Adaptive irrigation management in drought contexts: institutional robustness and cooperation in the *Riegos del Alto Aragon* project (Spain).

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Abstract

This chapter aims to understand the ability of more than 10,000 farmers in a large irrigation project to cooperate and adjust their water demands to cope with droughts. Causal inferences are formulated with the aid of common pool resource (CPR) theory as well as qualitative and quantitative evidence. According to the analysis, a series of robust water management institutions as well as additional land use factors contribute to the collective adaptation of farmers in drought conditions. Water management institutions include a flexible common property regime, effective environmental and social monitoring mechanisms, and decentralized administrative leadership. Land use factors include the existence of a moderate heterogeneity of farmers in their dependence from irrigated agriculture, the relatively substitutability of high and low water demand crops and a strong mechanism of government-sponsored income support subsidies. Overall, the analysis illustrates the interest of understanding adaptation from the perspective of CPR theory, as well as the usefulness of integrating the study of water and land use dynamics to understand sustainable management in the irrigation sector.

1. Introduction

The increased global exposition to climate change disturbances such as droughts and floods has generated a new interest in understanding the manner by which communities in specific productive sectors at different scales cope with those threats (UN/ISDR, 2004). This chapter aims to contribute to fill that gap by offering some explanations to the ability of more than 10,000 farmers in a large irrigation project in Spain to cope with droughts.

There is a long history of policy and research efforts focused on explaining the performance of large irrigation projects as a source of wealth and food security in developing and developed countries (Ostrom, 1992a, Subramanian et al., 1997). Scholarship aiming to understand the robustness of those projects to disturbances is much less developed. Spain has a century-long history of such type of projects (Melgarejo Moreno, 2000), many of which have successfully evolved to adapt to a variety of threats over time. In the last 20 years, however, a series of severe droughts, as well as other threats, have raised renewed concern about such adaptive capacity (Lopez Galvez and Naredo, 1997).

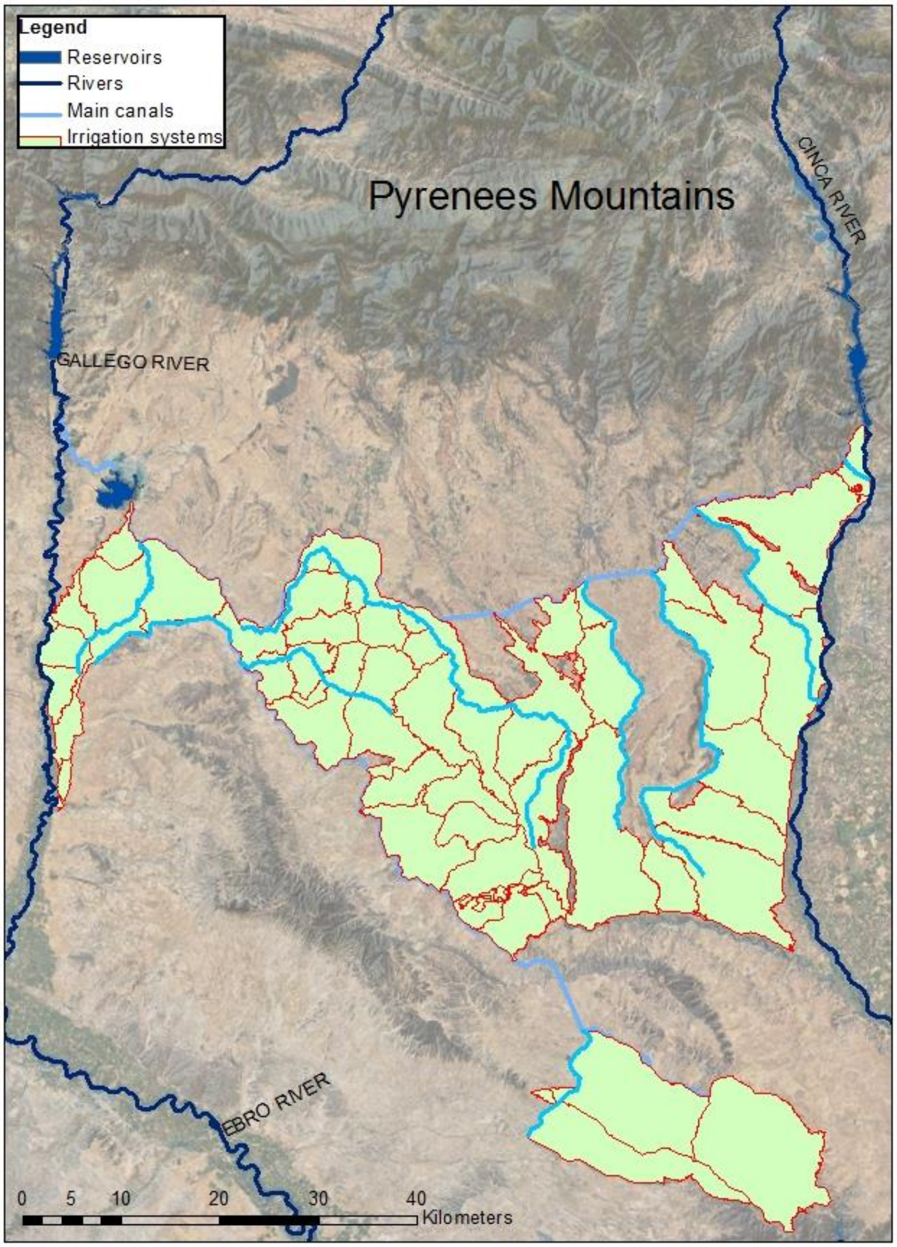
Natural resource management scholarship in general and common pool resource (CPR) theory in particular can be very productive starting points to understand adaptation and robustness. From the perspective of CPR theory, the success of common property regimes like those embodied by Spanish irrigation associations can be judged on the basis of their ability to promote cooperation among their members and guarantee that the water needs of every farmer are satisfied on time (Lam, 1998, Araral, 2005). In this chapter, such ability is explained both with regard to water management institutions and land use factors.

