GROUNDWATER GOVERNANCE: A SYNTHESIS

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Groundwater governance in the Arab World

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Foreword

This synthesis report is part of a project on "Groundwater Governance in the Arab World," funded by USAID, which includes a review of global groundwater management and policy options. It pays particular attention to the region of the Middle East and North Africa (MENA), with case studies in Tunisia (Haouaria region), Jordan (Azraq groundwater basin), and Lebanon (central Bekaa). Each country's case study was the object of two scientific reports: a study of the groundwater policy background and history and a report on field investigations in each basin. The latter were carried out to document the current dynamics and problems of groundwater-based agriculture. Further to these studies, dialogues were conducted with and between local stakeholders and policy-makers in each location.

The control and regulation of groundwater abstraction is perhaps the most vexing issue of water management worldwide, with very few encouraging 'success stories'. This broad synthesis exercise aims to present the variety of problems and challenges that exists around the world in relation to groundwater governance in order to inform management and policy pathways. With reference to history, politics, and regulation, we analyze the management tools available, reflecting on the laws, community action, and institutional structures that can be mobilized to curb groundwater over-abstraction.

The report is based on a selection of the existing and accessible literature, as well as direct email exchanges with several experts worldwide. However, we have not attempted to be exhaustive. The examples reported and analyzed here are organized in a comprehensive manner, with the objective of shedding light on the challenges posed by groundwater over-abstraction and identifying potentially effective action and enabling factors. We also aim to flag the limitations, or even irrelevance, of certain policies that have become standardized or seen as desirable.

The gravity and complexity of the situation requires a systematic and wide-ranging approach that builds on the existing knowledge and practices in and beyond the region. Innovations in groundwater regulation and legislation must be identified so as to reverse or dampen the current trend in groundwater depletion and avert greater environmental and economic disaster.

TABLE OF CONTENTS

Figures

Tables

1 Introduction

1.1 Groundwater depletion as a global phenomenon

Water found in rock and soil formations below the surface of the earth after infiltration from precipitation and streamflow, known as groundwater, sustains multiple human uses and users as well as the environment (e.g. water-dependent ecosystems, rivers, wetlands). The persistent use of groundwater resources above their ''safe yield' over an extended period of time is called over-abstraction and leads to depletion of groundwater stocks (Wada et al. 2010). Groundwater over-abstraction is a vexing and pervasive phenomenon. It has been quantified that about 1.7 billion people live in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat from overexploitation (Gleeson et al. 2012). Nearly a third of the world's largest aquifers are being depleted faster than they can be replenished (Richey et al. 2015) due to constant exposure to pumping by a scattered multitude of abstraction points.

With the advent of more modern drilling techniques and pumps, irrigators have reacted to shortcomings in the delivery of surface water, and users in general have adapted to local water scarcity, by resorting to groundwater. The use of groundwater is evolving from 'a reserve resource' tapped in times of crisis to a more systematic use by users who find it a more secure and reliable resource. Specific hydrogeological characteristics make this opportunity easier for some than for others, depending on aquifer yields, geomorphology, depth, storage capacity, etc. as well as the socioeconomic characteristics of the users themselves.

The over-abstraction of groundwater by a multitude of small farmers constitutes an extreme challenge to the sustainability of agriculture, especially in the face of sectoral competition and the gradual reallocation of water to urban uses. Still, groundwater contributes to 43% of agriculture's water needs (Dalin et al. 2017). While irrigation used 20% of non-renewable groundwater in 2000, this amount increased by more than a fifth by 2010 (Dalin et al. 2017; Wada et al. 2010). Such dependency is more acute in arid and semi-arid regions, where the use of non-sustainable groundwater can exceed 80% (e.g. Kuwait, Qatar) (ibid.). International food trade has also been found to contribute further to the depletion of groundwater reserves, with 11% of non-renewable groundwater embedded in traded food stuff (Dalin et al. 2017). The magnitude and importance of groundwater resources and their use by humankind is perhaps singularly heralded by a recent demonstration that the amount of water withdrawn from aquifers is, astonishingly, contributing to rising sea levels, although less than previously believed (Wada et al. 2016).

Of the arid regions in the world, the Middle East and North Africa (MENA) region is characterized by a very poor endowment of water resources with many countries having less than 500 m^3/capita/yr of renewable water resources (Al-Zubari 2012; World Bank 2007; UNDP 2013; UNEP/MAP/Plan Bleu 2009). This region has the highest use of renewable water in the world and relies heavily on groundwater (Allan 2007; Khater 2002; World Bank 2007), due in part to its growing population (with an estimated 634 million by 2050) (UNDP 2013), leading to many instances of over-exploitation (Al-Zubari 2012; Jagannathan et al. 2009).

1.2 The drivers of groundwater resource development

The explosion of groundwater use worldwide over the past 40 years is not just a Malthusian consequence of an increase in population. Rather it has been fueled by both states/donors and farmers themselves, for a variety of reasons:

- in response to particular drought periods and reduced surface water supply (e.g. Australia, Spain, Morocco, China, California);

- as a means of supporting rural livelihoods, reducing poverty, or tackling social unrest (e.g. Yemen, Algeria, India, Pakistan);
- as a means of increasing agricultural production, whether for purposes of increasing self-sufficiency, or export of cash crops (e.g. Saudi Arabia, Jordan, Syria, Morocco).

Governments, sometimes in tandem with development banks, have largely fueled groundwater development (World Bank 2007) through the following incentives and investments (some examples are given for the sake of illustration):

Tariff, output prices, crop protection, farm subsidies: price incentives to crops and subsidies (up to 40%), as well as market protections have been notorious in Saudi Arabia (Abderrahman 2005), in Syria, where diesel subsidies and crop procurement price support together accounted for 5% of GDP (Aw-Hassan et al. 2014; Gül et al. 2005), and in many other countries, notably in the Middle-East and Northern-Africa (MENA) region (World Bank 2007). In Oman, the Public Authority for Marketing Agricultural Products (PAMAP) supported expansion in groundwater-based irrigated crop and livestock production through subsidies, regardless of resource limitations and the quality of outputs (Allen and Rigsbee 2000; McDonnell 2016). In the US, irrigated agriculture (e.g. in the High Plains) has been driven by the ethanol/bio-fuel craze (Zellmer 2008) which poured targeted subsidies to encourage soy-based biodiesel (Jones 2012).

Subsidies for drilling: Drilling itself was very widely subsidized in the early days of groundwater development. In Yemen subsidies were provided to the private sector to import pumps, engines, and rigs, and also helped the drilling of more wells in the country. In Morocco the state exempted entrepreneurs from import taxes for drilling materials and is still subsidizing well drilling in some cases (Tanouti and Molle 2013).

Cheap credit and loans: Subsidized credit for farmers was found in 16 out of 19 countries analyzed in the World Bank (2007) study on the MENA region. Jordan's agriculture sector has benefited from loans granted at discounted interest rates and free of commission and fees through the Agricultural Credit Corporation (ACC) (Hjort et al. 1998). In Yemen the development of groundwater abstraction was also fueled by loans from the Cooperative and Agricultural Credit Bank for the purchase of pumps at subsidized interest rates (Ward 1998). In Morocco, the state encouraged groundwater abstraction in the 1980s via credits and subsidies for irrigation (Tanouti and Molle 2013).

Since the 1970s Saudi Arabia has supported agricultural expansion through sector-support policies, including interest-free loans, with a total value of loans given by the government to the agricultural sector between 1974 and 1998 of US$7.7 billion (Abderrahman 2005). In Algeria access to easy credit fueled an increase in the irrigated area between 1981 and 1985, with 650,000 new hectares (ha).

Subsidies for pumping equipment: In Yemen subsidies were given for importing pumps or free pump installation via donor-funded projects since the 1970s (FMWEY 2015), as in Saudi Arabia for machinery and farm equipment (including pumps and generators) (Abderrahman 2005). In Mexico the introduction of pumping technology from the United States was developed by former ministerial officials with a commercial interest in the venture (Wolfe 2013). In Oman through the 1990s the Bank for Agriculture and Fisheries emphasized infrastructure and equipment purchases including diesel and (later) electric pumps and other groundwater well-related services (McDonnell 2016).

Subsidies for micro-irrigation: subsidies for investment costs in water-saving technologies for irrigation, as in Tunisia (40% for large farms, 50% for medium farms, and 60% for small farms) (Frija et al. 2014), Spain (60% of subsidies by the "Shock Plan" (*Plan de Choque*) for micro-irrigation; López-Gunn et al. 2012), Mexico (up to 80% of investment costs of projects for small holders and 50% for farms larger than 50 ha) (Hoogesteger 2004), or Morocco (Plan Maroc Vert, 100% for smallholders under 5 ha and 80% for others) are supposed to promote water savings but also make wells more interesting (intensive agriculture associated with drip demands a secure supply), which may fuel the expansion of groundwater use. In Oman between 2000 and 2016 farmers buying modern irrigation technologies (and having a licensed well) received 100% subsidies as long as they gained prior approval from agricultural state services (McDonnell 2016).

Rural electrification: State investment in rural electricity supply, such as in Algeria, Tunisia, Jordan or India, makes groundwater use generally cheaper, and therefore more desirable.

Subsidies for electricity: Electricity for rural livelihoods is often subsidized, and sometimes even free, as in Andhra Pradesh, where, in 2004, the government announced free power to farmers (Birner et al. 2011), and a few other states. In Pakistan subsidized electricity contributed to fueling the drilling of 800,000 wells (Qureshi et al. 2010).

Subsidies for diesel (or gas): such subsidies are widespread and contribute to making many rural activities cheaper, such as in Syria, where, prior to reforms in 2008, they represented around 80% of the local purchase price (Aw-Hassan et al. 2014; Gül et al. 2005), or Yemen, where, in 2009, the subsidy for fuel accounted for 22% of all government expenditures (World Bank [2001], in Van Steenbergen et al. 2014). Morocco subsidizes domestic gas, with gas bottles being widely used in agriculture for pumping.

Drilling public wells: governments have also sometimes directly invested in public wells to promote the use of groundwater for agricultural development (e.g. the Laguna region in Central Mexico; Wolfe 2013), Algeria or Morocco (to offset large cuts in surface water availability during droughts), China in the 1970s (Kendy et al. 2003), Pakistan or India in the 1970s/80s (e.g. World Bank Project, and Indo-Dutch Tubewell Project in Uttar Pradesh; Alberts 1998). State-run, groundwater-based, medium-to-large irrigation schemes have also been implemented by the state (e.g. Tunisia and Spain).

The result of combined state incentives and farmers' strategies has been a dramatic expansion of the groundwater economy. For example, in Saudi Arabia the irrigated area increased from less than 400,000 ha in 1971 to about 1.6 million ha in 1992 – mainly wheat, cultivated by large agri-businesses (Ouda 2014), with more than 100,000 wells drilled for agricultural purposes between 1974 and 2000 (Abderrahman 2005). In Syria the number of wells rose from 53,000 in 1988 to 124,000 in 1994, spurred by input subsidies during that short period (Aw-Hassan et al. 2014; Gül et al. 2005). In Yemen data from 1990 indicate that 310,000 ha were irrigated with groundwater compared to 37,000 in 1974. In China the number of wells rose from 0.11 million in 1961 to 2.69 million in 1980 (Zhu et al. 2013).

While farmers have responded to these incentives they have also invested in wells and pumping capacity for a variety of other reasons, including:

- reduction in surface water availability (in most public surface irrigation schemes worldwide), and/or increasing water prices in public irrigation schemes (e.g. Tunisia, Kefi et al. 2003) have pushed farmers to resort to individual wells, leading to the conjunctive use of surface and groundwater;
- to adjust to crop calendars and water requirement of Green Revolution cultivars (India);
- to respond to market opportunities, whether because of trade agreements (NAFTA, Morocco-EU, etc) or otherwise;
- to respond to new market requirements in terms of produce quality (irrigation being needed to ensure uniform product for supermarkets);

- to intensify/secure crop production in order to reduce vulnerability and/or increasing incomes, notably in the face of uncertain or changing climatic contexts;
- to take advantage of various subsidies and incentives extended by governments; or from rural electrification (as illustrated above);
- to invest in agriculture, making use of remittances (e.g. from relatives established in the Gulf region), or of capital brought back from abroad (e.g. Yemen, Jordan, Egypt).

1.3 The impact of overexploitation and contamination

Aquifers are dynamic systems in constant interaction with areas of recharge and areas of discharge (e.g. streams or canals). Except in the case of fossil aquifers (confined and not replenished through recharge), the dependence of water bodies and ecosystems on groundwater is conditioned by larger-scale hydrologic exchanges between groundwater and surface water bodies (Winter et al. 1998; Sophocleous 2002). Groundwater pumping can affect aquifer recharge either by increasing recharge, if the pumping takes place in areas with temporary rising water tables due to rain or as a result of irrigation returns to the aquifer (e.g. Pakistan), or by decreasing recharge, if groundwater pumping alters the storativity or hydraulic conductivity of the recharging units (CGIAR 2015; Devlin and Sophocleous 2005).

Groundwater overexploitation has serious consequences, especially when aquifer recharge is comparatively slower, leading to increasing pumping costs, decreasing well yields and well failure due to seasonal/occasional or permanent water table decrease. In hard-rock areas groundwater abstraction is affected by high groundwater variability and fluctuations within aquifer systems across seasons, causing shallow wells to be severely affected by dropping water tables (Sundarajan et al. 2009).

Spring discharges can also be severely impacted by groundwater exploitation, and the common lack of protection of recharge areas has further increased these negative impacts. In Pegalajar (Andalusia, Spain) the drilling of unlicensed boreholes between 1988 and 2008 dried out an historical spring (Fuente de la Reja), which had traditionally been used for irrigation and is strongly linked to the local sociocultural identity (Castillo Martín 2008; De Stefano and López-Gunn 2012). In the Fatnassa Oasis in southern Tunisia, groundwater was traditionally exploited by collecting the discharge from natural springs and by allocating it according to water rights. However, since the 1950s the flow of water from natural springs and artesian wells started to diminish as groundwater was abstracted directly through deep public wells for the development of agriculture in other oases (Ghazouani et al. 2012). Numerous springs have dried up worldwide, notably in the MENA region (e.g. springs in Palmyra Oasis, Syria; Bahrain, Egyptian Western desert, Algeria, etc. see Al-Zubari 2012), because of the drop in water tables associated with over-pumping.

A similar impact is that of the drying up of *qanat*, from Pakistan to Morocco. These traditional 'artificial springs' or 'horizontal wells' capture superficial groundwater but are very sensitive to variations in the depth of the water table. Drawdowns generated by intensive pumping have led to the demise of many of those systems (e.g. none of the 500 *khettaras/qanats* of Marrakech is still in use).

A localized high density of wells can generate cones of depression and affect shallower wells. Increasing economic costs of depleting groundwater reserves can be disproportionately borne by small and marginal income farmers in rural areas. In extreme cases, the over-abstraction of groundwater can also lead to the abandonment of irrigation altogether, as seen in many coastal areas (e.g. Tunisia or Morocco).

In the Hadejia-Nguru wetlands in Northern Nigeria falling groundwater levels in the shallower aquifer have spurred a shift towards deeper boreholes (Acharya and Barbier 2000). Moreover, groundwater recharge has proved of considerable importance to wetland agriculture, and reduced recharge creates high welfare losses for floodplain populations of small-scale irrigation farmers (ibid.). A large number of wetlands have been affected worldwide by over-pumping, including, for example, the iconic cases of the Tablas de Daimiel in the Guadiana basin, Spain, and Azraq oasis in Jordan.

Groundwater over-abstraction can also cause quality degradation, with increases in salinity in coastal aquifers due to sea water intrusion (e.g. Tunisia), as well as from inherent saline groundwater or fluorite concentrations (e.g. Gujarat and Rajasthan, India) (Sundarajan et al. 2009). The case of Bangladesh is paradigmatic, as groundwater abstraction from shallow tubewells exposed the population to increasingly dangerous levels of arsenic, chronically affecting between 35 and 77 million people since the late 1970s (Qureshi et al. 2015). This is due to the natural concentration of arsenic levels in shallow aquifer formations (less than 70 meters deep).

Over-pumping in a given aquifer lowers static levels and affects the prevailing equilibrium and relationship with connected aquifers. This frequently induces inflows of water from more saline aquifers which impacts the quality of the resource. This also occurs in thick alluvial aquifers where lower saltier layers are brought to the surface by 'upconing', due to concentrated over-pumping (e.g. in the Nile delta, El-Agha et al. 2017).

Agriculture can also have an impact on groundwater quality. In Denmark, despite several decades of regulation, policies, and controls, concentrations of nitrate in groundwater in approximately 48% of monitored groundwater bodies studied by Hansen et al. (2012) across the country were still higher than the permitted drinking water standards of 50 mg per liter. According to these authors, 33% of monitored groundwater areas show an upward trend in nitrate concentration (Hansen et al. 2012). Due to pollution, availability began to decrease in the 1980s and, as a result, the groundwater resources deemed safe for abstraction were reduced.

Groundwater over-abstraction can also create land subsidence, a worrying situation that can lead to flooding in flat areas and coastal plains, mostly recent sedimentary basins and deltas, as in Tokyo, Bangkok and Venice; or the coastline may retreat, as in the Llobregat Delta, Spain (Margat and van der Gun 2013). Subsidence of several meters is well known in the Central Valley of California, in Arizona, and in areas of Mexico, such as the Capital and Guanajuato State (Custodio 2010). Sinkholes and dolines can appear, and the frequency of these events may increase when the water table is lowered (e.g. Florida). Conversely, coastal aquifers can be affected by the reverse effect, as industrial and agricultural activities are taken over by urban sprawl and move out of peri-urban areas, groundwater tables can recover and even rise higher than their initial levels, causing problems of inundation in underground structures, instability of building foundations and corrosion in basements (e.g. in Japan).

1.4 Putting groundwater governance in context

A study by the United Nations Development Program on water governance in the Arab World (UNDP 2013) identifies the need to achieve effective governance in order to improve the water crisis situation in the region. It also establishes the key elements of good water governance as including equity, transparency, accountability, environmental and economic sustainability, stakeholder participation, and empowerment. This generic appraisal frames the focus and debate on natural resource governance around a particular set of prescriptive interventions designed to improve the general situation of 'impoverished' governance systems. It is possible to find similar definitions and approaches in other documents on water governance published by the UN and other multilateral agencies such as the African Development Bank (e.g. AfDB 2010), the World Bank (e.g. World Bank 2007; Wijnen et al. 2012), or the Global Water Partnership (e.g. Rogers and Hall 2003).

'Good governance' approaches have found a niche within donor agencies. Their diagnoses tend to emphasize poor groundwater monitoring, lack of control of abstractions, weak or inexistent formal water management organizations and cross-sector policies, and the lack or poor enforcement of formal rules and regulations as pervasive aspects of dysfunctional governance systems (Pietersen et al. 2011). A study by the World Bank on groundwater governance defined a need for governance, "understood as the operation of rules, instruments and organizations that can align stakeholder behavior and actual outcomes with policy objectives" (Wijnen et al. 2012: 17). These recommended approaches often remain contingent upon a recommended path towards the decentralization of natural resource management (i.e. away from formal and centralized politics) via a more pro-market and free exchange of production factors, or via more community-oriented resource management (Petit 2004).

In contrast with these approaches, for Steenbergen and El Haouari (2010) the key issue regarding governance is about the creation of links between responsibilities and results rather than the analysis of the positioning of players as part of arrangements geared towards regulation. The issue is not good or bad governance but its effective presence or complete absence. The need to step out of these pre-formative systems has pushed authors such as Zeitoun (2009) and Van Steenbergen et al. (2014) to look inside the 'black box' of water politics and into the messiness of daily politics. As Abers and Keck (2013) put it with regard to Brazil, by looking at the political practices of actors seeking to influence policy processes in water resource management, and how these prompt institutional and policy change, it is possible to provide more general insights into "the construction of new decision-making arenas" in water management systems, and to examine what happens inside of institution-building processes. What these authors discovered was a tangle of institutions, organizations, and contradictory political traditions, immersed in path-dependent policy webs and interests.

In this report groundwater governance systems are taken as equally affected by policy interventions and historical and development paths, on the one hand, and by local sociopolitical and cultural issues arising from state and community relationships, on the other. Governance is therefore the processes and institutions involved in decision making and not the outcomes of those same processes (Lautze et al. 2014; Rauschmayer et al. 2009). Different forms of governance operate at the same time and their concentration is influenced by the political regime, history, economic norms, and institutions within the country (Hill 2013; Rogers and Hall 2003). As seen by Hill (2013), the three basic modes of governance: hierarchical, network, and market are all at play within a national, regional, or local social context. The emphasis on locality vis-à-vis the 'political center' (typically the state or a central government) is important as it de-emphasizes conventional recipes and brings up the specificities of each socio-environmental context. The center of policy-formulation widens, moving away from the more traditional forms of central government authority and becomes an amalgamation of multiple actors and resources (Bressers et al. 1994).

While the system and its boundaries remain in place, governance mutates and changes, undermines all notions of durability and defies the continuity and linearity of traditional development approaches (Lee 2005). As Castro (2007: 106) wrote, it cannot be reduced "to an instrument for the implementation of decisions taken" nor is it a strategy or "idealized scheme of interaction between also idealized actors". Governance is primarily about actors, interests, ideologies, discourses, legal frameworks, power and decision making, even if bio-physical constraints shape what is possible and what is not.

1.5 Objectives of the present review

Against this backdrop, this report synthesizes the work that has been done on groundwater governance by IWMI researchers over the past three and a half years, as part of a USAID-funded project in the MENA region. The goal was to address the following overarching questions: Why is there groundwater overdraft? And why is it so hard to curb or regulate? What governance options are available for different contexts and what can we learn from successful cases? The project therefore began with a review of past experience in global, regional and local groundwater governance, reviewing the laws, regulations, community-based actions, and institutional structures, as well as their efficacy in controlling access, abstraction and allocation of the resource under varying circumstances. (The reader interested in more details and more complete reference lists may complement this synthesis report with the five regional reports issued in parallel.)

The review of groundwater management practices and regulatory instruments provided evidence of the panoply of tools used in different countries as well as the diversity of practices and situations. As highlighted in this report, the application and implementation of these tools most often run into a logistic nightmare, and can be subject to arbitrariness and political influence. The search for perfect information on groundwater abstraction and users is in general limited by their high number and by the limited resources (financial, human) of state agencies. The existence of tools does not mean that the government or implementing agencies have the resources or capacity to enforce or implement them, nor that users will apply or abide by them. As Lee et al. (2014: 637) pinpoint, "[e]ven when citizens have internalized the state's rightfulness of rule today, there is no guarantee that citizens would continue to accept its rule and obey its dictates if the state began to fail with respect to output legitimacy."

The state has long held an apparent position of primacy via its numerous attempts to maintain and enforce the monopoly of force and the ability to rule over natural resources. Under this narrative, groundwater management and regulation includes the delivery of services, rules, and control relying on the threat of force and the implementation and enforcement of rules and regulations (Lee et al. 2014). However, as this report will show, forces and actors external to the state affect governance modes and belie the conventional command-and-control and centralizing view of the state as the sole actor capable of ensuring the provision of these services.

The 'mirage' of full regulation and control of groundwater is further fueled by the propensity or need for countries to implement regulatory tools and pass legislation that follow international legal guidelines. Also, state officials often operate within realms of bounded rationalities, oblivious and distant (willingly or not) from what is happening on the ground.

Alongside state rule and management of groundwater resources, a diverse array of community-based groundwater management spans across countries, from the traditional use of groundwater through springs and wells in oases and mountainous areas (e.g. Oman, Morocco or Algeria), to community wells in India, and cooperatives in Egypt or Bolivia. The extent to which these communities have been able to control groundwater resources locally has allowed them to develop agriculture through irrigation and sustain livelihoods.

As this report will show, pure forms of state-centered or community-centered groundwater governance are extremely rare. It will, therefore, investigate a continuum of co-management situations, where the distribution of power extends beyond the state and is constantly reshaped by socio-political and environmental dynamics. It will endeavor to review several cases where a degree of success in managing groundwater resources has been achieved, and to tease out the associated key drivers and specific conditions.

