February 2020

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Paper accepted to be published in
Land Use Policy
Editorial: Elsevier Science ISSN: 0305-0483
https://doi.org/10.1016/j.landusepol.2019.104368

This research is co-financed by the Spanish Ministry of Economics and Competitiveness (MINECO) and the European Regional Development Fund (ERDF) through the project EVAMODRE (AGL-2014-53417-R)

Drivers of innovation in groundwater governance. The links between the social and the ecological systems

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ABSTRACT

Global groundwater overexploitation positions groundwater governance as a critical issue for improving sustainable water management. Evidence of aquifer recovery after overexploitation is scattered, as is the research on the drivers behind recovery. The Fuencaliente Aquifer in Spain faced a tragedy of the commons situation, but after an innovative governance arrangement was implemented, the aquifer is gradually recovering. In this research, we identify the drivers that made possible the emergence and acceptance of such an arrangement using the social-ecological system framework. We identified external drivers such as market incentives and limited enforcement capacity of the water authority as the main factors that led to groundwater depletion, but we also found that these same drivers, under a new regulatory framework that reinforced monitoring and sanctioning capacities, are the basis for the effective recovery of the aquifer. Internal drivers such as the socioeconomic attributes of the users, their limited collective action and the power differences between traditional and commercial farmers are also critical in explaining the acceptance of the new governance arrangement. Even if these drivers are context-specific, we identified innovations that might be transferable and contribute to the literature on good practices in groundwater governance and management.

KEYWORDS: Groundwater governance; innovation drivers; social-ecological system framework; Fuencaliente Aquifer; governance arrangements; groundwater management; Mediterranean areas

1. INTRODUCTION

Current population and economic growth trends together with surface water resource scarcity and over-allocation are increasing the pressure on groundwater resources. In this scenario, groundwater governance is positioned as a critical issue requiring worldwide attention (Foster and van der Gun, 2016; Molle et al., 2018), as shown by several global initiatives such as the World Bank's Groundwater-MATE project and the Global Environmental Facilities' Groundwater Governance project (Villholth and Conti, 2017: 14).

Groundwater is a classic common-pool resource, characterised by its substractability and non-excludability (Ostrom, 2005), and as such, it is susceptible to Hardin's 'tragedy of the commons' (Hardin, 1968). According to Hardin, if abstraction rates are not regulated, individualistic competitive exploitation of open-access, common-pool aquifers will result in overexploitation, as users ignore or are unaware of the social cost of their own extractions. Furthermore, some inherent characteristics of this resource, such as its invisibility and relatively slow flow rates, can make excludability costs very high (Ursitti et al., 2018). As a result, the governance of groundwater is much more complex than the governance of surface water (López-Vera, 2012; Wijnen et al., 2012).

Groundwater governance is a relatively new concept in water discourse; however, different definitions can be found in the literature (Megdal et al., 2017; Varady et al., 2016). Villholth and Conti (2017) present a comprehensive analysis of the rationale and evolution of the concept. After analysing the different definitions provided, for this research, we used the following one: "Groundwater governance is the framework encompassing the processes, interactions, and institutions, in which actors (i.e., government, private sector, civil society, academia, etc.) participate and decide on management of groundwater within and across multiple geographic (i.e., sub-national, national, transboundary, and global) and institutional/sectoral levels, as applicable" (Villholth and Conti, 2017: 14).

Effective groundwater management remains a major and complex challenge, but it is essential for ensuring the long-term sustainable use of the resource (Bekkar et al., 2009; Ross and Martinez-Santos, 2010; Shah, 2005; Wang et al., 2006) and ending the rather extended phenomenon of abstraction rates exceeding replenishment rates in many parts of the world (Famiglietti, 2014; Gleeson et al., 2012; Molle et al., 2018). This situation is especially critical in semiarid regions such as the Mediterranean basin where limited and inconsistent precipitation and recurrent drought events lead to reliance on groundwater resources for agricultural irrigation.

In Spain, as in many other countries around the world, groundwater resources have enabled the development of an intense wealth-creating agricultural economy (Shah, 2009). Indeed, the agricultural development of many semi-arid areas in eastern and southern Spain has been due to, or was started by, intensive aquifer exploitation. Approximately one million hectares, representing more than 30% of the total irrigated area, are currently irrigated with groundwater resources (Molinero et al., 2011). Consequently, the use of groundwater in southern Spain has dramatically increased during the past two decades and has been called "the silent revolution of groundwater" (González-Ramón et al., 2013).

This phenomenon has greatly increased the rates of abstraction over the last four decades, from 2,000 Mm^3/year to 6,500 Mm^3/year and is currently a major cause for concern (Llamas et al., 2015). The overexploitation of aquifers generated important problems, such as depletion and reduced flows, in some areas, and created sharp conflicts among the users of groundwater resources. These conflicts have challenged traditional management and governance systems but have also created opportunities for innovative strategies to emerge (Megdal et al., 2017) to limit aquifer depletion.

In this research, we analysed the evolution of the Fuencaliente Aquifer, located in the Guadalquivir River basin. This aquifer has been exploited since Moorish times (9^{th}-14^{th} century). However, the emergence of new uses and users, the limited enforcement capacity and the ineffective monitoring systems for regulating abstraction rates led to a 'tragedy of the commons' situation. The depletion of groundwater resources steered important conflicts between uses and users that in return prompted innovative arrangements that shaped a new groundwater governance system, leading to recovery of the aquifer and more sustainable groundwater management.

Moench et al. (2016) noted that successes in managing groundwater at the local level are scattered and depend heavily on specific institutional, technical and economic conditions. For this reason, identifying the drivers that made it possible to move from a non-desired overexploitation situation to a more sustainable one and to analyse their potential replicability in other contexts opens a stimulating research scenario that might contribute to the development of wider policy and management perspectives.

The objective of this paper is to identify the internal and external drivers enabling the emergence of innovative arrangements in groundwater governance that mitigated the effects of groundwater overdraft and ensured the acceptance of these arrangements by different resource users. We distinguished three different periods in our analysis, namely, the traditional management of the aquifer, the period of overexploitation and the current situation with a new governance system that preserved the rights of traditional users, established the rights of new users and prompted a gradual recharge of the aquifer. For every period, we identified the main drivers.

We conceptualise the aquifer and the water users as a social-ecological system (SES), since they conform to a complex system resulting from co-evolution, adaptation, and mutual shaping between the users and their environment (Berkes and Folke, 1998). The social-ecological conceptualisation of groundwater systems and their management enabled us to consider the intrinsic interconnection between the environmental and the socioeconomic processes and the causal dynamics that lead to environmental and social problems (King and Salem, 2012).

For each period, the main variables and drivers characterising the aquifer management and the governance system were identified using the social-ecological system (SES) framework proposed by Ostrom (2009). This framework has been applied by several authors to analyse the governance of common-pool resources and, more specifically, to analyse water and groundwater governance (Azizi et al., 2017; Klümper and Theesfeld, 2017; McCord et al., 2017). It is an appealing framework because it permits the identification of the internal and external variables affecting an SES and an understanding of the complexity of the different interactions between the human and environmental systems by conceptualising not only the specific attributes of both systems but also the interactions and the resulting outcomes. Furthermore, it includes in the analysis the external influences on the SES and how an SES can influence or impact other SESs.

2. GROUNDWATER POLICY IN SPAIN

The Spanish Water Act of 1879 tied groundwater abstraction rights to land ownership. The Water Act of 1985 redefined abstraction rights and recognised all aquifers as part of the public domain, giving River Basin Authorities (RBAs) responsibility for the regulation of groundwater abstractions. The main Spanish RBAs are larger than a single region and are known as inter-regional RBAs. The management of the inter-regional RBAs is the responsibility of the national government, while the management of intra-regional RBAs is the concern of regional governments.

RBAs, in place since 1920, were initially in charge of surface water, dealing with issues such as water planning, resource management and land use, protection of the public water domain, management of water use rights, water quality control, planning and execution of new water infrastructure, dam safety programmes, etc. However, the legal framework put in place in 1985 granted RBAs extensive powers to enforce regulations in both public and private water regimes, to create groundwater user associations and to tax water.

The 1985 Act was modified in 2001 to adapt it to the implementation of the European Water Framework Directive (WFD), reinforcing RBAs capacity to ensure the good environmental status of all water bodies and, specifically for aquifers, their good quantitative and chemical status. A Register of Public Water and a Catalogue of Private Water were created as instruments for groundwater management, requiring the registration of all well owners. However, the regulation of well owners and abstractions has not been easy in the country due to the RBAs' lack of funding to install and monitor water meters and the difficulties in securing the cooperation of farmers and well owners.

The implementation of the WFD in 2000 obliged EU Member States to identify and classify all groundwater bodies as part of the 'Initial Characterisation Stage' in order to reduce overexploitation. In Spain, 699 groundwater bodies were officially identified, with 259 of them (37%) classified as 'at risk' of not attaining the environmental objectives set by the WFD for 2015 (Berbel et al., 2018b).