The analysis consists on a case study of the *Riegos del Alto Aragon* (RAA) irrigation project. Data to assess the performance of the project was collected from public records and included over time meteorological, hydrological and crop data, as well as and spatial data. Secondary documents about the history of irrigation in the area, formal regulations related to water management, meeting minutes, registers of water rights and organizational charts were also used as a source of information. A total of 61 interviews were also conducted with cadres of the irrigation and water organizations at different governance levels. The sampling method was purposive and aimed at having representative understanding of management in the RAA project as a whole.

2. Case background: The RAA project

The RAA project is located in the inter-basin of the Gallego and Cinca rivers. The Gallego and the Cinca are two snow-melt dependent rivers that flow from the Pyrenees Mountains to the Ebro river valley, from the North to the South of the Spanish region of Aragon (see Fig. 1). The local climate is semi-arid Mediterranean continental, with a mean annual temperature of 14.5 ◦C, an annual precipitation of around 400mm and an annual reference evapotranspiration (Hargreaves and Samani, 1985, cited in Lecina 2010) of around 1,100 mm (Lecina et al., 2010). A series of reservoirs and canals store and divert the water from the rivers to the 50 irrigation systems and more than 10,000 farmers who depend on the RAA project. The project encompasses more than 100,000 irrigable hectares and an average demand of around 750 million m^3 per year (according to 1970-2010 series). The reservoirs serve the RAA systems as well as other systems outside the project for a total average demand of around 1,500 million m^3.