The issue of groundwater management has become prominent in the past 15 years or so, and has been the subject of several global studies and research undertakings (Van der Gun 2007). These include in particular studies by FAO’s (2003) 'search for practical approaches', with a concern for the links between the social and technical aspects of groundwater management, various edited volumes or studies (e.g. Llamas and Custodio 2002; Giordano and Villholth 2007; Quevauviller 2008; Martínez-Cortina et al. 2010; de Stefano and Llamas 2012; Wijnen et al. 2012; Margat and van der Gun 2013; Jakeman et al. 2016), the Groundwater-MATE project supported by the World Bank, or the Groundwater Governance Project supported by various multilateral organizations (www.groundwatergovernance.org). Despite this wealth of publication, it is sometimes felt that still little is known about the institutions and policies that govern groundwater use in different societies (Moench 2004; Theesfeld 2010; Megdal et al. 2015). In OECD’s (2015) assessment, "groundwater is generally under-studied and there is a need for more in-depth assessment of groundwater stocks, use, and management practices."

Like any synthesis based on a literature review, the present work has both benefited from earlier works and faced the limitations associated with the substantial overlaps between them, and with the relative lack of details of the majority of the documents collected for this review. Reports or articles going into sufficient detail to allow a deep understanding of the context, as well as how governance effectively unfolds in the fields, are rare. We have attempted to overcome this deficiency by communicating via email with a number of knowledgeable scientists in various key countries. For the MENA region in particular, we also mobilized the field- and national-level knowledge gathered as part of the project. The review has three identified biases: it focuses on countries where groundwater overexploitation is a salient issue and where agricultural use of groundwater is massive. As a result it refers only in passing to countries, such as those of northern Europe, where climatic conditions are more favorable and the pressure on groundwater resources is lower, or not so acute. It also leaves aside the questions of groundwater quality and contamination and focuses on quantitative issues and overexploitation. In addition, it gives more attention to the situation in the MENA region.

The objective of this synthesis was not to come up with some 'recommendations' that could be applied to solve the problem of groundwater overexploitation. At any rate this would also be contradictory with the emphasis given to socio-political dimensions and their context-specific nature. Rather, we want to emphasize the numerous dead-ends to which may lead the blind application of standard policies and the overestimation of state power, delineate situations in which there might be some scope for co-management, and demonstrate the overriding importance of socio-political dimensions over what is too often considered as a technical issue.

We begin this review by examining the diversity of aquifers, wells, users, and legal backgrounds that combine to define governance configurations and give rise to a wide variety of problems. The review is then divided into three parts, which, for analytical simplicity, successively address state-centered, community-centered, and mixed governance (or co-management).

2 General characteristics of groundwater use

Just as major differences exist between irrigation systems, in terms of size, climate, technology, cropping patterns, users, management organizations, etc. that are insufficiently understood or taken into consideration when discussing irrigation as a whole, the use of groundwater for irrigated agriculture covers a wide range of situations, which may sometimes have little in common. Before examining groundwater governance it is useful to briefly illustrate the striking diversity of: 1) aquifers, 2) users, and 3) technology, and to show how they result in particular problems in terms of management and governance.

2.1 Diversity of types of aquifer

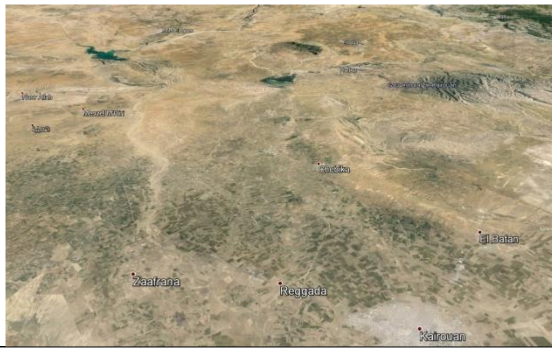
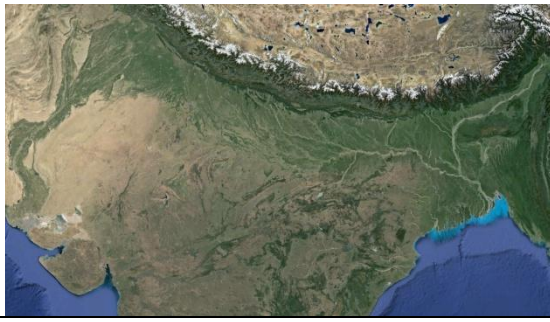
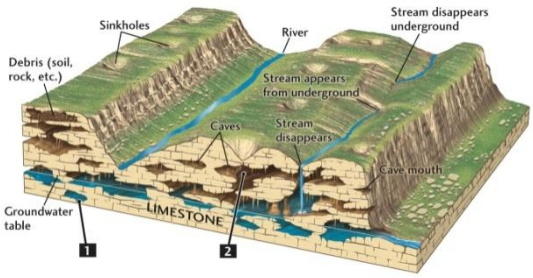
Although the diversity of water-bearing geological formations is an obvious fact of life for hydrogeologists and water specialists (Foster et al. 2008), it is not infrequent for discussions of groundwater management and governance to appear oblivious to it. Recognizing the significant differences between the main types of aquifer is an essential first step in contextualizing the lessons drawn from a particular case.

There is extensive literature on the characteristics of different types of aquifers worldwide (e.g. Zektser and Everett 2004; Foster et al. 2008; Margat and van der Gun 2013), from which we have borrowed a simplified 'typology' to illustrate the associated specificities of five main types of aquifer (Table 1).

A. Alluvial valley aquifers: Intermountane valleys and other small alluvial formations are generally formed by thick layers of sand and gravel deposits, possibly covered or interescted by clay layers or lenses. Abstracting water from the clay layers is problematic and generally achieved through the digging of large wells for limited uses such as domestic needs. The deposits are recent (quaternary) and have not yet been consolidated, meaning that they have a high porosity (to store water) and permeability (to release it when pumped out). They exist in close interaction with the river from which they are fed (especially where flooding is substantial, e.g. the Ganges) and to which they drain in low flow periods. In the case of gravity irrigation based on river diversion, recharge can be dramatically increased. In such situations superficial aquifers are replenished seasonally and the water table is maintained at a few meters below ground level (or sometimes less, in lower areas, generating waterlogging).

In certain cases the flow of the river is limited or has been severely abated by massive diversions upstream, meaning recharge from the river is substantially reduced. When riparian water users face surface water scarcity they turn to drilling wells in order to exploit groundwater resources. Where the alluvial valley is large groundwater abstraction may develop on a large scale and exceed the recharge capacity of the river, which causes the water table to drop gradually. The drop will be offset if rainfall and runoff are large (e.g. lower Ganges), or in case of recharge by infiltration from large-scale irrigation schemes (e.g. Tadla Plain, Morocco), but more pronounced when the river flow is reduced (Lower Yellow River), and/or the climate arid (Arizona; Tarim, China). The fate of the aquifer will depend on the subtle (im)balance between recharge by rainfall, river flows and flood, and return flows from irrigation on the one hand, and net groundwater abstraction on the other.

Table 1. Main types of water-bearing geological formations

Intermontane-fills and small alluvial formations are generally formed by thick layers of sand and gravel deposits, covered or intercut by clay layers or lenses (Nile Valley, intermontane valleys, etc). [Kairouan Plain, Tunisia] (Photo source: Google Earth)	
Large alluvial fans and valleys or deltas (Nile Delta, Mekong Delta, Ganges and Indus River valleys,…) [Ganges-Bramahputra valley] (Photo source: Google Earth)	
Sedimentary plateau/basins (limestone, sandstone, gravel, etc.) (Beauce, La Mancha, Jordan highlands, Ogallala, Guarani,...) [Yarmouk River, Jordan] (Photo source: https://waterinventory.org/surface_water/jordan-river-basin)	
Fractured rocks. Water is contained in the upper saprolite weathered layer and cracks and fractures (peninsular India, Sub-Saharan Africa,..). [Colorado] (Photo source: http://coloradogeologicalsurvey.org/wp-content/uploads/wateratlas/chapter7_5page2.html)	
Karstic aquifers (Florida, Edwards Aquifer Texas, Italy, Croatia, Spain, France, Lebanon,…) (Photo source: www.northeastern.edu/protect/2017-check-in-protect-develops-deeper-understanding-of-contaminant-transport-in-karst-aquifers/)	

B. Large- or coastal-plain and delta aquifers: Much of the above also applies to large alluvial valleys like the Ganges-Bramahputra valleys; as well as to coastal-plain and delta aquifers, except that an imbalance between recharge and net use will result in seawater intrusion into the aquifer. This can be quite extensive in large and flat deltas and more limited in rivers with a steeper slope (e.g. deltas of South India). Those affected include the Nile, Colorado, Sacramento-San Joaquin, and Pearl River deltas, but virtually all major cities sitting on coastal plains and aquifers, and abstracting water for domestic and industrial use, face this problem. Alluvial and coastal aquifers are the most widely tapped worldwide but are sensitive to both pollution and marine intrusion.

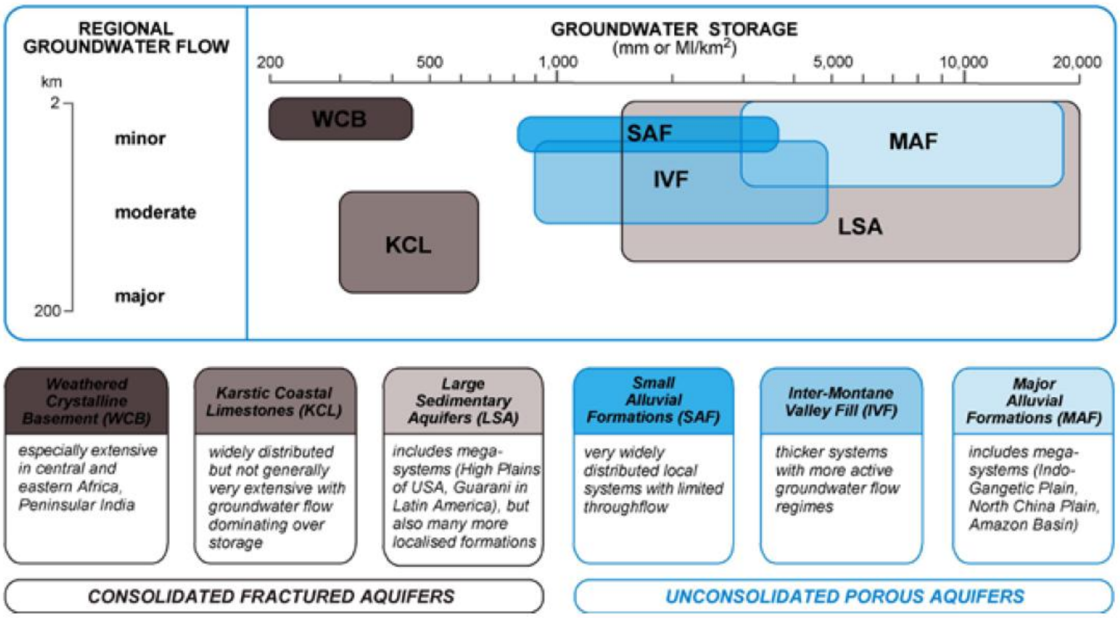
C. Sedimentary limestone/sandstone plateau/basins: These aquifers are created by the consolidation of sand and other deposits glued together by a cement of calcite, silica, clay or other mineral and compressed by overlying geological layers. As a result their water-bearing capacity is reduced but depends on the degree of compactation and more specifically on the presence of cracks or *fissures*. Sandstones are frequently interbedded with siltstones or shales. The Nubian sandstone aquifer in northern Africa or the Great Artesian Basin in Australia are well-known extensive sandstone aquifers, but there are many examples of local ones. These are mostly replenished by rainfall, and drain to springs, wetlands, and river systems. In many cases overexploitation of these aquifers quickly affects interconnected ecosystems. The water table must be maintained within a range of a few meters in order to avoid impacting spring, wetland, and river baseflows in the dry season. This is well illustrated by the Beauce aquifer, near Paris, and the iconic case of the wetland in La Mancha province, Spain.

D. Fractured-rock aquifers: Lava plateaus of volcanic origin, granitic and other metamorphic rocks, are poorly or not at all permeable. Their capacity to store water depends on how weathered and fractured they are. Water infiltrates into the cracks and can be easily abstracted as long as the well cuts across some of these fractures. The yield will be variable, however, and the resource very sensitive to the (rapid) infiltration of contaminants. In weathered crystalline aquifers water is chiefly contained in the upper weathered layer (saprolite), with a typical depth of 20 m in tropical countries.

E. Karst Aquifer: Outcrops of carbonate rocks (mainly limestones and dolomites) can be found in almost a quarter of the world, especially in the northern hemisphere. These old marine deposits are gradually dissolved by water, which creates sometimes extensive complexes of sinks, galleries, caves, drains, and springs. This *karstification* can be enhanced by tectonics, with further dislocation and uplifts. Such systems infiltrate a large part of the local precipitation and create generous springs, whose outlet may sometimes be found in the sea (e.g. Lebanon). Recharge is high and use of underground water can be increased, on top of the natural outflow in the springs, by wells that intersect underground galleries. These aquifers are of course extremely sensitive to pollution.

In practice many regions have multilayered aquifers, possibly associating several of the above types in complex and interconnected geometries. In Cartagena, Tunisia, for example, four successive water-bearing layers are exploited with that of the upper quaternary feeding those lower down. The city of Bordeaux in the Aquitaine region of France sits atop seven layered sedimentary aquifers.

Figure 1. Main types of aquifer and typical storage (Foster et al. 2008)



It is also worth remembering that aquifer systems are not necessarily coterminous with river basins. This is especially the case for deep aquifers but also sometimes for superficial/quaternary aquifers. The Ica aquifer, in Peru, for example, follows the Ica valley but also branches off to feed the adjacent Pampas de Villacuri aquifer system in the Rio Seco watershed. The Beauce aquifer, in France, is bordered by two major rivers, the Seine and the Loire. Water infiltrating into one karstic river basin in Lebanon may reappear in the adjacent basin.

Water quantity may also vary with the depth of pumping as well as with the dynamics of the aquifer. It is not uncommon for the drop in a water table to result in a modification of the flow between interconnected aquifers with different water quality, most notably salinity.

Significant differences also exist in terms of groundwater recharge and dynamics. In some cases it can take several decades (or even centuries) for water to reach the aquifer, while in certain coastal wetland areas, such as the Marais Poitevin, France, replenishment of the groundwater by waterways takes place in 48 hours.

2.2 How much is too much?

A common misunderstanding with regard to groundwater management is that abstraction should be maintained at a level below or equal to the recharge – in other words that the ratio of abstraction to recharge (the latter often being equated to "renewable resources") could be an indicator of sustainability (Bredehoeft 1997; Devlin and Sophocleous 2005; Alley and Leake 2004; Custodio 2000; van der Gun and Lipponen 2010). This is often conflated with the concept of "safe yield," suggesting that pumping anything less than the average recharge is "safe."

It is useful to develop a 'dynamic' view of aquifer balances, in which both the recharge and the outflow terms vary over time, while not independently from one another. Typically, the recharge of the aquifer includes the following terms:

- *A fraction of the rainfall* that infiltrates the soil and sub-soil. This component depends on the soil and geology (typically fractured or karstic plateaus will 'capture' a large share of rainfall, compared with alluvial aquifers covered by a clay cap) as well as on the structure of precipitation (short/long, intense/non-intense events, etc.).

- Water that comes from rivers (and waterways such as drains, canals, and wetlands). The exchanges between the river bed and the aquifer often show seasonal variations, with the river recharging the aquifer at times of high flow and draining the plain in times of low flow. In situations where the alluvial aquifer is depleted the river flow is partly 'captured' by the soil, and the net flow is a loss. This is a crucial inversion of the balance, which often goes unnoticed or is misunderstood, despite being responsible for the change of many rivers from perennial to intermittent status (e.g. Arizona).
- *Water coming from flood*, which perhaps deserves to be analytically distinguished from the riverflow itself, since the flood may concern a much larger infiltration interface, and also corresponds to a higher 'head' (i.e. pressure).
- *Recharge may come from the return-flow of irrigation*, in the case where water is brought from another basin, or diverted from the river system itself. The most striking example of how large this component can be is provided by Pakistan, where the recharge of the aquifer by excess irrigation water brought the water level close to the surface, which has damaged crops and salinized the soil through evaporation.[1] Return flow from groundwater-based irrigation is not taken into consideration because this abstraction has to be seen in 'net' terms (that is, in terms of consumption, the remainder generally returning to the aquifer[2]).
- *Recharge may also be artificially enhanced* by impounding water or injecting it under pressure into the soil.

Table 2. Examples of places with contrasting contributions of recharge components

Contribution	Rain	River	Flood	Irrigation
High	Ganges, India Chao Phraya	Mekong, Brahmaputra	Bangladesh	Nile delta, Indus
Low or nil	Jordan highlands Arizona	Arizona, Zayandeh Rud	Yellow river	(no surface irrigation)

These infiltration components vary in absolute and relative terms, depending on the climatic, hydrologic, and morphologic situation and the type of irrigation. In a situation that could be described as steady 'balanced exploitation' (Figure 2, left) the bulk of this recharge flows to outlets:

- Natural springs (or 'artificial' ones, e.g. qanats)
- River beds ('baseflow')
- Lakes
- Wetlands
- The sea
- Evapotranspiration of phreatic natural vegetation (Australia) or plantations (Eucalyptus in the Doñana aquifer[3], Spain, or pines in South Africa[4] or Western Australia).

[1] In order to lower the water table, the government prepared a project to drill 32,000 wells with the goal of pumping up to 70 Bm^3 of water per year (around half of the recharge by surface water).

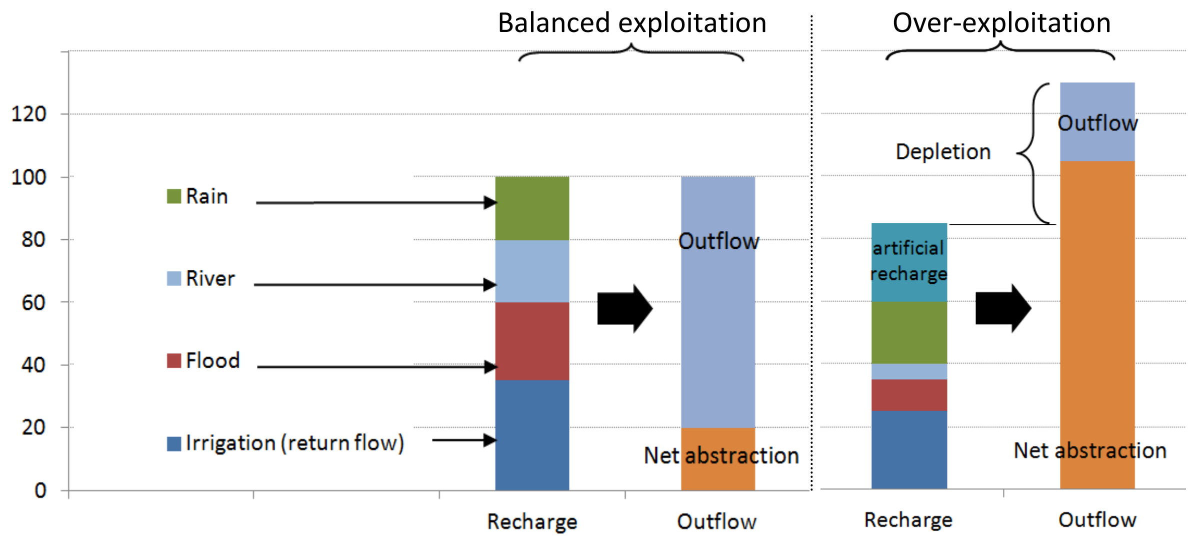
[2] Notwithstanding cases where the aquifer from which water is abstracted is different from the one to which the flow returns.

[3] These trees were eventually cut down on account of their high water consumption (Custodio 2010).

[4] Plantations are considered as 'water users' and pay for the water used accordingly.

In a situation of overexploitation (Figure 2, right), river and flood recharges are often minimized by upstream development (dams, diversions), which reduces average flows and extreme events. Likewise, irrigation supply (surface water) tends to decrease because of a growing overall demand (with users shifting to groundwater) and its role in recharge decreases accordingly. Some type of artificial recharge may then become desirable and be implemented. As net abstraction is magnified, outflow from the aquifer dramatically decreases, with all the usual associated negative impacts on the environment and existing return-flow users. Overabstraction can only be sustained for some time, through the depletion of the aquifer.

Figure 2. Aquifer balance in balanced and overexploitation situations



The key point to keep in mind is that *in a steady, undisturbed situation the average outflow of the aquifer is equal to its average recharge*. Any withdrawal, however limited, will be at the expense of both the outflow and the stock, in proportions which depend on the physical characteristics of the aquifer.

Therefore if "safe yield" understood as "the volume we can 'safely' pump without affecting anyone or the environment" is a clearly flawed and misleading concept (Sophocleus 1997; Custodio 2000; Bredehoeft 1993), "safe yield" understood as the level of pumping for which what is lost is considered 'acceptable', compared with what is gained[5], clearly opens a political question as to who decides the respective values of the acceptable gains and losses. The negative effects of altering the flow between the recharge and the outflow to the surface (and/or the sea) are difficult to evaluate in the sense that those affecting poor communities, next generations or the environment are invariably considered less important than the benefits from the exploitation of groundwater, and are certainly valued in different ways by different people (Molle 2012). The determination of the safe yield is made yet harder by the impossibility of accurately measuring both recharge and abstraction, two highly fluctuating variables, and by limited understanding of the way groundwater flows underneath and how it is delayed by varying time lags.

[5] Alley et al. (1999) defined groundwater sustainability as "the development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences". The definition of "unacceptable" is largely subjective, depending on each situation.

While these facts are well established and have been aptly discussed by key experts and institutions (see for example FAO 2003; Foster et al. 2008; GWP 2012), groundwater overuse or overexploitation is still very commonly described as pertaining to places with "concentrations of users exploiting groundwater storage at rates above groundwater recharge" (Siebert et al. 2010) or the threshold at which "resources are increasingly used to the point of being exploited beyond recharge" (OECD 2015). Wada et al. (2012) describe the amount of nonsustainable groundwater sustaining irrigation worldwide as "additional water gained by groundwater abstraction in surplus of groundwater recharge."

In most aquifer configurations, a situation where abstraction equals recharge actually means that the outflow is drastically reduced (or zero, the difference being made up by the depletion of the aquifer itself) and that negative effects are extremely high. Ironically, the rule only starts to make sense when the aquifer is 'clinically dead': that is, when overexploitation is so extreme that the outflow has been reduced to nil (and when this is accepted as a situation that cannot be remedied, like in Azraq, Jordan); in this case there is a more direct equivalence between recharge and net abstraction, any excess of the latter over the former resulting in further drawdown. In practice, things are often more complex because the quality of groundwater may be modified as the watertable drops. This may result from a modification of the flows between aquifers of differing qualities. In Mendoza, Argentina, for example, pumping fresh water from the deep aquifer has resulted in downward seepage of saline water from the upper aquifer (Foster and Garduño 2015).

As part of the water policy reforms enacted in Australia in the late 1990s and early 2000s, the concept of 'sustainable yield' was adopted in order to define sustainable abstraction limits. The level of sustainability was defined as "the socially acceptable level of the impact of groundwater abstraction." The definition used by the National Groundwater Commission was: "the groundwater extraction regime, measured over a specified planning timeframe, that allows acceptable levels of stress and protects dependent economic, social, and environmental values" (NCC 2004 in Turral and Fullagar 2007: 335). The rather subjective and loose definition of the concept of 'sustainable yield' also drives part of the regulation and management of groundwater resources and, as is the case for the concept of environmental flow, 'how much is too much' may be contested and revised. Not all national legislation and regulations embrace this complexity. The 1985 Spanish water law, for example, defines overexploitation as withdrawals approaching or exceeding the average annual renewable resource (Custodio 2000).

2.3 Diversity of types of user

In terms of management, the question of who abstracts water for what purpose is of course important. Users can be distinguished, for example, by the purpose of abstraction, the magnitude of the abstraction, and whether the use is individual, collective, public or corporate.