Neither the Water Act of 1985 nor the 2001 adaptation defined any services that groundwater users receive from RBAs; hence, groundwater users do not pay any tariff for water but only pay a fee when their well license is certified. In contrast, the users of surface water have to pay a tariff to the RBAs to use water as compensation for the cost assumed by the water agencies for storage, transport and monitoring services.

3. CASE STUDY

The Huescar-Puebla hydrological system (standard identification code: MAS 05.04) lies within the Guadalquivir River basin (the longest river in southern Spain) and is located in the north of the province of Granada (Andalusia) in the Los Llanos de la Puebla (or simply Los Llanos) Plateau. It covers an area of 430 km^2, of which 170 km^2 correspond to permeable geological formations. The area has semi-arid climatic conditions with an average annual rainfall of 300 mm.

The main towns are Huescar (7,498 inhabitants) and Puebla de Don Fadrique (2,308 inhabitants) (see Figure 1). The socioeconomic data mirror typical marginalisation levels of mountainous areas; the population density is 15.85%, the unemployment rate is higher than 17%, the average per capita income is 11.858 € and the ageing index is 124.69% (IECA, 2018). Agriculture is one of the main economic sectors in the region, and seasonal tourism plays an important role in summer when the population can increase by more than 50% (Altiplano de Granada, 2016).

[INSERT FIGURE 1]

This hydrological groundwater system is composed of an aquifer and a natural spring forming a pond, both named Fuencaliente. The Fuencaliente Aquifer is located 920 metres above sea level at the following UTM coordinates: X = 542194, Y = 4184143. The renewable groundwater resources are estimated at 9.51 hm3/ year and the water outlets to Fuencaliente spring were 8.62 hm3/year for the period 1974-2013 (Aljibe, 2014). The aquifer was classified as overexploited and in the "at risk" group when the WFD was first implemented in Spain (Table 1).

[INSERT TABLE 1]

The aquifer is used to irrigate crops, and the spring outlets are used for both irrigation and recreational activities in the pond. Traditionally, 477 hectares were irrigated using the spring discharge with 3 ditches, with the main crops including alfalfa, maize, olive groves, and almonds and fruit trees. In the 1980s and 1990s, approximately 2,500 hectares of uncontrolled open-air intensive horticulture were developed, leading to overdraft problems in the aquifer (see Table 1). The situation was regulated by the agreement that is analysed in this research, and the area used for intensive agriculture has been reduced to 1,219 hectares mainly devoted to broccoli production with a water allocation of 4,500 m^3/ha. Additionally, 761 hectares of traditional crops have been allocated with 3,925 m^3/ha.

In the nearby area, there is an irrigation system fed by the San Clemente Reservoir with a storage capacity of 120 hm^3 and a distribution network that serves the Canal del Guardal irrigation system (11.5 hm^3/year and 2,678 hectares irrigated) and other irrigation systems, granting a water allocation of 6.14 hm^3/year to another 1,223 hectares (CHG, 2016).

4. METHODOLOGY

The SES framework (Ostrom, 2009) has been used to identify the most relevant drivers of change and the factors explaining the governance system in our case study. This framework proposes four core subsystems: the Resource System (RS), the Resource Units (RU), the Users (U) and the Governance System (GS). Three additional subsystems analyse the mutual Interactions (I) between the core systems, the Outcomes (O) derived from these interactions, and how exogenous factors, such as market forces or political decisions, influence the SES in the so-called settings (S) subsystem. The final subsystem (ECO) focuses on the externalities of the SES in other SESs (Figure 2). Understanding the SES as a complex whole helps to identify the relevant variables for every system and provides a common basis for understanding how these variables relate to produce outcomes (Ostrom, 2009).

[INSERT FIGURE 2]

For each subsystem, Ostrom proposed a set of variables to describe its main features. Initially, she proposed 53 second-level variables (Table 2) but left open the option to choose other variables or add a deeper level of variables according to the particularities of the analysed SES (Ostrom, 2009).

[INSERT TABLE 2]

4.1 Data collection

We described all the variables in the framework using the different methods suggested by Delgado-Serrano and Ramos (2015) for each of the three periods analysed, highlighting the differences between periods, when any appeared.

To describe the conditions of the groundwater resources in the Huescar-Puebla hydrological system (Resource System and Resource Unit subsystems), we mainly used secondary sources, performing a systematic review of scientific and grey documents describing the area. Several reports were identified from government documents (Aljibe, 2014; CHG, 2016) and existing scientific publications (Berbel et al., 2018a; Berbel et al., 2018b).

To collect the data describing the Users and Governance subsystems, we used primary sources of information. Ten meetings and interviews were conducted with key informants in the area, including Guadalquivir RBA managers and staff, traditional and commercial farmers, RBA rangers, experts in hydrogeology and the mayor of Huescar. The interviews were semi-structured and focused on the main field of expertise and knowledge of each actor. We also used the interviews to triangulate information and to develop a timeline of the different changes that occurred over the last four decades in the analysed SES.

The information relating to the Settings, Interactions, Outcomes and Related Ecosystem subsystems was partially found in secondary sources and contrasted with the information from the key informants in order to create a broader picture of the situation. Additionally, media and news organisations were consulted to understand the different dimensions of the conflicts generated in the area.

Finally, several field visits provided in-depth knowledge and a better understanding of the social and environmental situation in the area. Field observations and conversations with farmers and elders from each of the towns were used to contrast historic and existing water-management practices in the plateau; to better understand farmers' demands, perceptions and beliefs; and to identify the water-related problems and the conditions that facilitated the new governance agreement.

4.2 Selection of variables

The characterisation of the Fuencaliente Aquifer using the SES framework variables offered a detailed picture of the situation during each of the 3 analysed periods. Following Ostrom's suggestions (Ostrom, 2009), for every period analysed, we focused on those variables that best explained the situation. Indeed, most of the variables proved to be important for identifying the drivers of innovation in the governance system in at least one of the periods analysed, as can be consulted in Appendix 1. We marked in italics the relevant variables for this case study in Table 2.

5. RESULTS

The characterisation of the different variables can be found in Appendix 1. Following Azizi et al. (2017) in the next sections, we develop a narrative linking the main variables in every period to show how they interact and what the main drivers are behind the innovative governance system convened for the Fuencaliente Aquifer.

5.1 The traditional management system in the SES (before the 1980s)

The settings in this period were characterised by limited economic development opportunities (S1) and low population density (S2) in mountainous and disadvantaged areas. Traditionally, the Los Llanos Plateau was devoted to rain-fed agriculture, mainly the cultivation of cereals and fodder (U3). However, groundwater (RS1) from the spring discharge was traditionally used for recreational and irrigation purposes. At that time, 477 hectares had customary irrigation rights without the need for groundwater pumping. The irrigation system was composed of three irrigation ditches and a management pond (RS4).

The main users (U2) of Fuencaliente's reservoir and spring were farmers whose irrigation rights dated back to Moorish times (9^{th}-14^{th} century) (RS4) and the residents of Huescar that used the pond for recreational activities. The most common irrigated crops were maize, alfalfa, olive groves and almond and fruit trees. The crop productivity values in the area were low due to the unfavourable conditions (long winters, short growing season and high risk of frost). On average, the gross margin was 1,307 €/ha for irrigated land. The apparent water productivity average of these crops is 0.66 EUR/m3 in terms of gross value added and 0.35 EUR/m3 in terms of gross margin (RS5) (Berbel et al., 2018a).

The management pond was traditionally used by local residents for recreational purposes due to its slightly warm water (average 19 °C). Some recreational facilities have been built, such as recreation areas, a bar and a rural hostel (RS4). The recreational site is located 3 km from Huescar but is close to other villages that also use the facilities. It is open to the public year-round, but visitor numbers (U1) peak during the summer season, reaching 500 per day on weekdays and up to 1,000 per day on weekends (*personal communication, municipal staff*).

During this period, they were no conflicts among users (I4) since their respective water harvesting levels (I1) did not clash.

5.2 New uses and new users in the SES (1980-2007)

In recent decades, south-eastern Spain witnessed the development of intensive horticulture production. Los Llanos Plateau was identified by horticulture developers in the Segura River basin (60 km east of Los Llanos) as a suitable place for the open-air cultivation of high-value crops (such as broccoli, cauliflower and lettuce) (S1), covering the summer season when greenhouses in Almeria and Murcia do not produce (S5). The modern and cheaper drilling and pumping technologies (U9) and the lack of monitoring and sanctioning capacities (GS8) led to a large expansion in the number of wells (I5). Consequently, new patterns of cropping characterised by an intensive use of resources (land, water, fertilisers, etc.) were developed (U9). Additionally, many traditional users (mainly older farmers) (U1) envisaged an opportunity to rent their lands at a higher price, receiving a safe income.

