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Co-management of Groundwater: A Review¹

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Abstract

The sustainability of groundwater abstraction is fast becoming a global challenge. This paper reviews cases and assess the potential of groundwater co-management, beginning by identifying a co-management spectrum with varying degrees of role sharing between the state and user communities. Twelve case studies selected from a global review illustrate varied levels of success. Key contextual elements are identified that contribute to raising the chances of success of co-management. These include certain characteristics of the user community, the existence of a credible environmental or legal threat, joint monitoring and transparency, and substantial available funding. State action is shown to involve a delicate balance between “carrots” and “sticks” as part of a wider political balancing between parties. The limitations of both state- and community-centered governance make co-management appear as a way forward but a delicate set of conditions is needed for it to be effective.

Keywords

Groundwater governance; co-management; participation; groundwater policy

INTRODUCTION

As surface water resources become fully exploited in many river basins worldwide, groundwater is increasingly mobilized by cities, industry, and agriculture. From Morocco to China, California to Chile, the water levels in major aquifers are dropping at alarming rates, with little evidence of solutions to this unsustainable evolution (Famiglietti 2014). About 1.7 billion people are believed to live in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat from overexploitation (Gleeson et al. 2012). Groundwater is key to agriculture and supplies 38% of irrigated areas worldwide and contributes 43% of its water consumption (Siebert et al. 2010).

How and why societies have so frequently lost control of their groundwater resources, and whether and how the trend could be reversed, interrogates governance frameworks. In other words, questions are raised as to what can be done to change behaviours, who has the legitimacy or power to act, and how the benefits associated with actual groundwater abstraction can be balanced with

¹ Preprint version of Molle, F. and Closas, A. 2020. Co-management of groundwater: A Review. WIREs Water.

long-term sustainability. FAO et al.'s (2015) recent findings showed that regulatory frameworks were proving to be problematic and that "non-compliance [was] pervasive". While we examine, in another paper (Molle and Closas 2019), the characteristics and performance of state-centered groundwater governance, this review paper looks at cases of groundwater co-management between the state and users. Due to the poor record of both state-centered governance and common-property resource (CPR) management at the grassroots level, it is often stated that involving both users and the state in the management of groundwater resources is a preferable solution (Agrawal 2001). Yet there is still limited evidence that such alternative governance patterns fare better, let alone constitute panaceas to the current gridlock.

A wealth of information and analyses on groundwater governance has been contributed by the Groundwater-MATE project supported by the World Bank, the Groundwater Governance Project, backed by various multilateral organizations, Varady et al. 2016), and various edited volumes and studies (e.g. Llamas and Custodio 2002; Giordano and Villholth 2007; de Stefano and Llamas 2012; OECD 2015, Jakeman et al. 2016; Villholth et al. 2017). Yet, in OECD's (2015: 15) assessment, "groundwater is generally under-studied and there is a need for more in-depth assessment of groundwater stocks, use, and management practices." The topic of groundwater co-management, in particular, is conspicuously largely absent from the afore-mentioned studies.

Co-management is defined here as management involving both users (generally organized into associations, "groundwater districts," etc.) and the state (often through various agencies), whereby "the responsibilities for allocating and using resources are shared among multiple parties" (Plummer and Armitage 2007: 62). This article sets out to review instances of groundwater co-management to better assess its potential and draw some general lessons.

The article is based on a comprehensive global desktop review² on groundwater governance that benefited from earlier works, but also faced the limitations associated with the substantial overlaps and relative lack of detail in the majority of the ~1,500 documents examined. We attempted to fill some information gaps by communicating via email with 40 knowledgeable scientists in various key countries, while drawing further insight from field and policy research conducted in the MENA region¹. The review has two identified biases: it focuses on countries where groundwater overexploitation is a salient issue and its agricultural use is massive. It also leaves aside the questions of groundwater quality and contamination, transboundary issues, and focuses on quantitative issues and overexploitation.

We start by identifying a co-management spectrum with varying degrees of role sharing between the state and user communities. A set of 12 case studies was selected from the review with the objective of both illustrating the range of institutional situations that may come under co-management (with their varied levels of success) and identifying contextual factors conducive to a degree of success. These include certain characteristics of the user community, the existence of a credible threat of tough state intervention (under environmental, legal or other overarching regulations), joint monitoring and transparency, and substantial available funding. State action is

² In many instances, we indicate relevant countries or cases without providing a full reference due to the limitations of space. Readers can refer to Molle and Closas (2010) and <http://gw-mena.iwmi.org/outputs/> for further detail.

shown to involve a delicate balance between “carrots” and “sticks” as part of a wider political balancing between parties.

THE CO-MANAGEMENT SPECTRUM

There is arguably no such thing as purely state-centered or community-centered governance, given that in general decision-making processes span various scales, constituencies, and organizations. Collaborative management, or co-management, has been defined as “the sharing of power and responsibility between the government and local resource users” (Berkes et al. 1991: 12). Yandle (2003: 180) proposes that “co-management can be thought of as a spectrum of institutional arrangements in which management responsibilities are shared between the users (who may or may not be community-based) and government”. Co-management goes beyond participation in terms of consultation or exchange of information and must include institutionalized arrangements with shared decision-making power (Berkes 2009).

The main stream of research in collaborative governance or co-management probably originates in rational choice institutionalism and its interest in the interaction between institutional constraints/rules and collective action/co-management (Ostrom 1990). This approach expanded from local CPR systems to nested systems of governance and polycentrism in order to better consider cross-scale resource management and the role of the state (McGinnis 2011). Another stream stems from sociological institutionalism and the political science’ interest in governance theory and decision-making, and is more concerned with process, social learning, social capital, trust, conflicts and power relations (Sandström 2009). Here we mainly discuss the co-management of groundwater resources framed as a CPR problem but also refer to sociological aspects whenever possible and relevant.

Pinkerton (2013) warns that co-management should not be seen as a diminished form of self-management parasited by the state. Neither should it be seen as an intent by the state to offload a regulatory or management function that has become too costly in a context of budgetary restrictions or rolling-back of the state (Plummer and Fitzgibbon 2004). As Schlager (2007: 144) rightly notes “given the very difficult physical, social and economic challenges surrounding provision problems and their solutions, groundwater users and governments, in general, will not be able to address such problems without assistance from each other”.

Local users have direct knowledge of the location and types of wells, how intensively they are used and for what purpose (particularly in case of conjunctive use), and the conflicts that may arise from specific spatial configurations (Berkes 1994). Indeed, outsiders cannot adequately comprehend the environmental (aquifers, water fluxes, and varying water quality) or the social (users’ diverse values and interests) heterogeneities that largely govern conflicts, third-party impacts, and individual access.

