Chapter 18

Taming the groundwater chaos[1]

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ABSTRACT: This chapter deals with how to tame the Spanish groundwater chaos by identifying examples- defined by the absence of actual control or order in the governance and management of the resource combined with physical deterioration. Aquifer use has intensified in the last 50 years, in many cases over the stipulated recharge rate. The Spanish law articulated since 1985 developed measures to regulate and control abstractions by declaring an aquifer overexploited, yet these measures have failed in most cases to make users comply and ultimately improve the quantitative and qualitative status of the resource as required under the Water Framework Directive (WFD). Yet there have been spontaneous user led initiatives, framing collective action institutions. These young groundwater collective institutions developed along a spectrum of available organizational formats, both in the public and in the private domain, reflect the diversity of groundwater rights. An evolution of collective action is emerging with the focus on reducing risk through the development of a portfolio of water resources: surface, groundwater, desalinated, recharged or recycled. The most important development has been the introduction of flexibility of access to multiple types of water resources. An example on this latter aspect is presented, with the case of three groundwater bodies in Almería: Campo de Dalías, Medio-Bajo Andarax, and Campo de Níjar, where a set of diverse institutional settings has been established in order to tame the *chaos*, but which leaves some questions unanswered on the overall resilience of the overall system to intensive groundwater use.

Keywords: chaos, overexploitation declaration, collective action, adaptation, Almería

1 INTRODUCTION

Groundwater has been largely *out of sight out of mind*, yet in the last decades a global silent revolution has come to the fore in many emergent and populous countries in the world. The case of Spain, which underwent this silent revolution four decades ago (Llamas &Martínez-Santos, 2005) offers useful opportunities for lesson drawing and learning in relation to groundwater management and collective institutions.

1 The title of this chapter is in honour of the classic book by W. Blomquist looking at the case of California (USA) (see Blomquist, William. 1992. Dividing the Waters. San Francisco: ICS Press).

Groundwater is currently one of the most extracted natural resources as well as globally the largest stock of freshwater resources, with increased accessibility due to technological advances. It is a new frontier in resource use when e.g. surface water is fully allocated and it is often (politically) easier to look for additional resources than to re-allocate between competing uses. Yet while groundwater intensive use is on the rise globally, groundwater governance is often lagging behind. Groundwater is a classic common pool resource (Ostrom, 1990), and this nature offers both management opportunities and inherent problems. In this chapter groundwater chaos refers to the often absent or ineffective control of groundwater use which often leads to physical deterioration and reengineering by farmers (Shah, 2009). At the heart of taming chaos lies the twin dilemma of ease of access and difficulty in excluding users (or closing the resource). In addition, important inherent resource qualities (like low upstart costs, on site availability, resilience to droughts, etc.), combined with increased uncertainty due to climate variability and change, make groundwater an increasingly attractive resource, and therefore even more pertinent to try and devise workable solutions for taming groundwater chaos. This chapter deals with the cause and consequences of the Spanish groundwater chaos, highlighting the strategies that have been taken by zooming into one specific yet notable example in the region of Almería to adapt to the consequences of intensive groundwater use.

2 THE ORIGIN AND MAGNITUDE OF CHAOS

Groundwater use in Spain has increased dramatically over the last few decades (see Chapter 7) with the total volume pumped growing from 2,000 hm^3/year[2] in 1960 to more than 6,500 hm^3/year in 2006 (Hernández-Mora *et al.*, 2007; Dumont *et al.*, 2011a). This is higher than the 4,000 hm^3/year estimated by MIMAM (1998) this latter estimate does not include groundwater abstracted informally (Dumont *et al.*, 2011b; De Stefano & López-Gunn, 2012), but recent estimates put this figure at 7,000 hm^3 (see Chapter 7). Aquifer intensive use has been the subject of long debates (Custodio, 2002; Llamas & Martínez-Santos, 2005), especially to find a solid definition which links to parallel debates on sustainable yield or the groundwater balance. A growing number of scholars have highlighted the simplistic nature of utilizing a decrease in aquifer reserves and annual discharge or water table level decline as indicators for aquifer overexploitation, since it may mean that the aquifer is evolving to a different equilibrium (Martínez Cortina, 2011). The preferred term of intensive use does not carry normative judgments, while taking into account the modification of the hydrogeological functioning of the aquifer regarding water abstractions (Llamas & Custodio, 2002). Beyond scientific discussions, the Spanish water law includes the concept and procedures to follow for overexploited aquifers, with criteria based on a negative balance between water abstraction and recharge, and where basin boards could declare an aquifer overexploited. Once this declaration is made final, it carries substantive changes in management (see Table 1). In the late 1990s a total of 77 aquifers or hydrogeological units, out of 467 were identified as having problems (ITGE, 1997). However,

2 hm^3 = cubic hectometre = million m^3 = 10^6 m^3.