Initially, the crop mix included broccoli, lettuce and cauliflower, but later, the area specialised in broccoli production due to the high demand and competitiveness of this crop in the European markets. The gross margin per hectare of broccoli has been estimated to be 4,450 €/ha, with the apparent water productivity of the crop being 1.54 EUR/m^3 in terms of gross added value and 1.14 EUR/m^3 in terms of gross margin (RS5) (Berbel et al., 2018a).

A new type of user emerged (U1): firms specialised in intensive farming (U2) that rented land from traditional farmers and initiated a period of intensive pumping. At the beginning of the period, the groundwater extraction rate was moderate (2.51 hm^3); however, it increased to 7.36 hm^3 by the end of this period (Table 1). Wells were built without control due to the limited monitoring capacity at that time. The access to groundwater resources was only conditioned on request of an administrative authorisation (GS4), and users did not have to pay any tariff for water consumption. Guadalquivir RBA was in charge of water management in the area. However, monitoring and sanctioning processes (GS8) were limited due to the lack of personnel to monitor and funds to install and monitor water meters.

The rapid development of this intensive agriculture created significant environmental problems. The overuse of the aquifer affected the flow of the Fuencaliente natural spring (I1) and generated a dramatic reduction in the spring discharge. Indeed, the aquifer accumulated storage capacity (RS6) was reduced by 2.56 hm3/year from 1974 to 2007; similarly, the spring discharge dropped from 12.99 hm3/year in 1974 to 5.94 hm3/year in 2007 (Table 1). The absence of norms and the limited social capital (U6) of traditional farmers, their limited entrepreneurship capacities (U5) and the difficulties in understanding the resource system as a complex and integrated system (U7) allowed the expansion of intensive agriculture and the overdraft of the aquifer.

The importance of groundwater (U8) prompted a great deal of concern in the citizens of Huescar (users of the spring pond) and the farmers with historical rights to irrigate their farms with the spring water (I4). Both users organised deliberation processes (I3) and demanded urgent action (I7) from the Spanish Ministry of the Environment (GS1).

5.3 The new governance agreement on the Fuencaliente Aquifer (from 2008)

An important change in the settings in this period was the WFD coming into force in 2000. The implementation of this directive (S4) obliged member states to identify groundwater bodies and to classify them according to the possibility of reaching the environmental objectives set by 2015. From the beginning, the Fuencaliente Aquifer was classified in the "at risk" category due to its overexploitation patterns. The abstraction rates described in the former period aggravated the environmental status of the aquifer.

In the previous periods, the main actors in the SES framework were the resource users. In this period, a new actor emerged (U1), the Guadalquivir RBA, with a reinforced authority to impose rules, solve conflict issues and create groundwater user associations. The conflicts of interest between traditional and new users (GS4) and the unsustainable exploitation pattern (I1) that contradicted the WFD led to an urgent intervention by the Guadalquivir RBA to address the problem. This RBA carried out an exhaustive geological and hydrogeological mapping of the aquifer system. As a result, 25 control points currently monitor the hydrological situation of the aquifer (for piezometric and quality levels) and the water flow of the Fuencaliente spring (GS8), improving the predictability of the system dynamics (RS7).

At the same time, an intense negotiation process (I3) was fostered by the Guadalquivir RBA to regulate the abstractions and the irrigated area in order to ensure sustainable groundwater management. As a result, a new governance system was implemented in Los Llanos Plateau in 2007. A Groundwater User Association (GWUA) was created to be the unique representative (GS2, GS3) of all water users and the responsible for delivering and sharing information (I2). New operational rules (GS5) were discussed and agreed upon between the RBA and the GWUA, including the next important changes. The abstraction capacity was dramatically reduced by dropping the permitted abstractions from 8.7 hm^3/year in 2003 to 5.6 hm^3/year in 2008 and to 4.7 hm^3/year from 2013 on. The irrigated area in 2013 was limited to 45% of the existing area in 2003, meaning that only 61 farmers were granted water rights with an annual water quota allocated to each farm of 4,500 m3/ha and a maximum of 20 hectares per authorised (licensed) pump point, with no rotation or changes in the location of irrigated land permitted. To assure compliance, a strict monitoring and sanctioning procedure (GS8) was implemented based on individual meters and strong control of annual withdrawals. Now, the total irrigated area is 1,219 hectares and the main crop is broccoli (>70% of irrigated area) due to its high profitability (RU4).

The agreement also preserved the property rights system (GS4) of traditional users. The farmers who traditionally used the spring were allowed to use surface water from the nearby San Clemente Reservoir (15 km from the spring). They received a water supply of 2.99 hm3/year, and water rights in traditional irrigated areas were granted. However, as the users of surface water have to pay a tariff in Spain, the agreement forced intensive farmers to compensate traditional spring users for their reduction in water allocation by paying the water surface tariff to the RBA. In 2017, the required payment was 0.012 EUR/m^3.

It is worth mentioning that although water rights were allocated to 61 farmers in Los Llanos, only two of them are still running their farms (U1). All the other farmers have rented their land to the main commercial broccoli producers; thus, all the irrigated area available for broccoli production is rented by just two commercial producers located in Lorca (60 km away), where the main economic activity is out-of-season open-air and protected vegetable cultivation.

The rights of the traditional recreational users of the Fuencaliente spring (GS4) have also been preserved by the new arrangement. To maintain the recreational uses of the Fuencaliente spring, a minimum spring discharge (currently 3.34 hm^3/year) is guaranteed.

After this arrangement was implemented, there has been a gradual return to equilibrium (RS6) in the Fuencaliente Aquifer. The increase in the inputs and the reduction in the pumping allowed an increase in the water storage (Table 1). The continuous decrease in the spring discharge also stabilised and has even recovered in the last several years (O2) (Aljibe, 2014).

6. DISCUSSION

In this section, we discuss the situation of the SES in the 3 analysed periods and identify the drivers that explain the innovative governance arrangements put in place in Los Llanos Plateau. Additionally, we identify the main lessons that might be replicated in other contexts facing similar problems.

6.1 Drivers of innovation in groundwater governance

In the first analysed period, the users of the groundwater resources did not overexploit them, and no tensions between the social and ecological systems existed.

In the second period, external drivers such as market incentives (S5) and internal drivers linked to the (lack of a) governance system pushed the SES to a tragedy of the commons situation. The consideration of the groundwater as a common-pool resource, the limited enforcement capacity in the RBA (GS8) and the absence of collective rules (GS6) to manage the resource led to overexploitation and the aquifer having difficulty recovering (RS6) (Araral, 2014). The legacy of unregulated access to groundwater (Evans et al., 2016) had a continued impact on the ecological system (Molle et al., 2018).

The rapid development of intensive agriculture and the associated increase in groundwater consumption led to a critical environmental tipping point that required urgent action. Groundwater supplies (RU5) to all users (traditional farmers, commercial farmers and recreational users) were threatened by over-extraction. Internal drivers linked to the governance system, such as the diffuse property rights of groundwater (GS4), the absence of operational rules (GS5) and collective-choice rules (GS6), the non-compliance with constitutional rules (GS7) and the lack of capacity of the government organisations (GS1) to put into force monitoring and sanctioning processes (GS8), contributed significantly to this situation.

The changes in cropping patterns and land use (I5) affected the water availability and made evident the need for new regulations for water use (Klümper and Theesfeld, 2017). A feature of our case study that is different from those of other aquifers is that the groundwater depletion became visible due to the decrease in the spring discharge. In most cases, groundwater invisibility makes supply reduction go unnoticed by most users until the damages are irreversible (Megdal et al., 2017).

During the third analysed period, the depletion of the aquifer required urgent decision-making and action to introduce a new governance framework that permitted the recovery of the ecological system and an acceptable agreement for the resource users. The first external drivers behind this shift were the reinforced legal power and the command-and-control mechanisms that the WFD gave to RBAs to act when the use of water resources led to unsustainable groundwater management (O2). The geophysical state and the European legislation fostered new approaches to water management (Megdal et al., 2017). The high number of aquifers in at-risk situations in Spain forced the government to act to preserve these natural resources. The new legal framework vested the water authorities (GS1) with a stronger capacity to exercise authority and to warrant the efficient utilisation of groundwater resources for the benefit of users and ecosystems (Foster et al., 2013).

The Guadalquivir RBA had to solve the conflicts between competing users, intervening to implement an acceptable solution and crafting new rules to exclude users and regulate new uses to avoid a tragedy of the commons. The WFD forced Guadalquivir RBA to shift from its role of 'water supply control' to one of 'resource custodian' and 'information provider' (Varady et al., 2016). The number and expansion of wells, the maximum amount of water to be abstracted in the existing wells and the land granted with water rights (I1) were regulated (Molle et al., 2018), and the ecological status of the aquifer was systematically monitored (O2).