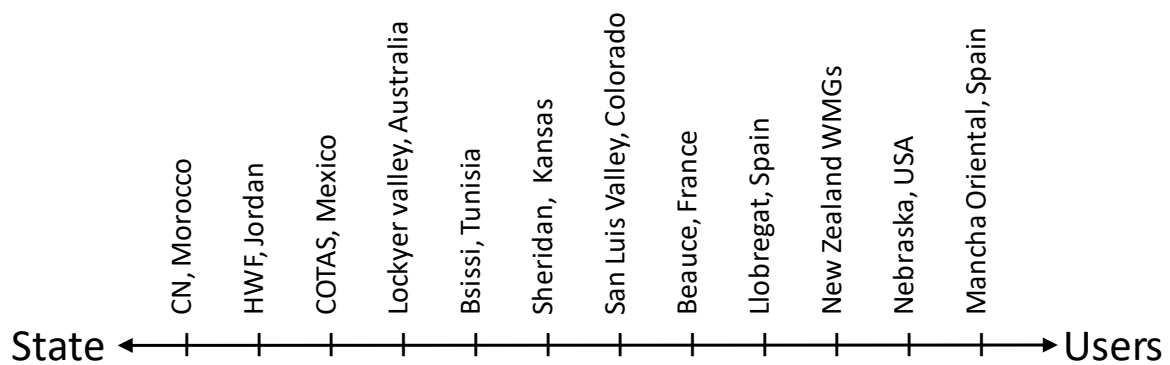
But such local knowledge can be insufficient because users tend to lack the technical capacity to process data and to understand the interconnectedness of surface and groundwater or the relationships between water use and ecological conditions at a larger scale (the basin or beyond) – in other words, the cross-scale nature of environmental problems. Thus it usually falls to state agencies to monitor the aquifer’s status and build a modeling system to achieve an accepted representation of the resource. When the problem reveals itself to be “more than local, [...] government is the only

body with the authority to protect the interests of the co-managers against other parties" (Pinkerton 2003: 66).

The ideal solution would be a synergistic relationship between communities and central authorities in which each party brings its strengths to address the weakness of the other. However, as Schlager (2007: 149) emphasizes, "the shape and form of productive and complementary relations among resource users and different organizations and governments is not well understood and requires substantial investigation".

Co-management thus applies to a wide range of situations where both the state and users play a role in the use and fate of an aquifer, whether regulated or not. We review here a number of cases that can be placed in a continuum between the ideal-types of state and community governance, a ranking that remains tentative and qualitative because no metrics of 'co-management' is presently available (Figure 1).

Figure 1. Examples along the co-management continuum



'Aquifer contracts' in Morocco

In recent years, Morocco has tried to implement an aquifer management model loosely inspired by France's *contrats de nappes* (aquifer contracts). The Ministry of Water presents these "contracts" as a groundwater management tool based on a collective process of dialogue over the shared problems within an aquifer. They are signed by the various public administrations and user associations and incorporate an action plan with the measures that must be implemented in order to protect water resources and sustain groundwater demand (GIZ 2011). Morocco's experience with *contrats de nappes* began in the region of the Souss Massa, which produces around 60% of the country's citrus fruits and accounts for half the country's agricultural exports (Houdret 2012). In 2004, the Basin Agency attempted to close illegal wells, triggering social unrest and the formation of a commission with representatives from 20 institutional partners (the river basin organization, local authorities, agricultural chambers, a federation of water users for agriculture, research institutes, and water suppliers).

An agreement was signed in 2007 by the parties involved in the *contrat de nappe*, including three large vegetable and fruit exporter unions. It included a mix of sticks (freezing the expansion of irrigated areas for citrus and vegetables, increasing the fees for groundwater use), with carrots (subsidies for drip irrigation, legalizing illegal wells, several surface-water infrastructure projects, and

a planned feasibility study of using desalinated seawater). User participation for these contracts was to be based on the concept of “participative planning” (BRLi and Agro-Concept 2012), with no strong delegation of management power to users.

Ten years since the signing of the *contrat de nappe* and despite a much better collective awareness of the problem, the situation is little changed. The contract was undermined by a general *laissez-faire* attitude, the failure of the government to deliver on the supply augmentation projects, and a reduced sense of urgency following a few good hydrological years (*ibid.*). Efforts to introduce a *contrat de nappe* in the Saïss Plain never reached the point of launching a new co-management dynamic and largely ended up in supply-augmentation projects (Del Vecchio 2018).

The Highland Water Forum in Jordan

Azraq Basin is a closed basin located 120 km north east of Amman, where surface and groundwater naturally flow to a central wetland. The abstraction of shallow groundwater to serve both Amman and 10,000 ha of irrigated agriculture resulted in a drawdown of the water table and the drying up of local springs and the wetland in the early 1990s (Mesnil and Habjoka 2012). Recent studies suggest that actual groundwater use for agriculture is more than double the officially recorded data.

The Azraq Basin has benefited from various local, regional, and international initiatives (by UNDP, IUCN, etc) to promote sustainable water management and preserve groundwater resources. A GIZ-funded project which ran from 2010 to 2013 established the Highland Water Forum (HWF) in the Azraq Basin, with the aim “[of] bring[ing] the conflicting water users, particularly the water-governing authorities and the agricultural community, to agreement regarding the causes for dwindling groundwater resources, and to collectively think of creative solutions.”³

When the forum began, farmers were optimistic about its aims and the idea of having an open dialogue with policy makers from different administrations (Al-Naber and Molle 2016). The resulting plan of action (GIZ 2015) mostly included measures sought by the Ministry (devising a fairer water pricing system, setting up a reliable repository of data and information, allocating water by sector, promoting crops with reduced water demand or the reuse of grey water, etc) added to mitigation measures (non-agricultural economic alternatives, awareness programs, or rainwater harvesting), but little in terms of tangible benefits to farmers (improving the efficiency of irrigation and establishing a compensation mechanism to buy out wells, a measure which never materialized).

The action plan was constrained by having to be compatible with the National Water Strategy, in which the ministry holds central and overriding power, with no devolution of decision-making powers to local authorities and/or to users. When the GIZ’s support ended, the HWF was institutionalized and now appears in the ministry’s organization chart, showing both the intent to institutionalize collaboration and that the state remains at the helm. Studies have been carried out recently to find ways of generating a steady and secure source of revenue for the Forum, but the dominant feeling between stakeholders is that its role is likely to remain limited—largely due to a lack of empowerment. It is apparent that the ministry saw the Forum mainly as a means to mediate its reforms, while farmers saw it as a means to claim benefits.

³ See <https://highlandwaterforum.wordpress.com/about/> (Accessed April 2017).

The COTAS in Mexico

In Mexico, water management coordination bodies, such as River Basin Councils and technical committees for groundwater management (COTAS), have been established since the 1980s (Marañón Pimentel 2010; Wester et al. 2007). To date, 82 COTAS have been created with the official objective of restoring and protecting groundwater bodies and reaching a balance between abstraction and recharge (OECD 2013). Studies (e.g. Wester et al. 2011; Marañón Pimentel 2010; OECD 2013) have identified several commonalities across the COTAS experiences.

First, despite being created to enhance and institutionalize user participation, COTAS retained a consultative role without creating the necessary space to share power with users. The National Water Law did not designate a clear role or prerogatives for the COTAS, instead leaving users with "subjective responsibilities to sustainably manage water in a context of already limited citizen participation" (OECD 2013: 117). Second, the development of such platforms was hindered by unreliable information on pump owners and abstracted volumes, as well as by a lack of infrastructure, human resources (Wester et al. 2007; Marañón Pimentel 2010), and expertise to deal with technical issues and hydrogeological data to make informed decisions (OECD 2013). Third, COTAS depend financially on CONAGUA and members received limited/poor training. Fourth, the COTAS' ability to reach agreements on the reduction of groundwater abstraction was undermined by the fact that only a small group of community representatives was invited to participate, and only commercial farmers and agro-industrialists. Agriculture represents around 80% of water use in Guanajuato but only had one representative out of a total of four on the board of COTAS (Pérez Fuentes 2010). Fifth, the lack of benefits accruing to farmers undermined their interest, trust and participation (only 10% of users attend the assemblies) (Valdés Barrera 2014). Last, COTAS have no power to control groundwater abstraction; only CONAGUA has the authority to issue pumping permits and enforce regulations.