Figure 1. The RAA irrigation project

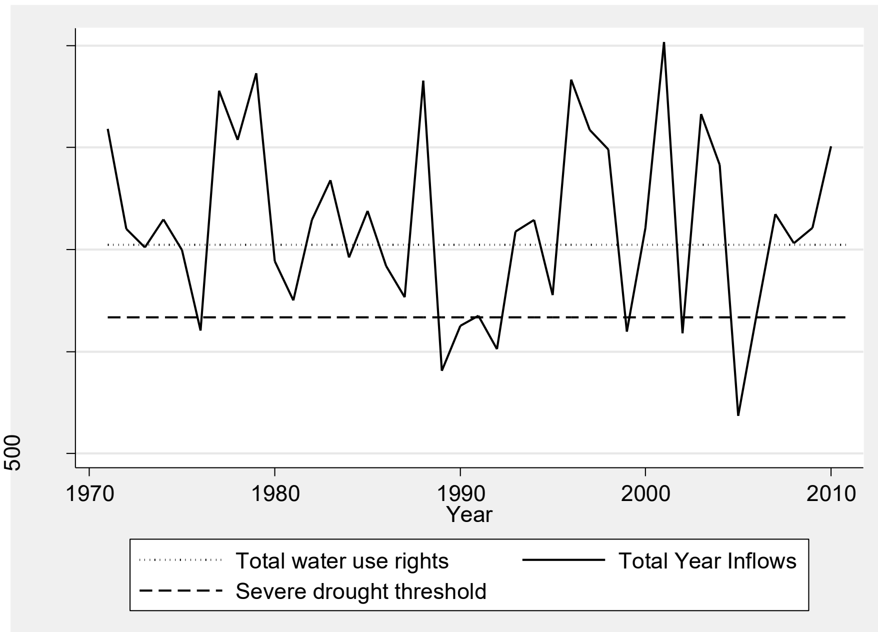


Source: Data obtained from GCRAA and Regional Government of Aragon

In the last 40 years the Ebro valley has indeed witnessed a negative precipitation trend (López-Moreno et al., 2010) and an increased climatic uncertainty caused by rapid changes between wet and dry periods (Vicente-Serrano and Cuadrat-Prats, 2007). As illustrated in Figure 2, droughts have been relatively frequent during at least the last 40 years. The drought of 2005-2006 stands out as the severest of the period. The reservoir inflows in

2005 decreased by more than 60% of the inflows in 2004 and slightly less than 60% of the average inflows from 1971 to 2003. Inflows in 2006 were also significantly lower than the series average. By 2007 inflows had recovered to normal levels.

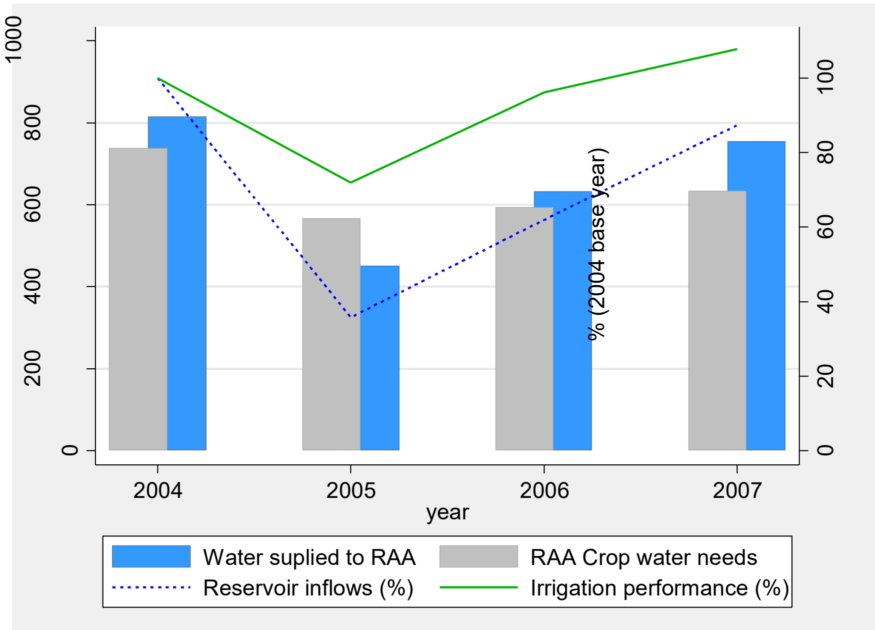
Figure 2. Series of total inflows in the RAA reservoirs (million m^3)



Source: Data obtained from Ebro water agency
Note: Series calculated from October to September of each year. Drought threshold: one standard deviation below the series mean (~1,200 million m^3) (Hisdal and Tallaksen, 2000)[1].

[1] 1,200 million m^3 is also close to the average consumption of water by the RAA project and the other irrigation systems that are served by the reservoirs (total demand of ~1,500 million m^3).

Figure 3. Percentage change of reservoir inflows and irrigation performance in the area of study (2004-2007)



Source: Data obtained from Ebro water agency
Note: All measures but the "Total water available" are calculated by aggregating irrigation system data (n = 38). The base year is 2004.
Note 2: Irrigation performance is calculated as the ratio between water withdrawn in an irrigation system and the system's water needs as estimated from the crops that were planted (Salvador et al., 2011).