Table 1 Comparing chaos: groundwater intensive use regulation in Spain.

	1985 Spanish water law	*2000 WFD adaptation*
Management units	467 hydrogeological units, of which 77 are classified as overexploited, and 17 officially declared overexploited.	Approx. 700 groundwater bodies of which 343 are declared as in poor quantitative and qualitative status.
Management implications	Aquifers declared over-used: 1 Close aquifers to new use. 2 Restrict existing water rights. 3 Creation (top down) of a groundwater user group. 4 Establishment of an Annual Abstraction Plan with a cap on annual abstraction.	Implementation of programme of measures to reach the objective of good status at the next planning stage, including the creation of groundwater body communities or *Comunidad de Usuarios de Masas de Agua Subterránea* (CUMAS), Andalusian water law since 2010
User Groups	User communities (wide diversity of both public and private institutions)	Will have to be re-arranged as CUMAS

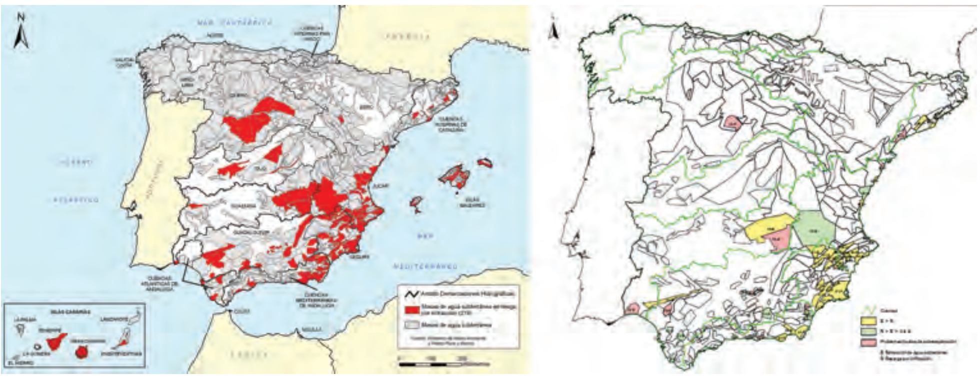


Figure 1 Map of groundwater bodies at risk (left) and map of hydrogeological units (right). (Source: Varela (2009) and MAPA (2001)).

only 17 have been declared legally overexploited and only two with a definite declaration of overexploitation. Accumulated experience has demonstrated that measures and designation of overexploitation have been heavily influenced by political reasons, since a restriction in water use has significant socioeconomic impacts in the area of application.

The European Water Framework Directive (WFD) uses a different terminology to refer to intensive groundwater abstractions. The units for management are designated as groundwater bodies, and the aim is to ensure good qualitative and quantitative status, understood as "the levels of groundwater in the groundwater body such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction". There are approximately 730 groundwater bodies in Spain and 297 were identified as either in chemical or quantitative risk or both and 41 are still under study (see Chapter 7). We see that in terms of number, the severity of groundwater at risk has increased with the WFD criteria (Figure 1). One of the pending challenges to tame the groundwater chaos will be to align the Spanish law with the European mandate where, for example, the declaration of overexploitation could be contemplated under the programme of measures (Rodríguez Cabellos, pers. comm). Nevertheless, taking into account the socioeconomic impact of this declaration, different criteria used, and the difficulties for the administration to make users comply with restrictions, it seems that the WFD provides an opportunity to review this declaration of overexploitation and to find workable measures to make this effective.

3 TAMING THE CHAOS: COLLECTIVE ACTION

It has been shown that users, with a joint objective, can cooperate for the conservation and management for resources used in common, not leading necessarily to a Common Pool Resource dilemma (López-Gunn, 2007). The emergence of collective institutions for groundwater management is part of the solution to chaos as heralded by Ostrom (1990), as a way to address the problem of information asymmetry and transaction costs. This is because the lack of administrative resources is a primary burden towards making a reliable inventory of water rights and extractions, as well as to control individual users' behaviour towards water use (Sahuquillo *et al.*, 2009), even when information technology can help. We see a comparative advantage that local users can have over government in controlling and monitoring groundwater use. In fact partnerships or collaborative approaches can act as complements to the *command and control approach*, particularly when these have not been successful (Rica *et al.*, 2012). Thus it becomes vital to somehow grasp the information held by users as a precondition or necessary step, to tame an inherent problem of uncoordinated – formal or informal – actions by thousands of users.