Decision-making processes by basin authorities are still politicized and dominated by unilateral actions by the federal water agency (Marañón Pimentel 2010; Wester et al. 2007). Most farmers receive no benefit from COTAS and they are not called upon to share responsibilities. Lack of means and social heterogeneity appear to be fatal weaknesses. To date, COTAS have failed to live up to expectations, signaling the pervasiveness of water politics, and the slow pace of democratization in Mexico.

Lockyer Valley, Australia

In Queensland, Australia, the proposed co-management for the Lockyer Valley aimed to develop effective sharing institutions among groundwater users, with the support of the regulating agency, and to find self-governing institutional arrangements. The Lockyer Water Users Forum (LWUF) was established in the mid-1990s to lobby for better water access (notably from the Wivenhoe Dam, and the piping of recycled urban wastewater to their farms) and to mediate conflicts between upstream and downstream users (Strang 2009). It includes representatives of all irrigation groups in the 18 sub-catchments (Baldwin 2008). Following the 2004 water Initiative, the Forum began negotiating with the Queensland government to develop a co-management approach to groundwater. This was largely motivated by a desire on the part of the users to avoid an inflexible regulatory approach imposed by the government, and to retain control over the resource that is key to their livelihoods (Sarker et al. 2009).

After 10 years of discussions between the government of Queensland and the LWUF, a co-management proposal for the sustainable management of Lockyer Valley surface and groundwater was developed. This effort largely lapsed, however, as the government was not forthcoming, partly due to its lasting perception that the Forum was merely a lobbying structure for farmers. This led to a slowing of progress in the implementation of groundwater management in favor of pricing reforms and the priority given by the government to ensure the financial stability of the water supply company. The government's current plan to reduce allocations and raise prices is viewed with deep concern, giving rise to calls for consultation and further socioeconomic studies on potential impacts, and lobbying against price increases. In summary, the co-management jointly discussed in the 2000s failed to bring benefits to users who resented the imposition of metering/pricing combined with the likelihood of seeing their allocation curtailed. Co-management arrangements were also made difficult by the government only including users in the upper valley (and not all users, some already being 'regulated'), a lack of shared knowledge of the resource, and the mix of small and large commercial farmers (ibid.). Ultimately, the government saw the LWUF as chiefly lobbying towards securing public support for supply augmentation rather than reflecting an interest in more demand management-oriented policies that would restore the balance between supply and demand, and, in turn, failed to engage the users with a view to sharing responsibilities and building trust.

Bsissi, Tunisia

The Bsissi-Oued El Akarit area, near Gabes, Tunisia, covers 5,122 ha, of which 1,619 are irrigated by 138 farmers relying on 213 boreholes tapping the deeper artesian aquifer (Frija et al. 2016; Hamdane 2015). In 1987, the administration issued a decree prohibiting well drilling and deepening in the area and attempted to crack down on violators, resorting to the police to help shut down illegal wells. This led to a very tense situation in 1997/8 when conflicts flared up; 79 criminal prosecutions were brought; some farmers were denied access to their farms; and protests were taken to the national government. As a result, the local administration (CRDA) changed its strategy and proposed negotiation and compromise as a way out of the gridlock. In 2000, the "Association for the protection and exploration of the aquifer of El Bsissi Oued Akarit" was formed in the presence of 103 farmers (out of 134 affected) and representatives from trade unions, the CRDA, and local authorities.

The CRDA agreed with the farmers upon a series of give-and-take measures to control abstraction from existing wells and the drilling of new wells. Members of the association would receive a number of benefits in return for respecting certain rules: limiting total abstraction to 6.3 Mm³/year (to be shared among members according to rules decided by the association); to pay the annual fee (already) dictated by the law for all water users in Tunisia; to report any illegal drilling; to adopt water-saving devices. In exchange, members' wells would be legalized; the administration would help if the well needed maintenance or replacement; members would be allowed to connect to the electricity grid (lowering pumping costs); and they would receive subsidies for micro-irrigation and other investments. The association committed to assisting the CRDA in closing disused or abandoned wells, with the backfilling of 46 tubewells that belonged to farmers who refused to become members of the association. Although 12 old borewells were replaced, and farmers consistently reported violations, it must be noted that only 10% of members paid their fee regularly and several farmers (presumably those not willing to enter the association) moved away to farm in nearby areas (not included in the agreement though using the same aquifer).

Restrictions on abstraction, as well as problems with groundwater salinity and the marketing of products, contributed to the leveling off of irrigated areas, with an additional shift from fruit trees to olive trees, and a decrease in the vegetable area. Several other contributing factors have been noted: the exceptional leadership of the association's second president, the supportive social capital of the farmer community (with a common origin in Ghannouch), shared tribal origin with CRDA staff, the limited number of users, the spatial extent of the group (only a portion of a larger aquifer), allowing some farmers (presumably those experiencing problems with their wells) to move to other land in the vicinity, an effective combination of carrots and sticks, together with the administration's initial resolve to enforce the law, making an "all-stick" scenario credible in the farmers' eyes (Frija et al. 2016; Hamdane 2015).

Sheridan County, Kansas

Although (or maybe because) Kansas relies on the prior appropriation right system, it recently opened the way for voluntary initiatives by groundwater users. A drought brought about policy changes in 2012, including the LEMA (Local Enhanced Management Area) framework that allows water rights holders to develop management plans that implement voluntarily reductions in groundwater use and are supported by regulatory oversight program.⁴ All counties voted down the proposal to reduce use by 20% except the Sheridan County LEMA where, after a process of 11 public hearings, farmers decided to adopt an irrigation target of 11 inches a year—20% less than historic use. Although rainfall has been plentiful in the past few years, and some producers question why they have to use less water when those on the other side of the road do not, after three years, total use has been significantly reduced (by 27%), and so has the drop in the aquifer.

This case of voluntary reduction is seen as successful and linked to several enabling factors: the exceptional leadership of the "skilled and visionary Director" of the local Groundwater Management Area (Owen 2016), the steep drop of the water table in the county, support by legislators in issuing legislation enabling the collaborative LEMA concept, a shared sense that the farmers' grandchildren should be able to farm the area in the future, a limited number of right holders (135), a preference for "local control," trust in a process in which nothing can be imposed without the right holders' consent, the idea that restrictions would otherwise sooner or later be imposed by the state (which can make use of stronger management tools, such as the Intensive Groundwater Use Control Area) (Lord et al. 2013; Owen 2016).

The San Luis Valley, Colorado

In 1966, New Mexico and Texas sued Colorado for violating the Rio Grande Compact that controls water sharing in the basin (Cody et al. 2015). The state of Colorado implemented certain measures but was sued by irrigators, resulting in a 1984 verdict that protected existing users but banned new wells. The drought of 2002 exposed the endemic situation of groundwater overexploitation in the valley and triggered state intervention and a Basin Roundtable of stakeholders and negotiations through which US\$9 million was secured in state subsidies between 2006 and 2013. The state also initiated a process of groundwater regulation which, following the example of the nearby South-Platte aquifer, had the potential to see the shutting down of most junior wells, in line with the

⁴ <http://kcur.org/post/kansas-plan-protect-water-looks-combine-carrots-and-sticks#stream/0>

state's obligations under the Rio Grande Compact. Special Groundwater Sub-District 1 (65,000 ha with 671 farmers), in San Luis Valley, was formed in 2009 and a majority (60%) eventually accepted metering and the establishment of a self-defined and self-enforced mechanism whereby users would be taxed at US\$75/AF,⁵ while those fallowing land would be compensated. Implemented in 2011, the sub-district's financial efforts (20% of the total) were supplemented by subsidies of US\$120 million from the federal Conservation Reserve Enhancement Program to pay farmers to fallow land (Smith et al. 2017). A 30% reduction in pumping was achieved between 2012 and 2013. By 2016, four years into the project, the aquifer was recovering, and 10,000 acres had been fallowed. Water users in sub-district 1 pumped around 200,000 AF in 2015, compared to more than 320,000 previously (HCN 2016).