Water use is typically divided into domestic (ranging from communal wells to well fields abstracting water for big cities), industrial (industry in general, for process or cooling, with the particular case of mining), and agricultural (for irrigation). There are cases of environmental use, such as the well used in Jordan to sustain water in the otherwise dried-up wetland of Azraq, or the oasis of Huacachina near Ica, Peru, that has long been naturally fed by groundwater but is now periodically artificially replenished (with groundwater pumped from the aquifer!). Many other wetlands have simply vanished (James 2015a). A Copenhagen water supplier even established an artificial spring emptying into the River Ledreborg to provide the stream with 'baseflow'. Even more striking is the case of San Antonio, Texas, which as early as 1911 pumped groundwater from the Edwards Aquifer to sustain downtown’s famed 'River walk' (a recreational function associated with the tourism industry that is now performed by treated wastewater) (Glennon 2002).

Domestic use, by households and small-scale gardening, is generally limited in terms of consumption. But there are cases (e.g. the Perth area in Western Australia) where the cumulated abstraction of these wells may be considerable. Abstraction can be large for big cities, which in general tap deeper aquifers (better quality). The larger share of groundwater use is for irrigation in many countries except those located in the north, such as Denmark, where agriculture is largely rainfed and two thirds of groundwater goes to urban areas and industries (Jørgensen et al. 2017).

Irrigation itself can be conducted by:

- large, private companies cultivating thousands of hectares through central pivot (such as in Saudi Arabia and Egyptian deserts) or mining companies;
- state companies abstracting water and distributing it to farmers (e.g. in Tunisia or Bangladesh);
- groups of farmers or cooperatives investing collectively (with various levels of contribution by the state) and sharing water from one or several wells (e.g. Spain, Bolivia, Egypt, Algeria, Morocco, Turkey, Botswana);
- individual users who drill wells to use groundwater either as a complement to surface water (e.g. in most large-scale public irrigation schemes; see Kuper et al. (2012) for an illustration on Morocco) or as a complement to rainfall (if any) (e.g. Jordanian Highlands, southern Morocco, Ogallala aquifer in the US).

Government/public wells can be drilled to serve collective irrigation schemes (possibly co-managed with users), cities, and occasionally the environment (e.g. river base flow in Denmark, or the Azraq wetland in Jordan).

Collective public schemes have mostly been seen as a solution in the 1960s to 1980s (e.g. (Mexico, India, Spain, Tunisia) but are still in vogue in Bangladesh, while some in Abu Dhabi see this recentralization as a solution to the difficulties of controlling diffuse wells.

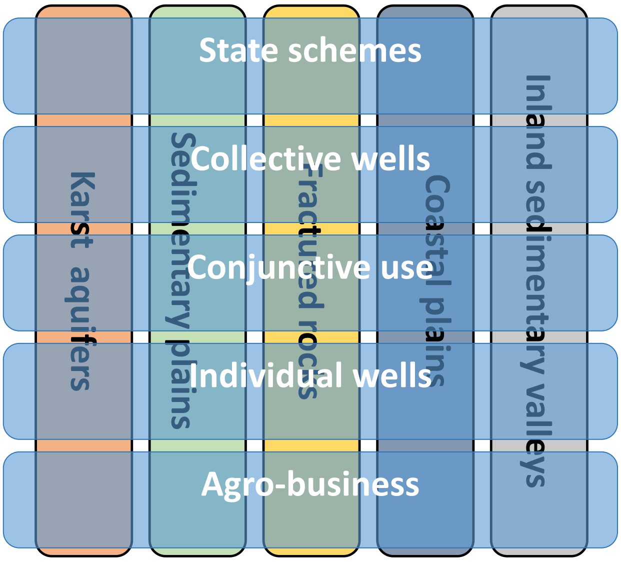
By combining the types of aquifer with the diversity of users (as illustrated by Figure 3) we may recognize that we are facing a large diversity of cases without much in common. This demands that the thinking and approach for each of them must be adapted accordingly. For example, the issue of a handful of large corporations exploiting the fossil aquifer of Disi, straddling the Jordan-Saudi Arabia frontier, radically differs from, say, a mix of small and big farmers in Mexico irrigating from a deep aquifer that is dropping 1 m per year, or from hundreds of thousands of small farmers in the Ganges valley using an aquifer (often as a complement) that is largely replenished each year. Likewise, quaternary and weathered rock aquifers have good storage capacity but while the former may be several hundred meters in depth, the water bearing layer of the latter hardly exceeds 20 m. Aquifer transmissivity is also a key factor: when it is high (e.g. karstic aquifers), a given abstraction will have a direct impact on other users, while in the opposite case (e.g. clay aquifers) the impact will be confined to the vicinity of the well. In the former case, groundwater is akin to a common pool resource, while in the latter it is more akin to a private resource (Huang et al. 2012). The combination of state legislation and local regulation required to ensure a degree of groundwater use which can be considered 'safe' and sustainable will vary greatly according to the context.

Table 3. A typology of wells according to ownership and management

<table>
<tr><th colspan="3">Typology</th><th>Examples</th></tr>
<tr><td rowspan="4">Individual wells</td><td colspan="2">Individual ownership and use</td><td>Pervasive worldwide</td></tr>
<tr><td colspan="2">Individual ownership with collective use (solidarity and exchange arrangements)</td><td>Lebanon, Morocco, Egypt</td></tr>
<tr><td colspan="2">Individual ownership and use, with 'water markets' (selling excess water)</td><td>India, Pakistan, Iran, Bangladesh, China, Algeria</td></tr>
<tr><td colspan="2">Individual ownership and water selling only</td><td>Jordan, Lebanon, India, Algeria</td></tr>
<tr><td rowspan="6">Collective wells

(with collective ownership and/or collective management)</td><td>Family driven</td><td>Through shared inheritance</td><td>MENA region</td></tr>
<tr><td rowspan="3">Collective wells</td><td>Joint investment and use (informal group)</td><td>Yemen, Nile delta, Spain, Morocco, China, India</td></tr>
<tr><td>Joint investment and use, and sale to others</td><td>Spain, Egypt, Iran</td></tr>
<tr><td>Cooperatives (endogenous) or village communities</td><td>Bolivia, Yemen, China</td></tr>
<tr><td rowspan="2">State initiated</td><td>Transferred (state to community, with a degree of control)</td><td>Tunisia, Algeria, Egypt
Mexico, Peru, China</td></tr>
<tr><td>Long-term concession, or handover</td><td>Algeria, Botswana, Turkey</td></tr>
<tr><td rowspan="4">Public wells and water distribution</td><td colspan="2">Public irrigated areas</td><td>Morocco (Souss), Algeria
Bangladesh, Libya</td></tr>
<tr><td colspan="2">Public drinking water supply (well fields)</td><td>Jordan, Bahrain, Tunisia, India, US, Denmark, France, Germany, etc.
(pervasive)</td></tr>
<tr><td colspan="2">Public investment and co-management with users (medium-scale schemes)</td><td>Tunisia</td></tr>
<tr><td colspan="2">Public wells for the environment</td><td>Denmark, Jordan</td></tr>
<tr><td>Corporate wells</td><td colspan="2">Corporate investment (mines, agro-business)</td><td>Australia, South Africa, Egypt, Saudi Arabia, Sudan, etc.</td></tr>
</table>

Figure 3. Combining the diversity of users and types of aquifer



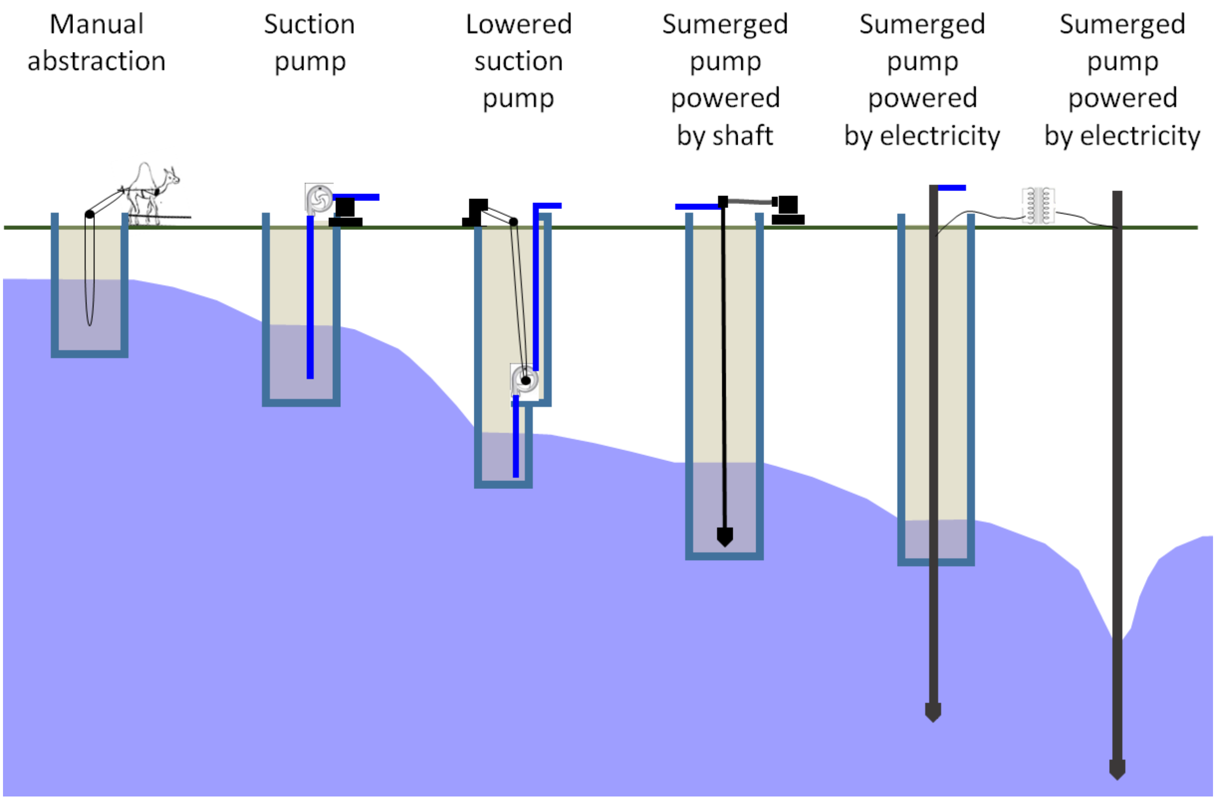
2.4 A diversity of wells

Lastly, technology matters and will have to be adapted to the aquifer, to the magnitude of the intended use, and to the available sources of energy (Figure 4).

Traditional wells are typically dug by hand, have a diameter of one to a few meters, and the depth between a few meters and, say, 60 m, although deeper ones can sometimes be found. Water lifting can be done by bucket systems powered by hand or animals. The dissemination of (suction) pumps driven by diesel/gas engines have allowed the abstraction of larger volumes, with the constraint that the section height should remain under 10 m (in practice ~8 m, a physical constraint linked to atmospheric pressure). A typical way to respond to a drop of the water level beyond that limit is to lower the body of the pump (and to deepen the well). In general, the engine remains on the surface and powers the pump through a belt, but electric engines can also be lowered with the pump. When the water table drops further it is possible to use a pipe with a submersible pump powered from the surface through a shaft. This system can be further lowered by drilling a borehole inside the dug well (so as to reduce the drilling depth and save costs). Once these wells become insufficient they tend to be replaced by (very) deep boreholes equipped with submerged electric pumps. This typical sequence of technical shift is illustrated in Figure 4.

Deep boreholes are, of course, an option only if electricity supply is available. Generally speaking particular technical options regarding both the pump and the engine (reuse of diesel or gasoline car engines, etc.) are driven by the choice of the source of energy, itself driven by financial considerations, in general heavily shaped by subsidies. In some areas of Morocco, for example, there has been a shift from gasoline to diesel, diesel to electricity, and electricity to butane gas, with a now incipient spread of solar energy.

Figure 4. A typical technological shift in groundwater abstraction.



2.5 Legal background(s)

The 'control' of groundwater use, understood here as the intent to keep abstraction in line with the potential of the aquifer and avoid its contamination and depletion, is one of the most vexing issues in water management. Because it is hard to control the expansion and magnitude of such a diffuse use of an invisible resource, often involving a large number of users and unclear water rights, the state – starting from various historical backgrounds – has commonly ended up asserting its control over (ground)water.

This had notably been the case when colonial powers (e.g. in northern, eastern or southern Africa) established water rights as a means of legitimizing the dispossession of local users to the benefit of colonizers (Van Koppen et al. 2014). In their American colonies the Spanish used the authority of the pope and the seal of the religion to vest water ownership in the king, who would grant permits for specific uses (Caponera 2007). In Morocco the French established new water legislation with a "juridical arsenal copied from the French system" (Ouhssain 2009) and a water law enacted two years after the beginning of the protectorate. In some British colonies permit systems were established and ownership vested in the Crown, such as in Tanzania, where the Water Ordinance of 1948 stipulated that "the entire property in water within the Territory is hereby vested in the Governor, in trust for His Majesty as Administering Authority for Tanganyika" (Van Koppen et al. 2004).

Following decolonization, newly independent states reasserted control over the nation's resources and often adopted the legal systems and the bureaucratic apparatus of former colonial rulers. This reflected, in part, the fact that reforming water rights was not seen as a priority in many countries which, at the time, faced much more urgent challenges (Van Koppen et al. 2014), as well as the fact that water rights were often associated with land formerly cultivated by colonizers and which had been shifted to national elites who, as a result, had no incentive to reform the land and water allocation system. An illustration of this is provided by Morocco, where the French 1914 Water Law and attendant successive legislations were "moroccanized" rather than repealed, the public nature of water ("*Domanialité publique de l'eau*") as well as all the water administration systems were maintained (Ouhssain 2009; Mohamed 1989), and most of the land previously under colonial control shifted to local elites or was transformed into state farms (Swearingen 1987).

India followed a unique course. Under Indian law, and as a legacy of British common law, surface and groundwater are differentiated, with the latter intrinsically linked to land (immovable property) (GoI 2007; Cullet 2014). The Indian Easements Act, 1882, served as a basis to grant landowners the right to extract and enjoy unlimited volumes of groundwater that percolates underneath, although it is clear that Indian law does not recognize ownership in groundwater (Water Governance Facility 2013). Based on the constitution, but also on the Environment (Protection) Act, 1986), the Supreme Court ruled that the central government was empowered to establish a Central Ground Water Authority (CGWA), under the Ministry of Water Resources.[6]

Private rights attached to land have come to be counterbalanced by the doctrine that water resources are held in 'public trust' by the state, which in turn confers to public authorities the obligation to appoint agencies and establish guidelines to restrict individual right-holders and safeguard the public interest. While surface water was recognized as a public trust by the Indian Supreme Court in 1996 (Cullet 2014), the situation has not yet been clarified with regard to groundwater, although the 2011 Model Bill proposed the principle that *"[g]roundwater is the common heritage of the people of India held in trust, for the use of all, subject to reasonable restrictions to protect all water and associated ecosystems. In its natural state, it is not amenable to ownership by the state, communities or persons*" (ibid.). The well-known case of the bottling plant of the Coca Cola Company in Kerala, sued because of its impact on neighboring farmers, illustrates this. The first decision of the High Court of Kerala ruled that groundwater should be considered a public trust (and regulated in the public interest), but the same court reversed this finding on appeal and deemed "that a person has the right to extract water from his property." An appeal has been lodged with the Supreme Court and is still pending.

Most countries following the civil law system inspired by the French Napoleonic Code and based on early Roman law principles (according to which the landowner owns everything located above and below the land) have evolved towards a state-administered system of licenses defining usufruct rights and restricting the "use and abuse" of groundwater (Caponera 2007). In France there has long been debate on the necessity to bring water under state ownership, but this prospect was challenged by persons or groups who could exhibit ancient documents showing rights granted by the crown and asked for compensation. The idea was therefore discarded during the preparatory phase of the 1964 Water Law and legal experts, taking inspiration from Germany, dissociated the formal right from the usufruct right (Barraqué 2004, 2015), developing a category of common property which already included all flowing surface water (except the large navigable ones). This was translated in the 1992 Water Law as national heritage (*Patrimoine commun de la Nation*), which by and large corresponds to what Anglo-Saxon countries call 'Public trust' (Barraqué 2004). According to this doctrine, water-related

[6] The mandate of this authority includes in particular the duty to 'notify' areas where environmental sustainability is severely threatened by overexploitation of groundwater (and where further drilling of wells can potentially be banned), the establishment of quality standards, awareness-raising and education, and support to the states for setting up their own groundwater authorities.

problems trigger the establishment of '*Comités locaux de l'eau*' and the elaboration of SAGEs (a sort of 'master plan' collaboratively developed at the level of the watershed).

Spain has followed a slightly different path. Its 1985 Water Law put water under the public hydraulic domain (*dominio público hidráulico del Estado*) (Spain 1985), whereby the state would regulate and control groundwater abstractions via concessions for all users (except wells under 7,000 m^3/year) issued by River Basin Authorities (Closas 2012). Italy followed a similar path, with the 1989 and 1994 laws placing water in the public domain (*acque pubbliche*), and in Portugal, where a 1977 decree-law established licensing systems for water abstraction. Although the state in these three countries has reestablished its ownership over water, in practice it established a system to administer water rights, in particular in the face of water scarcity, and the question of possible compensation for ancient rights is still partly pending.

In Spain this has been accompanied by an obligation to form Groundwater User Associations where groundwater is considered to be overexploited, also showing an intent to co-manage resources. For fear of having to pay compensation for all pre-existing water rights, the government proposed a complex alternative between a Registry of Public Waters (where users would be granted a temporary but secure state of private ownership for 50 years, after which time they would receive priority concessions) and a Catalogue of Private Waters (where a claim of historical use or ownership would have to be made and be disputed). In either case a modification of the originally declared characteristics of the well or groundwater volumes abstracted (location, depth, or abstraction capacity) required a new concession granted by the River Basin Authority.

The change in ownership of water (from private to public) was put in place by the socialist party (PSOE) but was later challenged by the conservative Popular Party, which considered this measure to be unconstitutional as it would infringe on private property and individual rights and liberties (BOE 1985).[7] The Constitutional Tribunal[8] considered, however, that the 1985 Water Law did not infringe on individual rights, as the constitution did not grant the right of private property in absolute terms (Moreu Ballonga 2002).

Likewise, in legal contexts inspired by Anglo-Saxon Common Law (e.g. UK, eastern US, Australia), where private rights are traditionally attached to land ownership, the state has in general been gradually led to impose rules of 'reasonable use' or 'correlative rights' that effectively restrict use. The state of New South Wales, Australia, for example, moved to a permit system as early as 1912 (McKay 2007, 2008). Although the understanding and control of groundwater lags behind that of surface water (Neville 2009), and although entitlements are adjusted each year based on the situation, both resources have now been made tradable in the Murray-Darling Basin. Western Australia departed from the Common Law rule of capture in 1914 and grants volumetric entitlements to groundwater, which can be reduced in time of crisis without compensation (Bennett and Gardner 2014).

Landowners in many parts of the US are entitled to abstract as much water as they can put to 'beneficial and reasonable use', but the doctrine of 'correlative rights' allows for proportional reduction of their rights.

[7] There was a lot of resistance and discussions in parliament about the alleged 'nationalisation' of natural resources, which would have meant significant compensation to private right holders. A 'hybrid system' was then introduced, which meant that, in theory, all groundwater abstraction rights would eventually migrate to the public registry (López-Gunn 2014, personal communication).

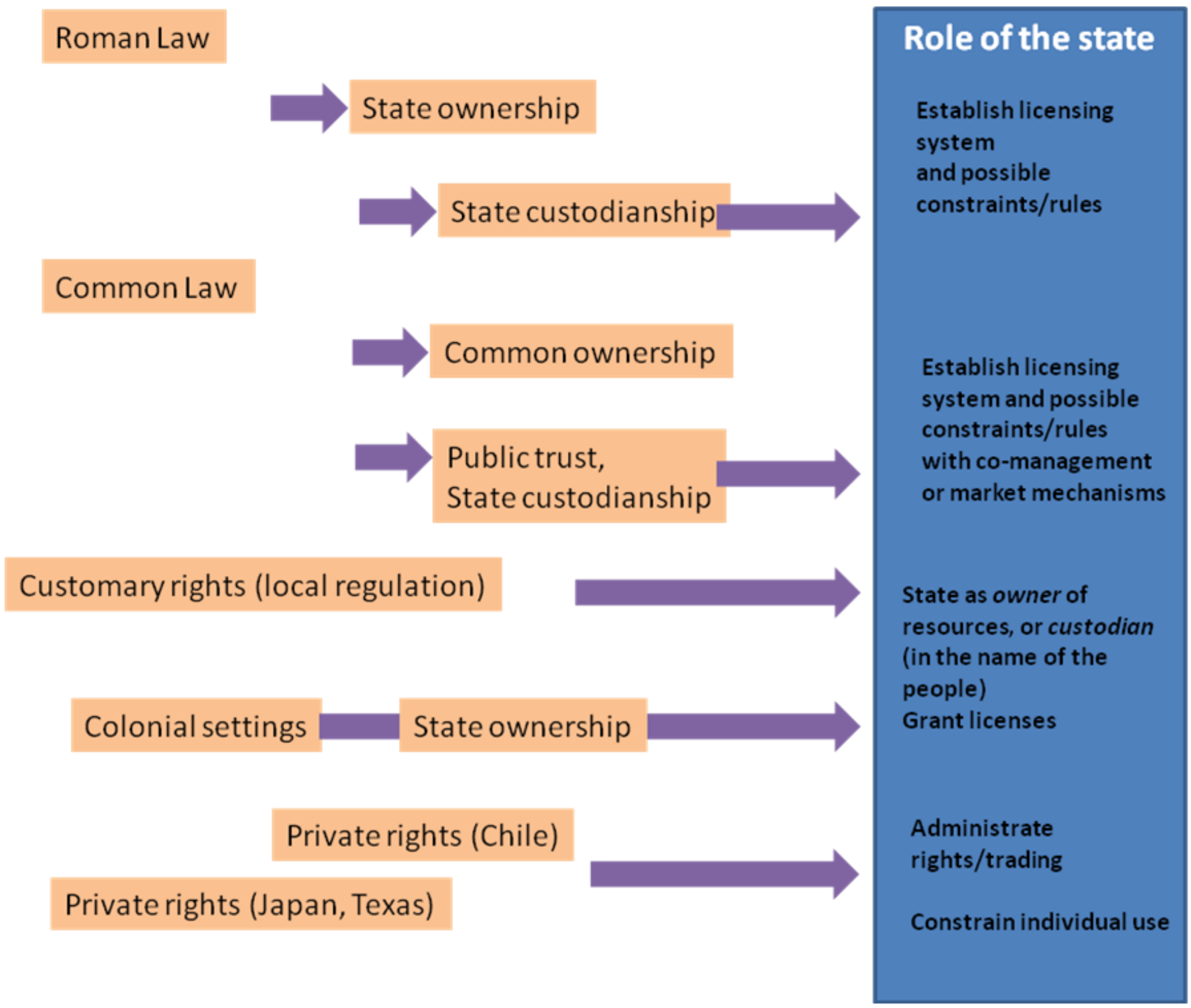
[8] The highest court in Spain, which rules on the constitutionality of laws.

In Islamic countries groundwater is seen as a gift from God and cannot formally be owned. Most, however, have established permit systems, although implementation proves to be problematic. Egypt declares all river channels and infrastructures as 'public property' and prohibits any abstraction without authorization, which is tantamount to state ownership of water. In Jordan the 2000 groundwater By-Law stipulates that, "underground water is owned and controlled by the State;" extraction or utilization thereof is prohibited except by license. Ownership of land does not entail that of its underground water.

In countries with a communist background, resources fall under state ownership. The 2002 Chinese Water Law stipulates that "water resources shall be owned by the state. The State Council shall exercise ownership of water resources on behalf of the state" (China 2002). Vietnam’s 1998 Law on Water Resources provides that "the water resources come under the ownership of the entire people under the unified management of the state."