Spain, together with countries like Mexico or India, has accumulated valuable experience on a range of self-regulation initiatives led by users. Well known globally for its millenary tradition of surface water irrigation communities (see the case of *Heredades* in the Canary islands – Chapter 22), in Spain almost 60% of irrigated land is in hands of irrigation collectives (Valero de Palma, 2011). In the case of groundwater, there are 40 years of accumulated experience by the oldest groundwater user associations (GWUAs) and a new trend in the emergence of new organizations. By exploring the Spanish case, this chapter provides information on lesser known aspects in collective institutions, like the increasing number and diverse range of user communities, focused on groundwater and more recently on other resources like desalinated, recycled or recharged water. The emergence and evolution of collective institutions experienced three waves. The first wave refers to the long and well documented history of surface water irrigation communities. The second wave refers to younger groundwater collective institutions. The third wave marks the appearance of user collectives linked to the use and exploitation of a new range of water resources like desalinated or recycled water, made possible due to technological advances and knowledge. This chapter will only reflect on the last two waves.

Analysing the second wave of collective action, groundwater collective institutions have developed mainly through user initiative along a spectrum of available organizational formats both in the public and in the private domain, reflecting the diversity of groundwater rights (Figure 2). Until recently the nature of the water right (public or private) in many ways marked a path dependence in the nature of the organization. The first groundwater collective institution was established in 1976 in Delta del Llobregat, and since then another 19 collective institutions have emerged. Of these, only a minority (3) were created because of state *dictat* following the Water Act. The majority emerged spontaneously due to user self-interest (Rica *et al*., 2012), as a reaction to droughts or, in most cases, farmers organizing to defend their private water rights when confronted by a potential declaration of aquifer overexploitation. Another important factor to define the nature of the organization is tradition and culture of the region. Many GWUAs along the Mediterranean coast opted for civic associations such as Societies for Agrarian Transformation or Societies of Goods, due to their historical prevalence around Valencia, whereas in Catalonia the choice was to seek the protection of the administration by opting for state water concessions and the constitution of a public Water User Community. Apart from this division according to law, there are other typologies based on their constitutional structure and the categorization by the Water Act as third, second and first order, third order being the most complex (López-Gunn & Martínez Cortina, 2006).

However, there is increased evidence that the nature of the institution, whether public or private has not been a determining factor in effectiveness and performance. More than the juridical nature of the water rights and collective institutions, a number of factors have been important for the effectiveness of institutions: first, issues like secure and agreed resource entitlements, joint infrastructure ownership, or collaborative