This case demonstrates a successful mobilization from within a farming community facing the threat of tough state intervention. It was able to exploit its existing social capital based on the degree of homogeneity within the local farming culture and its earlier struggles against the state of Colorado and water export threats. It was also spurred by the realization—triggered by drought events—that the entire valley would likely become bankrupt if no action were taken. The process was aided by sophisticated modeling developed for sub-district 1, the possibly exhaustive knowledge of abstraction points (aided by the geometric pattern of central pivots), the possibility of enforcing measurement, and the relatively limited number of farmers involved (671 in sub-district 1). In this case the “stick” was limited but both the “carrots” (large state subsidies and a self-imposed tax that would be used internally) and the threat were quite high.

Beauce, France

The Beauce Aquifer is a calcareous aquifer shared between six *départements* and located between the Seine and Loire rivers, south west of Paris. It covers around 10,000 km². Agriculture abstracts around 420 Mm³ of groundwater per year for irrigation through 2,138 wells on around 3,600 farms (declared since 1993) (Lejars et al. 2012). During a series of droughts between 1989 and 1992 the wetland of La Conie, fed by the aquifer's high water table, began receding as a result of increased irrigation. An association for the protection of the La Conie wetland petitioned the state about the weakness of the measures in place to limit irrigation (Petit 2009).

In March 1995, an agreement named the Beauce Aquifer Charter (*charte nappe de Beauce*) was signed between the administration and irrigator representatives. It set three alert thresholds associated with increasingly restrictive measures (e.g. prohibiting irrigation for 24 or 48 hours on certain days of the week) (ibid.) to maintain environmental flows in the basin's rivers. It is worth noting that the environmental impact of a water drawdown is very sensitive, and management rules are expected to keep the water table within a range of 3-4 m only. In 1999, the water management plan used the principle of thresholds but also introduced a new system of abstraction quotas. It established the total annual average for volumetric abstractions for irrigation at 525 Mm³, to be shared between farms (with variations according to crop). With a new integrated water resource plan for the river basin in 2007, distinct thresholds and corresponding reduction coefficients were specified for each of four newly defined sub-basin units (Petit 2009). In 2010, a reduction coefficient of 0.8 was applied to all farms (to reach a total of 420 Mm³).

⁵ 1 acre-foot (AF) = 1,234 m³.

Meanwhile, the 2006 Water and Aquatic Ecosystems Law initiated a process of the state's disengagement from groundwater resource management and promoted co-management (Montginoul and Rinaudo 2009). The state remained responsible for setting the maximum volume of groundwater to be abstracted in each basin declared as overdrawn through the designation of water allocation areas (*Zone de Repartition des Eaux*). However, it delegated the task of allocating this volume between users to a "Unitary Body for Collective Management" (*Organisme Unique de Gestion Collective*, or OUGC) (Figureau et al. 2012), often formed under the aegis of the Chamber of Agriculture.

Although the OUGC is responsible for allocating the shared groundwater quota, this is a burden rather than a boon that the state is happy to divest on users. As Lafitte et al. (2008) have discussed, the OUGCs are defined as "hybrids"—part body delegated to fulfill a public service and part irrigator association. Although OUGCs can penalize their members, police functions remain in the hands of the state (Figureau et al. 2012), with the prefect also approving the OUGC internal rules, validating the groundwater abstraction multiannual plan, or imposing one if it is judged unsatisfactory.

Llobregat, Spain

The Community of Users of the Lower Llobregat Valley and Delta (CUADLL) was created in 1975 in order to manage groundwater abstraction in the Lower Llobregat aquifers (south of Barcelona). At the time of its creation, the community of groundwater users requested a "Special Legal Regime" to protect groundwater resources in the area, stop groundwater quality degradation due to significant seawater intrusion, and represent the users with the authorities. The CUADLL was created as an association of individual users (from all sectors) intending to implement a sustainable regime of abstraction for the Llobregat Aquifer, solve allocation conflicts, and manage common interests and the functions delegated by the administration (such as enforcement, monitoring, and control). Its final statutes, approved in 1981, are organized around: a General Assembly of users (each paying a fee based on the volume abstracted), a Governing Board (eight members), a Court (to resolve any conflict), a Technical Commission, a consultative council, and a technical department. The decisions of the board are binding and the CUADLL has legal powers. Voting rights in the community of users are allocated depending on the volumes of groundwater abstracted.

The community of users covers an area of 120 km² where groundwater abstraction represents around 50 Mm³ per year. There are 150 users registered with 800 wells. The groundwater from the delta and Llobregat river aquifer is used to supply drinking water to Barcelona (70%), industry (24%), and agriculture (6%) (1,755 ha).

The main problem facing the CUADLL is seawater intrusion affecting groundwater abstraction and drinking water supply. It is controlled through groundwater recharge creating a "hydraulic barrier" in the Low Llobregat Aquifer, including surface water infiltrations from the river and, since 1969, 20 boreholes injecting treated water into the aquifer. Since the 1970s, piezometric levels have recovered (CUADLL 2014) and total abstraction halved between 1965 and 2005 (López-Gunn and Martínez Cortina 2006). This was mainly due to a dramatic decrease in abstraction for industrial use thanks to developments in water-efficient processes as well as the relocation of several industries, even allowing irrigation to increase slightly. The CUADLL succeeded in controlling illegal well drilling, halving abstraction and restoring groundwater levels. The success can also be attributed to the absolute necessity of controlling seawater intrusion to protect Barcelona's drinking water supply, as

well as the limited number of users, strong governmental support (and control), and the availability of funds for artificial recharge.

New Zealand's Water Management Groups

In New Zealand, recent changes in regulation, such as the National Policy Statement—Freshwater Management (2017), reflect increasing public concern over the cumulative impacts of intensified agriculture and dairy farming on long-term environmental sustainability (e.g. nitrogen contamination). Regional councils have been endowed with increased "responsibility and authority to address cumulative effects of diffuse resource use and have increased pressure on agricultural communities to farm within environmental constraints" (Boone and Fragaszy 2018: 795). Water Management Groups (WMG) have emerged in response to these challenges. They come in many forms—from informal institutions constituted by agreements among neighbours to formal corporate entities.

Boone and Fragaszy (2018) illustrate how some WMGs have successfully engaged with water quality issues and broader environmental challenges while seeking to ensure their members' economic viability. Central Plains Water Ltd in Selwyn Waihora has organized to raise share capital to fund the replacement of groundwater with surface water irrigation sourced from an upstream river offtake. It also requires stringent self-monitoring regimes and reductions in nutrient losses, providing information to permit auditing, metering "consents" greater than 5 l/s, and severely limiting the situations in which new abstractions can occur (*ibid*).