All parties understood that they were reliant on the water provided by the aquifer and that the prior appropriation patterns were no longer possible due to the gaps between water supply and demand (Megdal et al., 2017). The credibility, legitimacy and authority of the RBA negotiator also played an important role in the acceptance of the arrangements. This was the first time in Spain that RBAs forced groundwater users to pay a tariff for water use that was not included in the water cost recovery prescribed by the Water Act (O1). Nevertheless, the agreement also developed an enabling framework for intensive producers, securing new water rights associated with land tenure rights (GS4), backing their investments (I5) and their willingness to pay the extra costs for water (King and Salem, 2012).

A second external driver explaining the willingness of commercial farmers to accept the agreement is market incentives (S5). The high productivity of intensive agriculture, the high price of broccoli (RU4) in the European markets and the well-established commercialisation channels made the crop profitable even after paying a higher cost for the use of water. This situation made acceptable the trade-off between the extra costs borne by the broccoli producers and the granted access to land and water resources (U8).

The public-private agreement to exchange water rights, whereby new groundwater users in Los Llanos Plateau were forced to compensate irrigators with historical rights to use the Fuencaliente spring resources in return for securing their water rights, is a major innovation. Traditionally, surface water shortages are supplemented with groundwater resources; however, in our case, groundwater shortages were replaced with surface water resources allocated from the San Clemente Reservoir. The Guadalquivir RBA re-structured the existing institutional arrangements and permitted the tradability of unused water resources (Evans et al., 2016).

Both external drivers, the command-and-control power of the state (represented by the Guadalquivir RBA) and the market dynamics (Ruiz-Ballesteros and Gálvez-García, 2014), fostered collaboration and acceptance of trade-offs in order to continue using groundwater resources.

Internal drivers also contribute to explaining the situation, such as the differences in power relations among the users (I6) and the absence of real collective action (I7) in the area. Local residents and traditional farmers self-organised (I7) to force the Ministry of Environment and the water authorities (GS1) to act to preserve their traditional rights and avoid the depletion of the resource. The increasing environmental awareness in recent decades and the need to improve the sustainability of the intensive agriculture model in the south-eastern Spain supported this action. However, the users only organised and mobilised when the water availability dramatically dropped. Once the new agreement was in place, the traditional users continued with their traditional cropping systems, and the new users only rented their land to the 2 broccoli producers, which resulted in a change in the power relation between farmers. The limited number of new users (U1), the reduced social capital (U6) and entrepreneurship skills (U5) of traditional farmers and the differences in power between commercial and traditional farmers (I6) facilitated elite capture of the benefits of groundwater (Villholth and Conti, 2017).

The preservation of the traditional rights (GS6) of local users was fundamental because if economic circumstances change (S5), these users will still remain in the area and might guarantee the sustainability of the SES. At the same time, the agreement granted water rights to the intensive producers that can also advertise that their products are grown with sustainable water use methods (O2), which may respond to a growing demand from European consumers.

Other attributes of the traditional farmers and local inhabitants, such as the ageing farmer population, their lack of financial and technical capacity to afford the intensive inputs and labour costs (I5) associated with broccoli production, their poor collective action tradition (U2), and factors linked to the high barriers to entry in the export markets and the integrated value chain of broccoli (U9), support the preference to secure incomes by renting the land to the commercial producers.

Another driver that facilitated the new arrangement was the availability of surface water in the reservoir to be allocated to traditional farmers. The Guadalquivir basin is a closed basin (Expósito and Berbel, 2017), but some factors related to the mentioned socioeconomic attributes of the local inhabitants (i. e., the lack of entrepreneurship capacities to shift from traditional rain-fed to irrigated agriculture and the lack of financial capacity to invest in irrigation infrastructure) made it so that not all the stored water had a previous allocation.

6.2 Learning from Los Llanos groundwater governance system

This research has identified several lessons that might be of interest to be replicated in other groundwater overexploitation contexts and shape the policy and management frameworks. An initial issue to be considered is the need to understand the social and the ecological systems as intrinsically connected and mutually shaping each other. The recovering of the aquifer (ecological system) was only possible taking decisions that could be accepted by the different users (social system).

Additionally, the government crafted a new governance system that combined command-and-control power and mechanisms with deliberation and mediation processes. This governance system was based in an innovative public-private arrangement that safeguard the groundwater resource and at the same time secured rights to different users. The arrangement was negotiated with the different stakeholders and took in consideration their different needs. It guaranteed the water to traditional users. For new users, it introduced important restrictions to the use of water, but at the same time granted access to land and water and offered a sustainability label to their products, opening new market opportunities in a time where sustainability practices are gaining momentum. As a result, the arrangement enabled traditional and emerging production and use patterns, decreased the level of conflict and did not prevent livelihoods options in this deprived region.

Finally, prescriptive rules and rigorous monitoring, control and enforcement systems were also essential aspects in the recovering of the aquifer. Likewise, the combined consideration of surface and groundwater resources provided the best possible allocation and at the same time contributed to its sustainable management.

7. CONCLUSIONS

Our research contributed to the current debate about the local arrangements that might improve groundwater governance, using the social-ecological systems approach. The analysis of the Fuencaliente Aquifer showed how the complex structure of interactions between the social and ecological aspects led to decisions to adapt over time to different internal and external disturbances. At the same time, we demonstrated that innovative governance arrangements linking public and private interests and bottom-up and top-down decisions can be implemented to address vulnerability and unsustainable use of resources.

External drivers, such as market incentives and limited enforcement capacity, and internal drivers linked to the socio-economic attributes of users and to the lack of governance rules prompted the depletion of the aquifer. However, these same external and internal drivers, under a new regulatory framework that reinforced the jurisdictional authority to implement new policy and control systems, were the origin of an innovative groundwater governance arrangement that is leading to the effective recovery of the aquifer.

The research disclosed the enabling conditions for the different users accepting cooperation in resource management and rule compliance to halt aquifer degradation. A new regulatory framework, deliberations with all the relevant actors, preservation of traditional rights and incentives for the different parties in conflict were necessary to accept the agreement. The Guadalquivir RBA had the enforcement power to impose rules, but it preferred to address conflicts using deliberation and negotiation processes that included all stakeholders and searched for an agreement that could be accepted by all of them.

Groundwater is mostly a local issue, and governance arrangements need to be rooted in the political, economic and socio-cultural settings. Groundwater governance incentives must be context-based and adaptive, and effectively engaged in the social and economic contexts. The socio-economic drivers that made it possible to accept the trade-offs and to put into place the governance system in Los Llanos Plateau are quite unique and, as such, legitimated a customised strategy that might not always be replicable in other SESs. However, the innovations in groundwater governance and management identified and the lessons learnt might be transferable to other SESs facing similar problems.

The results highlighted how innovative groundwater governance arrangements emerged and were applied and provide insights into potential good practices linking social and ecological aspects to be applied in other SESs. The arrangement took into account the interactions between the social and ecological contexts and provided a solution that improved them both. The improvements in the ecological system of Fuencaliente Aquifer were driven by changes and negotiations in the socio-institutional system. Actions that affected both systems were put into practice, balancing ecosystem health with socioeconomic goals in an equitable manner (Rica et al., 2017).

ACKNOWLEDGEMENTS: The authors have received financial support from MINECO-Grant AGL-2014-53417-R and Sustainable Land Management Network (SULANET) (564651-EPP-1-2015-1-SK-EPPJMO-NETWORK).

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APPENDIX 1. DESCRIPTION OF THE VARIABLES INCLUDED IN THE SES FRAMEWORK

SOCIAL, ECONOMIC AND POLITICAL SETTINGS (S)

S1 Economic development

Development opportunities in mountainous semiarid areas in southern Spain are limited. The main economic sector is agriculture, often rain-fed agriculture, and productivity has traditionally been low. However, during the 1980s and 1990s, in south-eastern Spain, horticulture and greenhouse production opened up a market niche for high-value crops in areas with water availability. These trends affected our study area due to its potential for the open-air cultivation of high-value crops such as lettuce and broccoli that are in high demand in Europe.

S2 Demographic trends

Predominantly rural areas in Spain present a situation of decline marked by population ageing (31% of the population is older than 65 years), depopulation (average population density, 19.79 inhabit/km^2) and a significant technological lag behind the urban world. Agriculture is not an attractive sector for young people, and most migrate to cities searching for new opportunities. Currently, rural employment in Spain represents less than 6% of total employment.

S4 Government resource policies

Surface water is in the public domain in Spain and is regulated by River Basin Authorities (RBAs). Historically, groundwater abstraction rights in Spain were tied to land ownership (Water Law of 1879). The Water Law of 1985 redefined abstraction rights and established all aquifers as part of the public domain, with the RBAs assuming responsibility for regulating groundwater abstractions. A Register of Public Water and a Catalogue of Private Water were created as instruments for groundwater management, requiring the registration of all well owners.

The implementation of the Water Framework Directive (WFD) in 2000 obliged all the member states to identify and classify their groundwater bodies as part of the 'Initial Characterisation Stage' defined in the Directive. In Spain, 699 groundwater bodies were officially identified, and 259 (37%) of them were classified as "at risk" of not attaining the environmental objectives set by the WFD in 2015. Llamas et al. (2015) estimated current aquifer storage depletion in the Iberian Peninsula at approximately 15 km^3, causing water table drop, water quality degradation, land subsidence and other negative ecological impacts.