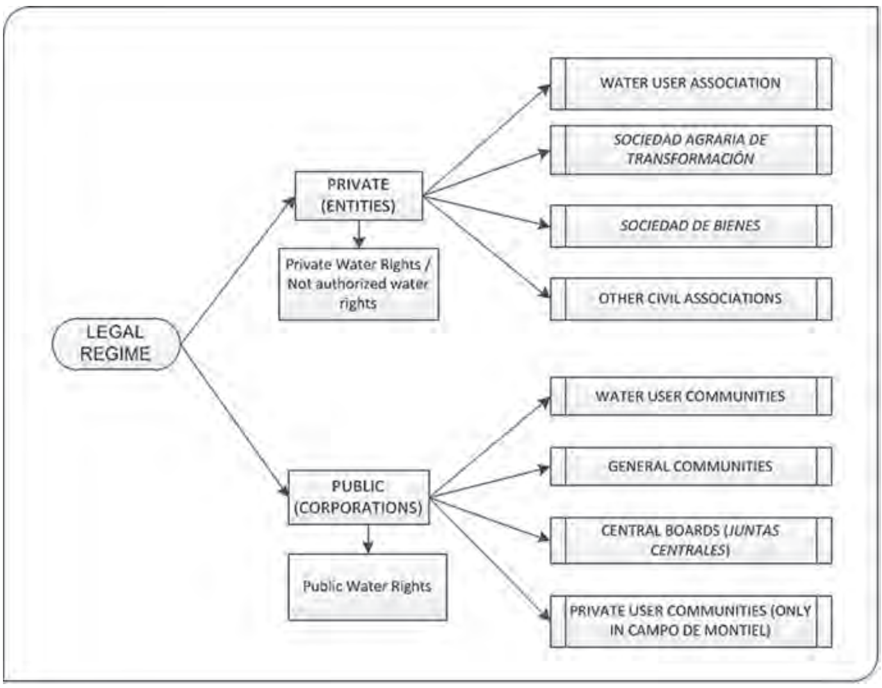


Figure 2 Legal options for the creation of groundwater user organizations. (Source: modified from Rica *et al.* (2012)).

Esquema del corte de un acuífero

Roquedo granítico
Hace de embudo que recoge el agua de lluvia. Es impermeable

Caliza segoviana
Admite aguas y corrientes superficiales

Acuífero detrítico
Gravas y arenas muy porosas y permeables

Arenales
Es donde se forman las lagunas salinitrosas y donde se produce la evaporación

El recorrido del agua

Río Duero

UN MODELO PARA LA RECUPERACIÓN DE LOS RECURSOS

La recarga del acuífero de Los Arenales en el Carracillo es el ejemplo para la zona de Valladolid

MÓNICA RICO / TERESA LAPUERTA

La agricultura depende del agua, un bien escaso a pesar de que el volumen de líquido que existe en el planeta es enorme. Pero, hoy por hoy, podemos aprovechar muy poco: el 97% es agua salada, casi el 2% está congelada en los polos y en forma de nieve en las montañas y solo el 1% es utilizable para el abastecimiento humano y para el regadío. Y de ese 1%, alrededor de una tercera parte, algo más del 30%, es agua subterránea que se filtra a

Figure 3 Newspaper reference to aquifer recharge management model in the Douro basin. (Source: Rico (2011)).

development between users and the administration of abstraction plans, strong internal monitoring and sanctioning mechanisms, and finally, legitimacy of water rights and recognition and support of water user collectives by higher level authorities such as the water boards (López-Gunn & Martínez Cortina, 2006). A third wave of collective action is emerging (as will be analysed below in the case of Almería), with the focus on reducing risk through the development of a portfolio of water resources, which in effect *enlarge* available resources: surface, groundwater, desalinated, recharged or recycled. The most important development has been to introduce flexibility of access to multiple types of water resources. Therefore it no longer makes sense to sectorialize collective action on origin of water or type of water right. For example, in the Júcar basin, *Juntas Centrales* are by norm responsible for groundwater and surface water, acknowledging the complementarity in the use of both resources. Meanwhile in the Douro, there have been interesting experiments with the creation of communities for recharged aquifers (Huertas, 2011) (see Figure 3). Two GWUAs in El Carracillo and Cubeta de Santiuste, established after the recharge projects led by the administration, are facing the complexity of managing a conjunctive use of surface and groundwater, where there is still juridical uncertainty regarding recharged water use (Huertas, 2011).

4 CASE STUDY: GROUNDWATER IN ALMERÍA, INSTITUTIONAL AND RESOURCE DIVERSITY AS ADAPTATION TO CHAOS

Surface water irrigation communities were created almost exclusively by state initiative, whereas in the case of groundwater this was mainly user led. In this context the most striking example of private entrepreneurship is the case of *plasticulture* in Almería, an extensive area of greenhouse agriculture, with up to 27,000 ha the largest in the world, in the Southeast of Spain. This offers a microcosm on the emergence and evolution of collective action in groundwater, while it showcases many of the remaining challenges and available opportunities for taming groundwater chaos. Almería is the most productive agrarian province of Spain and the best example of the silent revolution. In less than half a century the region has catapulted itself from one of the poorest regions in Spain to become a European leader in agri-business. To understand this transformation, it is necessary to take a look at the past, and the growth of collectives managing water from wells. The agrarian policy after the civil war from 1939 was a determining factor for the establishment of agriculture in Almería. Irrigation districts were designed by the *Instituto Nacional de Colonización* (INC), whose objective was to support rural development through irrigation projects. In 1971 the INC became the *Instituto de Reforma y Desarrollo Agrario* (IRYDA), and in 1984 in Andalucía it was named the *Instituto Andaluz de Reforma Agraria* (IARA). In Almería, settlers were established in certain areas, particularly in Campo de Dalías, Campo de Níjar and Huércal-Overa. Technicians from these agrarian reform institutes researched on greenhouse technology on artificial soil to improve land productivity, and the transformation began (Rivera, 2000). Irrigator communities emerged in different ways. The pioneering case was the irrigation districts designed by INC, whose management was then transferred to its users. For example, in Campo de Dalías a number of wells provided groundwater to six irrigation sectors, with land plots linked to a certain well.