As a consequence of the drought, the water effectively supplied to the project decreased by 45%, from 815 to 451 hm^3 (see Figure 3).The irrigation performance of the RAA project, however, only decreased a bit more than 20%, meaning that the RAA project was able to mitigate an important portion of the drought's impact. This can be explained by the ability of the ensemble of farmers in the project to reduce their crop water needs by more than 20% as well as the performance of the project's water allocation institutions. The project did not implement any infrastructure improvements to increase efficiency from 2004 to 2005 and 2006. Also, the use of sprinkler irrigation increased only in two irrigation systems (by 6% and 5% of the irrigable area, respectively). It is expected that farmers apply water to their crops more carefully during droughts without necessarily changing their irrigation technologies; however, the potential increases in efficiency resulting from it are unclear.

3. Explaining drought performance in the RAA project

From a political economy perspective, water in an irrigation system is an example of a common pool resource (CPR), i.e., is difficult to partition for private consumption and can be depleted (Ostrom and Ostrom, 1977). In CPRs, sustainable management is usually tied to the resolution of cooperation problems, which are in many cases the result of social dilemmas. A social dilemma emerges because individuals can obtain joint benefits as a result of their joint actions but they are each tempted to refrain from contributing since they may receive part or all the benefits of the contributions of others whether they contribute or not. In irrigation systems, the development of and compliance with water allocation and infrastructure maintenance rules are good examples of the ability of farmers to overcome cooperation problems (Ostrom et al., 1994).

Droughts can threaten the ability of farmers to cooperate vis a vis water allocation in at least two interrelated ways. First, severe drops in water availability can increase uncertainty among farmers about the performance of the water allocation rules and thus augment the risk of water allocation problems. Promoting the robustness of those rules thus constitutes a first condition for an irrigation system to cope with droughts. Second, and most important, there is the challenge of adjusting water demand to the decreased water availability. No matter how well water is allocated, if water supply and demand are not balanced, some fields will receive less water than they should and risk crop loses. Water demand strongly depends on the quantity and types of crops that are cultivated. Thus, given appropriate water availability information, the ability of farmers to cooperate and collectively adjust their cropping patterns constitutes a second important condition for an irrigation system to cope with droughts[2].

[2] Generally speaking, larger quantities of cultivated land as well higher water demand crops tend to yield higher returns. Thus, everything being equal, farmers would tend to resist reducing cultivated land or switching from high to low water demand crops during droughts. This would be aggravated by the existence of a collective action problem, as the costs of adjusting one's water needs are private but the benefits in terms of water conservation are shared. In irrigation systems individual farmers may not have the right to exclude other regime members from the benefits of water conservation efforts, unless there are specific rules about it. In that scenario, farmers who do not bear the water conservation costs may still receive enough water and enjoy similar production yields to those who do bear the costs. This would discourage farmers from making any water conservation efforts. Individual investments in irrigation efficiency via new technologies or practices would face a similar problem.

CPR theory (Poteete et al., 2010) emerged in the 80s as an effort to understand whether, how and why some CPR users are able to cooperate and self-regulate their resource use. According to CPR theory a number of institutional and social factors can contribute to the emergence and endurance of cooperation in CPR management regimes (Poteete et al., 2010). Some of those factors can help to understand the ability of farmers in the RAA project to collectively cope with droughts.

3.1 Performing water management institutions

Flexible property rights: enhancing a common property regime through temporary quotas

Scholars contributing to CPR theory have traditionally focused on common property regimes. Water use and management in the RAA project is articulated through one such common property regime. All farmers across the systems share an equal right to use the water and then coordinate through a series of rules to allocate the resource. The water allocation process involves three organizational actors, from the bottom to the top: water user associations (WUAs), the General Community of RAA (GCRAA) and the Ebro river water agency. The WUAs operate at the irrigation system level and the GCRAA and the water agency operate at the project level.

During the irrigation campaign (mid-March to October), water is allocated across and within the systems according to a request system. First, guards in each WUA are responsible for placing daily water orders to the GCRAA according to requests made by farmers. The staff in the GCRAA is in turn responsible for compiling the water orders from all WUAs and placing a unified order to the water agency. The water agency officials are then in charge of regulating the reservoirs that are connected to the project according to the water request made by the GCRAA, as well as serving the water to the irrigation systems. Once the water gets to the irrigation systems, WUA guards or the farmers are in charge of guaranteeing that the water gets to the plots as requested.