Water tariffs in Spain are tied to the services provided by RBAs. Since the Water Act does not define any services received by groundwater users, they do not have to pay any tariff to RBAs. They only pay a fee when the water abstraction license is guaranteed.

S5 Market incentives

The weather and technological conditions in southern and eastern Spain favour intensive horticulture production to supply European demands, especially during winter. Indeed, Spain is called “the orchard of Europe”. The high European demand, the established niche market, the integrated value chains and the high profits obtained from intensive-horticulture crops have made Spain the world’s leading exporter of some products such as broccoli (currently representing 30% of the international trade in this crop).

S6 Media organisations

Specialised media in environmental issues exist in Spain. Water and groundwater depletion, inefficient use of water in irrigation, transfer of water between basins, conflicts between different users, etc. are recurrent topics in the news.

RESOURCE SYSTEMS (RS)

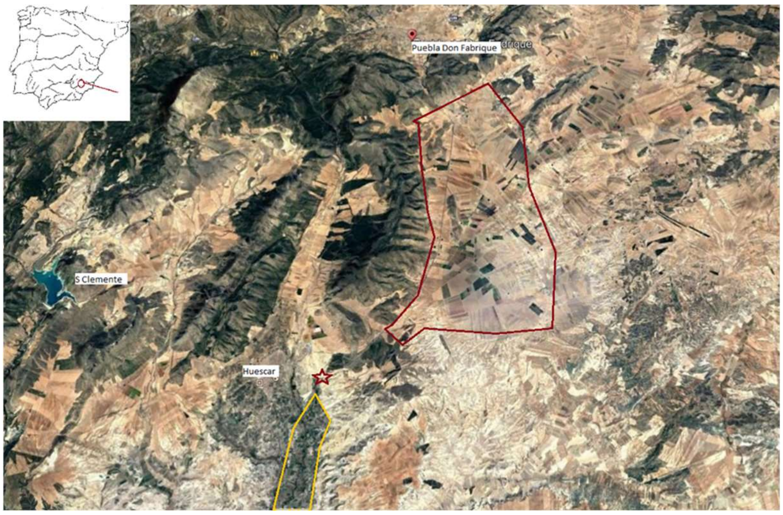
RS1 Sector

The sector analysed is groundwater. Our study focuses on analysing the Fuencaliente Aquifer. This water is used for both irrigation and recreational purposes by local inhabitants since the aquifer discharges into a pond.

RS2 Clarity of system boundaries

The physical limits of the system are clearly delimited (Figure 1). The Fuencaliente Aquifer is part of the Huescar-Puebla hydrological system (MAS 05.04), located at the foot of Los Llanos de la Puebla Plateau, surrounded by the Baetic Mountain Ranges in the north of the province of Granada (southern Spain). The report elaborated by Aljibe (2014) confirms the insignificant connections of this water mass with adjacent water bodies.

Figure 1. Location of the Fuencaliente Aquifer (red outline), Fuencaliente spring (red star) and the area traditionally irrigated with the Fuencaliente spring (yellow outline).

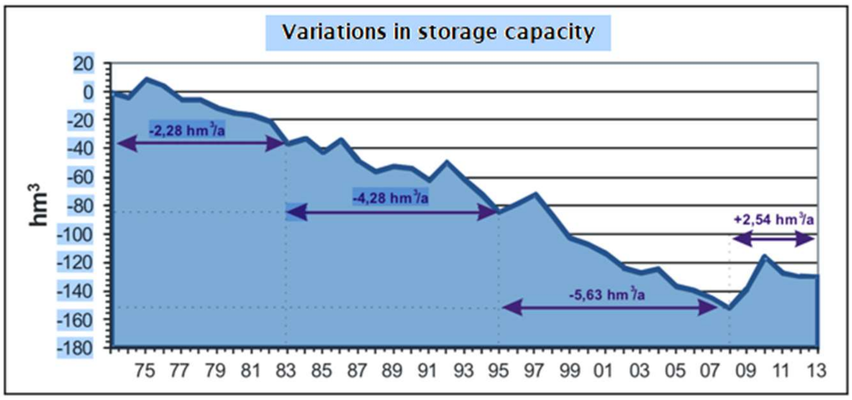


Source: Google Earth.

RS3 Size of the resource system

The Huescar-Puebla hydrological system covers an area of 430 km^2, of which 170 km^2 correspond to permeable geological formations. The area has semi-arid climatic conditions with an average annual rainfall of 300 mm. The variations in the storage capacity are displayed in Figure 2.

Figure 2: Changes in the aquifer storage capacity in hm3/year during the period 1975-2013.



Source: Aljibe, 2014

According to CHG (2016) the land currently irrigated in the area is:

1) Intensive agriculture: 1,219 irrigated hectares
2) Traditional irrigation with spring discharge: 477 irrigated hectares
3) Traditional irrigation supplied with surface resources from the San Clemente Reservoir: 761 irrigated hectares

RS4 Human-constructed facilities

Three irrigation ditches dating back to Moorish times (9^{th}-14^{th} century) exist (as evidenced by their Arab names Alquivira, Almazaruca and Almohala). The recreational site consists of a small reservoir that regulates water supply to traditional farmers, channelling water through three gates that conduct water to the crop fields located downstream, but no other irrigation or water management facilities have been built. Additionally, 102 wells have been legalised in the area of the aquifer (Aljibe, 2014). Some touristic infrastructure, such as wooden infrastructures, a bar and a rural hostel, have been constructed. The site is open to the public year-round.

RS5 Productivity of the system

The productivity of the water resource system has been calculated by Berbel et al. (2018a) for both traditional and intensive crops.

Although the crop mix in the 1990s was more diversified (including lettuce and cauliflower), over the last two decades, the area has specialised in broccoli due to the competitiveness of this sector in export markets. The high apparent water productivity of the crop is 1.54 EUR/m^3 in terms of GVA and 1.14 EUR/m^3 in terms of gross margin (GM) (Table 1).

Table 1. Indicators for broccoli cultivation (data refer to 2017).

Indicator	
Yield (kg/ha)	18,000
Water use (m^3/ha)	3,900
Price (EUR/kg)	0.55
Income (EUR/ha)	9,900
Direct cost (EUR/ha)	3,895
GVA (EUR/ha)	6,005
Salaries (EUR/ha)	1,555
Gross Margin (GM) (EUR/ha)	4,450
Rain-fed agriculture GM (EUR/ha)	250
Productivity ratios (EUR/m^3)	
GVA / m^3	1.54
GM / m^3	1.14
Threshold price	1.08

Source: Berbel et al. (2018a)

The apparent water productivity average of traditional crops is 0.66 EUR/m^3 in terms of GVA and 0.35 EUR/m^3 in terms of gross margin (GM) (Table 2).

Table 2. Indicators for traditional agriculture (data refer to average values 2015-2017).

Indicator / Crop	**Maize**	**Alfalfa**	**Olive (oil)**	**Almond & Fruits**	**Average**
Irrigated area (ha)	25%	15%	50%	10%	-
Water use (m^3/ha)	5,000	4,500	3,000	5,000	3,925
GVA (EUR/ha)	1,519	1,630	2,781	3,231	2,338
Gross Margin (EUR/ha)	900	1,031	1,332	2,610	1,307
Rain-fed GM (EUR/ha)	250	250	600	600	460
Productivity ratios (EUR/m^3)					
GVA /m^3	0.30	0.36	0.93	0.65	0.66
GM /m^3	0.18	0.23	0.44	0.52	0.35
Threshold price	0.13	0.17	0.24	0.40	0.22

Source: Berbel et al. (2018a)

RS6 Equilibrium properties

Different phases can be distinguished based on the exploitation regime:

- 1974-1982: practically no pumping
- 1983-1994: moderate pumping
- 1995-2007: intensive exploitation
- 2008-2013: reduction of abstraction rates

Table 3 shows the average estimated annual volume of exploitation in the aquifer for every period and the storage variation:

Table 3: Annual average balance in Fuencaliente Aquifer, 1974-2013 (hm^3/year).

Period	**Inputs**		**Outputs**			**Storage variation**
	Recharge	**Side transfer**	**Pumping**	**Springs**	**Side transfer**	
1974-1982	10.16	0.45	0.00	12.99	0.43	**-2.81**
1983-1994	9.53	0.44	2.51	10.27	0.45	**-3.25**
1995-2007	7.79	0.42	7.36	5.94	0.28	**-5.37**
2008-2013	12.02	0,39	5.80	4.60	0.10	**1.92**
1974-2013	**9,48**	**0,43**	**4,01**	**8,62**	**0,34**	**-3.07**

Source: Aljibe, 2014

The difference between inputs and outputs corresponds to variations in water storage in the aquifer. For the whole period analysed, the difference is negative, indicating a deficit in the system reserves of 3.07 hm^3/year for the period. However, in the most recent phase, 2008-2013, a return to equilibrium can be seen, with an increase of 1.92 hm^3 in the water storage of Fuencaliente Aquifer.