This initiative was adopted by the rest of the population, who either contributed with financial resources or labour efforts to build a common well to irrigate their land (Cuadrado, pers.comm.), or bought a small plot from big land owners who sold their hours from the well to land tenants (Jiménez, pers.comm.). These initiatives became *Sociedades de Bienes* or *Sociedades Agrarias de Transformación*, a formal associative figure to regularize the situation of water sharing and land under private law.

Three contiguous aquifers all located in the province of Almería offer insights into existing and future challenges and opportunities for groundwater management (see Table 2). The three aquifers share similarities like climatic conditions and for all, groundwater is a key factor for economic development, based on the export of highly profitable greenhouse crops (estimated at 60,000 €/ha/year) (Dumont *et al*., 2011b). Water demand has grown at a higher rate than the available water resources, leading to a situation of groundwater level decline, made worse by deteriorating groundwater quality and marine intrusion. The three aquifers hold, totally or partially in certain areas, overexploitation declarations from the late 1980s. However, the irrigated surface experienced an increase of more than double, from 15,000 to 30,000 ha approx., that only seems to have stabilized due to the current economic crisis. In terms of actions to address problems with groundwater quality and quantity, a number of initiatives are taking place: the first initiative is based on drilling deeper wells and/or intensifying greenhouse activity with the introduction of more and better water saving devices (see Chapter 19). The second initiative has been collective action by users around organizations within a nested GWUA, making collective efforts to get better energy prices after sector liberalization (Poveda, 2011), together with a better knowledge on the aquifer. And finally, a third initiative is based on water recycling and desalination techniques, allowing both diversification of risk and access to supplementary water resources.

Table 2 Groundwater resources in case study areas.

Name	Campo de Dalías-Sierra de Gádor	Medio-Bajo Andarax	Campo de Níjar
Area	797,09 km^2	341,9 km^2	466,15 km^2
Declaration of over-use (1985 Spanish Water Law)	Declared over-exploited in 1986 and 1995. No management plan.	Declared over-exploited in the lower area in 1986. Management plan in construction. Inventory and process of regulation for private water rights.	Declared overexploited in 1987. Initiative to develop management plan, never implemented.
Groundwater body in new Basin Plan	Gw. body No. 060.013. Bad global state, 2010.	Gw body No. 060.012. Bad global state, 2010.	Gw. body No. 060.011. Bad global state, 2010.
Aquifer	Mixed: carbonitic in mountains and lower aquifer; detritic in coast.	Mixed: carbonitic in mountains; detritic in plains.	Detritic nature.
Water Distribution control	Each GWUA manages own well water rights over the excess water from Beninar reservoir.	Groundwater and surface water in wet years, GWUA manage own well, marketing water to most demanding.	Desalinated water through Water User Associations, farmers manage own well in addition to GWUAs.
Agricultural model	20,940 ha of greenhouses (95% of irrigation in the area)	2,400 ha of greenhouses and 4,200 ha of fruit trees, olives and citric produce.	4,500 ha of greenhouses, 700 ha of horticulture, olive and fruit trees.

Water User groups	Individuals, 60 GWUA (3 delivering surface water partially). *Comunidad General Usuarios/ Junta Central Usuarios.*	Individuals, around 53 WUAS; 14 delivering groundwater totally or partially; 1 using recycled water from city of Almería. *Junta Central de Usuarios* within groundwater body limits.	Individuals, 37 WUAS (2 delivering surface water totally or partially; 1 delivering totally desalinated water to mix with ground-water)
Associative milestones	*Junta Central de Usuarios del Poniente Almeriense*, public corporation created on users' initiative since 1991 incorporating: 7 municipalities, 3 industries, 38 GWUAs from public and civil regimes and around 118 individual users. In parallel there is *Comunidad de Usuarios del acuífero Sierra de Gádor*, which is also a public corporation entity composed by different GWUAs, who refuse to take part in the *JCUAPA* as a General Community.	*Junta Central de Usuarios del Medio-Bajo Andarax* was constituted as a public corporation, including the main WUAs, municipalities, industries and individual users. 16 private entities, and integrating 4,000 members. Besides these small communities that use groundwater, a larger one, *Las Cuatro Vegas de Almería is* responsible for the tertiary treatment by ozone and more recently chlorine of the secondary treated waste-water from Almería city, and for the delivery of the recycled water among its associates.	*Comunidad de Usuarios del Campo de Níjar (CUCN)* was created to manage desalinated water for irrigation from the desalination plant constructed. This is a public corporation in charge of delivering desalinated water, regulated by users.