During droughts the water use right that is normally shared among all farmers in the project is "privatized" across systems according to a quota institution. Whenever water reserves at the beginning of the campaign and estimations about snow pack and snow melt are below a security threshold, the quota institution is implemented. According to the institution, the water that is available in the reservoirs at the beginning of the campaign is allocated among the systems on a per hectare basis. Quotas are non-transferable among WUAs by default, meaning that if a WUA does not use up its quota the water cannot be used by other WUAs. That said, farmers who own land in different systems can request a transfer of the quota that theoretically would correspond to their land from one of the systems to the other.

Probably the most persuasive argument for the use of private property rights is that owners, whether individual or collective, have an incentive to make efficient investments in resource conservation because they can be assured that only they will receive the benefits of such efforts (Copes and Anthony, 2004, Acheson, 2006). Common pool quotas, like those shared by farmers within the systems under study, have been also praised in other resource sectors as an effective way to balance resource use efficiency and risk under uncertainty conditions. When there is uncertainty about resource availability, pooled quotas allow users to share the risk of financial losses if the resource is more scarce than expected. In the irrigation sector, the mechanism would theoretically allow using the water conserved by farmers with lower dependence on irrigated agriculture to serve the needs of those that are more dependent on irrigation and tend to incur in riskier cropping plans during droughts (Holland, 2010). As further illustrated in the sections below, this mechanism seems to be at play in the RAA project.

Transferability of rights can also facilitate rationalization and risk reduction by enabling the concentration of rights into uses that are more efficient or necessary (Copes, 1986). This can be particularly beneficial in the irrigation sector during droughts, as water use rights can be transferred from areas where the costs of reducing acreage or switching crops are higher to areas where the costs are lower (Chong and Sunding, 2006, Garrido, 2007). Indeed, as reported by farmers and illustrated in Table 1, landowners in the RAA use the above mentioned quota transfer mechanism to concentrate the water in the systems where they can use sprinkler irrigation and where property is less fragmented. Everything being equal, sprinkler irrigation tends to be more water efficient than furrow irrigation (Lecina et al. 2010). Similarly, larger farms enable scale economies and reduce the transaction costs of participating in the water allocation process. The correlations between in-flow transfers and sprinkler irrigation and average farm size are significant; however, the strength of the relationship is only moderate. As mentioned, only landowners with land in two or more systems can request water transfers. This would be limiting the influence of technological improvements on transfers. Also, as shown in Table 2 (section 3.2) there is a high correlation between average farm size and farm size heterogeneity. The coexistence of small number of large farms with large numbers of small farms would be moderating the impact of the former on water transfers. Finally, other factors like irrigation dependence, or the distance between the systems may affect the willingness of farmers to request water transfers. This would further limit the influence of both the technological and the farm size variable on the transfers.

Table 1 Correlations between water, land and technology variables across RAA systems (2005)

	In-flow transfers	**Average farm size**	**% sprinkler technology**	**% hydric soils**
In-flow transfers	1			
Average farm size	0.2443*	1		
% sprinkler irrigation	0.4009*	0.2923*	1	
% hydric soils	-0.05	0.1	0.15	1

n=50
*= 10% significance
Note: The quota transfers are measured in hectares, i.e. the number of hectares that would stop being irrigated in the system of origin, and would be in turn irrigated in the receiving system. Here the variable is computed as a percentage of the size of the receiving irrigation system.
Source: Data obtained from GCRAA and fieldwork.

Clear physical boundaries and decentralized management

The possibility to partition the collective water use right into pooled quotas effectively is enabled by a particular structure of physical and social boundaries. The irrigation project consist of two main canals that branch into a series of minor canals that allocate the water across the systems. The intersections of the infrastructure and the topography of the terrain result in a series of hydraulic sectors with clear physical boundaries[3]. The clarity of the boundaries facilitates a common understanding about which plots belong to which irrigation system and thus contribute to the enforcement of water use rights (Ostrom, 1990, Cox et al., 2010).

Although the right to use the water in the RAA project is common to the ensemble of farmers, the water management right (Schlager and Ostrom, 1992) is decentralized across systems, i.e. across WUAs. Decentralized management has been pointed as a factor of sustainability by CPR scholars because it permits decreasing the number of individuals involved in resolving collective-action problems (Coward Jr, 1977, Ostrom, 1990, Cox, 2010). And, everything being equal, individuals in smaller and relatively autonomous groups can more easily come to and monitor collective action agreements than otherwise (Ostrom et al., 1994, Agrawal, 2001).