The legal formulation of ownership ('public ownership', belongs to 'the people' or 'the nation', 'common heritage', etc.), with the role of the state described as 'manager', 'trustee', 'custodian', etc. of the resource, opens the way to different interpretations that need to be checked against the effective power of the state and the definition and restraints of the 'entitlements'.

Figure 5. Growing centrality of the state in groundwater governance



In summary (Figure 5), whether groundwater rights emanate from colonial systems, Roman Law, Civil law, communist or Islamic traditions the great majority of policy and legal reforms since World War II, and particularly since the 1980s, have worked to constrain individual rights and further strengthen or formalize usufruct water rights systems and their registration under the control of the state. Observed worldwide, such reforms reflect a need to gain control of a sector that had run riot, with dire consequences. They also represent a trend towards water rights systems that were expected to strengthen the security of those rights, facilitate investment, and (if possible) to allow the trading of those rights to enhance 'economic efficiency'. More generally, and not unrelated to this, conventional IWRM 'best-practices' have also promoted "enabling environments [that] include establishing government as the 'owner' of all water resources and a selected ministry as a water resource management authority and regulatory agency" (Cap-Net 2010).

3 State-centered regulation

Neither the civil or common law traditions were prepared for the explosion in groundwater use fueled by growing demand and new drilling and extraction techniques (Hodgson 2004). In this section we review in greater detail how the state practically took over groundwater management as the 'owner' or 'custodian' of the resource, based on "a declaration of state ownership, the inclusion of water within the public domain of the State, vesting water resources in the President of the State on behalf of its people, or bringing water resources under the superior use right of the state" (Hodgson 2004).

The importance of groundwater resources for domestic water supply and industries, and in many places for agriculture, on the one hand, and the widespread negative impacts of their dramatic overexploitation on the other, have led governments to implement a panoply of measures and regulations. Where overexploitation exists, the main policy objectives can typically be divided into four categories:

1) preventing the drilling of *new* wells and an increase in the depletion of the aquifer,

2) controlling or reducing the water abstracted by *existing* wells,

3) increasing supply through water transfer and/or recharge (artificial or water harvesting),

4) avoiding the degradation (contamination or salinization) of aquifers.

These objectives are discussed in the following sections, as well as the different tools and measures than can be mobilized by the state to achieve these objectives. In this review emphasis is placed on the first three objectives, as illustrated in Figure 6.

3.1 Controlling the number and expansion of wells

It is obvious that the first task of a state bent on regulating groundwater use in a given aquifer is to control and limit the *number* of wells extracting water from it. As a result any kind of state-centered groundwater management begins with 1) knowing who is abstracting how much, where and for what purpose, prompting inventories, registration campaigns, and then 2) organizing the process of authorizing drilling, licensing new wells, and permitting alteration (cleaning, deepening, replacement), in order to control the number and expansion of wells (Figure 7).

3.1.1 Regularizing existing wells

As indicated earlier, from the 1980s onwards many countries either established new systems of water rights or revitalized those that had been lying dormant. A key consideration is whether to integrate existing uses and users into the new registration system. Where no system of declaration existed it is hardly possible to deny the well user the right to 'regularization' or legalization. Where a system was already in place, however, existing legal (declared and/or licensed) wells are in general systematically licensed (subject to conditions such as reasonable or productive use, and proof of use). When the period for the regularization of wells expires those which have not been legalized may remain in a separate category and be granted temporary authorization (e.g. in Jordan, Spain or Tanzania, or Murray Darling basin’s Namoi catchment) (Figure 8).

Figure 6. Main groundwater policy objectives and tools (and local adaptation – inner circle)

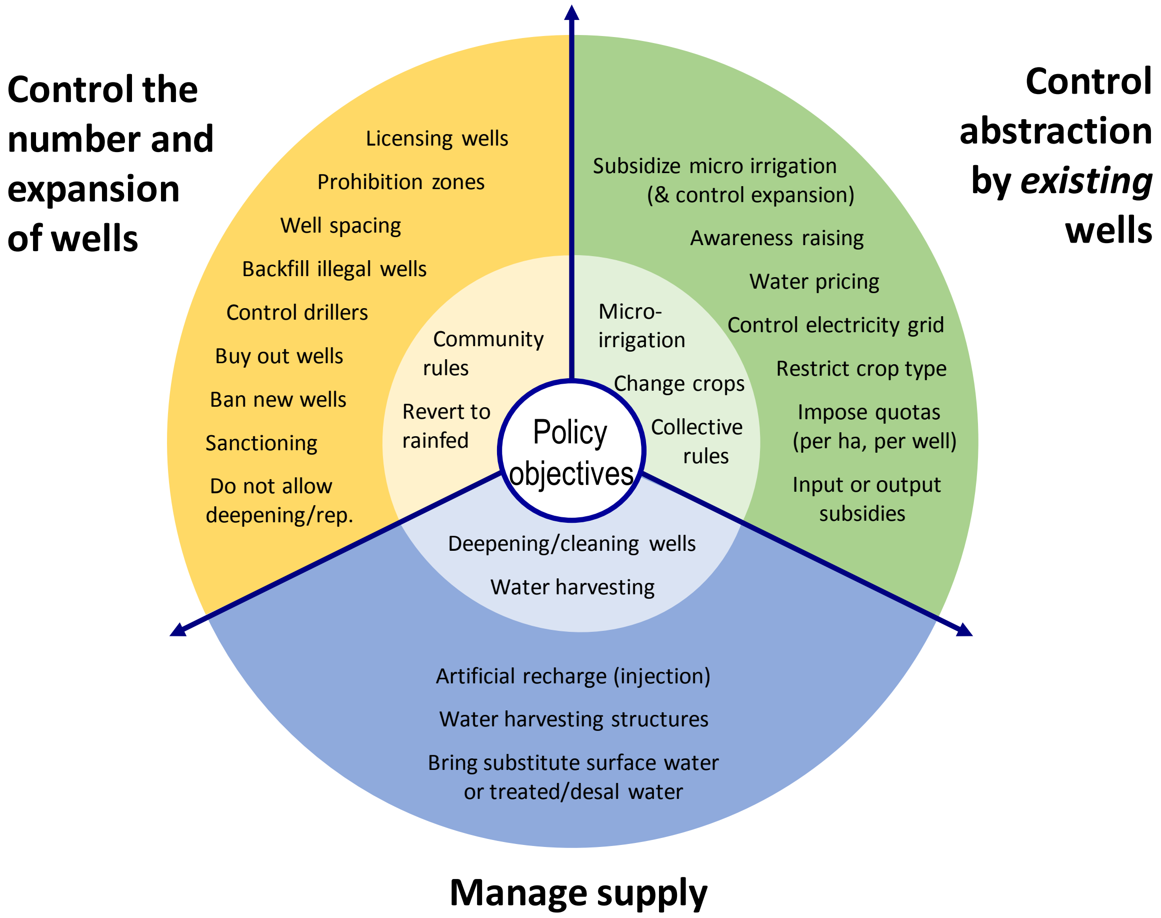


Figure 7. Authorizations and well licenses

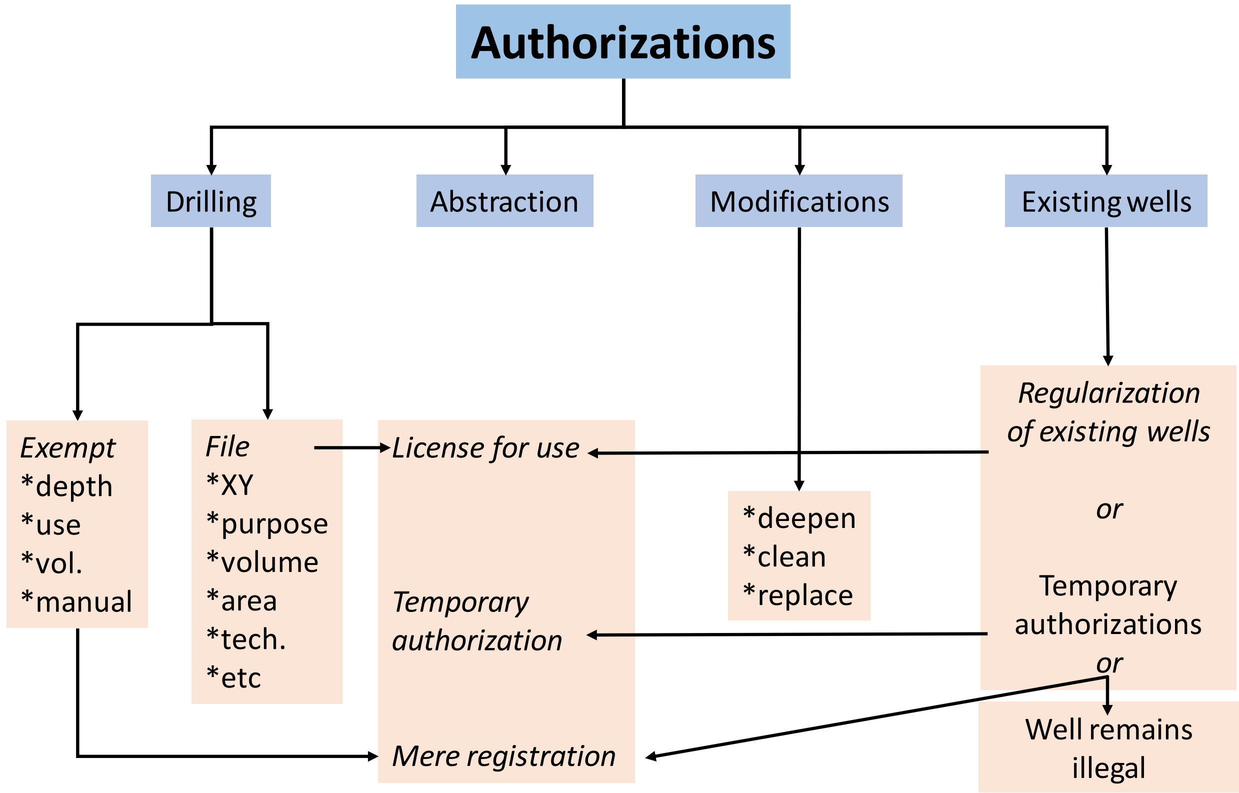
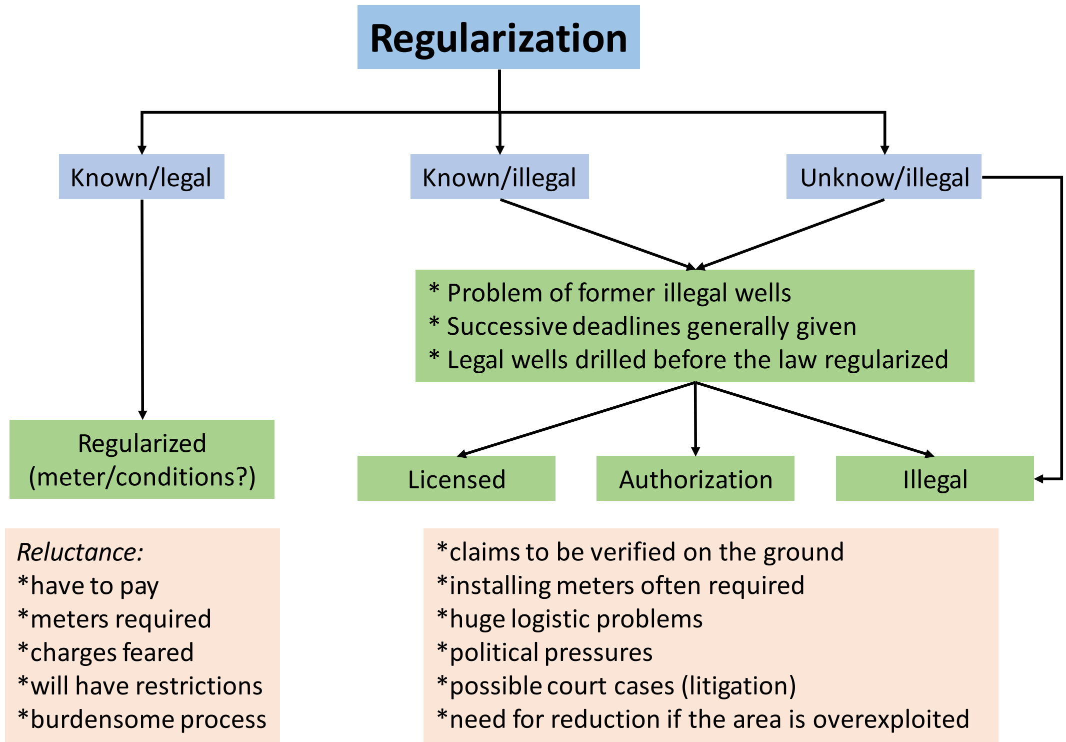


Figure 8. Regularizing/legalizing former uses or rights



3.1.1.1 Legal and hydrologic challenges

A problem arises when the consolidation of water rights comes with a shift from a private right system to a public one with concessions (see Section 2.5). In Spain the 1985 law declared water to be in the 'public domain' and that the state would regulate and control groundwater abstractions via concessions issued by River Basin Authorities for all users of wells over 7,000 m^3/year) (Closas 2012). This new law allowed well owners to register their historical rights in the Registry of *Public* Waters within three years of the Law's approval or, as explained earlier, to register their private right in the Catalogue of *Private* Waters and remain in the private property regime indefinitely. The decision to maintain a Catalogue of *Private* Waters was designed to avoid the risk of having to compensate users financially for the loss of their private right (Cabezas Guijarro and Sanchez 2012) as dictated by article 33 of Spain's Constitution in the case of the state's privatizing or limiting access to a good or property (ibid.). After three years only 10 to 20% of all private groundwater abstraction rights were entered into the registry, and only 8% in the catalogue (Fornés Azcoiti et al. 2005).

In South Africa several categories of entitlement were created as a way of bridging the gap between the old water legislation and the new National Water Act. The *Existing lawful water use* category was "intended as an interim measure to allow water use to continue until converted to a license."[9] This 'lawful water use' permits users to continue using the level of water that lawfully took place during the two years prior to the passing of the National Water Act. The intention was to avoid the high cost of revoking all pre-existing rights, which would have caused "a barrage of cases to be brought against the State" (Movik and de Jong 2011: 72). These abstractions must be validated and verified, however, to confirm how much water was used during the two years prior to the promulgation of the National Water Act, whether it had been correctly registered, and whether the water use was lawful and fair depending on the use and volumes for irrigation, hectares owned and used, and the crop types.[10] With compulsory licensing these 'late registrations' will be converted to licenses, with a specific abstraction volume authorized. The lack of knowledge or data about certain aquifers is an additional burden on the administrative system. In certain regions of the country water-use licenses can take up to 30 months to be processed (Anderson et al. 2007).

While on the face of it, it does not make sense for a legal well to become illegal, it must be noted that the strengthening of registration policy generally arises in contexts where overabstraction has been recognized. As a result one could infer that there is a need for a reduction in (rather than merely regulating) existing use, as was the case in South Africa where new and priority uses were recognized by the 1996 law: a reserve was allotted to the environment and to poor people, implying a possible reconsideration of the rights formerly ascribed to white farmers in basins where the resource would be found to be over-allocated. The legal challenges and political difficulties associated with such a move against powerful entrenched interests, together with the hydrologic uncertainties over how much water is to be allocated, are still largely contributing to current gridlock (Movik and de Jong 2011).

Similar difficulties with getting a sense of the degree of use/overuse before regularizing existing rights are routinely observed. In Peru, for example, despite having issued numerous censuses and studies of the availability of groundwater in the Ica valley, the ANA (National Water Agency)

[9] Department of Water and Sanitation, Republic of South Africa, www.dwa.gov.za/WAR/determine.aspx (Accessed August 18, 2015).

[10] This verification is based on previous records, information provided by the user (on file and through interviews), and also on remote sensing and satellite imagery. Department of Water and Sanitation, Republic of South Africa, www.dwa.gov.za/WAR/determine.aspx (Accessed August 18, 2015).

had not determined the values of groundwater availability and use for the valley, nor the maximum annual groundwater volume to be abstracted (Ministerio de Agricultura 2012). Moreover, the ANA had not been registering or maintaining up-to-date information on the well permits granted in the valley for agriculture (with 127 resolutions issued between 2009 and 2011 pending to be registered and updated in the database). The granting of licenses for agriculture has therefore been done without serious oversight or control of the volumes abstracted by the wells. (During the period 2009-11, 81% of authorized wells did not have a meter installed and no regular control or checks were done on the monthly reports submitted by the owners of metered wells) (Contraloria General de la Republica 2011; Ministerio de Agricultura 2012).

The question then arises as to whether those having illegally dug or drilled wells, which should have been declared to the administration, should be able to have them legalized. They could be disqualified for having failed to register in the past. In practice, it would be a tall order for a state to invalidate such wells, which often constitute the overwhelming majority of those in use. Introducing criteria as to which wells should be invalidated would also be clearly conflict-prone.

3.1.1.2 Identifying existing users and proving past reasonable use

Another difficulty comes from the need to identify who was using the water and how much. It is obviously tempting for people to register higher than actual use in order to protect against any future limitations, or even to declare nonexistent use if there is no control (e.g. in Kairouan, Tunisia, Massuel 2015) for fear of a ban on well drilling. In Chile the 2005 reform of the Water Law sought to address the situation of irregularity of groundwater rights. The DGA was therefore allowed to deliver permanent abstraction rights to any abstraction of less than 2 liters/second, as long as they had been established prior to June 30, 2004 and justified with a mere declaration from the user. The deadline was established for December 16, 2005 (500 applications had been submitted for the whole Atacama region).

In Spain all groundwater users had to present proof that they had been abstracting water prior to the enactment of the 1985 Law. This led to substantial administrative chaos, since neither the law nor subsequent ministerial regulations specified the documents that could be given as proof.

In 1992 a new National Water Law in Mexico declared both surface and groundwater to be in the public domain and required groundwater users to register all abstraction points in the Public Registry of Water Rights. These users were granted the right to abstract a certain amount of groundwater for each well (called a 'concession')[11] (CONAGUA 2009). The multitude of 'irregular' or provisional extraction authorizations needed to be regulated and added to the Registry of Water Rights. Due to insufficient institutional and human resources, however, the water administration could not verify the authenticity of the permits or confirm the legitimate use of groundwater (World Bank 2009). The result was that many farmers were granted legal rights to much more water than could sustainably be abstracted. In Toluca Valley, for example (Reis 2014), to establish volumetric concessions officers used information such as the characteristics of the construction and operation of the well and the number of hectares irrigated (e.g. 6,000 m^3/year), etc. But it also surfaced that agricultural users could state any volume they wanted in their application and the concession would be granted; as a result most agricultural users are 'over-concessioned', having rights for higher volumes than they actually use.

In South Africa the Department of Water Affairs has "very limited capacity to evaluate and judge each application on its own merits, check on-site or enforce the licensing process. Administrative

[11] Concessions would be calculated by CONAGUA according to the groundwater needs of the user and the availability and state of groundwater resources in the aquifer. In many instances, farmers are not even aware of their official concession volumes (World Bank 2009).

pressure, and the proven threat that vested applicants can report any delays to the Water Tribunal, pushes officials towards allocating whatever is being asked for" (Funke and Jacobs 2011: 90). In addition, the attempts to actually determine the extent of lawfulness of existing users through the Validation and Verification process are proving to be very difficult and time-consuming (Movik and de Jong 2011).

In 2012 the Bangalore Water Supply and Sewerage Board requested well owners to register their wells but stated that it had neither a plan nor sufficient staff to check on existing wells.

The identification of existing users can have some perverse effects: pumping levels for the Raymond Basin, California, were adjudicated in 1945 as a 30% reduction of the 'present unadjusted rights' that occurred during the previous five years. However, the establishment of quotas based on historic use tended to promote, according to Lipson (1978: 12), "a race to the pump house to establish a high quota" as users' attorneys advised them to "keep pumping despite the cost, since reduced pumping might damage their groundwater rights" (Lipson 1978: 29).

3.1.1.3 Shifting deadlines

Regularization procedures generally give well owners (whether legal or illegal) a specified period of time (typically ranging from three months to three years) to declare their wells. But the expectation that people will be ready to comply and happy to legalize their well is (almost) always proved wrong. Reluctance to register has various reasons, including the fear of being taxed or seeing use restricted in the future, a burdensome administrative process, or the fees to be paid for registration (e.g. US$935 in Lebanon), the imposition of a water meter, or the contestation of state ownership and intrusion in private or local affairs.

Consequently, registration procedures are lengthy, partial, and give way to renewed and successive deadlines[12]:

- In South Africa the legalization period began in 1998, but only 20% of applications had been processed by 2012, with permits distributed in only two basins.
- In Morocco a legalization period for wells dug before 1995 was open in 1998; in 2009 wells dug before 2009 were allowed to be registered within a three-year period, later extended to 2015.
- In Jordan the 2002 Bylaw gave six months to owners of illegal wells to register their situation (if they fit a socioeconomic criterion); an amendment in 2003 gave another year, and in 2007 the possibility was restricted to wells drilled before 2005 and waiting for a land settlement. Eventually, in 2014, all wells older than 2005 were considered illegal and liable to be backfilled (Al-Naber and Molle 2017).
- In Chile the modification of the Water Law in 2005 aimed at ending the situation of non-registered groundwater wells, giving well owners the option of registering their wells (provided that they had been drilled before 2004) with a simple declaration.
- In Lebanon, the Minister for Electricity and Water issued a Decision (No.118) in 2010 giving one year for well owners to register their wells but the application decree only came in 2015. After one year it was necessary to extend the period by another year, at the end of which only 200 domestic and industrial well owners had come forth… (Molle et al. 2017).

[12] Oman seems to be an exception, since all wells dug after 1990 without licenses cannot be registered and must be backfilled (as per a decision in 2009; Oman, 2009).

- Despite making existing well registration mandatory, as well as the application for permits for new wells after December 2012, the BWSSB (Bangalore Water Supply and Sewerage Board) had only recorded 135 bore wells three months later, considered a "drop in the ocean." The deadline established by the Board to register existing wells was extended three times; yet by December 2013 still only 66,000 wells had been registered by their owners (Water Governance Facility 2013).
  Board officials sent contradictory messages through various media, stating that the Board had no specific rules to be applied to limit illegal wells or penalize users, while at the same time threatening to cut the power supply to those without permits (something outside the powers of the Board) (Water Governance Facility 2013). Enforcement of these measures is lax, however, and has resulted in a growing disrespect for legislation, fueling a culture of non-compliance with the law (Water Governance Facility 2013).

3.1.1.4 Logistical nightmare

Registration processes are fraught with false declarations, litigation, in some countries corruption (see Section 3.5.2.3), and what almost invariably turns out to be a logistical nightmare. In Spain, on the last day of the registration period in 1988, 12,000 applications for permits for groundwater abstraction rights overwhelmed and crippled the Guadiana River Basin Authority (Fornés et al. 2005). Subsequent governmental programs to regularize groundwater abstraction also proved to be insufficient and very costly: at between €150 and €300 million for the 500,000 wells to be registered in Spain (some estimate their number at one or even two million) at a unit cost per well of €300 to €600 (Fornés et al. 2005).

In South Africa the regulation of groundwater abstraction through the issuing of licenses has hit difficulties due to the administrative burden of a large number of licenses requested by small-scale users, as well as delays due to difficulties in obtaining all the information from applicants (Seward 2010). Under the new water law, it was expected that the authority to allocate licenses "would be transferred to the level of the Catchment Management Agencies […] however it has proved very difficult to set up CMAs and there are only three CMAs in South Africa to date, none of which has been given the full powers of licensing" (Movik and de Jong 2011: 68).