RS7 Predictability of system dynamics

The system dynamics were characterised by a constant rise in water demand and water abstractions until the reductions in the stored water and the spring discharge became evident (Table 2). Pumping increased from 0.00 hm^3/year in 1974 to 7.36 hm^3/year in 2007. The aquifer accumulated storage was continuously reduced from 2.81 hm^3/year in 1974 to 5.37 hm^3/year in 2007. A similar situation was observed in the spring discharge that changed from 12.99 hm^3/year in 1974 to 5.94 hm^3/year in 2007.

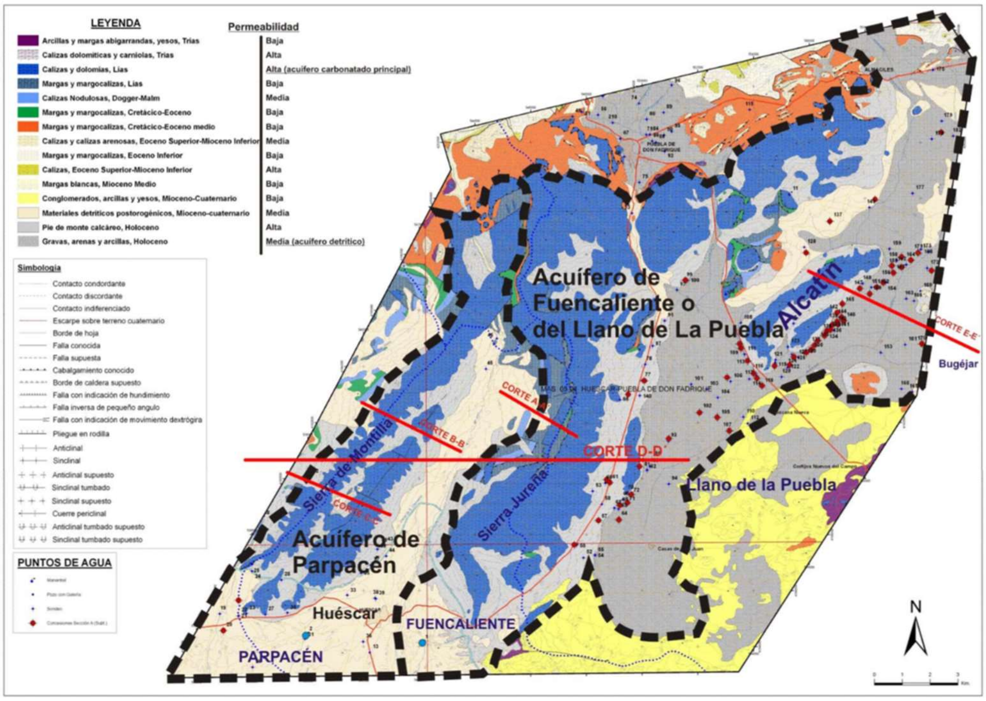
However, the trend changed in 2008 due to an increase in the inputs to the system and a reduction in pumping that led to an increase of 1.92 hm^3 in the water storage.

The rainfall variability in the area makes it difficult to predict annual inputs, but the existing control of the abstraction rates (control points and individual meters in every licensed well) allows some optimism regarding the possibilities for recovery in the aquifer and increased predictability of the system.

RS8 Storage characteristics

The storage capacity of the aquifer is well known. The geological composition and hydrogeological analysis show that the water is confined and disconnected from other water bodies. Figure 3 is a hydrogeological map of the aquifer.

Figure 3. Hydrogeological map delimitating Fuencaliente Aquifer and adjacent aquifers.



Source: Aljibe, 2014.

RS9 Location

The Fuencaliente Aquifer is located 920 metres above sea level at the following UTM coordinates: X = 542194, Y = 4184143.

RESOURCE UNITS (RU)

RU1 Resource unit mobility

The mobility of groundwater resources can be considered low to moderate, as part of the water flows through the spring discharge.

RU2 Growth or replacement rate

The Guadalquivir River Basin Management Plan (RBMP) for 2009-2015 estimates the renewable groundwater resources in the aquifer at 12.7 hm^3 per year (CHG, 2016), although recent studies using a shorter time series put this figure at 9.51 hm^3 per year (Aljibe, 2014).

RU3 Interaction among resource units

The water outlets from the Fuencaliente Aquifer to the Fuencaliente spring are estimated at 8.62 hm^3/year (average) for the period 1974-2013 (Aljibe, 2014). Since Roman times, the Fuencaliente spring has had a very stable outflow and has been used for recreation due to its slightly warm water (average 19 °C). During the Moorish era (9^{th}-14^{th} century), a distribution system was built to irrigate land with this water.

RU4 Economic value

Berbel et al. (2018a) calculated the following economic value for the different uses:

1) For intensive agriculture, the GVA calculated is 6,005 EUR/ha (Table 1).
2) For traditional agriculture, the average GVA is 2,338 EUR/ha (Table 2).
3) The recreational value of the pond has been estimated to be 3€/person/day.

GOVERNANCE SYSTEM (GS)

GS1 Government organisations

The government organisations in charge of groundwater resources are the Spanish Ministry of Environment and the Guadalquivir River Basin Authority.

GS2 Non-governmental organisations

The only non-governmental organisations in the area are the Fuencaliente Irrigation Community, which is not very active and has limited collective action and bargaining power, and the Groundwater User Association, which has been in place since 2008; its creation was part of the agreement reached between the Guadalquivir River Basin Authority and the groundwater users to solve the depletion problems.

GS3 Network structure

No active networks linked to groundwater resources exist in the area. After the problems with spring discharge and aquifer depletion were evident, local people mobilised, but they did not constitute formal networks.

GS4 Property-rights systems

During the period analysed, the groundwater property-rights system changed dramatically in Spain.

"According to the 1879 Water Law, ordinary (domestic use) wells were the property of the landowners, while water from artesian wells or galleries was owned by whoever found them. Legal constraints on the private ownership of groundwater were generally minor and arose as a means to avoid damage to third parties. These included a minimal distance between wells, as well as other limitations designed to avoid interference with public surface waters and to guarantee the safety of buildings, railways and roads.

The 1985 reforms of Spain’s Water Law put groundwater under public ownership. The Preamble to Spain’s 1985 Water Law declares groundwater and surface water as part of the same hydrological cycle and thus in the public domain. Therefore, its main innovation is that the state, not individuals, is responsible for groundwater management.

Article 72 of the 1985 Water Law states that basin authorities will set up a “Public Water Registry” and a “Catalogue of Private Waters”. These administrative bodies were designed to keep track of the ownership and characteristics of every well. Under the law, all well owners must be registered in one of these bodies, and basin authorities can apply coercive fines to enforce this rule. Existing wells included in the registry acquired the legal status of “temporary private wells.” In practice, this means that private ownership is respected for 50 years. After that period, ownership is transferred to the state, although an “administrative concession” is to be granted so that the former owner can still make use of the well. A three-year deadline (December 31, 1988) was set to join the registry.

Alternatively, well owners wishing to maintain private ownership might choose to apply for inclusion in the “Catalogue of Private Waters”. Groundwater users failing to comply with the three-year deadline would be in a similar situation (maintaining private ownership) but would still be under a legal obligation to apply for the catalogue. Thus, those who privately owned wells under the 1879 Water Law might continue to do so. However, they would not be granted administrative protection under the 1985 Water Law. As a consequence, the inclusion of wells in either the registry or the catalogue constituted a legal imposition on all owners. However, those failing to join would still be in full possession of their rights because inclusion in the catalogue was not a prerequisite for ownership (Del Saz, 2002). To address this problem, the 2001 National Water Plan Law added a Transient Disposition, which made it difficult to obtain recognition for those private waters not yet included in the catalogue.

The three-year deadline and the legal advantages of the registry had a two-fold aim: first, to ensure diligence among applicants so that an inventory of wells could be compiled as soon as possible; and second, to encourage applicants to join the registry instead of the catalogue so that, ideally, all groundwater would be public domain within 50 years. The desired effect was not achieved. Moreu (2002) estimates that only 10-20% of well owners joined the registry in time. These owners will lose their private ownership in 50 years (between 2036 and 2038). In contrast, those who, because of either distrust or misinformation, did not join (an overwhelming 80-90%), will forcefully maintain their private ownership for an indefinite period. Thus, even if the 1985 Water Law states that groundwater is in the public domain, the reality is quite different. In fact, most water is still under private ownership by law. This situation is further aggravated by a newer constraint: illegal wells. “Hydrological insubordination” has become widespread in many Spain’s aquifers” (Fornés et al. 2007:677-678).

In our area of study, well drilling mainly started after 1985 when groundwater was already recognised as a public domain resource. Most of these wells were illegal since until 2013, there was no abstraction licensing system in force. In fact, access to groundwater resources was open, only conditioned to a provisional administrative authorisation. This led to uncontrolled pumping while definitive administrative licences were obtained.