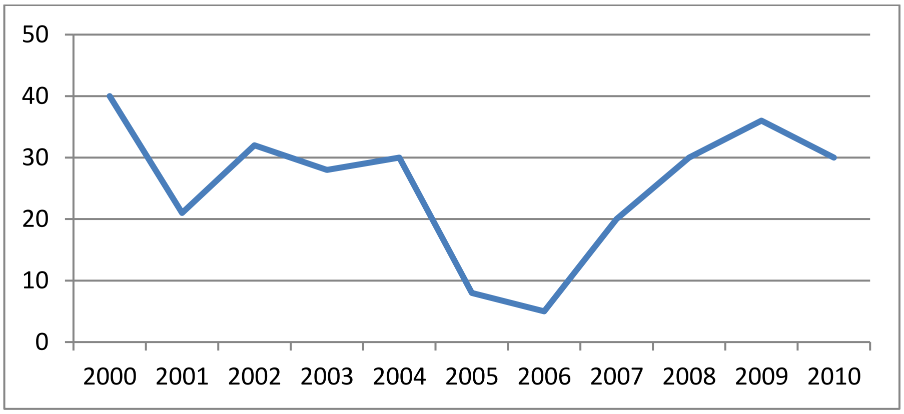
Environmental and Social Monitoring

Finally, the robustness of the water allocation institutions in the RRAA project is enhanced though the effective monitoring of resource conditions and resource use. Environmental monitoring contributes to reduce uncertainty about resource availability and thus helps collective choice and institutional compliance (Cox et al., 2010). A good indicator of the environmental monitoring capacity in the RAA project is the amount of data generated and shared among the water agency, GCRAA and WUAs about reservoir levels and water use. Much of these data are used by leaders of those organizations to decide whether to activate the quota regime and to monitor its performance during the irrigation campaign. Monitoring of resource use makes those who do not comply with rules visible to the community, which facilitates the effectiveness of rule enforcement mechanisms and the performance of CPR management regimes (Cox et al., 2010). A good indicator of the

[3] Both main and minor canals follow the contour lines of the terrain so water can be transported and then distributed to plots by gravity. Similarly, the drainage system is located at lower elevation than the conveyance canals but still at higher elevation than the hydrological system so runoffs can flow by gravity from the plots to the drainage system and then to the hydrological system.

strength of social monitoring in the RAA project is the notable decrease in the number of rule violation cases brought to the GCRAA executive board during the 2005 drought (see Figure 4). As reported by officials from the GCRAA, that responds to the high visibility that rule infractions have during droughts, as well as the existence strong social norms about the need to cooperate particularly during periods of crisis.

Figure 4 Number of rule infraction cases brought to the GCRAA court per year (2000-2010)



Source: Data obtained from GCRAA.

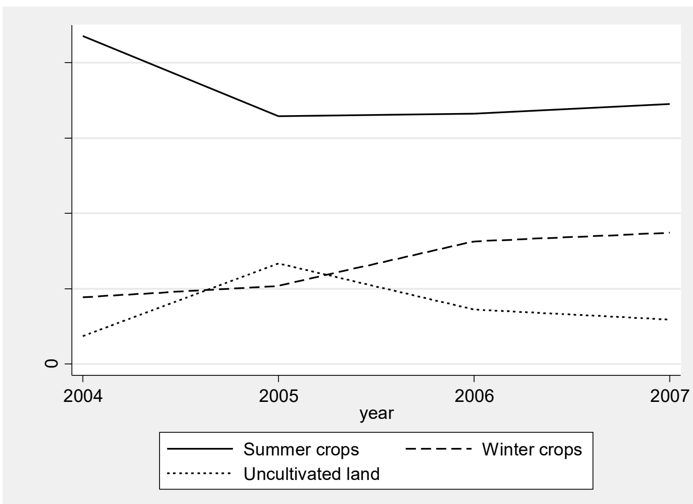
(Decentralized) Administrative leadership

Monitoring entails costs (Ostrom et al., 1994). Decisions about who should carry the monitoring and at which cost are thus a crucial aspect of monitoring effectiveness. In many long-lasting CPR regimes such monitoring as well as more general coordination roles are to a great extent carried by leaders (Ostrom, 1992b, Agrawal, 2001, Meinzen-Dick et al., 2002). In the RAA project, leadership is decentralized at different governance levels. That helps reducing the monitoring and coordination costs. As mentioned in the section above, the water agency, GCRAA and WUA representatives are all crucial in the activation of the quota regime during droughts. Additionally, secretaries from the WUAs are responsible for generating records of water requests and deliveries within the systems and use them to double-check that the systems do not go over their quotas. Finally, there is the monitoring carried by the water agency and WUA guards who provide first-hand information about incidences in the water delivery as well as non-forecasted changes in water availability.