The licensing process can take two years or more to complete. It "is often regarded as a tedious piece of bureaucracy rather than a powerful tool for ensuring sustainability, especially when license applicants usually expect the process to be completed in a few months" (Seward 2010: 242). Out of a sample of 23 licenses studied from the Department database by Movik and de Jong (2011) the average runtime taken to process licenses was of 5.7 years (instead of the target of 5 months), resulting in acute backlog (Pietersen et al. 2011). This has meant that water use has been taking place without proper regulation and that illegal use abounds (only about 20% of groundwater use has been verified by the DWA) (DWA 2010). Human resources are lacking, as well as socioeconomic data related to groundwater resources, and technical and professional expertise is missing at all management levels (centrally and locally) (Knuppe 2011; Seward et al. 2015). The lack of trained officials in the DWA is due to an ageing workforce, the emigration of professionals, and constraints of university and higher education systems (Anaman 2013); poorly paid staff positions and poor working conditions drive candidates or staff to more desirable posts elsewhere (Seward et al. 2015). In 2011 the Department of Water Affairs aimed to address the backlog of applications, increasing its target for successfully completed authorizations to 40% by 2014 (Funke and Jacobs 2011). According to Pietersen et al. (2012), only 20% of groundwater-use applications had been processed by 2012.

In the city of Cape Town the delegation of the Department of Water Affairs found itself to be "capacity constrained," limiting the ability of its staff to monitor groundwater and process license applications (which could take up to nine months) (Colvin and Saayman 2007). Likewise, the implementation of rules in the city is curtailed by a lack of administrative capacity and resources.

In Tanzania only 3,680 water-use permits (and effluent-discharge and drilling permits) had been allocated across the entire country by 2014. This prompts van Koppen et al. (2016) to observe that the overwhelming majority of informal small water users in Tanzania were *de jure* criminals, theoretically facing a legal threat of six months imprisonment. "However, even if the hundreds of thousands of smallholder irrigators had been informed about the law and had applied for a permit, state capacity would have been too limited to process even a fraction of their applications. The Water Resource Management Act recognizes this by asking Basin Officers to also maintain an Unauthorized Abstractions Register" (ibid.).

3.1.1.5 Incomplete inventories

Inventories and registration processes are, with few exceptions, partial and patchy. This is due to 1) lack of capacity on the part of the administration to process applications, 2) some well owners preferring not to declare their wells, 3) the continuous drilling of illegal wells. In Spain, while official estimates refer to around 500,000 wells, the Water White Book put their number at one million (MMA 2000), and Llamas et al. (2001) at around two million. In 2005 the former Spanish Ministry for the Environment estimated that the country had about 510,000 illegal wells (WWF 2006). To take an example, according to Martinez-Santos et al. (2008), nearly 40,000 wells existed in the Western Mancha aquifer in 2008, of which only 17,000 had been registered with the Guadiana River Basin Authority.

In 2009 the Mexican National Water Commission (CONAGUA) estimated that there were around 140,000 wells in the country, 42,600 of which were officially registered, while another 10,000 had some kind of authorization. Official statistics for the state of Guanajuato show that there are 250,000 ha irrigated with wells. However, alternative methods used by the Secretariat for Agriculture (aerial photography and on-site visits) have quantified the irrigated area at around 326,000 ha (ibid.). The agency also concluded that despite the official number of registered wells being 13,500, the real number is closer to 18,000 (OECD 2013).

Peru's water authority has inventoried 1,700 wells in the Ica valley, of which 451 have a license (Ministerio de Agricultura 2012). In the Ica sub-aquifer, 71% of all wells inventoried have no license, as is the case for 70% of all wells in the Villacuri sub-aquifer (ibid.).

A report by the European Academies Science Advisory Council (EASAC 2010) concluded that, in Southern European Union Member States (SEUMS), "a common concern is the rapid growth in the number of users of groundwater, which has, in many parts, led to a significant unregulated community of users. In some parts of the SEUMS, these unregulated users are in number equal to the regulated sector and make a similar level of demand" (EASAC 2010: 1). In 2010 a conference of the European Commission on unauthorized water usage in agriculture provided an interesting picture of the challenges of regulating water use in Europe (Dworak et al. 2010). Estimates suggest that unauthorized water use can possibly be larger than authorized use in several regions of the EU, particularly in the more arid and semi-arid southern member states. For example, on the island of Malta in 2007 official sources acknowledged an unlicensed groundwater abstraction of 18.5 Mm^3/yr, on top of an authorized pumping of 15 Mm^3/yr (Times of Malta 2008 in De Stefano and López-Gunn 2012). In the Roussillon aquifer, south of France, in the late 2000s only 10-20% of the wells were officially registered (Montginoul and Rinaudo 2009).

In Morocco the total number of existing wells is unknown (low estimates put it at 75,000 or 100,000, but there is evidence that it is far higher). Officials still cite statistics on private groundwater-based irrigation that date back to 2004 (Molle 2017). In the El Ghrouss area, Algeria, while 200 tubewells have been authorized, a recent survey put their number at 1,500 (Amichi 2015). The Mitidja Plain Management Plan (2013) observes that for the Wilaya of Blida 2,000 illegal wells can be found alongside the 1,200 legal wells. Information from a UNDP-funded project in Lebanon in 2014 estimated that there are around 59,124 unregistered private wells and 20,537 registered private wells in the country (MoEW and UNDP 2014). In Jordan, a recent (partial) survey identified a rate of illegal wells around 15% (USAID 2014), but higher in Azraq area, where illegal drilling is continuing (Al-Naber and Molle 2017).

Yet identifying wells may not even be enough. Studies carried out in North Africa (Massuel et al. 2017) point out that the number of wells (and year of construction) is not necessarily a good indicator of abstraction: some farmers record the last time they deepened the well as the drilling year; when the land is divided within the family people may prefer to drill their own well, to be independent or for social status, even though these new wells will be much less utilized (because the plot is smaller); sometimes two or three older wells are abandoned and replaced by a deep borehole. In these situations the fact that old wells are not used anymore is not recorded. The amount of water abstracted is also not proportional to the number of wells because, as the aquifer drops, the yield of each of the wells also declines (not to mention the possible effect of the decrease in pump efficiency with time).

The number of wells in Kairouan, Tunisia, is not well known. Before the revolution official figures would indicate that between 2,000 and 3,000 wells were licensed. The study carried out by a private company found a total of 6,600 wells (active or disused) on one part of the plain, which, after extrapolation provides an estimate of between 8,000 and 9,000 wells for the plain (Massuel 2015). In 2011, however, the ministry gave farmers the option of being connected to the grid. In a matter of two months 12,000 applications were made, in addition to the already connected wells (ibid.)…

In Syria, despite the fact that the 1999 'Circulaire 13' banned new wells as well as the renewal of licenses for dried-up wells, and that the government issued a further decree in 2001 demanding the licensing of all illegal wells, 57% of all wells were estimated to be still unlicensed in 2010, while more wells continued to be drilled without permits (de Châtel 2014; Saade-Sbeih 2011). As an example, in the region of Salamieh, east of Hama, 80% of the 6,356 wells inventoried in 2005 lacked a permit (Saade-Sbeih 2011). In Yemen between 2003, when the Water Law was passed, and 2007 the National Water Resource Authority received around 2,000 license applications of which 47% had been approved. This of course has to be contrasted with the close to 100,000 wells existing across the country (Redecker 2007).

In conclusion it can be said that registration processes take much longer than anticipated and are never completed (see next section). Some users choose to remain illegal for a variety of reasons, and drilling bans that are not sufficiently enforced continuously fuel new illegal wells. The examples of countries such as Spain and Jordan suggest that it could take 20 years or more to achieve registers that include say at least 80% of existing wells.

Registration of existing wells (or at least knowledge of existing use) is facilitated by particular contexts: where groundwater is the main resource (e.g. 100% of supply in Denmark), where the wells are limited in number and managed by companies or municipalities (e.g. coastal California), where the identification of farms is simplified by their size and layout (e.g. Texas or Nebraska, or central pivots in the desert of Saudi Arabia).

3.1.1.6 Incentives to register

The incentives to register, and even to legalize wells when a window of opportunity opens up, are not always compelling for farmers. In South Africa, for example, users having received licenses do not perceive any advantage as "they observe that their fellow water users continue to draw water as before whereas they, who now possess licenses, have to pay fees and comply with the conditions in the license in order to be able to continue with their use" (Movik and de Jong 2011: 73). Most commonly farmers fear further taxation and monitoring of the volumes abstracted. In some cases the conditions for registration/legalization are too restrictive, and it is very common, in particular, that this process is obstructed by a lack of clarity about land ownership (e.g. Morocco, where many farmers cultivate collective lands).

Observations from our various case studies suggest that 'sticks'/threats do not work well. The only situations where farmers have been willing to come forth and declare their wells are those where the state had extended attractive 'carrots'. These incentives include:

- credit or subsidies; a neat example is provided by the *Plan Maroc Vert*, in Morocco, which distributes subsidies for micro-irrigation of between 80% to 100% of the investment costs; in Mexico, regularization has been encouraged through a subsidy on electricity (Shah 2009);
- (legal) connection to the electricity grid (3-phase and/or higher voltage)(e.g. Tunisia);
- the allocation of EU subsidies (e.g. the western Mancha aquifer, Spain, see Closas et al. 2017).

Sticks may also encourage official drilling requests and regularization. When the cost of drilling is extremely high and when the likelihhod of sanction is perceived as high enough, farmers are loath to take the risk of such investments. This is the case in Mafraq, northern Jordan, where a 300 m deep well equipped for a 50 ha farm involves an outlay of US$60,000 (Al-Naber and Molle 2017).

A way to improve the interest of farmers in legalizing their existing wells could be to *associate* stick and carrots – 'take the later before you get the former' – in the following way: farmers would be given given a certain time to make their wells lawful under the new regulation/law, at no or minimal cost/burden[13], and informed that a national inventory will, in a subsequent phase, be carried out by field survey, with the help of satellite imagery. Wells inventoried and not formerly declared will be taxed, declared illegal and disconnected from the grid (if they are connected), and possibly deprived of other benefit (e.g. subsidies for investments).

3.1.2 Exemptions

In most countries licensing (acquiring official authorization) or registration (notification) are required for certain types of wells only, with thresholds defined by parameters such as the well depth, the diameter of the bore, the type of use, the area irrigated, the capacity of the pump, the volume abstracted (per day or per year), etc. as illustrated in what follows:

- In Lebanon wells requiring drilling permits are those deeper than 150 m. All wells with abstraction higher than 100 m^3 per day should be registered and taxed (Molle et al. 2017).
- In South Africa groundwater entitlements used for reasonable domestic purposes, small garden plots, and livestock are termed *Schedule 1* and are not required to register.

[13] In part of the US this can be done through internet with a fee of 10US$.

- In the Orange County Water District, California, wells with outlet diameter less than 1 inch do not have to be declared.
- In Australia, although in Groundwater Management Units all irrigation uses are to be licensed, mining leases benefit from license exemptions. These do not have to provide metering or report abstraction levels to the agency responsible for water management.
- In Perth, Western Australia, garden bores are exempted from licensing if they are used for "watering an area of lawn or garden that does not exceed 0.2 ha" (Bennett and Garner 2015). By 2009 there were an estimated 167,000 domestic garden bores in the Perth metropolitan area, using approximately 15% of all groundwater taken in the region. Other exemptions from licensing include: 1) firefighting, 2) watering cattle or other livestock (not raised intensively), 3) watering gardens smaller than 0.2 ha, 3) other domestic uses, 4) short-term dewatering, 5) taking water for monitoring purposes.
- In Yemen, since the Water Law of 2002, it is mandatory to apply for permission to drill a new well, to deepen it, or to repair an existing one, when the well is deeper than 60 meters (Lichtenthäler 2014).
- In Saudi Arabia permits for well drilling apply to farmers whose land exceeds 2.5 ha (Burchi and D'Andrea 2003).
- In Turkey groundwater abstraction permits are required only for wells deeper than 10 meters, and not excavated by hand. This limit is 40 m in Morocco, but in Marrakech there was a limit of 200 m^3/d in 1972, later reduced to 40 m^3/d in 1981 (Buchs 2012).
- In Flanders (Belgium) farmers pumping less than 500 m^3/year only need to notify their use to the local council, while those over this limit require authorization.
- In France wells shallower than 10 m do not need to be licensed but should be declared.
- In Portugal this limit is expressed in horse power of the pumping equipment (5hp).
- In Poland, Bulgaria, and the UK only extraction over 5, 10, and 20 m^3 per day, respectively, requires authorization or a license; in Spain the limit is 7,000 m^3/year.
- In West Bengal, India, farmers located in groundwater blocks not designated as overexploited, and owning pumps of less than 5 horsepower, discharging less than 30 m^3/hour, are exempt from permits (Buisson 2015).
- In Sweden irrigation does not need authorization as long as it does not cause any harm to public or private interests (Dworak et al. 2010).
- In South Australia wells for livestock and domestic use do not have to be registered (except in the Eastern Mount Lofty Ranges and Northern Adelaide Plains Areas, which are highly allocated).
- Rules sometimes define whether the authorization is provided by the local, regional or national authorities, such as in the Czech Republic.

These examples largely reflect differences in terms of water scarcity, relative levels of irrigation and other uses, as well as the historical background of water rights (Roman law, Germanic tradition, former communist countries). Exemption given to a certain category of wells may prove to be problematic with time, as in Prescott Arizona for example, where the combined abstraction of exempted wells is the third largest water use (Trout Unlimited 2007).

3.1.3 Licensing and water-use entitlements

Would-be groundwater users have to follow a formal procedure to obtain an authorization, except in situations where a drilling ban has been decreed (see next section) or when the use is not liable to licensing (section above). This authorization can be composed of a drilling (or 'exploration') permit, followed by authorization to use groundwater. These are not groundwater 'rights' *per se*, with the exception of Chile and a few situations where historical rights have been requalified to some degree (see Section 2.5). Users are granted *usufruct* rights, under the name of licenses, authorizations, concessions, permits, entitlements, or allocations, for a period which can vary between 1 and 50 years. Although these terms are often used in a rather loose and inconsistent way, in Australia a useful distinction is made between the legally defined 'entitlement', and the actual 'allocation', that is the amount of water that farmers are allowed to use *in a given year* depending on the hydrologic situation of the river basin. The allocation is often less than the entitlement but can also be higher.

State regulations are often quite demanding and burdensome. In addition to land titles and personal identification, applicants must provide information on depth, intended use and volumes, maps of well location (drawn by a certified engineer), drilling technique used, etc., and must generally pay fees. The request often has to go through several administrations/ministries and requires field visits and checks. In some cases the technical administration takes direct responsibility for the granting of licenses, but in others the process includes prior publication of the intended license in public places to allow for possible contestation by neighbors and the public at large (e.g. Morocco).

In Lebanon well permit applications are sent to the Water Rights and Expropriation Service which evaluates the technical and legal aspects of the application. Once confirmed, the Hydrogeological Service sends the permit request to be signed by the minister (it is a license delivered as a decree published in the state's official bulletin). After having issued a well drilling permit the ministry has to issue a second permit allowing for the exploitation and use of that well. Due to a lack of staff (the ministry has no hydrogeologist and the Hydrogeology Service operates with 9 staff instead of 49 official positions), the application procedure has been outsourced to certified private companies which have to examine the well drilled, the yield obtained, etc. and issue a report (Nassif 2016). Those who have declared their wells have rarely applied for a permit to use it (which entails taxation) and, as a result, the number of licensed wells barely exceeds 300 (Official Ministry of Energy and Water 2015; Molle et al. 2017). The ministry's officials cannot enter any site where there is a well as they need authorization from the Ministry of the Interior and ministry's staff will have to be accompanied by police officers (ibid.).

In Turkey an exploration license is required to drill a well (Apaydin 2011). This license is valid for one year, during which time the borehole must be drilled. The owner can then apply for a "license for use." This is granted by DSI if the legal and technical requirements are met, in particular the minimum proximity of the new well and others. It is not known whether people do request a drilling license in Turkey but in many countries this requirement is just disregarded. Wang et al. (2007a) who surveyed 448 villages and 126 townships in China, found that "inside China's villages few regulations have had any effect", with only 10% of well owners having requested a drilling permit, no water charge, and no fixed water quota.

In India the State of Andhra Pradesh issued a Water, Land and Trees Act in 2002, instituting a permit and registration system for wells. It mandated that well owners (including those not fitted with power-driven pumps) should register their well with the authority, and set up well spacing rules (Taylor 2013). In Karnataka state anyone wanting to drill a new well is also required to obtain a permit (but not those deepening existing wells). Applicants for new wells have to provide information about the location of the well, its purpose, and the distance from already existing wells (ibid.). The authority's decision is based on additional considerations such as the availability of groundwater, the volume expected to be abstracted, the quality of groundwater in the area, and the potential effects on any drinking water sources in the vicinity (wells need to be placed at least 500 meters from a public drinking water source) (ibid.). Likewise, the

Maharashtra Groundwater Act of 1993 specified minimum well distances between drinking water wells and other wells (500 meters).

Syrian legislation put in place in 1999 regulated groundwater abstraction. It limited well depth to 150 m, as well as the duration of permits (which would be granted for either one to three years or for 10 years) (Saade-Sbeih 2011). It also instituted an annual fee dependent on the power of the pump (Marina Stephan 2007). The Ministry of Irrigation, responsible for issuing the permits, also establishes the maximum volume of groundwater to be abstracted, the irrigable area, and limitations regarding boring and drilling techniques (Saade-Sbeih 2011).

In South Africa, whether for legalizing a well or requesting a license for a new one, an applicant first has to consult with an area or regional official from the Department of Water Affairs and Forestry in order to determine the water-use category in which theirs would qualify. If the use falls into the licensing category, the applicant and the department official have to gather information related to the water use, the catchment area, and the 'Reserve' for the area (the flow to be left for the environment). They can then determine the amount of allocable water in the area in which the water use will take place. Once all the information is gathered (such as title deed, application forms, technique used to capture the water, risk assessment and reserve determination) and the payment for the application is received, it is filed on a computerized system and reviewed at the Regional and later National Office for a final decision. The policy guidelines for licensing include the socioeconomic as well as technical and ecological considerations that have to be taken into account in order to authorize or decline the license application (Movik and de Jong 2011). This extremely complex process, due to the post-apartheid redistribution of water rights, is mired in all sorts of technical, legal and ground-level monitoring difficulties, as described earlier.

In the Haouz of Marrakech, Morocco, groundwater abstraction permits are required only for wells deeper than 40 meters. The 1998 decree mentions that water withdrawals for irrigation must be accompanied by a study showing the impact of the project on water resources, cultivable lands, and aquatic ecosystems (but in practice this requirement does not even feature on the official form provided for permit requests). When a request is made a public inquiry (*enquête d'utilité publique*) is conducted by a commission with representatives from the local commune (*qaid*), the ABH (*Agence de Basin* or River basin organization), the *Office de mise en valeur agricole* (ORMVA) (if the land is part of a large-scale public irrigation scheme), and a representative of the provincial or regional services of the Ministry of Agriculture. This inquiry is to be carried out within 30 days of the announcement of the proposed abstraction in the Official Gazette (*Bulletin officiel*) and its display at the local administration and ABH. If the commission issues a positive recommendation, the director of the ABH can decide whether a concession can be granted. This would require the approval of the management board (*Conseil d'Administration*) of the ABH. In the case of the drilling of a well the authorization must also specify the technology to be used, the characteristics of the casing, and the minimum distance to other wells or water sources to be respected. This distance is supposed to vary depending on local conditions but the standard distance to other wells is often taken as 100 m. At the end of the work, the grantee is in theory given 60 days to submit a report indicating the results of the pumping tests (to be conducted in the presence of a representative of the ABH), the level of the static level of groundwater, the results of chemical and bacteriological analyses (a requirement dropped in 2009), soil samples taken at each meter excavated. This demanding procedure is complex and costly for farmers who, unsurprisingly, prefer to continue drilling wells illegally. In 2009 requests for drilling and withdrawal authorizations were combined into a single procedure.

As with the legalization procedure discussed earlier, registration and licensing processes are bedeviled by the cost and time needed to process files, the lack of capacity to check reality on the ground, the lack of budget and staff of agencies, political pressure, and the capacity of influential people to circumvent the rules to obtain authorizations.

3.1.4 Licenses for altering wells

Licensing wells generally means that bureaucratic processes must also be established for requests of well deepening, cleaning, or replacement (well clogged up or dried up), since otherwise groundwater users could use these categories as a way to camouflage the drilling of new wells.

In Oman, for example, permits are required for new wells, deepening, changes in purpose or in pumping equipment, use of formerly disused wells, and prior to any transaction. The applicant and driller each have to pay a deposit of 500 JR before receiving their respective permits (which are returned once the work has been completed and checked) (Oman 2009). A request for well deepening cannot be justified by the objective of improving water quality or yield, and the irrigated area cannot be enlarged. Jordan also places the same conditions and requires similar permits for all well maintenance operations (deepening, cleaning, replacing) (Al-Naber and Molle 2017). In Turkey groundwater users must apply for a "license for reclamation and alteration" if they want to deepen or change the characteristics of their wells. In Yemen, no permit is required to deepen a well if it is the first time and the additional depth does not exceed 20 meters. In Karnataka state, India, no permit is required for those deepening existing wells.

The Spanish water authority must be notified of any changes to the characteristics of a well (deepening, widening). If such changes are not reported, the water right holder operates beyond the protection of the administrative system. The administration typically uses situations where deepening is necessary to force users into an administrative process whereby a private water right associated with the well is converted into a public concession for water use (De Stefano and López-Gunn 2012). Likewise, in Jordan the need to alter a well is used to change the category of the right or even to reduce the entitlement (Al-Naber and Molle 2017). The application of the law is tightened on those users needing a reconsideration of their status or entitlement.

But this is not always the case. The first prohibition on well drilling in part of the Ica valley, Peru, was decreed in 1970, but time was allowed for the legalization of existing wells. The ban was extended and reinstated in June 2011 by the national water agency, again leaving a loophole: a well that had become disused (due to a technical problem or having dried up, for example) in the past six months could be replaced by a new well. This last condition, however, is hard to ascertain because the agency only monitors 100 wells out of the 869 registered in the valley (Cardenas Panduro 2012). Many old nonfunctioning wells have therefore been replaced by new ones, increasing overexploitation. Likewise, the regulation has been circumvented in Jordan, where some farmers apply for a well-cleaning license but instead deepen the well to get more water; others who would obtain a well-deepening license would not respect the stipulated depth. Field observations showed that farmers can also seemingly damage a working well in order to be able to apply for a replacement license. They may fill it with soil or obstruct it superficially, so that when the WAJ inspects it a replacement license is approved. After the new well is finished they remove the obstacles and reopen the original well (Al-Naber and Molle 2017).

There is a further noteworthy constraint to authorization for well alteration. It has been observed that emergency interventions can be required in the course of an irrigation, in order to save the crops, which is incompatible with the slow pace of administrative procedures (De Stefano and López-Gunn 2012).

3.1.5 Zoning and special management zones

It is a standard groundwater management tool to entrust the water administration with the power to identify and declare particular areas as under threat, overexploited, and/or in need of protection: such problem areas are referred to as 'notified areas' (India), 'designated areas' (Japan), 'protected zones' (Namibia), 'prohibition zones’ (Yemen, Iran, Spain), 'resource preservation areas' (France), 'water control districts' or 'prescribed well areas' (Australia), 'quantitative, or qualitative, protection areas' (Algeria), 'groundwater conservation areas' (Kenya), 'groundwater management areas' (Texas, US), 'Red Zones' (Abu Dhabi), etc. Two (or more) categories are often distinguished, depending on the severity of the problem, such as the 'zones of protection' and 'zones of prohibition' in Morocco, which are each associated with a number of measures. In Iran out of 609 aquifers 203 are classified as 'normal prohibited aquifers' and 67 as 'critical prohibited aquifers' (Assadollahi 2009). The idea behind defining special zones is to limit the use of policy constraints to areas where the situation is critical enough to warrant special state intervention.

Turkey also has a mechanism whereby overexploited aquifers can be declared as critical or semi-critical basins. In such cases, all wells have to be equipped with flow meters, according to a regulation issued in 2011. Four basins have been declared as critical (including the Konya closed basin) by ruling of the cabinet, which has followed the recommendation of DSI and banned further well drilling, as well as the allocation of licenses (Doğdu 2013).

Since 1948 Mexico has attempted to use pumping bans to regulate groundwater abstraction in the 50 so-called '*zonas de veda*', established as early as between 1948 and 1963. In December 2011 there were 160 *zonas de veda* in Mexico (CONAGUA 2012: 86), covering 55% of the country (CONAGUA 2012; Reis 2014).