Source: Own elaboration, based on Junta de Andalucía (2010), and Van Cauwenbergh&Francés (2010).

These three case studies highlight a dual strategy to *augment* water supplies which are intensively used, while the *institutional or formal arrangements* to redistribute good quality resources and stop abstracting in sensitive spots are being worked out (Domínguez Prats & Franqueza Montes, 2009). In the interim, user communities' representatives admitted to informal arrangements to share water with those that had serious quality problems as well as selling *water turns* at the same price or at a higher price, sometimes reinvesting the money on the community and sometimes representing extra income for the water turn owner. This issue requires more attention, since it is

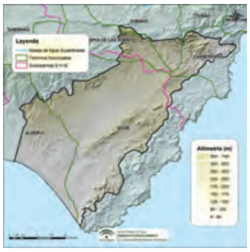
Box 1 Comparative data on the Campo de Dalias, Medio-Bajo Andarax and Campo de Nijar aquifers

Source: Junta de Andalucía (2009).

Campo de Dalías: Regional studies from the Spanish Geological Institute are currently assessing the relocation of wells from areas that are highly sensitive to salinization from abstraction (Domínguez Prats & Franqueza Montes, 2009). Water overexploitation is currently located in the lower aquifer which has better quality and better storage, while upper layers are no longer being used, causing waterlogging as these layers are recovering their recharge balance. There is a plan to diversify the origin of the water, giving particular attention to the nearby reservoir-Benínar, about 3–6 hm^3/year, the de-brakishing of the upper aquifer in an emerged wetland for 2 hm^3/year, the reuse of wastewater from the main cities up to about 10 hm^3/year and desalination for up to 30 hm^3/year. Groundwater wells reach depths of 300 m with pumping costs estimated at 0.13 €/m^3 to 0.19 €/m^3 (Martínez, 2011).

Source: Junta de Andalucía (2009).

Medio-BajoAndarax: The main problems are related to groundwater overexploitation and salinization, contamination of surface and groundwater with badly treated wastewater and diffuse contamination of agricultural origin (Van Cauwenbergh *et al.*, 2008, and Van Cauwenbergh & Francés, 2010). The WUA has a temporary license to use wastewater from Almería city, with a maximum of 12 hm^3/year for agricultural purposes. In 2009, 6.6 hm^3 of recycled water were delivered, where WUA members are not obliged to buy recycled water. However, the use of recycled water does not mean that less water is being abstracted from the aquifer. In wet years, this amount decreases as the WUA then uses available surface water. The price of recycled water is 0.25–0.30 €/m^3, in comparison to the estimated pumping price of 0.13–0.20 €/m^3). Both are significantly more expensive than surface water (estimated at 0.01–0.02 €/m^3) (Pérez Sánchez, pers. comm.). Quality problems with wastewater effluent call for a renewal of reuse infrastructure that has to go hand in hand with establishment of new organizational structure.



Source: Junta de Andalucía (2009).

Campo de Níjar: The alternative resource to increasingly saline groundwater is desalinated water from a desalination plant in Carboneras, the largest one in Europe, with a capacity to generate 42 hm^3/year, not yet used to its full potential. The plant and the secondary distribution network were built mostly through public investment, with users responsible for water delivery in the tertiary network and management. Its construction purpose was to reduce pressure on the aquifer, while securing the relevant economic activity in the area. However, it is not clear whether the use of desalinated water has meant a parallel reduction in groundwater use. Users blend desalinated water with saline groundwater from the aquifer, with price and final water quality being the determining factors on the amount of water used from each source. Depending of the crop produced more (e.g. raff tomato) or less (e.g. watermelon) saline water mix will be used. The user price of desalinated water is 0.48 €/m^3, compared to 0.10–0.30 €/m^3 of cost for groundwater pumping (López, pers. comm.).

an informal way of water redistribution, an informal water market (see Chapter 16 on Water trading in Spain).