After the agreement, only 102 wells were licensed to abstract water, and the abstraction rate regulated and controlled.

GS5 Operational rules

Before the 1980s, the operational rules for the traditional irrigated areas were structured around the use of the spring discharge to irrigate traditional crops without using wells or pumping water. Farmers were organised in the Fuencaliente Irrigation Community, which was in charge of the administrative relations with the RBA.

Between 1980 and 2007, a kind of lawless situation existed. The absence of public and private operational rules, due to the lack of collective action to protect the resource and the limited enforcement and monitoring capacity of the Guadalquivir RBA, was the origin of the illegal construction of wells and the intensification of illegal pumping that generated the aquifer depletion and reduction in the spring discharge and prompted a 'tragedy of the commons'.

In 2008, the agreement forced by the RBA put into force new operational rules for the use of groundwater, increased the monitoring and sanctioning capacities and obliged all the water users to abide by them. According to Berbel et al. (2018b) these rules are:

1) Reduce abstractions from 8.7 hm^3/year in 2003 to 5.6 hm^3/year in 2008 and 4.7 hm^3/year in 2013 (54% reduction).
2) Limit the irrigated area in 2013 to 45% of the area in 2003.
3) Monitor with individual meters and control the annual withdrawals.
4) Allocate an annual water quota to only 61 farms that had granted rights by licence. The maximum water allocation is 4,500 m^3/ha.
5) Only authorise a maximum of 20 hectares per (licensed) pump point, with no rotation or changes in the location of irrigated land allowed. Thus, only 1,219 hectares have irrigation rights.
6) Total abstractions are limited to 4.7 hm^3 per year (49.4% renewable resources).

GS6 Collective-choice rules

Before the 1980s, there were no collective-choice rules. The absence of conflicts between farmers and the water availability explains this situation.

Between 1980 and 2007, there were also no collective-choice rules, but conflicts arose between water users, especially between the new intensive farmers and the traditional users (farmers and local inhabitants). The conflict prompted a local mobilisation to defend the traditional users' customary rights to use the water in the pond.

After 2008, the new institutional arrangement enforced by the RBA required the creation of a Groundwater User Association (GWUA) to be the interlocutor between the RBA and the farmers. Additionally, the arrangement established as obligations to 1) ensure a minimum spring discharge (currently established at 3.34 hm^3/year) to maintain the recreational uses of the Fuencaliente spring and 2) compensate traditional farmers for the drop in water availability in the spring by allocating surface resources from the nearby San Clemente Reservoir (15 km from the spring); the tariff for this compensation had to be paid by the intensive farmers that created the problem with their overextraction.

GS7 Constitutional rules

The constitutional rules in Spain establish water as a public good, the use of which is regulated by the state through RBAs.

The Water Framework Directive (WFD), with which compliance is mandatory in all EU Member States, was approved in 2000.

The following paragraphs are extracted from EC (2003). Article 5 of the WFD requires the analysis of the characteristics of every river basin and water body, the review of the environmental impact of human activity, and an economic analysis of water use. With regard to groundwater, the characterisation process involved an initial characterisation of all groundwater bodies to assess their uses and the degree to which they are at risk of failing to meet the objectives of Article 4 of the WFD, namely, the achievement of good (quantitative and chemical) status of groundwater at the latest by the end of 2015. Groundwater bodies may be grouped for the purposes of this initial characterisation, which may be based on existing hydrogeological, geological, pedological, land use, discharge, abstraction and other data. In particular, the first step is to identify the location and boundaries of the groundwater body or bodies. Then, pressures to which the groundwater bodies are liable to be subject to shall be identified (including diffuse and point sources of pollution, abstraction, and artificial recharge). In addition, the general character of the overlying strata in the catchment from which the groundwater body receives its recharge shall be described, as well as the groundwater bodies for which there are directly dependent surface water ecosystems or terrestrial ecosystems. Following this initial characterisation, a further characterisation was carried out for those groundwater bodies or groups of bodies that have been identified as being at risk to establish a more precise assessment of the significance of such risk and identify any measures required under Article 11 of the WFD. Accordingly, this characterisation shall include relevant information on the impact of human activity and, where relevant, information on:

- Geological characteristics of the groundwater body, including the extent and type of geological units;
- Hydrogeological characteristics of the groundwater body, including hydraulic conductivity, porosity and confinement;
- Characterisation of the superficial deposits and soils in the catchment from which the groundwater body receives its recharge, including the thickness, porosity, hydraulic conductivity, and absorptive properties of the deposits and soils;
- Stratification characteristics of the groundwater within the groundwater body;
- An inventory of associated surface systems, including terrestrial ecosystems and bodies of surface water, with which the groundwater body is dynamically linked;
- Estimates of the directions and rates of exchanges of water between the groundwater body and associated surface systems;
- Sufficient data to calculate the long-term annual average rate of overall recharge; and

- Characterisation of the chemical composition of the groundwater, including specification of the contributions from human activity. Typologies for groundwater body characterisation may be used when establishing natural background levels for these bodies of groundwater.

Connected to this further characterisation, the WFD also requires the identification of those bodies of groundwater for which lower objectives are to be specified under Article 4, including as a result of consideration of the efforts of the status of the body on:

i. Surface water and associated terrestrial ecosystems.
ii. Water regulation, flood protection and land drainage.
iii. Human development.

Finally, Member States have to identify those bodies of groundwater for which lower objectives are to be specified under Article 4(5) of the WFD where, as a result of the impact of human activity, and as determined in accordance with the analysis of pressures and impacts under Article 5(1), the body of groundwater is so polluted that achieving good groundwater chemical status is infeasible or disproportionately expensive. It should be clear that the identification of groundwater bodies is, first and foremost, based on geographical and hydrological determinants. However, the identification and subsequent classification of water bodies must provide a sufficiently accurate description of this defined geographic area to enable an unambiguous comparison to the objectives of the Directive.

After this initial characterisation requested by the WFD, the Fuencaliente Aquifer was classified in the 'at risk' group, and the Guadalquivir RBA commissioned the abovementioned comprehensive characterisation (Article 11) to Aljibe Consultants.

GS8 Monitoring and sanctioning processes

Before 2007, monitoring and sanctioning procedures were practically absent due to the limited resources available to the Guadalquivir RBA. Once the conflicts emerged, and with the greater power derived from the WFD, effective monitoring and sanctioning procedures were put into practice.

After the thorough geological and hydrogeological mapping of the aquifer system carried out by the RBA, 25 control points are currently hydrologically monitored (for piezometric and quality levels), as well as the water flow of the Fuencaliente spring. Additionally, water meters were installed in all the licensed wells in order to control water withdrawals, and illegal wells were sanctioned.

USERS (U)

U1 Number of actors

The main actors in the SES are the users of the resource: traditional and intensive farmers and local inhabitants that use water for recreational purposes.

The number of users is as follows:

1) Intensive agriculture users: Initially, 61 farmers received a water allocation of 4,500 m3/ha for a maximum of 20 hectares. However, currently, only 2 of those farmers cultivate their lands, while all the others rent their land and the associated water rights to 2 main commercial broccoli producers from the Murcia region.
2) Traditional agriculture users: They irrigate 477 hectares, but we could not access to any register of farmers.
3) Recreational users: All the inhabitants of Huéscar and Puebla de Don Fadrique and nearby villages are potential users of the pond and recreational facilities. The number of inhabitants in summer can increase by 50%. According to the municipality responsible for the site, in summer, visitor numbers might reach 500 per day on weekdays and 1,000 per day on weekends. Outside the summer season, the number of visitors drops to an average of 50 per day.

In the last analysed period, the Guadalquivir RBS emerged as a new actor with reinforced power to make decisions about the use of the water and the permitted uses.

U2 Socioeconomic attributes of users

Traditional farmers are local people, predominantly over 55 years old (35% are over 65 years old); most of the farms are less than 10 hectares in size, and farmers have a low educational level (Altiplano de Granada, 2016). Table 2 shows that the gross added value of traditional crops is 2,338 EUR/ha and the gross margin is 1,307 EUR/ha.

During the period of overexploitation, some intensive farmers were also people from the area with similar socioeconomic attributes as the traditional farmers. However, the actual intensive farmers are not locals. As mentioned in U1, only 2 commercial farms are now cultivating the irrigated area. They have substantial experience in intensive commercial farming, are experts in the integrated value chain of broccoli and have access to European markets. As mentioned in Table 1, the gross added value of broccoli is 6,005 EUR/ha, and the gross margin is 4,450 EUR/ha.