In Maharashtra the Groundwater Act of 1993 specified minimum distances between drinking-water wells and others (500 meters). The act gave power to the Groundwater Agency (GSDA) to regulate groundwater in areas decreed with scarcity. Amongst the GSDA’s powers is the right to impose controls on existing wells used for irrigation, regardless of whether they are a safe distance from public drinking sources, to authorize bans on new wells in overexploited watersheds, and to prohibit farmers from abstracting groundwater from wells for certain periods of time for purposes other than for drinking water (Phansalkar and Kher 2006). Likewise, in Andhra Pradesh the 2002 Water Act allowed the Authority to forbid individuals from pumping in areas where it was likely to damage groundwater levels or harm the environment or natural resources (the prohibition can extend to six months or more if the Authority considers that harmful conditions are still present) (ibid.).

In Australia general legislation also enables each state to delineate a specific area or aquifer, determined under statutory power or in accordance with a policy initiative (e.g. a water-resource-management plan), and establish it as a 'Groundwater Management Unit'. In Japan 'designated areas' (Endo 2015) were defined as where land subsidence was established and where substitute surface water was available, or where works to bring such water were underway.

In sum, restricted zones highlight the difficulty, and sometimes the irrelevance, of registering and controlling well drilling all over the country. They are specific areas where land subsidence, overexploitation, or water quality degradation warrant state intervention. But their features are not only technical or administrative. In legal systems where the intervention of the state in groundwater management is not fully accepted/acceptable, states often claim that the public interest is at stake, or threatened, in those particular areas, to justify intervention that may override customary rights.

3.1.6 Buyback of wells and licenses

Controlling wells (where groundwater has been over-allocated) may include buying them back from right/entitlement holders. This is the most straightforward way to decrease use, but of course 1) it requires (potentially very substantial) outlays from the government; 2) the administration has to make sure that corresponding wells are effectively left unused; and 3) such a policy is obviously nonsensical where the drilling of illegal wells is not first of all put under control. This may explain why buying back entitlements is uncommon. Examples include Mexico, Australia, Spain, China, Namibia, and the US.

In Mexico in 2003 the Water Rights Use Adequacy program (PADUA) (2003-06) sought to reduce overallocation of water in Mexico by, among other things, paying back water rights. A total of 112 Mm^3 of surface water rights and 18 Mm^3 of groundwater rights were bought from two irrigation districts, at a cost of US$25.6 million (Speed et al. 2013). In the Altar Pitiquito irrigation district more specifically 30 wells were cancelled by the program and purchased back at the average price of US$243/1000 m^3 – a price that was largely unconvincing for most farmers due to the high economic return of intensive agriculture.

In the Murray Darling Basin the federal government earmarked Au$3.1 billion to purchase water entitlements and return them to the environment. By 2010, 0.9 Bm^3 had already been purchased by the federal government, and the MDB plan aimed to extend this work, proposing that an additional 2.1 Bm^3 be purchased from farmers to reach a target of 3 Bm^3 (Weir 2011). An initial budget allocation from the state's purse had been secured in 2008 through the Water for the Future Initiative for 0.7 Bm^3 of surface-water entitlements, and the government had US$1.8 billion remaining for future entitlement purchases, indicating "a willingness to draw deeper into the public purse to close the environmental watering gap if required" (Bjornlund et al. 2011: 291). As of September 2015 purchases secured under the Restoring the Balance in the Murray-Darling Basin Program amounted to 1.16 Bm3[14], most of which was surface water, but the program is now also buying groundwater[15]. However, the sales were agreed, according to Bjornlund et al. (2011), by irrigators "forced to sell as a last resort due to financial stress, not least as a result of the current prolonged drought (…) few regard[ing] themselves to be willing sellers of water entitlements" (ibid.). Another noteworthy point is that the water right holders in south-east Australia who engage in trading generally sell a part rather than the entire right (Turral 2015).

The story of the PEAG (Plan for the Upper Guadiana Basin) program in Spain offers a wealth of lessons. Facing a situation of dramatic overallocation of groundwater resources, the plan set out to acquire 130 Mm^3 of water rights between 2008 and 2015 via the purchase of private groundwater abstraction rights and concessions through a 'public water bank' (*Centro de Intercambio*) and the purchase of land around the Las Tablas de Daimiel National Park (López-Gunn et al. 2013). The state would buy user rights voluntarily offered through public acquisition offers and reassign up to one third of the rights to professional farmers without legal water rights or to other priority uses defined by the government of Castilla La Mancha. The rest was designated to improve aquifer levels, with the environmental target that a minimum of 35 Mm^3 per year would reach the Tablas de Daimiel National Park before 2027 (WWF 2012). Groundwater abstraction rights were purchased by the state based on the number of hectares irrigated from the well, with prices ranging between 3,000 and 10,000 €/ha for herbaceous crops and 3,000-6,000 €/ha for vineyards (Cabezas-Guijarro and Sánchez 2012). Farmers could choose

[14] Source: www.environment.gov.au/water/rural-water/restoring-balance-murray-darling-basin/progress-water-recovery (Accessed April 2017).

[15] Such as the current Groundwater Purchase Tender in Queensland Upper Condamine Alluvium.

only to sell part of the abstraction rights from their wells, in which case the River Basin Agency would control the meter installed in the well in order to monitor the actual groundwater consumption and limit the remaining abstraction right to what was allowed (Calleja 2014). Farmers having sold water rights would have to keep the land under dryland farming (López-Gunn 2014). Within a month of the sale well owners would have to remove pumping equipment and other machinery and seal the wells (Requena and Garcia 2010).

The PEAG disbursed almost €66 million for the purchase of groundwater rights (only 10% of the initial budget component allocated for the purchase of rights alone) (Fernández Lop 2013). Although the PEAG established rules aimed at controlling the sale of groundwater rights with proven groundwater abstraction for at least three years before the sale, research by WWF (2012) found that 83% of the rights purchased by the government had not been used for five years prior to the sale. In addition, the WWF study established that 95% of the rights sold to the ministry were located outside the priority area designated for purchase. The majority of rights acquired were used to legalize abstraction, while the total volume allocated to the environment reached only 9% of the planned value.

In the Upper Republican River basin, Nebraska, US, the groundwater district, through a partnership with the Natural Resources Conservation Service, spent US$2.1 million in land purchases from willing sellers easements for 1,546 acres (NARD 2015), corresponding to land close to streams with groundwater pumping rights. The Middle Republican District also purchased the Riverside Irrigation Company (672 acres), freeing nearly 2,000 acre feet of groundwater to be used for meeting requirements of the interstate Compact.

Another interesting case is provided by China's Minqan district, where 3,000 wells have been closed against compensation in cash, between US$ 800 and 5,000 per well (Aarnoudse 2012). The special reasons behind this achievement are detailed later (see Section 3.5.8.4) but include the need to save the oasis that constituted a barrier to the sandstorms threatening the capital and other cities. The drastic reduction in abstraction was also made possible by supply augmentation and other measures (Aarnoudse 2015).

Similarly, farmers in Namibia have agreed to be compensated, in cash or in kind, should their boreholes run dry because of well fields installed by the national water company NamWater. Compensation in kind includes the deepening of existing boreholes or being connected to piped water supply lines (Burchi and Nanni 2003). The buyback option was also considered by the government of Jordan (Chebaane et al. 2004; Venot and Molle 2008), where a survey discovered that 50% of farmers were in favor of such a measure (Chebaane et al. 2004). The government, however, is not inclined to consider such an option, especially for illegal wells, since it would belie the principle that water resources belong to the state.

A buyback mechanism is far simpler where a water market mechanism already exists, as in the case of Australia discussed above. Yet market prices can be very high and discourage the government from buying entitlements. In the Copiapó basin, in northern Chile, it has been estimated that US$300 million would be necessary to buy back sufficient water rights so as to rebalance the aquifer (RedAgricola 2013). If the prices offered are below the market rate, as in the Mexican case above, few transactions will be recorded, unless the state has coercive power and the groundwater economy is already in decline (Minqan case).

Finally it is crucial to investigate whether the entitlements that are bought back are for wells that are sealed, backfilled or destroyed. In Australia the wells are decommissioned but not backfilled. Control *a posteriori* is exercised centrally through metering and inspections (individual users also report on any neighboring irregular activities) (Turral 2015). In Minqan wells were filled with cement and disconnected from the grid. In Spain some of the rights purchased continued to be used after the sale (around 8% according to WWF 2012), and no proper check of prior use was carried out.

3.1.7 Canceling licenses and backfilling illegal wells

Many groundwater laws specify that illegal wells should be backfilled or destroyed, and that this should be done at the expense of the violators. This would appear to be the most effective and straightforward way to control abuse. In practice such a drastic measure is extremely rare, and the case of a productive plantation having to be abandoned after the well has been destroyed by the state remains to be seen. Jordan claims to have recently backfilled several hundred illegal wells but they were in fact disused (Al-Naber and Molle 2017). In Algeria in 2006 the Oran Province (wilaya) decided to inventory and destroy illegal wells. There is no sign that this decision was followed by any action on the ground (Amichi 2015). Since the "overwhelming majority" of farmers' wells are not registered, controlling or rationalizing the use of water is an elusive goal (Bellal et al. 2015).

In Mexico in 2011 and 2012 the CONAGUA (National Water Commission) repeatedly attempted to close down unlicensed wells in five regions (reportedly achieving a 10% success rate) but failed to curb the overabstraction of its aquifers (101 out of 653 are declared as overdrawn) (OECD 2013).

In Bsissi, near Gabes, Tunisia, farmers assisted the local authority (CRDA) in closing disused or abandoned wells in exchange for certain benefits. Forty-six tubewells, belonging to farmers refusing to become members of the Association and preferring to relocate to nearby areas, were said to have been backfilled.

In 2004 the Souss Massa River Basin Agency in Morocco carried out an awareness-raising campaign about the new water law aimed at farmers, while at the same time deciding to close two wells drilled without authorization. Various agricultural unions saw this as a potential precedent, putting many wells at risk. Following several protests the *wali* (governor) of the region suspended the decision, instead creating a commission that included representative members of agricultural unions in order to find a solution. Despite farmers requiring authorization to drill wells, the regulation was never seriously implemented and unauthorized pumps (around 70% of those in the Souss, for example) were never dismantled or closed (BRLi and Agro-Concept 2012). The situation prevails elsewhere: for a number of reasons, to be clarified later, with such a large number of illegal wells the state often lacks the will to intervene effectively.

In Oman all pending procedures or registrations have been cancelled for wells dug after 1990 without licenses, or by persons with no land title, or that are permanently dry. Such wells should theoretically be backfilled (*radam*) within 30 days, before legal action is taken (Oman 2009). This is commonplace in the water laws of the MENA region but is rarely acted upon.

In 2007-08 in the Werribee Irrigation District (west of Melbourne), during the seven- to eight-year drought, many cases of illegal pumping/drilling were witnessed (Turral 2015). Eventually, however, illegal wells were forcibly decommissioned and dismantled and their owners prosecuted. This (rare) instance of full application of the law was partly associated with the dramatic situation brought about by the prolonged drought.

In some cases, it is at the time of the renewal of a permit that a license can be refused because of their impact on river base flow and/or a Ramsar site is negative, as could be seen in UK.[16]

A further mechanism for the cancellation of licenses concerns those water entitlements distributed and managed at the basin level, such as in south-east Australia, Spain, Argentina (Mendoza), and Chile, where the granting of licenses can be subject to effective use. Groundwater users failing for any reason to put the water to which they were entitled to beneficial use would lose their license. This provision is particularly important to avoid hoarding and speculation, and has been the topic of heated debate in Chile (Bauer 2015). The 'use it or lose it' option has been implemented in Western Australia (Bennett and Gardner 2015) and may be a means of discontinuing (and reducing) entitlements. At the same time it has become apparent from several states in the US, such as Nevada, Utah, Idaho, and Oregon, that such policies encourage farmers to use their full entitlement, despite their actual need being far lower. This may work against water savings, although farmers have the option of selling on the proportion of their water entitlement that they do not use (Nevada), or to lease it (Idaho), or they only need to use a fraction of their entitlement to keep it (Oregon), or use it fully at least once in seven years (Utah)[17]. Likewise, in Mexico, the *caducidad* system was supposed to annul rights that were not put to use, but industrial users have so far used lawyers to successfully challenge this provision (Reis 2014).

3.1.8 Controlling drillers

A potentially straightforward way of limiting the drilling of new wells is to control drilling companies. In many countries with critical groundwater overdraft, drillers need to be registered and report on their activities. In contrast, in some countries such as France, they may be unregulated.

In Turkey the construction of groundwater facilities must be carried out by an expert on drilling, gallery and tunnel construction. To obtain a license one must pass tests set by the DSI every year. Licensed drillers work in accordance with the groundwater regulation (Apaydin 2011). In Oman well construction, maintenance, yield testing, and pump installation must also be carried out only by government-registered contractors (with licenses to be renewed every two years), and drillers must pay a fee for each well drilled (to be returned once the work is completed and checked) (Oman 2009). In Abu Dhabi drilling can only be undertaken by the private sector National Drilling Company, which is under contract from Abu Dhabi Food Control Authority for this work (Fragaszy and McDonnell 2016). In the Upper Republican District, Nebraska, well drilling can only be carried out by licensed drilling companies and illegal well drilling is hardly an issue (Fanning 2016).

The 2002 Groundwater Bylaw in Jordan also requires licenses and authorizations for drilling equipment and drillers (MWI 2002). New legislation since 2013 has allowed the cooperation between the Ministry of Water and Irrigation and Jordanian security forces to confiscate drilling rigs (up to 159 rigs appropriated by April 2015 since the campaign started in 2013).[18] In 2005 in the Souss-Massa, Morocco, the River Basin Agency launched an initiative to control borehole drilling and by 2006 70 drilling machines had been impounded; between 2006 and 2010 another 120 drills had been seized (BRLi and Agro-Concept 2012). The Souss River Basin Agency is also

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[16] www.gov.uk/government/publications/catfield-fen-decision-on-licence-application/catfield-fen-decision-on-licence-applications

[17] See www.unce.unr.edu/publications/files/nr/2013/fs1339.pdf for further information (Accessed April 2017).

[18] The Jordan Times 2015 "748 illegal fixtures removed from water mains in March", April 18, 2015, http://www.jordantimes.com/news/local/748-illegal-fixtures-removed-water-mains-march (Accessed August 17, 2015).

trying to organize drilling companies into a professional association, which could potentially become a management interlocutor.

Several Indian states have also moved towards tighter regulation of drilling companies. The state of Karnataka ruled that they and their equipment must be registered by a given deadline. The states of Karnataka and Andhra Pradesh adopted legislation in 2011 stipulating that the registration of wells and drilling companies be completed by a set date. In Maharashtra drilling contractors must register and require permission before drilling new wells in notified and non-notified areas (Aguilar 2011).

In China the drilling industry in some places has also been gradually controlled. Although in the early 1980s "household enterprises specializing in well-drilling emerged to compete with government drilling teams" (Wang and Huang 2002), local administrations have issued regulations to license and train all companies equipped with drilling rigs, such as in Sanxi Province (Guisheng et al. 2013).

However, controlling drilling companies may prove to be as difficult as controlling farmers, despite their more limited number; and regulations concerning companies might be as ineffective as those concerning farmers (possibly for the same reasons). In Yemen all heavy drilling rigs and water metal casing must meet technical specifications issued by the Water Authority (NWRA) (Morill and Simas 2009). While 125 drilling contractors became licensed by the end of 2006, there were around 409 drilling rigs known to be in operation in the country, most of them unlicensed (NWSSIP 2008; Redecker 2007); other estimates put the number at 900 (former Minister of Water and Environment, Yemen, personal communication). Despite the use of sophisticated technology (e.g. GPS tracking, which has never been made operational [Van Steenbergen et al. 2014], and satellite imagery in the hands of a 'rig tracking unit'), illegal drilling has continued in Yemen, with blatant regulation violations carried out by influential people (Ward 2015). In the Souss and Chtouka regions of Morocco the water police remained short-staffed, while users drilled overnight and during holidays and weekends (BRLi and Agro-Concept 2012). In Marrakech it was reported that existing wells were being deepened, with the advantage that this could be done behind the walls of the household compound (fieldwork 2014). In Algeria, and elsewhere in the region, fingers are pointed at Syrian operators specialized in legal/illegal well drilling.[19]

Apaydin (2011) remarks that in Turkey existing penalties for unlicensed drillers are very light and insufficient, allowing them to continue working in another region even if they are fined. Licensed drillers can see their license canceled but unlicensed drillers can only be fined. The relative lack of willpower to regulate drilling companies reflects the considerable financial interests related to this activity, which is sometimes controlled by influential people.

Drilling companies also have an often unnoticed 'wandering capacity': Syrian well drillers are famous for having spread across northern Africa and other parts of the Middle East. Saudi companies have also migrated to Sudan and elsewhere, since restrictions in their own country. In Turkey recognition of the overdevelopment of groundwater has directed focus onto surface water and many rigs have been transferred to Africa for domestic water wells. In some locations, such as Cochabamba, Bolivia, drilling companies are proactive in expanding the business and, often in association with local leaders, try to convince residents of the need to invest in new wells. (Similar behavior by diesel-pump dealers has been observed in Uttar Pradesh, India (Shah 2001), or with micro-irrigation dealers in Morocco.)

[19] See www.djazairess.com/fr/infosoir/80977 for reference.

3.1.9 Indirect regulation tools

Another way to limit the expansion of wells is to regulate other production factors or the economic environment in which irrigated agriculture develops. An effective option is to control the establishment of electricity connections to the grid, allowing or preventing the use of electricity, which is often the cheapest source of energy for pumps, or the only one as far as boreholes with submersible pumps are concerned. In Kairouan, Tunisia, illegal wells are generally connected to the domestic grid (causing overload problems) or powered by other sources of energy, and the opportunity to become connected is a key incentive. In Peru in 2007 a decree established that applicants for an electric connection for groundwater wells would have to present to the utility a copy of the permit to abstract groundwater granted by the National Water Agency (Ministerio de Agricultura 2012). In Egypt investors expanding groundwater-based agriculture on the margins of the Nile Delta must also obtain at least one license for a legal well in order to become connected. Owners of illegal wells in Tunisia cannot connect to the electricity grid. In other instances the restriction applies to land ownership, as in Jordan, where farmers without official land titles are normally not entitled to a connection (Al-Naber and Molle 2017).

In West Bengal state, India, the number of electric pump connections between 1990 and 2010 was largely stabilized. This resulted from 1) difficulties in obtaining new electricity connections for wells, 2) increasing diesel costs and declining water-table levels, 3) in 2003 the West Bengal State Electricity Distribution Company requesting the full cost of the investment (ranging from 1,000 to US$4,000), a figure beyond the financial means of smallholder farmers (spurring informal groundwater markets), and 4) the Groundwater Act of 2005, which required permits for wells (64% of the applications were reported to be turned down, although this may partly be due to some rent-seeking behaviors; Buisson 2015). The leveling off of electric connections was reversed in the early 2010s (with the introduction of subsidies and the removal of permit requirements in the case of good status of the groundwater). Whether intentional or not, this shows the relationship between the control of electric connections and the use of groundwater, and how changes in policy can influence the expansion of wells.

Yet coordination between sectors does not always work. In Maharashtra the government declared that the banking sector would not lend farm credits for sinking wells and the installation of pumps in zones designated as overexploited (Phansalkar and Kher 2006). However, national guidelines issued by the National Bank of Agriculture and Rural Development about restrictions of bank credits to farmers proved to be ineffective, without really implementing restrictions on accessing groundwater (ibid.). In some cases, such as in the El Ghrouss area, Algeria, there is no link between the department of hydraulics and rural electricity administrations, although electricity could in theory be used as an effective control mechanism, if there was any intention to control agriculture (Amichi 2015).

Jordan offers a very interesting illustration of how actions on related sectors can be used to instill changes in the groundwater economy. Like in other countries mentioned above, the well needs to be legal for the farmer to obtain a connection to the electricity grid. But farming in the deserts of Jordan is also based on the hiring of foreign labor (mostly from Egypt), through permits to 'import' foreign laborers. Linking this to compliance with specific legal requirements, such as having a legal well, is now increasingly used to control the expansion of groundwater-based agriculture in Jordan. More recently the Ministry of Water Resources and Irrigation has developed another means of action allowed by the interconnection of state administrations through a computerized system. People needing/willing to go through an official procedure, for example to renew a passport, issue a driving license, or buy a house, will see their request denied if they have not paid their water bills, for example.

As described in Section 0, many governments, development banks, and donors have in the past either subsidized programs to directly develop groundwater resources, or developed agricultural performance with a negative effect on the rate of groundwater overabstraction, or established incentives such as domestic price support, barriers to imports or energy subsidies, all of which have fueled the expansion of groundwater-based agriculture (World Bank 2007). Yet governments can modify this economic structure so as to make the development of groundwater less profitable, thus contributing to curbing the expansion of wells, or even to their abandonment. A spectacular illustration of this was provided by Syria, when, in 2008, diesel subsidies were discontinued. A large number of agricultural productions irrigated with deep groundwater became unprofitable and farmers reverted to rain-fed agriculture (Aw-Hassan et al. 2014). Likewise, changes in the European agricultural policy, with the end of subsidies favoring water-intensive crops, such as maize, have reduced the pressure on groundwater. Such policies, however, are uncommon because they invariably result in curtailing economic opportunities in the farming sector, as well as rural incomes. Political constraints explain why such macrolevel changes tend to be imposed for overriding financial or political reasons, rather than being actively chosen as a management option.

3.2 Controlling abstraction by existing wells

Reducing abstraction by existing wells is the next (uphill) battle. It is important to understand that little can be done on this front if the number of wells is not *first* brought under control (as discussed in the preceding section). It is indeed very hard to obtain reductions in abstraction levels by, say 0-30%, but it is illusory to imagine achieving this if a user from whom the effort is demanded has a neighbor who is drilling new illegal wells at the very same time.

3.2.1 A typology of tools

What tools are at the disposal of the state to control groundwater abstraction in existing wells? If this use is defined as "*groundwater abstracted through the consumption of energy and applied on agricultural land to grow crops*," the three main parameters which can be acted upon include 'water', 'energy', and 'land'. Measures, regulations and policies may concern two dimensions of these three parameters: type and amount. We distinguish between 'stick' measures, which include here both command-and-control measures (e.g. registration) that are perceived, negatively, as constraints by farmers, and negative incentives (sanctions, pricing, etc). 'Carrot' measures include positive incentives (subsidies, byback, etc). 'Sermons' are actions that talk to the heart and mind and influence people's behaviors in the intended direction.[20] Figure 9 summarizes six corresponding subsets of measures:

Water: acting on the amount of water used (in practice limiting this amount) can be achieved by fixing quotas or pricing water ('sticks'), subsidizing more efficient technology, paying farmers for not using water ('carrots'), or conducting awareness campaigns to change behaviors ('sermons'). This can also be achieved indirectly, by banning certain crops with high water requirements or, more generally, by influencing crop choice through targeted subsidies or taxes.

But it is also possible to act on the source/type of water, notably by replacing groundwater with alternative sources, for example water transferred from neighboring basins. It is possible to reinject surface water (treated or otherwise) into the aquifer, or to enhance infiltration in different ways.

[20] This characterization of 'sticks', 'carrots', and 'sermons' follows Bemelmans-Videc et al. (1998).

