Fluvisol Eutric soils, which have poor drainage but high AWHC.

Box A1.2 Selection of questions used during semi-structured interviews

Questions to public officials from Ebro Water Agency (2 interviews)

- Is there a protocol for water allocation during droughts that affects the RAA project?
- How does the Ebro Water Agency support the GCRAA during droughts (e.g., for the implementation of the quota policy)?
- Why have some WUAs engaged in infrastructure modernization projects? Why do you think many of them are Asian type of WUAs?

Q*uestions to members of GCRAA management board (5 interviews)*

- Which are the main measures taken at the RAA project level to cope with droughts?
- What is the history behind those measures?
- Which measures do WUAs in the RAA project use to cope with droughts?
- If you were to group the WUAs in the RAA project, how would you do it? Based on which features? Would you agree with our classification of WUAs into types?
- Which kinds of farmers tend to use the transfer system? Why do you think the American type of WUAs tend to rely on transfers during droughts?
- Why have some WUAs engaged in infrastructure modernization projects? Why do you think many of them are Asian type of WUAs?
- What in your experience explains farmer attendance to assembly meetings?
- Why in your experience some WUAs do not have guards and/or do not strengthen monitoring during droughts?

Box A1.3 Calculation of irrigation performance index

The calculation of the irrigation performance variable is derived from the integration of meteorological, crop and water supply data at the irrigation system level. Monthly meteorological data were obtained from a series of weather stations that are distributed across the area of study and managed by the Spanish Meteorological Agency (AEMET). Yearly crop data at the farm level were obtained from the Regional Government of Aragon (DGA). Data on water supplied to the irrigation systems were obtained from the GCRAA. Another important source of data to calculate the performance variable was a 2004–2007 series of digital maps including the limits of the irrigation systems and the farms within each system. The maps were obtained from the DGA and the GCRAA and constituted the basis to integrate the meteorological, crop and water availability data. A geographic information systems software (ArcGIS 10.0) was used for that purpose.

The performance index was selected as an indicator of irrigation performance for three reasons: It is the result of an standardization effort led by FAO's International Program for Technology and Research in Irrigation and Drainage (IPTRID); it does not require field data collection beyond the use of publicly available meteorological and crop data; and it has been previously used to characterize irrigation performance in Mediterranean environments (Salvador et al. 2011).

$$\text{ARIS} = \frac{\text{Irrigated Water}}{\text{Crop Water Needs}} = \frac{\text{Irrigated Water}}{\sum_{i}^{k} (NHn * ha)_i}$$

Where:
i = specific crop; k = number of different crops in the irrigation system; NHn = Net Crop Water Needs (in m3); ha = hectares

The most important factors that condition NHn are the crop evapotranspiration (ETc) and the amount of rainfall that can be effectively used by the crop (PE) (Tejero 2003). Following Allen et al. (1998), ETc was obtained from multiplying a crop water coefficient (Kc) and a potential evapotranspiration coefficient (ET0):

ETc = ET0*Kc

Kc is a theoretical index of the water that a crop needs depending mostly on the species and life cycle stage (Allen et al. 1998). ET0 measures the amount of surface water that is removed to the atmosphere due to plant transpiration or direct surface evaporation in a hypothetical reference surface of grass with an assumed crop height of 0.12 m, and a moderately dry soil and radiance reflectance (Allen et al. 1998).

Although the FAO provides Kc values of reference on major crops across climatic regions, it has been recommended using site specific Kc values whenever available (Allen et al. 1998). Monthly Kc values of the dominant crops in the area of study in 1995 were obtained from Martínez-Cob et al. (1998) and used as reference for the period under study. The ET0 was calculated following the Hargreaves method, as adapted to the study area by Tejero (2003). Finally, monthly total rainfall data was transformed into PE measures following the method recommended by the *Soil Conservation Service (SCS)* (Dastane 1978. cited in Tejero 2003).

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