U3 History of use

For centuries, the Los Llanos Plateau was devoted to rain-fed agriculture, mainly the cultivation of cereals and fodder. During the 1980s and 1990s, the development of horticulture in the Segura River basin (60 km east of Los Llanos) and the groundwater availability opened up a market niche for open-air cultivation of high-value crops (*e.g.*, broccoli, cauliflower, lettuce, etc.), covering the summer season when production stops in the greenhouses and intensive cultivation areas of Murcia and Almeria. This rapid development of intensive agriculture led to the overuse of the aquifer and affected the flow of the Fuencaliente natural spring, which had been used by Huescar inhabitants since Roman times.

This situation prompted a great deal of concern from the local residents (users of the pond) and the farmers with historical rights to irrigate their farms with the spring water. As a result, the citizens organised themselves and organised different demonstrations to demand urgent action from the Spanish Ministry of the Environment.

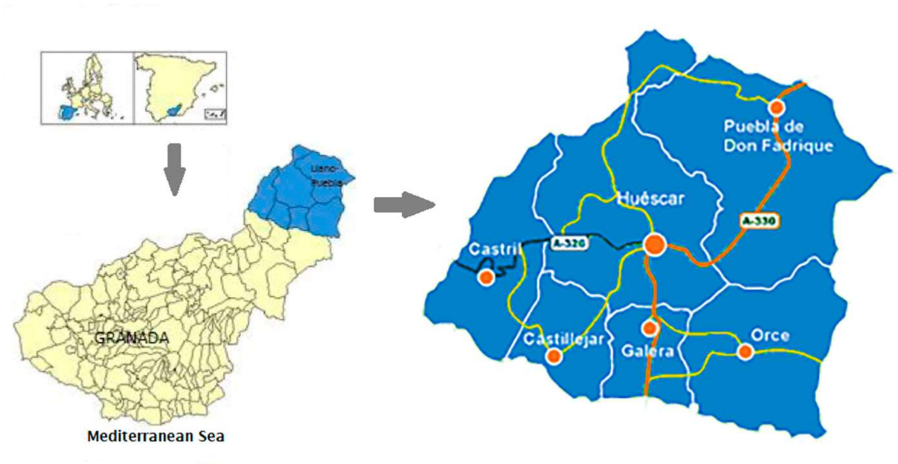
The Guadalquivir RBA was in charge of solving the problem, preserving traditional rights to use the aquifer, both for farming and recreational uses, stopping illegal pumping, and enforcing WFD compliance. The first step was to create a Groundwater User Association acting as the intermediary between farmers and the RBA. An agreement was finally put into force that limited the abstraction rates to approximately half of the renewable resource, reduced the amount of land with irrigation rights and controlled the number and abstraction rates of licensed wells. To ensure compliance, a strict monitoring and sanctioning procedure was implemented based on individual meters and strong control of annual withdrawals. Now, the total irrigated area is 1,219 hectares and the main crop is broccoli (>70% of irrigated area) due to its high profitability.

Additionally, in order to preserve the rights of traditional farmers affected by the reduction in the spring discharge, traditional farmers were allowed to use surface water from the nearby San Clemente Reservoir (15 km from the spring), receiving a water supply of 2.99 hm3/year. However, as the users of surface water have to pay a tariff in Spain, the agreement forced intensive farmers to compensate traditional spring users by paying the water surface tariff to the RBA. In 2017, the tariff was 0.012 EUR/m3.

U4 Location

Users are mainly located in Huéscar and La Puebla de Don Fabrique villages in the province of Granada (Figure 4).

Figure 4. Location map.



U5 Leadership/entrepreneurship

Local farmers are mainly older populations with limited leadership/entrepreneurship capacity. They prefer to rent their land and guarantee some income rather than cultivate their land and assume risks. The main commercial broccoli producers come from the Murcia region and have strong leadership and entrepreneurship capacity.

U6 Norms/social capital

In the area, collective and cooperative actions are limited.

U7 Knowledge of SES/mental models

In general, farmers have limited knowledge of the SES and do not consider the side effects of increasing extraction rates. They do not understand groundwater resources as part of a complex and integrated system where actions in some resource units might have (unexpected) results for others. For several years, the number of wells rose uncontrolled, and the farmers were not aware of the depletion of the aquifer until the effects were evident in the reduction in the spring discharge and the related problems.

U8 Importance of the resource

Groundwater is a valued resource in the area for both farming and recreational uses. Local residents of Huescar have used the spring since Roman times for recreational and irrigation purposes, and the irrigation rights of traditional cultivated areas date back to Moorish times. However, traditional farmers do not have the means or the knowledge to use the water for high added-value crops such as broccoli.

For commercial farmers, the situation is different. The high gross margin of commercialised broccoli in the European markets justifies their willingness to pay an extra cost, the compensation they have to pay to traditional farmers for using surface water to irrigate instead of the spring discharge.

On the other hand, local residents allocate a high value to the use of the pond for recreation.

U9 Technology used

Before the 1980s, farmers used traditional surface water irrigation systems based on ditches and surface irrigation. The development of intensive horticulture in south-eastern Spain, mainly in Almeria and Murcia, and the profitability of these crops, attracted the interest of nearby areas. During the 1980s and 1990s, the open-air cultivation of high-value crops (*e.g.*, broccoli, cauliflower, lettuce, etc.) led to an important change in the patterns and techniques of cultivation, supporting the intensive use of resources (land, water, fertilisers, etc.) and more efficient irrigation systems. The current models to produce fruits and vegetables are based on fertigation technologies.

<u>INTERACTIONS (I)</u>

I1 Harvesting levels of diverse users

Before the 1980s, the harvesting level in the aquifer was zero, since farmers only used the spring discharge. However, in 2007, the pumping increased to 7.36 hm^3/year. After the new institutional arrangement, the maximum pumping allowed is 5.80 hm^3/year.

I2 Information sharing among users

Information sharing procedures in the area are not well developed. Neither farmers nor residents are organised in effective networks, and the relationship with commercial farmers is rather limited. The agreement forced the creation of the Groundwater User Association (GWUA), but it is more symbolic than a fully operational organisation. Its role is restricted to the administrative relations with the Guadalquivir RBA.

I3 Deliberation processes

Once the aquifer depletion was evident, the town of Huescar requested action from the Spanish Ministry of Environment, leading to an urgent intervention by the Guadalquivir RBA to address the rising conflicts among the inhabitants and the intensive farmers. The intervention led to the aforementioned negotiation process aimed at regulating water use by the different users in the Los Llanos Plateau.

Since the new institutional arrangement has been in force, and due to the limited number of commercial farmers using water and land resources, no more deliberation processes have been recorded.

I4 Conflicts among users

The dramatic reduction in the spring discharge prompted a great deal of concern among the local inhabitants and farmers with historic rights to use water that led to important conflicts in the area. After an agreement that could be accepted by all parties was reached in 2007, the situation has been characterised by stability.

I6 Lobbying activities

Lobbying activities are limited in the area.

I7 Self-organising activities

Self-organising activities were only relevant at the time of the water conflict; since then, they have been rather limited.

<u>**OUTCOMES (O)**</u>

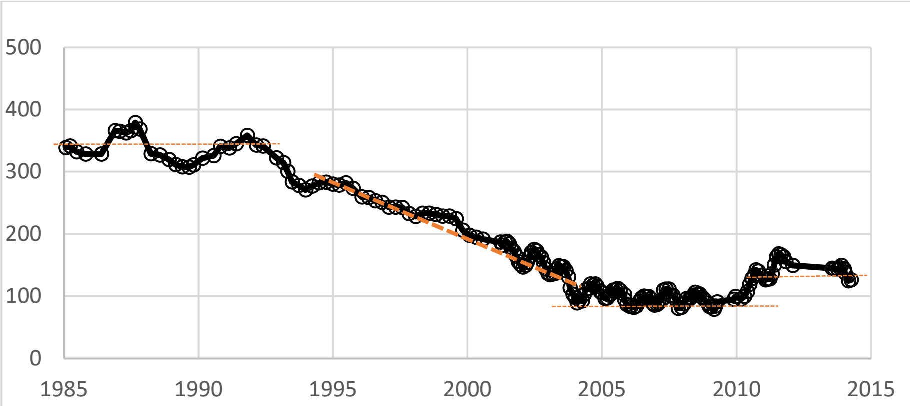
O1 Social performance measures

The agreement was accepted by all parties; hence, the social stability in the area was preserved. Traditional farmers were granted their water rights. Commercial farmers secured water rights associated with land tenure and the high price obtained by broccoli allows them to pay for the extra cost of water. The older farmer population receives now safe incomes by renting their land, and the drop in extraction rates permitted the recovery of the spring discharge in the pond to safeguard the recreational use by local residents.

O2 Ecological performance measures

Figure 5 illustrates the evolution of the Fuencaliente spring discharge over the last 30 years as a six-observation moving average. The continuous decrease in the spring discharge appears to have stabilised after the agreement was reached (2007-2009) and has even been recovering in recent years.

Figure 5. Fuencaliente spring discharge (l/s).



Source: Guadalquivir RBA (nd).

O3 Externalities to other SESs

As mentioned, the aquifer is confined by its geological composition; hence, no externalities to other SES have been identified.