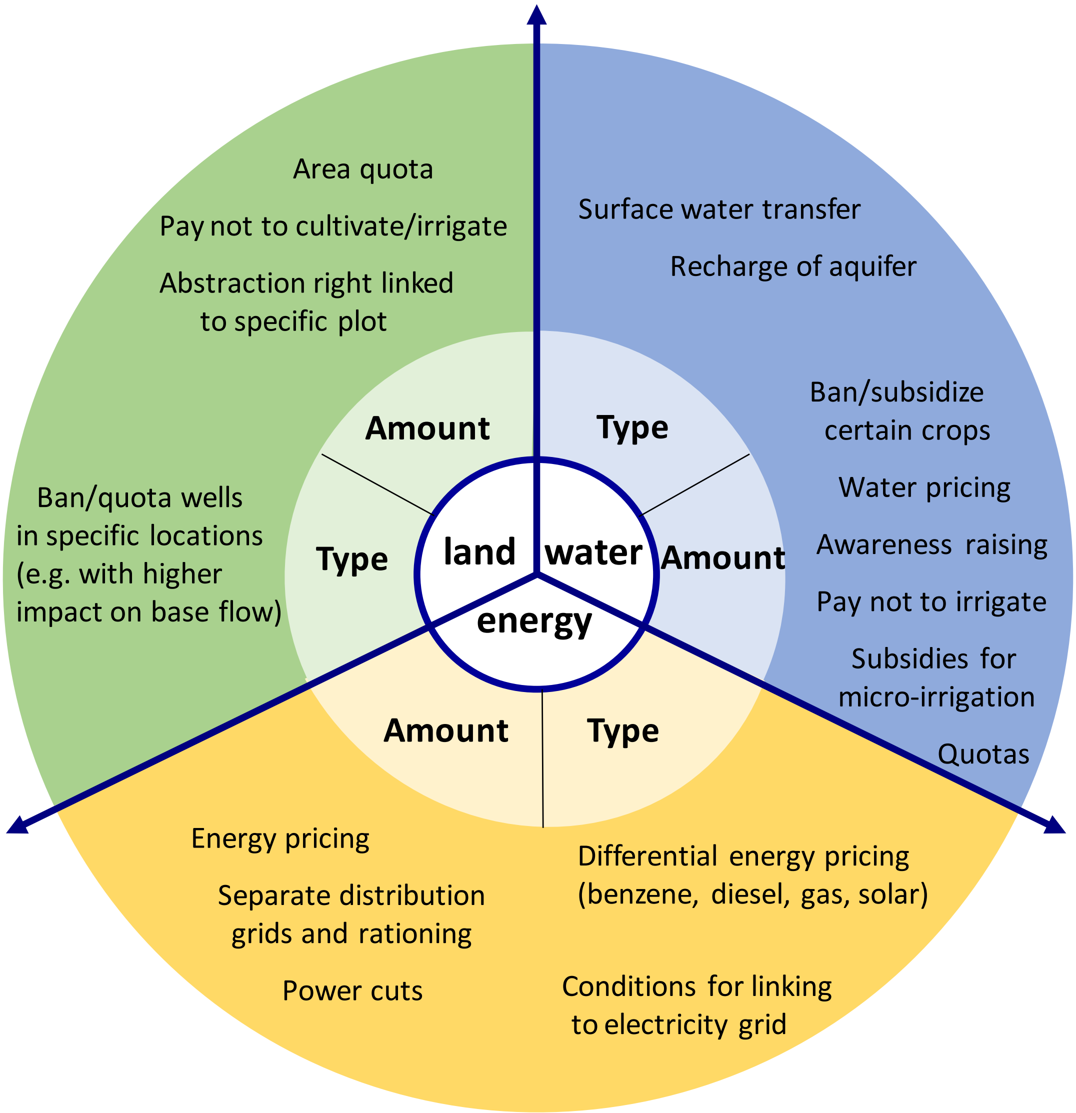
Energy: the amount of energy used can be controlled by rationing supply, especially when using dedicated power grids ('stick'), influencing behavior through energy pricing ('carrots'), and raising awareness about scarcity ('sermons').

The source/type of energy used (benzene, diesel, gas, electricity, solar) can be influenced through the relative prices/subsidies of the different sources of energy available, or for electricity) by controlling and setting conditions for a connection to the public grid.

Land: the amount of land cultivated through the application of groundwater can be limited by restrictions such as on area (for example the area defined in well licenses) ('stick'), or by paying farmers for leaving the land fallow or letting it under rain fed conditions ('carrot').

The type of land can also sometimes be subjected to regulation. For example, land close to to the river can be specifically targeted because wells have a higher impact on river base flow.

Figure 9. Policy measures to reduce abstraction by existing wells



3.2.2 Metering

Reducing use involves establishing a benchmark against which the reduction will be measured. This means that enforcement has to go through quantitative estimates of water use, which can be made through metering or indirect estimates of consumption through energy consumption or area irrigated (+ crop type and irrigation technology). Introducing the metering of groundwater use does not help to control abstraction per se, but it is a prerequisite to the implementation of pricing, quotas and other policies, and has therefore been promoted as 'best practice'.

3.2.2.1 Metering: a ubiquitous 'best practice'

It is common to repeat the motto "you cannot manage what you cannot measure," [21] but the paramount importance of measurement is frequently taken as an injunction urging managers to introduce water meters. This is too often the case in contexts where the conditions to pay for, maintain, monitor, and replace meters are not met.

In Australia most states require metering under various conditions. In Victoria, for example, meters shall be installed in all wells for which the annual entitlement is >20,000 m^3. Where Water Management plans are in place, more stringent metering thresholds of 10,000 m^3 per year are imposed. In Western Australia metering is required for the abstraction of groundwater from all artesian wells and sub-artesian wells in Groundwater Management Areas. Regulation is established following metering thresholds, which can vary. In low-priority areas they are required for wells abstracting at least 50,000 m^3 per year, and in priority areas for wells abstracting at least 5,000 m^3 per year. Attempts to roll out the metering/monitoring program have involved public subsidy of the cost of the meters, which stopped when national government funding ceased (Bennett 2015), with a new threshold set at 500,000 m^3 per year. This points to the first constraint to imposing meters: their cost, and raises the question of who is expected to shoulder it. A similar situation was found in the Copiapó basin, Chile, where in 2003 the groundwater agency sought to regulate and control all groundwater abstractions by demanding the installation of water meters on wells (DGA 2009b). Due to a lack of funds, logistical capacity, and staff, the program was cancelled and then re-launched in 2009, this time only targeting the largest groundwater users (14 users with more than 300 l/s of abstraction capacity granted) (DGA 2009b). In Texas an accommodation was granted to the agricultural sector when it was decided that the cost of meters (imposed by the 1993 House Bill) would be paid by the Edwards Aquifer Authority (Gulley 2015).

The Environment Agency Abu Dhabi (EAD) aims to achieve some volumetric management of its resources, but metering wells is first challenged by the cost of equipping/maintaining over 100,000 wells in the very harsh conditions of the UAE desert, let alone the fact that the issue is socio-politically highly contentious (McDonnell and Fragaszy 2016). In Bahrain, after two attempts, in 1982 and 1997, to impose meters paid by the users (and subsequent decisions by the state to shoulder the costs, after facing protests and vandalism of meters) the government decided in 2010 to make *new* licenses conditional upon users installing a meter at the cost of the owner (Al-Zubari 2016). There, just as in Oman or Bahrain (where new wells must be fitted with a meter), political opposition to metering, seen by farmers as a threat, has kept this measure at bay.

[21] The director of Stanford University's Water in the West program was reported to comment on California's situation as follows: "If everyone had a meter on their well and you knew how much everyone was using, you could sort of calculate everyone's contribution to aquifer depletion. But if you don't know any of those things, they just become things to fight about" (Elias 2017).

In Syria the installation of a meter for every well follows Resolution 2165 issued in 2000 by the Ministry of Irrigation, which defines the maximum quantity of groundwater that can be pumped and the area to be irrigated (Marina Stephan 2007). According to Law 165, groundwater abstraction limits are fixed depending on the abstraction possibilities in each basin and the surface of land to be irrigated (ibid.). Yet a lack of training affected the implementation of metering (Albarazi 2014). Engineers and public officials lack technical skills and were unable to train farmers in the proper installation and use of the devices (ibid.) or to monitor use effectively. This, however, is a common explanation from an administration's point of view and obscures likely political difficulties in enforcing such regulations.

Jordan prescribes the obligatory use of meters, which control the extraction and the different charges for groundwater (Venot et al. 2007a, 2007b). However, in the Amman-Zarqa Basin in Jordan, where metering was reported to be in place in almost 90% of the wells, only 61% of the meters were working in 2004 (Chebaane et al. 2004). The results of a socioeconomic survey on groundwater in Jordan suggest disparities in the implementation and installation of water metering. In Azraq, for example, 192 water meters were reported to be working but 136 had not been installed (of a total of 334 wells surveyed) (IRG 2014).[22]

By contrast, in Tunisia well metering is not required, even for deep wells (deeper than 50 meters). Meters have never been made compulsory in tubewells, first, because of their relatively high cost (~US$250) and second, out of a (sound) recognition that they would be tampered with and that serious monitoring would by far exceed the capacity of the local administrations (CRDAs) (Hamdane 2015).

In the Souss, Morocco, the installation of meters was a key measure of the aquifer management plan envisioned (*contrat de nappe*), but this measure was eventually postponed and the 'contrat' not signed due to delays in the completion of various infrastructure projects by the state (promised as a counterpart to the agreement) caused by budget limitations. This was used by farming associations as an argument for the postponement of meter installation (BRLi and Agro-Concept 2012).

In Mexico further regulations arising from the Water Law demanded groundwater users to install water meters in their wells, with administrative and financial sanctions for non-compliance (OECD 2013). The system of sanctions is, however, perceived by users to be ineffective. Extremely high fines are sometimes imposed for the violation of concession limits but are criticized as unfair and unrealistic by users (OECD 2013). In the Ica valley, Peru, "The farmer only wants to have a water right and is not too concerned with the amount of water specified." For obvious reasons farmers are opposed to metering, and in any case "many of the large investor farms would not let you in to supervise them" (Cardenas Panduro 2012; Oré et al. 2013).

The problem of costs is often addressed by requesting users to install meters at their own cost. In Egypt for example, the proposed draft law (still to be approved) provides that the owner of the well has to install a meter to measure groundwater use and if it is not installed or remains unrepaired for more than a week and without informing the Ministry, the well owner would be subject to a fine of 5,000 EGP (US$620) (El Arabi 2012).

An example of the difficulty of implementing flowmeters in groundwater exploitation systems was a case in the upper basin of the Guadiana (Spain). To monitor and control groundwater extractions in overexploited aquifers in the Western Mancha and the Campo de Montiel, the water administration invested more than €6.5 million between 1994 and 1996 to install a

[22] According to the results of this survey, Azraq is the basin in Jordan with the highest number of uninstalled meters. Mafraq basin has eight uninstalled meters (out of 298 wells); Deir Alla has 52 (out of 110 wells) (IRG 2014).

network of 4,820 well flowmeters (Díaz-Mora 1999). Once installed, it was necessary to put in place a system to ensure that the flowmeters were maintained and the measurements collected. An economic evaluation of these aspects is complex. Díaz-Mora and managers of the Western Mancha and Campo de Montiel aquifers recognized that it is very difficult, if not impossible, to manage the water administration system by direct measurement flowmeters. In the final report of the Upper Guadiana Plan it is indicated that the total cost of implementing flowmeters amounts to an investment of €100 million, with a maintenance and monitoring cost of €6.5 million per year" (Sanz et al. 2015). Remote sensing and GIS provide an alternative and/or a complementary approach to the flowmeter method, and ten years of experience in the Eastern Mancha region pointed to an estimated cost type by yearly campaign of €150,000 for a typical area of 150 km x 150 km (Sanz et al. 2015).

In Mendoza, Argentina, the capital costs and logistical problems of installing meters have deterred their installation. Existing rights to groundwater are based on the diameter of the wells (as a proxy for the volume abstracted) (Foster and Garduño 2015). In Abu Dhabi there is opposition to metering in agriculture but the power of the pump is limited, although enforcement is lacking (Fragaszy and McDonnell 2016). In Texas farmers succeeded in having the 1993 bill that established the Edwards Aquifer Authority state that the new authority would bear the cost of meters (Gulley 2015).

The monitoring of wells is more feasible in regions with a smaller number of wells, limited irrigated area, and good access roads. In Bahrain, for example, around 800 wells out of 1,200 working wells reportedly have their meters monitored on a monthly basis (Al-Zubari 2016).

While metering is commonplace for large users (especially domestic water suppliers or industries), it is less common in the agricultural sector and is only found in contexts where the number of wells is manageable, the state or the user can afford to pay for meters, no or moderate pricing is attached to them, and authorities have credible sticks/carrots to enforce metering. It is clearly difficult to impose meters when they have not been installed from the start. In many US states most farmers do not have meters (see Elias 2017 on California).

3.2.2.2 Do meters really meter?

Expectedly, groundwater users are generally meter-averse, especially when they (rightly) suspect that the government wants to use metering to impose volumetric restrictions or charges. Governments have never succeeded in imposing meters on overexploited aquifers with many farmers, especially so when users are supposed to pay for it. In California, local agencies have however historically resisted groundwater metering (Nelson 2011). Recently, although there is great variation in the motivations and practice of metering, many special districts and some general districts in California started to apply mandatory or voluntary groundwater metering.

Even where meters have been imposed the central question is whether they work on the ground. If pricing or another kind of negative incentive starts to 'bite', meters are almost invariably found broken, by-passed, or tampered with in increasing numbers, field staff bribed, and self-reporting distorted. In Jordan, one of the countries with a long history of groundwater policies, recent field surveys and studies through remote sensing have estimated that actual water use was anywhere between 2 and 3 times the official amount.

In Jordan, most farmers interviewed by Chebaane et al. (2004) claimed that metering is not a reliable tool for monitoring and control of groundwater pumping as tampering and vandalism is common. In eastern Jordan, whenever wells are licensed, owners "tamper with the meters and do not report the exact amounts of water consumed" (Barham 2014).[23] Field research in Azraq has documented the many ways found by farmers to circumvent taxation and regulations (Al-Naber and Molle 2017), including, for example, using a driller to rewind the meter backward or bypassing the meter with a parallel derivation pipe, so that not all the water pumped is metered.

In West Bengal, India, the government embarked upon the task of installing meters for agricultural electricity consumers, mainly due to the fact that there are no strong farming lobbies that could oppose such a policy (Mukherji et al. 2010). The government installed remotely sensed tamper-proof meters operating on the '*time of the day*' principle (i.e. recording daily electricity consumption at different rates based on the time of the day, to discourage users to utilize electricity during peak hours) (Mukherji et al. 2009; Mukherji et al. 2010). Through this system, meters can be read *remotely* from more than 100 feet, and readings are transferred in real time to the regional and central commercial offices of the electricity supplier (Mukherji et al. 2009). Additionally, power theft and meter tampering were made punishable offences under the Indian Electricity Act of 2001 (ibid.).[24] This new technology was used as a tool to manage peak time requirements but, due to the fact that it is done remotely, villagers and groundwater users cannot intimidate meter readers anymore (ibid.). The system design also avoids the collusion of meter readers with the users as, according to the design of this system, the meter reader neither knows nor can tamper with the meter readings (ibid.).

Since monitoring or enforcement are so hard and costly to implement, countries sometimes resort to voluntary declaration, as in France and other European countries. In southwestern France, farmers have to note down their consumption monthly and report them one a year. But when restrictions are imposed on them during summer months they often shift the excess consumption to the values declared for spring months (Loubier 2017).

If metering is so difficult to establish, what are the alternatives? Where technology is mastered, like in Eastern La Mancha, Spain, remote sensing can be used for routine management. In Altar-Piriquito, Mexico, use is controlled only through electricity bills; likewise in Rajasthan or Maharashtra there are no meters for agricultural power consumption, and electricity is charged on the basis of connected load (Bassi 2014). In Mendoza, Argentina, well diameter is used as a proxy of the amount of water used; the installed power capacity or the land areas irrigated or owned can also be used as proxies.

3.2.3 Pricing policies

Agricultural water pricing was promoted in the 1990s as one of the most promising options in the water-demand toolkit (Molle and Berkoff 2007). As far as large-scale public irrigation schemes are concerned, a host of reasons for the ineffectiveness of pricing have been identified (Cornish et al. 2005; Molle and Berkoff 2007). Even in the few irrigation schemes where water was distributed volumetrically and users were faced with water shortages it was found that water scarcity was never managed through administered pricing but, rather, through establishing and managing quotas (the few cases of water markets constituting a separate mechanism). Groundwater-based irrigation holds the promise to be better amenable to regulation through water pricing since water abstraction can be more easily metered at the well and therefore priced *by volume* (or indirectly, by the proxy of electricity consumption: this aspect is addressed in Section 0). This is a *sine qua non* of the possibility of pricing influencing use and conservation.

[23] Quoting a water expert, former employee of the Ministry of Water.

[24] According to Mukherji et al. (2009), offenders can be imprisoned for up to 5 years or fined up to 50,000 Rupees. From 2002 to 2003, 2,000 raids had been carried out, and 73 arrests made.

The first constraint to administered pricing—that is, a situation where a public agency charges groundwater users for the water they abstract—is the legal background (where farmers are or were enjoying private rights to water, in which case they are unlikely to accept being charged for it) and the perception that groundwater has nothing to do with the state. The second constraint comes from the fact that the cost of accessing groundwater is generally much higher than that of surface water, usually amounting to a substantial portion of production costs. And farmers understandably resent being charged for something they already pay for.

A special case is that of public groundwater irrigation schemes, such as those found in Tunisia. Prices are not generally high enough to affect behavior but if they rise, farmers tend to shift to individual wells (Ghazouani and Mekki 2016), which defeats the purpose of the pricing strategies. This may also happen in surface-water schemes, where water prices are fairly high compared with individual wells. In Iran, for example, energy pricing does not help to limit groundwater use since pumping costs represent less than 2% of the total production costs in agriculture (FAO 2009b). While surface-water prices are high (around US$1-2/$m^3$) groundwater is free of charge for well holders. A tax on groundwater use equivalent to around 0.25-0.5% of crop production was levied at one point but was discontinued (ibid.).

In Bahrain a licensing system was introduced in 1980 giving the Water Resources Authority the right to determine the quantity of groundwater required for each agricultural land plot and to charge for any excess water pumped (Al-Zubari and Lori 2006). In California some local agencies are using a system of extraction reporting and a tiered pump-fee structure to discourage excessive groundwater extraction in the basin (but with no cap on extraction) (Osuji et al. 2003; Harter 2001). The management authority that determines and collects fees and establishes these assessments is subject to obtaining a majority of votes in favor of the proposal in local elections. In spite of the fact that more than 200 agencies have adopted a groundwater-management plan, according to Assembly Bill 3030, none of these is known to have exercised such authority (Harter 2001).

In Jordan, groundwater pricing is in place via a system of block tariffs. This system was introduced in 2002 by the Groundwater Bylaw and charged any water use over a threshold of 150,000 m^3 per year per well. A 2003 amendment, repealed one year later, aimed to double tariffs of the first block (Venot et al. 2007a; Yorke 2013). Water bills have however not been paid until 2008, when the government asked for arrears to be paid.[25] Recent policy changes include a drastic increase in the price of water for non-licensed wells, as well as an intent to reduce the 'free block' from 150,000 to 75,000 m^3. With people not paying their bills now being barred from accessing other state services or obtaining official documents, this double pressure is now starting to be felt and sends a strong signal about the growing resolve of the ministry.

Although in many OECD countries, such as the Netherlands, Denmark or France, groundwater users have to pay a management or environmental tax for their use, this is not conceived as a tool to achieve water savings (and in any case is always far too low to be relevant in terms of such an objective) (Custodio 2010). Jordan is currently the only identified case where pricing is credibly utilized for water conservation, although it is currently *only* applied to illegal wells. The prices established in 2015 are high enough even to deter continued agriculture (except in greenhouses), but it remains to be seen whether this new price table will be enforced and farmers made to pay. Excessively harsh pricing and sanctions may threaten the system's credibility.

[25] In Jordan, the debt from fines from illegal groundwater abstraction by farmers exceeds JD24 million (around US$34 million in 2015). See www.jordantimes.com/news/local/farmers-should-seal-illegal-agricultural-wells-year-end-%E2%80%94-water-ministry (Accessed 17th August 2015).

Differential pricing may also be used to encourage farmers to substitute groundwater with other sources, such as in the Pajaro river basin in California, where the district distributes groundwater blended with treated wastewater at a price lower than that of direct groundwater abstraction (Levy and Smith 2011).

3.2.4 Quotas and reduction of entitlements

3.2.4.1 Characteristics of quotas/entitlements

The most straightforward way to reduce abstraction would appear to be the fixing of an appropriate maximum quantity (from the aquifer and/or for the user), according to a sustainable or 'safe' management of the aquifer. Quotas are widely used in irrigation schemes or at basin level because they are seen as the most acceptable and transparent way of 'allocating scarcity' (Molle 2007). However, they may have the effect of 'freezing' entitlements, with a possible growing mismatch between individual quotas and actual needs, resulting in allocation inefficiency. As a result it is often advocated that quotas be transformed into entitlements, which can either be adjusted each year to reflect the status of the resource (yearly 'allocations') and/or made tradable (this issue is discussed in Section 3.4). In practice, the distinction between a quota system and a system of licenses/entitlements is very narrow and often just a question of vocabulary. Quotas tend to refer to a centrally administered system of allocations which can be modified and priced at will by the government, while licenses/entitlements tend to be associated with historical backgrounds of water rights, with varying degrees of control by users and the government.

By definition, the use of quotas implies that consumption by individual users is monitored volumetrically through meters (or through proxies, such as the area and type of crop irrigated). A degree of effective monitoring and enforcement of regulation is therefore a prerequisite but is harder to achieve than commonly believed (see the discussion in Section 3.2.2). It also includes limiting illegal wells to a negligible fraction, which also generally proves to be a tall order (see Section 3.1.1.5), especially in the case of numerous and diffuse abstraction points for agriculture.

Defining an overall quota for the aquifer also means that what is to be the 'desirable' level of abstraction is defined. As alluded to in the introduction (see Section 2.20), the definition of a 'safe yield' is fraught with the substantial technical/hydrologic difficulties associated with a lack of knowledge of hydrogeology in general and surface water-groundwater interactions in particular. Beyond these difficulties establishing a safe yield involves decisions on the negative effects that can be accepted and the point at which the aquifer will be considered to be overexploited. The establishment of quotas is therefore a highly sensitive and politically charged aspect of groundwater governance, which partly explains why they are frequently based on optimistic hydrologic estimates and/or take a long time to be defined (see Section 3.5.6).

A key aspect of quotas/entitlements is whether they can be modified and under which conditions (an issue addressed in the following section). The question of the expiration period of entitlements is also crucial. Concessions are sometimes very long (several decades), but there is value in choosing a duration that is neither too short (creating uncertainty and affecting investment) nor too long (preventing their revision in line with changing conditions). Between five (South Africa) and 10 years (Mexico) appears to be a sound duration. Flexibility must be attuned to local climatic and hydrogeological conditions (Bennett and Gardner 2015).

In France the 2006 Law states that OUGC (*Organismes unique de gestion collective*), the group of users concerned, should decide how to allocate the overall quota between users. Moreau et al. (2013) presented a set of seven allocation options to a sample of farmers to gather their views and assess the feasibility of each. The options were: basing allocations on average use over the past five years ('*grandfathering*'), considering existing and projected use (next five years), setting up a bidding system (*water markets*), following the historical sequence of use ('*prior appropriation*'), using a proportion of the initial declaration of need (or of the farm area, with a diminishing per-ha quota as size increases), and allocation modulated by crop or soil type, or whether surface water is also accessible. Results show the importance of perceptions and cultural values in the acceptation (and therefore likelihood of success) of the different methods.

Entitlements/licenses can (preferably) be granted in situations of sufficient available resource based on some criteria such as a fixed amount of water per hectare of irrigated land [in Syria, for example, the decree from 2000 imposed a limitation of 7,000 m^3 per hectare of groundwater abstracted (Saade-Sbeih 2011)]. They can also be granted at the time of the registration of all wells including illegal ones (as discussed earlier), except where previous use (far) exceeded the safe yield. Regarding the Murray Darling River basin in South-East Australia, for example, Neville (2000) observed that, given the level of over-allocation and over-use in some areas, a reduction in abstraction should have been achieved rather than a cap (the freezing of use at its actual level in 1994). The cap was the politically acceptable solution, rather than being scientifically or environmentally sound (ibid.). Earlier we discussed the case of South Africa, and the difficulty of introducing changes to the prevailing distribution of water rights.