During the 2006-09 drought, the Hawke's Bay Regional Council (HBRC) put severe restrictions on irrigation to protect ecological flows and ecosystem health, prompting agricultural water users to lodge an appeal. A group of users in the Twyford district joined together to represent their interests. The HBRC encouraged the group to establish a "global consent" (allocated abstraction level), including both surface and groundwater and to manage it collectively. The Twyford Co-operative Company Ltd. was formally established and received its global consent in January 2015. Individual members have a binding legal contract with the group that specifies their allocation, and the group retains the right to exclude individuals who do not comply with the terms of their allocation (this is made possible by members' own telemetered well data and continuous streamflow measurement). The company charges dues to pay for an administrator. With time, greater formalisation of New Zealand's WMGs and increased authority become a necessity. Emerging scholarship on WMG signals a context where a diversity of arrangements is possible and where the state devolves substantial power to users.

NRDs in Nebraska

In the midst of the "Little Dust Bowl" drought, Nebraska passed the Groundwater Conservation Act in 1959, allowing the creation of local Natural Resource Districts (NRD) authorized to establish corrective measures to ensure the proper conservation of groundwater. In the 1960s and 1970s, new laws reorganized the state's water management by merging and forming districts along hydrologic units rather than county lines. They empowered the districts, enabled integrated management of resources (connecting groundwater to surface water) (Jones 2012), and allowed the establishment of designated "groundwater management areas" (GMA) where restrictive measures could be enacted. Each NRD has a governing board (5 to 21 members) and runs a groundwater

management plan supervised by the Department of Natural Resources (DNR) (Hoffman and Zellmer 2013).

Despite huge reserves, Nebraska faces localized groundwater depletion problems that reduce well discharge and groundwater baseflow to some rivers. The Upper Big Blue NRD established a GMA for quantity control purposes in 1977 in response to declining groundwater levels. This includes provisions for high-capacity well users to report water use and certify irrigated areas as well as the number of active wells if average groundwater falls below a “reporting trigger” level (Upper Big Blue NRD 2014 and Upper Big Blue NRD website). If groundwater falls below the “trigger 2” level, allocation will be curtailed (ibid). In the Upper Republican NRD, the allocation for the 2013-17 period was a total of 65 inches—or 13 inches annually, with mechanisms for possible "carry-over" between years.

The Central Platte NRD has adopted a "fine-grain" approach, having mapped soils and groundwater resources, and defined 24 groundwater supply management areas. A maximum acceptable decline for each was calculated (in relation to the 1982 level), with increasingly restrictive measures (e.g. reductions in irrigated acres, establishing spacing limits for new irrigation wells) declared as the water table falls to fixed percentages of the maximum decline.⁶ A similar system in the Lower Platte South NRD, in place since 1995, includes five separate “groundwater reservoirs” (LPSNRD 1995), each of which is managed with its own monitoring network, aquifer level "triggers" and associated set of actions to be taken (LPSNRD 1995).

Law enforcement is made easier by the fact that it is exercised locally by district staff. In the Upper Republican NRD, for example, district officials read and service meters and verify their accuracy. Well-drilling can only be carried out by licensed drilling companies and illegal well-drilling is hardly an issue. Violations are also dealt with locally (and in the rare cases where this is not possible, conflict resolution involves the DNR, or goes to litigation). Penalties can be financial or in the form of restrictions on irrigation. In an extreme case, several thousand acres lost the right to irrigate (Fanning 2016).

Longo and Miewald (1989: 753) see Nebraska’s groundwater management as an example of how the resource is managed "tangentially by authoritative policy statements by the legislature," with NRDs being a "major repository of legislative power in the field of water policy." Yet, according to Peterson et al. (1993: 46), NRDs are subject to intense pressure from local right holders, which makes it difficult for them "to guide the redefinition and reassignment of water rights without support from institutions established at the state or federal levels." Other features explaining the relative effectiveness of NRDs in Nebraska include: a consistent monitoring network, the maintenance of a split hierarchy between state bodies and NRDs, the local enforcement of rules thanks to the self-interest in compliance, graduated sanctions, adequate funding mechanisms with support from the state, having ample taxing authority to pay for water conservation projects, and allowing anyone eligible for public office to serve (rather than just farmers) (Bleed and Hoffman Babbit 2015). In many cases, the enforcement of restrictive measures in NRDs has been triggered by overriding legal considerations, in particular those related to the Endangered Species Act and the Republican River Compact, which governs the sharing of water between Colorado, Nebraska, and Kansas.

⁶ Source: <http://cpnrd.org/groundwater-quantity> (Accessed April 2017).

Eastern Mancha, Spain

The JCRMO (*Junta Central de Regantes de La Mancha Oriental*) was established in 1994. It distributes water across an area of 114,000 ha, of which around 100,000 ha depend on groundwater alone (JCRMO 2014). The average annual abstraction peaked at around 435 Mm³/yr in 2000 (Sanz et al. 2011), against 320 Mm³/yr allocated to the area by the Júcar River Basin Plan. The environmental impact includes desertification and the drying up of springs and river base flow (López Sanz 2008). To achieve “good ecological status,” a target of 260 Mm³ was set for 2027, while an additional 33 Mm³ of surface water were granted by the Basin Plan. Although current efforts by farmers “are not enough for a rapid recovery of the water table” (Esteban and Albiac 2011), they have stabilized abstraction at under 300 Mm³ (JCRMO 2014).

The JCRMO and the Júcar River Authority jointly carried out an inventory of water wells and use, and by September 2002, water entitlements were being allocated (JCRMO 2002). Any farmer attempting to drill a well or abstract outside the Water User Association (declared by the authority to be the only official actor) is reported by other farmers to the Júcar Water Authority. If an individual abstracts water over the authorized cap, incremental fines are imposed by the River Basin Authority, after which the Irrigation Court of the Eastern Mancha Groundwater User Community can launch disciplinary procedures against its members (JCRMO 2014) backed by the basin Water Authority. Yet, no water meters have been installed or made compulsory. The JCRMO has secured technical assistance from universities and external projects to divide the overall area into 1,400 units (largely corresponding to areas served by wells), for which total water rights are compared with theoretical crop requirements (based on land-use maps derived from satellite imagery) (Castaño et al. 2010; Sanz et al. 2016).

Several factors have contributed to the emergence of cooperation in Eastern La Mancha (López-Gunn 2009, 2012; Esteban and Albiac 2011): the credible threat that the Júcar Basin Authority would declare the basin overexploited and establish a far more restrictive system of entitlements (as in the upper Guadiana), should no improvements be made to meet the needs of downstream Júcar users, the relatively limited number of users (around 1,000, some of whom are bulk users), the bottom-up creation of the user association and local social capital (López-Gunn 2012), support from the basin’s authority (JCRMO), the state government, and local universities. Factors contributing to control abstraction included:

- a considerable increase in pumping costs due to the drop in the water table (up to 80 m in some locations);
- the substitution of groundwater by surface water transfers (39 Mm³ in 2014);
- the planting of less water-intensive crops, switching from summer to winter crops, and planting one crop instead of two per year (Esteban and Albiac 2011);
- a (subsidized) shift towards pressurized irrigation, which reduced gravity irrigation to 4%;
- a reduction in abstraction of between 20% and 45% during the 2004-08 drought ordered by the water authority, with the state buying back entitlements from farms located near the

river in order to protect environmental flows (Sanz et al. 2011; JCRMO 2008). This explains the drop in total abstraction from 379 to 270 Mm³ between 2005 and 2007.