3.2 Beyond control and water institutions

The ultimate performance of the RAA project during droughts need also to be understood with regard the capacity of farmers to cooperate and collectively adjust their crop water needs to the decreased water availability (see Figure 5). At least three factors contribute to that capacity in the RAA project.

Figure 5 Evolution of land use (hectares) in the RAA project during the 2005 drought



Source: Data obtained from Regional Government of Aragon.

First, there is the relatively high substitutability of high and low water demand crops like corn and alfalfa and barley and wheat, respectively. The production and market price of high water-demand crops is usually higher[4] and can yield notable returns; however, those crops also require more agricultural and labor inputs (i.e. herbicides, fertilizers, and water) and thus are more costly and risky to grow than low water demand crops what becomes especially relevant in drought periods.

The second factor is the existence of strong income support subsidies sponsored by the European Community Agricultural Policy (CAP). Currently those subsidies amount to

[4] From 1990 to 2010, the average prices of corn and alfalfa (high water-demand crops) have been ~15.8 and ~10.8 E/100kg respectively; and that of barley and wheat (low water-demand crops) ~13.5 and ~16.7 E/100kg, respectively. That being, the average production of corn and alfalfa for years 1998, 2000, 2002, and 2007 was around 9,000 and 11,000 kg/ha respectively; and that of barley and wheat as around 4,000 kg/ha (Elaborated from data from Regional Government of Aragon)

26% of net farm incomes (Lecina et al., 2010). Indeed, much of the agricultural activities in the area would not exist without such subsidies (Arrojo and Bernal, 1997). Most importantly, since the last reform of the CAP in 2003 the subsidies have been decoupled from production, meaning that farmers receive a fixed lump sum every year regardless of the crops cultivated and yields (Moreddu et al., 2004).

The third factor is the existence of heterogeneity in the dependence from irrigated agriculture by farmers. In the last decades, a series of migration waves from rural to urban areas in the region have resulted in a progressive lack of labor factor in the agricultural sector (CESA, 2002). Also, the increasing price of agricultural inputs and the internationalization of agricultural markets have put the Spanish agriculture under the need to increase its productivity (Mas Ivars, 2012). In the RAA project, those phenomena have resulted in the progressive concentration of land in the hands of a small number of big landowners who aim to increase productivity by investing in economies of scale. This group coexists with an increasing number of part-time, small landowners who have found in the industrial and service sectors their main source of income. While big landowners are increasingly dependent on high-water demand (and more profitable) crops, smaller landowners enjoy more flexibility to combine high water-demand crops with lower water-demand crops if necessary. As illustrated in Table 2, small numbers of big farms tend to coexist with big numbers of small farms and with higher percentages of high water demand crops. As confirmed by farmers, during drought years, small landowners would be more willing to modify their cropping patterns and reduce the amount of high water-demand crops they grow; this in turn would allow big landowners to grow a higher percentage of such crops than otherwise.

Table 2 Correlations between crop and land variables across RAA systems (2005 drought)

	% high water-demand crops	**% low water-demand crops**	**Farm size heterogeneity**	**% number of small farms (< 30 has.)**	**Average farm size**
% high water-demand crops	1				
% low water-demand crops	-0.8*	1			

Farm size heterogeneity	0.367*	-0.522*	1		
% number of small farms	-0.337 *	0.484*	-0.993*	1	
Average farm size	0.44*	-0.567*	0.939*	-0.939*	1

n=50
* = Significant at 5%
Note: Farm size Heterogeneity is measured as a fractionalization index. The fractionalization index measures the chances that two random hectares in an irrigation system belong to a small farm (< 30 hectares) and to a big farm (>30 hectares) respectively.
Source: Data obtained from Regional Government of Aragon

4. The RAA case in global perspective

The RAA case illustrates a specific combination of factors contributing to successful resource management under drought conditions. A number of those factors echo findings from similar studies in other countries and irrigation contexts.