In summary, taking into account the tendency to substitute or supplement the use of groundwater resources under stress with other supplies in order to meet demand, it could be argued that groundwater mismanagement acts like a magnet for additional resources. Groundwater chaos makes users vulnerable since there is no insurance against mining the resource in terms of quantity or deteriorating water quality, to the point that it could threat users' livelihoods. Groundwater users to minimize risk – if no management measures are introduced – start to look for additional, non-conventional, resources to secure water availability. These additional resources tend to be more expensive. Yet users pay subsidized prices, which do not internalize the large infrastructure investment, and – when combined with cheaper groundwater resources since environmental externalities are not included (like e.g. reduction in groundwater quality) – means that there is no incentive, signal or internalisation of environmental externalities and no reduction in intensive groundwater resource use. These new water resources are not a substitute, but rather become both additional resources and insurance for risk to a potential lack of water. These non-conventional (better quality) water resources are then blended with existing (poorer) quality groundwater. However, when claiming for additional water, groundwater users are *de facto* reacting to a deteriorating aquifer of which they are both victims and executioners. Yet the necessary signals for social learning from mismanagement are masked, and both the emergence and user engagement in new types of user organizations go hand in hand with a process of legitimizing claims to water and securing access to water. It also gives groundwater users of overexploited aquifers the grounds to apply for subsidies in order to construct expensive infrastructure.

5 CONCLUSION: THRIVING IN CHAOS: THE PROBLEM OF INCENTIVES AND MOTIVATION

In this chapter we have analysed the inherent problems and opportunities of groundwater as a common pool resource, its intensification in use and a range of emergent institutions and strategies that have been adopted. Taming groundwater *chaos* is partly a problem of lack of information by the Water Boards which impinges on the capacity to control and manage. This is partly the reason why the declaration of overexploitation was a not a successful measure and should be revisited in the on-going WFD adaptation. We have demonstrated how the declaration was ignored in the province of Almería, where groundwater use for irrigation intensified after being declared overexploited. This chapter has highlighted that collective action is a spontaneous emerging property of chaotic systems. Through collective action, current lack of information regarding water use, e.g. in terms of inventories of groundwater use rights, could be overcome. The chapter has also identified that whereas debates before were centred on the nature and characteristics of water rights, on the lack of definite water rights inventories and the problem of over-allocation of water rights, now it should also consider the search for additional resources. This is triggered by the inherent difficulties in establishing clear resource boundaries. Regulatory frameworks like the European Water Framework Directive however, raise questions on what kind of incentives can help to keep resource use within its natural (fluctuating) resource boundaries. The question is whether, in order to maintain the resilience of the system, there should be additional water sources as a palliative measure to satisfy current demands or, instead whether before new resources are brought into play, this is made conditional on a previous necessary step like e.g. the development of a groundwater management plan, which maps how the economy can adjust gradually to existing resource limits. That is in many ways the opposite concept to *managed depletion* used in some Western USA states. The examples of recent collective action in Almería show how the introduction of new non-conventional (desalinated, recycled water resources) is an effective way to minimise the risk that lack of water means for a high value agricultural activity, where water is an essential production factor with no substitute. However, using new water resources does not necessarily mean that the quantitative and qualitative status of the aquifer is improving. Therefore, it seems that technological improvements have allowed the socioeconomic system to function. This might however go against the motivation and collective action potential of users to preserve the resource, catalyse social learning and trigger adaptation when faced by resource limits, thus halting necessary innovation. Hiding signals from the system on its vulnerability due to intensive use, if no alternative sources were available, prevents learning from reaching resource limits. In these areas, strategies have emerged to maintain system resilience in a collective way: first, actions towards a decrease in energy price and water efficient infrastructure; second, the acceptance on the need to devise and agree on a groundwater abstraction management plan; and finally, use of alternative sources such as recycled water or desalination. All these strategies point towards a more efficient use of resources. However, only the first two would increase the resilience of both the socioeconomic system and resource base, thus *taming the chaos*. In the final option, users have opted to draw upon external resources rather than self-regulate, breaking the dependency from the groundwater resource. Furthermore, legitimizing GWUAs gives users the possibility to reclaim the financial support needed to develop new infrastructure for alternative sources to be available. Groundwater chaos in the case studies discussed, known as *the orchard of Europe* highlights that taming groundwater chaos is at a cross roads between solutions which emerge and are locally driven and contained, and solutions which require of (subsidised) external resources to make up the water deficit.

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