KEY CONTEXTUAL ELEMENTS OF CO-MANAGEMENT

In this section we attempt to discern the key elements in instances of (relatively) successful co-management, mainly drawing on the 12 examples above but also providing additional illustrations from other cases (not presented above for lack of space), wherever relevant.

There is a large body of literature on the factors associated with a higher likelihood of collective action taking place, beginning with Ostrom's (1990) design criteria and the many authors who have built on them. This includes Agrawal (2001) and, to take a few examples related to groundwater, López-Gunn and Martínez Cortina (2006), Schlager and López-Gunn (2006), Ross and Martínez-Santos (2010), Bleed and Hoffman-Babbitt (2015), and Langridge et al. (2018). We do not seek to identify or confirm all these factors here but single out the most relevant features.

Nature of the user community

Firstly, co-management is clearly facilitated when the transaction costs of collective organization are low. The number of groundwater users affected by the future of a given aquifer is of course a key feature. Some examples of the numbers involved are: the Namoi (~450), Lockyer (600), and the Lower Murrumbidgee (315 deep groundwater licenses) in Australia, Bsissi (100+), Sheridan County (135), Twyford Co-operative Company (196), Llobregat (150), Selwyn Waihora (934), Eastern La Mancha (~1000), the Beauce (2000+ wells), and the San Luis Valley (3000+ wells). This suggests that a few hundred, even up to a thousand or more, farmers might be a "manageable" number for collective action and co-management. Those with larger numbers, such as Western La Mancha Aquifer (17,000), the main aquifers in Moroccan (tens of thousands), India or China, are understandably (much) harder to manage. Of course, while a smaller number may help, this factor cannot by itself ensure effective management.

A second characteristic is social homogeneity and social capital. Bsissi and Eastern La Mancha display high levels of trust and reciprocity amongst users, and bonding social capital (López-Gunn and Martínez Cortina 2006; López-Gunn 2012) as is the case in San Luis Valley and many parts of the US. By contrast, where groundwater users have unequal means and power, and divergent interests, it is hard to reconcile their objectives. Typical cases include Mexico's COTAS (see Hoogesteger 2018), Peru, Morocco, and the western fringe of Egypt's Nile Delta (see Molle and Closas 2017).

The cases of Bsissi, Sheridan County, JCRMO, and Twyford Co-operative Company underline the importance of local leadership. Indeed, López-Gunn and Martínez Cortina (2006) showed this to be a primary factor in the successful self-regulation of uses by users in Spain, one that features prominently in the CPR literature.

Credible threat

In several cases, groundwater users were encouraged/compelled to organize in the face of a credible threat to the *status quo* in case of inaction. The threat can be the looming collapse of the groundwater economy or the imposition by the state of a non-desirable solution. In the Eastern La Mancha Aquifer, the Júcar Water Authority threatened to declare the basin overexploited and to

establish a far more restrictive system of entitlements (as in neighboring Upper Guadiana) if no improvements were made (López-Gunn, 2012; Esteban and Albiac 2011). In France, agricultural users in overexploited areas must now form OUGCs in order to be granted a quota they can manage and apportion themselves. The OUGC must submit its plan for approval by the prefect (*préfet*), failing which, top-down administrative orders can be imposed on users. Farmers in San Luis Valley, Colorado, also designed home-grown measures for the reduction of abstraction so as to avoid state intervention (a threat made vividly credible by the shutting down in 2006 of 440 wells in the nearby South Platte River). In Bsissi, initial moves by the administration to close wells also made credible the threat of more authoritarian measures.

In the US, state policies and laws have frequently evolved under the pressure of threats. Arizona belatedly adopted groundwater legislation when facing the withholding of federal funding for the Central Arizona Project (Schlager 2006). In Texas, the legislature passed Senate Bill 1477, creating the Edwards Aquifer Authority, not only to preserve and protect the aquifer but also to avoid federal intervention (Dupnik 2012; Gulley 2015). More generally, the Groundwater Conservation District Act of 1949 was passed as a political compromise, with the sole purpose of avoiding centralized control and granting counties the responsibility of creating Groundwater Conservation Districts (Dupnik 2012). Likewise, in California, the last protracted drought led the state to issue a new bill (2014) that empowers local groundwater agencies but also forces them to design management plans with “minimum thresholds” and “measurable objectives” under the threat of intervention by the State Water Resources Control Board.

Environmental or legal trigger

In other cases, decisive moves towards negotiated (sometimes top-down) management rules are also linked (at least in northern countries) to environmental degradation or third-party impacts and the resulting legal challenges.

In Spain, the Western La Mancha Aquifer was declared to be overexploited in 1987 after an iconic spring feeding the Tablas de Daimiel Wetland dried up due to over-pumping. In 1991, the Guadiana River Basin Organization imposed volumetric restrictions for individual wells, prohibited the drilling of new wells, froze all new groundwater abstraction concessions, and enforced the creation of a community of groundwater users (Closas et al. 2017). Similarly, the co-management of the Beauce Aquifer, France, began when the La Conie Wetland started to recede due to increased irrigation and a local environmental protection association lodged a complaint with the state (Petit 2009).

The over-abstraction of the Edwards Aquifer, Texas, triggered a lawsuit by the Sierra Club in 1991 against the US Fish and Wildlife Service for failing to enforce the Endangered Species Act and protect the species that depend on adequate flows in springs and rivers. This led to the creation of the aquifer authority (Gulley 2015) and the establishment of volumetric allocation and management rules (Dupnik 2012; Gulley 2015). In response to an impending crisis in Tampa Bay in 1972, the Florida legislature passed the Florida Water Resources Act, requiring water management districts to establish minimum flows and levels for surface water bodies and aquifers to protect ecosystems and livelihoods.

The Nebraskan legislature’s initial measures of the 1950s (the registration of large wells, well spacing, etc.) arose from the Little Dust Bowl drought, while dropping water tables motivated the

1975 Groundwater Act (Bleed and Hoffman-Babbitt 2015). Today, NRDs deemed to be over-appropriated must make management plans to protect stream flows under the Federal Endangered Species Act. A similar situation is found in the Rio Grande River Basin (De Stefano et al. 2018). Interstate compacts can also impose supra-state restrictions, as described in the cases of the San Luis Valley and the Republican River Compact discussed earlier.

In Australia the "Millennium drought" triggered several changes. The management plan for the Murray-Darling basin was enabled by the Water Act of 2007 that redefined the priorities of the basin's water policy and led to the creation of the Murray-Darling Basin Authority (Weir 2011). Most of the policy measures of recent years are motivated by the objective to establish environmental flows in the Murray-Darling River (Marshall and Alexandra 2016).

The threat of state direct intervention and/or strict enforcement of legal obligations casts a "shadow of hierarchy" (Börzel and Risse 2010: 116) that is key to making co-management work. This means that "the state threatens – explicitly or implicitly – to impose binding rules or laws on private actors in order to change their cost–benefit calculations in favor of a voluntary agreement closer to the common good rather than to particularistic self-interests" (ibid.).

Transparency and scientific knowledge

The enforcement of jointly agreed (or imposed) management rules is greatly enhanced by accountability mechanisms, transparency with regard to the rationale behind the measures, the data/models used, and the distribution of costs and benefits (Varady et al. 2016). (This is a common thread in the CPR literature.)