Some of the findings of this study about water management institutions are congruent with the literature on irrigation policy and governance. Much of this literature developed from the 1970s to the 1990s with regard to the implementation and reform of state-promoted irrigation projects in developing countries (Uphoff et al., 1985, Cernea and Meizein-Dick, 1992, Ostrom, 1992a, Subramanian et al., 1997, Knox and Meinzen-Dick, 2000). Factors contributing to successful management in those contexts include the multilevel organization of management tasks, monitoring and leadership, moderate water dependence, social cohesion among farmers, financial viability and agricultural policies that allow crop choice and provide adequate returns to irrigated production (Tang, 1992, Subramanian et al., 1997). As illustrated in this study, a good number of these features, can also help understand the ability of irrigation projects to cope with external disturbances like droughts.

The results about the role of water management institutions are also convergent with the insights from drought robustness studies in other irrigation contexts. Cox and Ross (2011) and Cox (2014) assess the robustness of more than 70 traditional irrigation communities in the Taos valley, New Mexico. Similarly to the RAA project case, irrigation communities in Taos rely on decentralized common property regimes, the duties and initiative of strong leaders, and effective monitoring mechanisms based on both third party and mutual surveillance. Although coordination across the Taos communities is not institutionalized through a central organization like in the RAA project, the leaders of the communities do meet to coordinate whenever is necessary. Contrary to the RAA case, water allocation institutions appear to be sufficient to cope with water allocation uncertainties during both normal water availability and drought conditions. This is partially aided by the widespread access of the communities to ground water, which is a feature that is absent in the RAA case. Lam (2006) reviews the case of irrigation institutions in Taiwan. Similarly to the RAA case, the multilevel organization of leadership and tasks like monitoring contribute to performance during droughts. According to Lam (2006), the possibility that leaders and organizations at different governance levels and scales complement each other in activities like monitoring or conflict solving is an important factor of performance under disturbance conditions. Also like in the RAA case, Taiwanese irrigation systems use quotas; however, the quotas are used both during normal and drought conditions and are granted directly to farmers. During droughts, efforts at different scales are made to coordinate the allocation of the quotas depending on the severity of the drought.

Finally, the interest of this study on land use factors vis a vis drought adaptations resonates also with findings from drought studies in the agricultural sector in semi-arid countries. Liverman (1990, 1999), reports findings from studying drought management in Mexico. Like in the RAA project, irrigation in Mexico benefits from notable price support mechanisms and agricultural subsidies (Liverman, 1999). As pointed by the author and others (Naylor and Falcon, 2012), those subsidies have an important role to mitigate the economic impact of droughts in the short term but can also crowd out learning and innovation in the long term. Additionally, Liverman (1990) highlights the contribution of fertilizer use and improved seeds to reduced crop loses during droughts; as well as the advantages of private land ownership as compared to communally ownership. Mert et al. (2009) and Deressa et al. (2009) synthetize findings from agricultural adaptations to climate change in the Sahel, Africa. Like in this study, the authors highlight a correlation between reduced cropping efforts and drought periods. Additionally, the authors point to the widespread use of short cycle crop varieties, shifts in farming location, early and late planting strategies, and soil conservation practices as measures that contribute to reduced water needs during drought periods.

5. Discussion and conclusions

As illustrated above, the RAA project has been able to mitigate to a great extent the impact of severe droughts like that of 2005. This can be understood with regard to (1) institutional robustness factors, such as the flexibility of the common property right regime, the strength of monitoring institutions and leadership; and (2) factors contributing to water demand adaptability such as crop substitutability, income support subsidies and heterogeneity of farmers in their dependence on water. While the former group of factors is under the relative control of farmers and public authorities in the area, the latter group is not. This constitutes a source of vulnerability in the RAA project.

The findings of this study are specific to the RAA case; however, they also resonate with findings from similar studies in other countries and irrigation contexts. Relevant factors highlighted both in this study and other studies include the decentralization of water management tasks and leadership, moderate water dependence, crop substitutability and agricultural subsidies. Further research might explore the impact of technological improvements and the intensification of water transfers on cooperation and robustness; whether the factors identified in this study are relevant to cope with disturbances other than droughts and in other productive sectors; and the implications of assessing irrigation performance both over time and space through a diversity of indicators.

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