In the cases of Nebraska, San Lluís, France and Spain, credible modeling was essential (particularly of surface-groundwater interactions and flows). In Eastern La Mancha, Spain, theoretical crop requirements are based on land-use maps derived from satellite imagery (Castaño et al. 2010). The public are able to check whether the information for a particular plot is correct, and the transparency of this system won the support of members (Sanz et al. 2016). Ross and Martínez (2010) refer to cases in Spain and Australia that show that, while elaborate groundwater modeling is needed to determine desirable action, great effort must be made to explain outputs and hypotheses, with the involvement of both scientists and practitioners.

The Edwards Aquifer Authority has been promoting the use of remotely sensed meters and meter-tampering detectors. Its website is remarkable in terms of transparency, providing a list of all license-holders and hydrological data. The Orange County Water District, California, promotes mutual checks by publishing the annual pumping volumes of major groundwater users (non-irrigation users over 25 acre-feet per year).

When it is expected that rules will not be adhered to, indirect transparency can be enhanced by other means. In Peru, the National Water Agency provides a phone number and email address for people in areas with prohibited well-drilling to "report clandestine drilling," as indicated in street posters (James 2015a). In the San Luis Valley, Colorado, in 2006, some urban communities hired private investigators to discover which farmers were not abiding by the pumping ban (Cech 2008). Jordan's Ministry of Water Resources and Irrigation now publishes in newspapers the names of

illegal groundwater users and the amount of their unpaid water bills (“naming and shaming”) (Al Naber and Molle 2017).

Funding and legal empowerment

Co-management implies user participation at a level that requires funding for their activities, and/or to implement agreed measures. The Highland Water Forum in Jordan has produced an action plan but, as yet, no mechanism for its self-funding. The water roundtable for the Copiapó River, Chile, had no independent funding, depending instead on the state's agencies (DGA 2009). In Morocco, the Souss-Massa's first aquifer contract was reportedly undermined by the state failing to provide the agreed funding (for new dams, etc.) A lack of earmarked funding or internal mechanisms to raise funds is generally a sign of a weak and/or transient initiative.

By contrast Nebraska's NRDs are authorized to raise funds. In 2013-14, their budgets ranged from a low US\$900,000 to US\$17 million (Edson 2014). They also have access to state and federally funded programs, but the grant application must be approved by the funding agency and these funds often require a local match. Since 2007, they can levy an occupation tax (per acre of land) and production fees.

In Texas, Groundwater Districts have limited revenue and operational efficiency due to their insufficient jurisdictional area. Funds from taxes and fees are a hindrance for the GCDs with taxing authority, as many local communities are hostile to further taxation (Dupnik 2012). Likewise, California's state-wide groundwater monitoring programs and water regulatory agencies are said to be “chronically” underfunded, contributing to “decades-long backlogs in processing water rights applications” and reflecting, in part, “political opposition to action by those who benefit from lax enforcement” (Grantham and Viers 2014: 8).

Funding is key to the “professionalization” of NRDs in Nebraska and elsewhere, and is still missing in New-Zealand's WMG, or Idaho (Bray et al. 2018), where groundwater districts have no paid staff and little power of enforcement, and in the Texas High Plains (Closas and Molle 2018). The cases of San Luis Valley and Central Plains Water Ltd. Also demonstrate the importance of users tangibly benefitting from the money collected.

THE POLITICAL PROCESS

A balance of carrots and sticks under a "shadow of hierarchy"

The state's limited capacity to control diffuse groundwater pumping on the ground (see Molle and Closas 2019), extends to co-management situations, as does the evidence that “stick only” policies are unlikely to work. Case studies suggest that co-management is more likely to succeed in a context that associate 1) a “shadow of hierarchy” with a 2) delicate balance of sticks and carrots.

“The Damocles sword of threatened direct state intervention” appears as a key element of inducing collective private self-regulation (Schmitter and Streeck 1985: 131, in Börzel and Risse 2010). However, a country with limited statehood is generally unable to enforce its own regulations and is therefore unlikely to be able to cast a credible “shadow of hierarchy” (ibid.). Conversely, a strong state might not see the benefit of resorting to co-management in lieu of hierarchical action (as the Lockyer Valley case study suggests).

Once the shadow of hierarchy is established, users need to perceive individual benefits and costs as largely commensurate (echoing one of Ostrom's design principles), with the collective objective of restoring a degree of sustainability as a credible prospect. The “stick” side is generally associated with obligations such as declaring illegal wells, metering, imposed quotas, banning drilling or specific crops, or disincentives such as water pricing or penalties for illegal practices. These measures, by nature, result in curtailing access to water and reduce the stream of benefits to users.

Governments must come to realize that water regulation in general requires substantial funding, and that restoring a balance requires massive outlays, proportional to the shortfall in the water equation. Lopsided propositions only breed discontent and are unlikely to be adhered to. The benefit side may include incentives such as compensation for land fallowing (La Mancha, San Lluís Valley), subsidies for irrigation technology or growing certain crops (Morocco), connection to the grid (Bsissi), the buyback of wells, water market mechanisms, supply of other economic opportunities, etc. But the main measure awaited by users is that of substitution of surface water for groundwater, either through local storage or inter-basin transfers (e.g. Mexico, Morocco, Spain, Central Plains Water Ltd in New Zealand, Lockyer Valley).

In 2007, in the midst of the millennium drought, the Australian government funded a package of A\$12.8 billion, named Water for the Future, that earmarked A\$3.1 billion for the purchase of water entitlements from willing sellers (Grafton 2017). In the Guadiana Basin, Spain, the state used EU funds to compensate farmers willing to stop or reduce groundwater abstraction to preserve natural ecosystems (Closas et al. 2017). In France, irrigators in critical areas used their OUGC status to negotiate benefits, such as subsidies for on-farm storage as an alternative source of water (Loubier 2017). In Nebraska, a Water Sustainability Fund created in 2014 dedicates US\$11 million of public money per year to support programs that increase aquifer recharge and streamflow and reduce aquifer depletion (Bleed and Hoffman-Babbitt 2015).

Access to carrots must be linked to compliance with constraints. In 2002, the California Legislature approved Senate Bill 1938 establishing a system of carrots and sticks by requiring local agencies to establish and implement groundwater management plans with specific components in order to be eligible for state funding (Osuji et al. 2003). Similar incentive-requirement schemes were associated with the 2014 bill. In contrast the case of the Guadiana Basin, Spain, signals a failed stick/carrot scheme because the authorities did not have the necessary enforcement and monitoring capacity (Closas et al. 2017).

Although the financial dimension of the cost/benefit equation is fundamental, other benefits and costs are associated with the division of power between the state and the users, the latter being granted prerogatives or support, but also responsibilities or duties.

Ideally maximum decision-making is left to the users, *within* a set of overarching rules (e.g. access to the aquifer granted only by the state or banned altogether) and management targets, e.g. the abstraction level compatible with "sustainability" levels that are either jointly defined (e.g. Texas, California), or imposed by ecological realities (e.g. minimum river baseflow), or legal obligations (e.g. inter-state compact). Users can, for example, share a total abstraction volume between themselves (like in Bsissi, Spain or France). Quantitative monitoring of actual use, and possibly of groundwater levels, is best left to the users but it is crucial that they draw a benefit from this and understand how the information is used.

Formation of the state-user interface

The balancing of the roles and power of the state and the user communities varies (widely) according to local socio-political circumstances and dynamics. Whether some form of co-management can emerge depends on particular political processes. Users must make their own tradeoff between their short-term interests and the gradual degradation of the resource. The state must also weigh the political cost of its (in)action with regard to short-term electoral considerations and the wider long-term public interest, considering its room for maneuver and the resources it is able or willing to devote to mitigating/solving the problem.

Our review allows us to distinguish three main situations. In Situation 1, the state sets the stage for some token co-management that provides a gloss of participatory governance as a gesture to national politics and/or in response to donor pressure/solicitations (e.g. Jordan and Morocco). There is no participatory culture within state institutions and no strong intention to “share decision-making power.” The co-management façade may be a fig leaf for conventional command-and-control approach or even for conventional capital-intensive solutions (wastewater treatment stations, desalination, or inter-basin transfers) that provide respite by bringing in more water rather than curtailing supply. In some cases, the “space” created for users is filled by building lobbying power for certain farmers, as in the case of COTAS in Mexico. Benefits are few, the sticks and the threat lack credibility.

In Situation 2, degraded local conditions clearly threaten the sustainability of both livelihoods and capital accumulation by agribusiness, prompting some collective reaction from groundwater users. In Spain, the CUADLL was formed in response to the threat of salinization, while dropping aquifers motivated farmers in Almeria to organize and lobby the state for more water (Petit et al. 2017). In Australia, the Lockyer Water Users Forum began negotiating with the Queensland government to develop a co-management approach to groundwater but with a focus on augmenting surface water supply (at public expense). In eastern England, Water Abstractor Groups (WAGs) have emerged as a way of creating a "robust lobby to better defend and secure their water rights, especially in the face of a growing risk of scarcity" (Holman and Trawick 2011). In the Altar-Pitiquito District, Mexico, producers of all stripes felt pressed into action because of several mounting threats and uncertainties (Wilder and Whiteford 2006). In Ica, Peru, a groundwater user association (JUASVI) was created by a group of businessmen (Cardenas Panduro 2012).

In most cases, thus, these bottom-up processes hope to lobby the government into granting more permits or increasing supply by water transfers or other means rather than being motivated by a desire to jointly achieve sustainable management. The local political economy framework and the socio-political context dictates the attitude of the state (e.g. refuse co-management as in the Lockyer Valley, or support it like in the Llobregat), the eventual distribution of costs and benefits between the state and the users (e.g. public investment, PPP, shared funding, etc.). Users attempt to limit or reverse growing costs and to diffuse the threat of state intervention.

In Situation 3, the state is urged into action by a perceived crisis situation (such as land subsidence, saline intrusion, farmer bankruptcy, wetland destruction) and sometimes its legal implications, and co-management appears the only viable option, whether this is seen as desirable, a lesser evil, or the only solution by default. It is interesting to note that co-management often follows earlier unsuccessful attempts by the state to enforce the law unilaterally, notably by closing illegal wells.

This was the case in Bsis and the Souss, where social unrest triggered by such measures forced the state into a compromise and setting up a participatory process. In the Copiapó Basin, Chile, the public opposed a project by a Canadian mining company and the DGA felt forced to initiate a “water roundtable” (Dourojeanni et al. 2010).

Co-management can be constrained by past legislation, such as in South Africa or several parts of the US. In Texas, the laissez-faire rule of capture and a policy platform premised on private property rights have limited the state’s power to influence behavior (Kaiser 2006; Closas and Molle 2018).

Whether users are coerced into participation (gently or otherwise) or they realize the need for state support of their local actions depends on a variety of social, legal, and political factors, the delicate balance of carrots and sticks, and the credibility of the “shadow of hierarchy”. While in the Beauce case, farmers and OUGCs were left with no choice but to comply (albeit after negotiation), in the cases of eastern La Mancha, Nebraska, and New Zealand, a better synergy between the state and users was achieved.

Three qualifications are in order here. First, it is not always easy to distinguish between bottom-up, user-driven and top-down, state-driven processes, as they can coincide (e.g. La Mancha). Second, the state/user divide is a simplification that ignores social complexities, for example the financial and political interests of local ruling elites that can override state power (e.g Yemen). Third, neither the “users” nor the “state” are homogeneous entities. States are composite and efforts at co-management can be thwarted by the development drive of different ministries (typically agriculture). Users may include heterogeneous “farmers” (smallholders to transnational agribusiness) with different political connections and interests.

Co-management must consider the dynamics that exist within the user group and establish mechanisms to deal with internal disagreements. These could include elaborate internal structure (such as the CUADLL's internal court), the authority to issue penalties or even to exclude users (Nebraska), and to issue binding decisions (New Zealand). The state can provide conflict resolution mechanisms, legal legitimacy, support for data analysis, subsidies, financial autonomy and the power to raise funds and levy fees, etc. so as to support the group leaders' position vis-à-vis their members (e.g. in Nebraska).

CONCLUSION

A severe imbalance between the availability of the resource and its use can hardly be remedied by mere top-down regulatory pressure and decrees (Molle and Closas 2019). Co-management is thus often touted as the answer but is usually a hasty response based on the widespread failure of both state- and community-centered governance rather than empirical evidence of its virtue. Cases of successful aquifer co-management remain relatively rare, not allowing for a systematic identification of commonalities, but the examples examined here allow us to single out some contributing factors and draw some conclusions.

First, it should be noted that while arrangements may be limited to specific processes or times of crisis, as in Lockyer Valley or San Luis Valley, co-management implies a gradual institutionalization of strong and legally empowered groundwater user associations (as in Nebraska or Spain), the cases of

New Zealand, France and California showing a gradual institutionalization process. In all cases this is a long process that extends over decades.

In line with the CPR literature, our examples confirm the positive influence of factors such as a limited number of users (a few thousands at most, preferably tens or hundreds), the relative social homogeneity of users (and presence of bounding social capital), large autonomy with regard to funding, transparency in the use and sharing of information on the availability of the resource and who uses it, and sophisticated modeling capacity to assist negotiations—particularly a better understanding of surface water-groundwater interactions.

Regarding the resource itself, it is apparent that management is easier where it is not too degraded—where its recovery, or at least its stabilization is a credible objective (France, New Zealand, Nebraska, Llobregat). As with state-centered governance (see Molle and Closas 2019), the physical and financial possibility of additional/substitute water appears to be key in reaching an agreement in which supply is not (significantly) curtailed.

But the most important conclusion of this review is the usefulness of combining three factors: a "shadow of hierarchy" whereby the threat of state intervention is made credible. Credibility, and compliance, depend on the state's legitimacy to impose restrictions: legitimacy is clearly boosted in times of crisis, when everyone stands to lose if external intervention is not forthcoming and when legal changes are often made to reinforce the power of both the state and user organizations; but also when the state is seen to implement a higher-order law (protection of prior appropriators or endangered species, or interstate agreements in the US) or directive (EU principles on "the good status" of water bodies). Second, within the overall framework of management constraints and targets, users must be left with maximum decision-making autonomy, an autonomy—together with the means of dealing with internal disagreements—that can be enhanced and supported in various ways by the state (funding, data analysis, legal framework, conflict resolution mechanisms, etc). Third, a delicate balance must be struck between sticks (the fees and restrictions imposed) and carrots (all types of benefits), as users are unlikely to accept the former without corresponding benefits at the same (or higher) level. This means that substantial state funds are required, especially for supply-augmentation options. The optimal combination is when benefits equal or exceed costs, but with a looming threat of state intervention that influences individual benefit-cost analysis by making credible a default scenario with much higher costs. Examples in the US, Europe, and New Zealand suggest that co-management can work, but they also signal a number of demanding prerequisites that must be assembled.

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