In Oman, Morocco, Tunisia, etc. the quantity of water that can be abstracted from a well is specified by licenses issued by the ministry, but there is no control or monitoring of actual use, primarily due to a lack of functioning meters.

3.2.4.2 Legal difficulties in reducing quotas/entitlements

The modification of entitlements may face legal difficulties in countries with a background of private groundwater rights (particularly with regard to the question of compensation), but recent legal trends have strengthened the hand of governments in intervening in case of structural deficit (see Section 2.5).

In Spain the conservative Popular Party (PP) challenged the constitutionality of the 1985 move towards public water status, arguing that it would infringe on private property and individual rights and liberties (BOE 1985). Discussions in the parliament about the alleged 'nationalization' of natural resources largely revolved around whether large compensation would have to be made to those who had held private rights. The Constitutional Tribunal ruled that the 1985 Water Law did not infringe on individual rights, as the constitution did not grant the right of private property in absolute terms (Moreu Ballonga 2002).

In Western Australia the government may use the Environmental Protection Act 1986 or the Environment Protection and Biodiversity Conservation Act 1999 to impose restrictions on abstraction in the case of a proven impact on wetland water levels, on Ramsar sites or on nationally threatened species or ecological communities. The minister can also publish in the Gazette an order declaring that a water shortage exists in the area and restrict use as a result, or activate the Rights in Water and Irrigation (RIWI) Act from 2001, to "modify any term, condition or restriction in a license on a broad range of grounds, including to protect the water resource or the associated environment from unacceptable damage" (Bennett and Gardner 2014). But here too there are subtle distinctions and exemptions in terms of how and why entitlements are curtailed that govern whether compensation can be claimed and granted (and therefore the associated litigation). Volumetric groundwater entitlements may be reduced permanently on various grounds, and no compensation is payable *if the reduction is 'fair and reasonable' amongst licensees*. In practice, this power has rarely been exercised in over-allocated groundwater areas in the South West. This may be because licensees have an expectation of a fixed annual entitlement and because "it would be administratively onerous to amend a large number of licenses individually and deal with the resulting appeals to the State Administrative Tribunal" (Bennett and Gardner 2015). Each licensee has rights of comment and review of the license, which means that amendments would have to be completely reconsidered by an independent external tribunal: "given that a single review application can cost the Department of Water tens of thousands of dollars in legal fees and staff time, the department would be reluctant, to say the least, to issue hundreds of directions or license amendments to address the widespread allocation problem" (ibid.).

In Jordan abstraction levels and quotas were fixed between 1962 and 1992 through abstraction licenses specifying the amount to be pumped (two thirds of the licenses were granted by the government during that time) (Venot et al. 2007b). These quotas were most commonly 50,000 or 75,000 m^3 per year but in some cases were up to 100,000 m^3 per year after 1990 (ibid.). In the preparation of the Groundwater Control Bylaw of 2002 farmers fought for the new quota system to include a free volume equivalent to their earlier (free) legal use of groundwater. Their activism ended up achieving a 'free block' of 150,000 m^3 per year, in effect negating the associated pricing policy (Venot et al. 2007a).

In Texas claimants sued the Edwards Aquifer Authority when it refused to grant them pumping rights they considered to be their historical constitutional property rights. In its ruling the Texas Supreme Court held that groundwater users have an absolute vested property right to groundwater just like oil and gas, and that "landowners do have a constitutionally compensable interest in groundwater" (Texas Supreme Court 2012). This created a legal precedent in Texas meaning landowners could argue the case that GCDs should pay compensation for denying or limiting pumping (Texas Observer 2013).

3.2.4.3 Adjusting quotas to the status of the resource

A well-identified drawback of quotas is that they are 'sticky', that is, not easily changed or attuned to the status of the resource. In some situations the amount of water allocated can vary each year; in which case, following the convention used in the Murray Darling Basin, a distinction is established between entitlements/licensed volumes and annual 'allocations'.

Where there is clear over-allocation of the resource there is the need to reduce quotas/rights accordingly, although the legal difficulties underlined above can prove problematic. In Mexico, following the transfer of management responsibilities to farmers in 1994 in the Altar-Pitiquito-Caborca irrigation district, water users drew up a water-use reduction program based on their entitlement. It specified a gradual decrease in the volume of each well over a period of ten years in order to reach a target of 300 Mm^3, (wrongly) considered as the safe yield (Wilder 2002).

In the High Plains Underground Water Conservation District (HPUWCD), Texas, in fulfillment of the Texas Water Code and the District's management goal of a 50% depletion of the Ogallala Aquifer by 2060, the district defined an allowable production rate for any well within the district at 5,334 m^3 per hectare per year between January 2012 and December 2013. A further reduction to 4,572 m^3 per hectare per year then followed between January 2014 and December 2015, and to 3,810 m^3 per hectare per year from January 2016 onwards (Rule 5.3) (successively 1.75, 1.50 and 1.25 acre-feet per acre of land).

A similar situation can be found in the Murray Darling basin's Namoi catchment, where there was a drastic need to address an inherited state of over-allocation. In 2003 13 sub-areas were defined and a Water Sharing Plan devised with the desired coefficient for the reduction of licenses of 56% on average. However, its implementation was challenged, including in court, and was delayed. In order to smooth the transition, the reductions were temporarily granted in the form of water-access licenses to be gradually decreased over ten years. The Achieving Sustainable Groundwater Entitlements Program (ASGEP), jointly funded by federal and state governments and water users, was also set up to provide AUD60 million of financial compensation to irrigators (Ross and Martinez-Santos 2010). A similar process ensued in the Lower Murray basin, where the relationship with users was much improved (ibid.).

Similarly, individual quotas are adjusted each year in some aquifers in France, most notably the Beauce and Clain (see 5.2.7 for more details). Based on the level of the aquifer at the end of the winter season, correlated with the risk of river baseflow coming under environmental pressure in summer, the administration established a table of coefficient for the adjustment of (full) quotas downwards (if need be).

In the Eastern Mancha aquifer the Water Authority ordered reductions in abstraction during the 2004-08 drought of between 20% and 45% and buy-back by the state of entitlements of farms near the river in order to protect environmental flows (Sanz et al. 2011; Ferrer et al. 2008, JCRMO 2007, 2008). This explains the drop in total abstraction from 379 to 270 Mm^3 between 2005 and 2007.

In Turkey the DSI allocates entitlements and in theory reserves its right, when necessary, to decrease or increase the allocated water indicated on the licenses. It can also control at any time groundwater works carried out by engineers, drillers, and users. It is not clear whether this is effectively practiced, but it is debatable whether the actual control over abstraction and the number of wells is sufficient to allow this level of sophistication in management.

Quotas can also be regulated by pricing. In Shanxi province, south-west of Beijing, overdraft has been tackled by defining annual quotas for all well users in Qingxu county (a total of 1,473 wells are concerned) (Guisheng et al. 2013; Li He 2011; The Water Channel 2012). The wells are operated by farmers through a 'smart system' using swipe cards to activate water pumps (ibid.). Swipe cards are allocated on an individual basis, allowing farmers to source their quotas from different collective wells.

The price of electricity is fixed if abstraction remains within the allocated volume per household. If users exceed their quotas, prices rise: for an excess of less than 30% the price for the block is 50% higher; between 30% and 50% of excess the price is doubled, and over 50%, it is tripled. These prices, however, are not sufficient to allow for full coverage of operation, long-term maintenance, or deepening of wells, so a contribution is made by the village budget (Li He 2011). Yet, because the cost of water corresponds to 15-25% of the net profit of wheat and corn, it is believed that water prices are high enough to encourage farmers to save water, or at least not to exceed their quota (Guisheng et al. 2013). This system is effectively a block tariff, in that quotas can be exceeded at a price, but also a quota system, in that it is possible to trade quotas. Following the introduction of the system, an increase in groundwater levels was observed of up to 4.8 meters and a reduction of abstracted volume (from 59 Mm^3 in 2004 to 30 Mm^3 in 2010 by county) (ibid.). But it is hard to ascribe reductions in abstraction to a particular measure, since the implementation of the policy also included the adoption of micro-irrigation, better field preparation, plastic mulching, greenhouses, and drought-tolerant cultivars and crops (Li He 2011). Similarly, improvements in efficiency have been achieved in the industrial and domestic sectors.

Quotas cannot be adjusted each year, but another opportunity to reduce entitlements can arise when they expire, if the law allows. When the resource is clearly over-allocated the administration may be empowered to grant a new license with a reduced allocation, as occurred in Western Australia: the Perth Water Corporation’s allocation was reduced upon the renewal of its license in 2012. Similar measures may also be associated with permits to clean wells, as in

Jordan, where a reduction of quotas for registered (but unlicensed) wells is applied (Al Naber and Molle 2017).

3.2.4.4 Interannual quotas and carryovers

In some (rare) cases if quotas are not fully used in a given year, the remainder can be carried over to the following year(s). This is practiced, for example, in the Qingxu County case discussed earlier. In other cases farmers are given the option to exceed their quota in a given year (within certain limits) on the condition that their abstraction the following year (or years) will be reduced accordingly. This system was implemented for some years in the Beauce aquifer in France (but was later abandoned). In both cases this management rule takes advantage of the buffering capacity of the aquifer, a decisive asset in weathering and responding to droughts.

In the Eastern Mancha aquifer, Spain, farms under 70 ha can transfer up to 50% of any unconsumed volume to the following year, during normal hydrologic conditions (JCRMO 2014). The water plan allows for the carryover of unused allocations, added to the yearly allocation for aquifer licenses up to a maximum of twice the licensed amount (NSW Government 2015). In the Lower Murrumbidgee, Australia, the water plan also allows for the carryover of unused allocations to be added to the annual allocation for aquifer licenses up to a maximum of twice the licensed amount (NSW Government 2015). Positive or negative carryovers must be compensated within a period of three successive years.

In the High Plains Underground Water Conservation District (HPUWCD), Texas, a water-banking system was put in place in January 2013 to allow producers to bank groundwater during normal and above-normal precipitation years for use during drought periods. By the end of 2014 approximately 67 producers had participated in the system. For 2015 the banking system was replaced by a 'Conservation Reserve' of 0.50 acre-feet per acre of land for eligible users.[26]

In the Upper Republican River Basin, Nebraska, groundwater users were allowed to carry over unused water from one allocation period to the next and to combine allocations from different wells (as long as the combined allocation did not exceed the total allowance) (Stephenson 1996: 769). For 2013-17 the Upper Republican District had an established allocation of 65 inches (13 per year). According to the Management Plan, water users could distribute the 65 inches over the five-year period as they wished, as long as the allocation was not exceeded. In 2013, however, the district enacted new rules with the objective of reducing water use. Changes in regulation limited to 7.5 inches "the amount of unused allocation from previous allocation periods that can be used in a current allocation period without incurring a penalty" (NARD 2015: 2). Half of the groundwater districts in Nebraska allow carryover within periods of between three and five years.

In the Main San Gabriel Basin, California, the system is slightly different. In the case of excessive pumping the user could provide make-up surface water from water rights and sell it to agencies in the Central District. Pumping levels above the defined safe yield can be compensated by the use of aquifer recharge and imported water.

3.2.5 Technology fixes to reduce groundwater use

Water shortages in general, and problems of overexploitation of groundwater in particular, have spurred calls for 'improving efficiency'. A standard and almost knee-jerk policy response has been the promotion of micro-irrigation by a "wide coalition of international and national development organizations, policy makers, drip irrigation manufacturers, NGOs, social

[26] According to the HPUWCD website, www.hpwd.org/reporting/ (Accessed January 27, 2016).

enterprises and influential spokespersons [who] have actively shaped, promoted and legitimized a [...] 'drip dream' that fits and reinforces the values and interests of those actors" (Venot et al. 2014). In countries where irrigation is key to agriculture there is hardly an agricultural policy that does not promote or subsidize micro-irrigation as a key to achieving efficiency and poverty alleviation. In Morocco the 'Plan Maroc Vert' is fueling the over-exploitation of groundwater as it provides farmers with incentives to invest in micro-irrigation systems (subsidized at a level of 80-100%) and sometimes even in well drilling. The resulting intensification and expansion of agriculture result in an increase in evapotranspiration (Molle 2017). In Tunisia the National Program for Water Savings, established in 1995, offers subsidies for farmers of 40-60% of the total investment costs for water-saving irrigation technologies (Frija et al. 2014). In Algeria a program adopted in 2000 (PNDA) subsidized micro-irrigation (among other things) at a level as high as 100%. This chiefly benefitted investors with capital or land deeds (Amichi et al. 2015).

There are three major problems with micro-irrigation that have long been identified but still struggle to make their way to decision-makers. The first relates to the distinction between gross and net abstraction (Perry et al. 2009). A study on Luancheng County, in Hebei province, China, has illustrated that it is evapotranspiration that needs to be reduced (as is indeed partly achieved through plastic mulching and all other on-farm techniques) rather than abstraction per se, given return flows to the aquifer[27], even if the latter has other benefits in terms of savings in energy costs (Kendy et al. 2003).

The second problem is observed in regions where water is scarce relative to land. Here, a reduction in the amount of water applied by unit of surface area frees water to be used to expand cultivation (assuming the discharge of the well and the entitlement are unchanged). While benefits accrue to those expanding their area, the fraction of water depleted typically rises, and return flows and aquifer recharge decline. Such a situation has been observed in numerous places, such as Spain (Berbel et al. 2014; Playán and Mateos 2006; WWF/Adena 2015), Morocco (Jobbins et al. 2015; Tanouti and Molle 2013), Tunisia (Bachta and Elloumi 2005), India (Bhamoriya and Mathew 2014; Moench et al. 2003), Israel (Dinar and Zilberman 1994), China (World Bank 2015, Zhang et al. 2014), and the US (Huffaker et al. 2000; Huffaker and Whittlesey 2003).

The third problem is that, for a given plot, drip-irrigation may not significantly affect the overall depletion of water, and may even increase it: a) first micro-irrigation does not necessarily much reduce non-beneficial soil evaporation (this depends on several factors such as the soil texture and the density of the drippers; less soil is wet but it is wet for longer periods); b) it generally increases crop transpiration due to more frequent and timely irrigation (Burt et al. 2001; Perry et al. 2009; Ward and Pulido-Velazquez 2008); c) in addition, the more intensive system of agriculture often comes with increased plant densities and/or intercropping in tree plantations [a very clear illustration is provided by Morocco, with tree densities which may change from around 200 trees to up to 800 trees per hectare, (Tanouti and Molle 2003; BRLi and Agro-Concept 2012)]; and d) it may encourage the production of more water-intensive crops, such as banana or fruit trees.

This means that, contrary to common belief, which sees micro-irrigation as a water-saving technology, its implementation can result in greater groundwater consumption and aquifer depletion. This is often obfuscated by the benefits generated in terms of increased productivity

[27] Arguably this depends on local conditions. When the aquifer is very deep there is a perception that water does not really go back to the aquifer. This was the case in the Highlands of Jordan. Although it is possible that a fraction of the water percolating is taken up by evapotranspiration (capillarity and phreatophytes), studies on water quality have identified a high level of nitrates near agricultural wells (JICA 2001), pointing to a significant return flow to the aquifer.

and farm incomes, and diversification to cash crops, but a careful and balanced analysis is required for each different setting. A recent review has found that the 'null hypothesis' (water consumption should be considered as basically unchanged, unless there is evidence to the contrary) is the most reasonable working hypothesis (Perry and Steduto 2017).

But technology also offers ways to improve irrigation processes. In the lower Republican NRD in Nebraska the district subsidized the use of water-saving soil-moisture probes across 60,000 acres in two years.[28] Precision irrigation has the potential to improve water control in the field, but 1) it is chiefly suitable for large-scale intensive farms, 2) its benefits, as with micro-irrigation, must be assessed based on the changes in evapotranspiration and on the fate of return flows.

3.2.6 Temporary retirement of irrigated land

A more radical measure than reducing entitlements in times of drought (see Section 3.2.4.3), is the temporary 'retirement' of irrigated land, which can either be cultivated under rainfed conditions or left fallow. The Natural Resource Districts in the Republican Basin, Nebraska, have been utilizing federal programs and partnerships to conserve water. This basin is the first in the USA to utilize the federal Conservation Reserve Enhancement Program to temporarily retire irrigated land, with approximately 40,000 acres enrolled in the program for that purpose (NARD 2015). In the San Luis Valley, Colorado, the US Department of Agriculture has approved $120 million to pay farmers in Sub-district No.1 to stop farming land. The goal is to have 80,000 acres of land in the valley left fallow, but recent rises in commodity prices have made the choice to fallow land less attractive and only 10,000 acres have applied to the program (Conran 2013; HCN 2016).

The drought that spread across the south and west of the USA in 2013-14 led the managers of the Edwards Aquifer in Texas to ask farmers and ranchers to stop irrigating in exchange for a check, called the 'Voluntary Irrigation Suspension Program Option' (or VISPO).[29] This was part of the Habitat Conservation Plan, triggered by the Endangered Species Act, to provide various conservation measures to protect endangered species living in rivers with spring flows threatened by withdrawals from the aquifer. Under the Habitat Conservation Plan, the EAA is willing to pay 150 US$ per acre foot (1,233 m^3) for farmers to stop abstraction. Over a period of three years the Authority has already paid money (50 USD) to farmers "just for agreeing to be on standby." The Authority’s goal in 2015 was to get 40,000 acre feet (49 Mm^3) of groundwater enrolled in the program. The program was envisaged for a duration of 10 years.[30] Enrolled users have the option to apply for a five- or ten-year payment program (EAA 2012). The program for 2015 was full.

In 1993 the European Agro-Environmental plan (AEP1) was established in the Western Mancha aquifer, Spain. It aimed to reduce the volumes abstracted by farmers through financial compensation. This was calculated on the basis of the level of reduction (50%, 70%, and 100%) of an average consumption established at 4,200 m^3/ha/year (Hernández-Mora 2002), and paid per hectare of irrigated land (Varela-Ortega 2007). The European Institution provided 75% of the funds, Spain’s Ministry of the Environment 12.5%, and the government of Castilla-La Mancha the remaining 12.5%. The first phase of the program was approved for a five-year period (1993-1997), with a total budget of €96 million (Hernández-Mora 2002). Farmers could join the plan on

[28] www.nrdnet.org/sites/default/files/downloads/republican_river_basin_sustainabilitysteps.pdf

[29] 'Edwards Aquifer offers cash in exchange for reduced irrigation', KVUE ABC, September 8′ 2014, www.kvue.com/story/news/local/2014/09/08/edwards-aquifer-offers-cash-in-exchange-for-reduced-irrigation/15297653/ (Accessed September 10, 2014).

[30] EAA n.d. VISPO White Paper, www.eahcp.org/files/minutes/03-17-11VISPOWhitePaper.pdf (Accessed January 25, 2016).

a voluntary basis, which they did since the monetary compensation per hectare by and large offset the income losses of the imposed quota program, estimated at around €200-250 per hectare (Rosell and Viladomiu 1997; Varela-Ortega 2007). Rosell and Viladomiu (1997) estimated that in the Western Mancha and Campo de Montiel aquifers, 2652 farmers had signed up to the program by 1995, representing 85,410 ha of irrigated land and 298 Mm^3 of water saved in 1995 (AEVAL 2008).

As reported earlier, the Water Authority of the Eastern Mancha aquifer, Spain, also resorted to the temporary buy-back of entitlements from farms near the river in order to protect environmental flows (Sanz et al. 2011; JCRMO 2007, 2008). Similar programs have been tested in California's Central Valley (Piper 2003) and in the Flint River Basin, Georgia. The latter saw the Flint River Drought Protection Act in 2001, which ensured acceptable streamflows in the river, using auctions to pay farmers to retire land temporarily (Wright et al. 2012). In 2002 41,000 acres were 'removed' at a cost of US$5.3 million. It became necessary, however, to adjust the rules to prevent those with very marginal or long-fallowed land from abusing the scheme. A similar program is active in Oregon, where the State approved provisions for both permanent mitigation, and mitigation water banks. In exchange for payment, water users voluntarily relinquish the right to use groundwater either temporarily or permanently. The extra resource is then available for "withdrawal" to provide increased water to surface-rights owners as well as to maintain instream flow (Trout Unlimited 2007).

In France agri-environmental measures (AEMs) are followed in line with the second Common Agricultural Policy. For example, in exchange for closing a water abstraction point farmers are entitled to five years of compensation (152€/ha left unirrigated) (Loubier et al. 2017).

In some cases, land retirement is imposed without compensation. In the South Platte River, Colorado, senior surface water rights holders (the Cities of Boulder, Highlands Ranch and Sterling, and some old irrigation districts) were affected by groundwater pumping by junior wells, which reduced both surface water flows and the riparian groundwater on which they relied. The Colorado Supreme Court demanded protection for the senior water users following the 2002 drought, but groundwater irrigation well owners failed to produce adequate response plans. When the spring of 2006 again turned extremely dry, and given that the well owners still had no augmentation plans in place, the State Engineer was forced to act and in April 2006 banned pumping in 440 groundwater wells irrigating 200 farms across 30,000 acres (out of 3,000 illegal wells, Cech 2008)[31] (Trout Unlimited 2017). Because of the nature of the prior appropriation right system, the reduction in allocation is fully imposed on junior right holders and not proportionally across all users.

3.2.7 Indirect regulation tools

It has been demonstrated how a degree of control exerted on associated production factors, such as energy or labor, can be instrumental in reducing the expansion of wells (see Section 3.1.9). Similarly, rationing or pricing energy has been proposed as an indirect way to regulate abstraction, especially in situations of numerous and diffuse groundwater users.

3.2.7.1 Energy prices and tariff structure

Energy pricing and disincentives

[31] Around 50 out of the 200 farmers failed to obey and were fined (ibid.). Over the past two years 2,000 well shutdowns were ordered for farmers who failed to prove they could replace their withdrawals from underground aquifers linked to the South Platte River (Cech 2008).

The most common causal relationship between water abstraction and energy prices is adverse to conservation policies: in a majority of countries the encouragement of groundwater abstraction as a rural development strategy (Section 1.20) manifested itself through subsidized energy schemes, which in turn stimulated the use of groundwater rather than restrict it. India, in particular, is conspicuous because of the free-rural electricity policies adopted in certain states (Shah 2009), such as Andhra Pradesh.

In Syria the development of groundwater abstraction wells and irrigation in the 1980s (from 53,000 wells in 1988 to 124,000 in 1994) was spurred by input subsidies sponsored by the government, including diesel fuel subsidies representing around 80% of the local purchase price (Aw-Hassan et al. 2014; Gül et al. 2005). In Yemen, in 2009, the subsidy for fuel accounted for 22% of total government expenditure (van Steenbergen et al. 2014). In Iran it was estimated that farmers paid less than 7% of the actual cost of the energy they used (Tavanir 2008 in Karimi et al. 2012). In Mexico electricity used in agriculture (mainly for pumping groundwater from wells) benefits from a special tariff, according to which farmers pay only 23% of the actual cost of electricity (OECD 2013). In Dongola, Sudan, groundwater abstraction is being developed via the electrification of the area. This followed the completion of the Merowe Dam, which halved electricity prices and attracted major investment, including from Egypt and the Gulf (Fragazy 2015). In the Batinah Plain of Oman farmers using less than 7,000 kWh receive a direct 50% subsidy, and those using over 7,000 kWh a 33% direct subsidy. This does not account for Oman's natural gas being utilized in electricity generation (provided to power companies at below-market rate), meaning the total economic cost of electricity subsidies is actually far higher (IRENA 2014). Electricity subsidies were estimated to cost the state nearly $700 million in 2012 (United Securities 2011, in McDonnell 2016).

Applying disincentives

Removing subsidies and increasing energy prices are believed to encourage water savings and the cultivation of higher-value crops. Indeed, pumping costs usually make the accessing of groundwater far more expensive than surface water, and therefore flexibility in the use of each in accordance with changing prices is likely to be greater. In many instances, though, the removal of subsidies is the result of severe fiscal constraints and/or donor or IMF pressure.

The Syrian government's cancellation of diesel and fertilizer subsidies for farmers in 2008 and 2009 as a move to integrate the country into the global trade system (while bidding to join the World Trade Organization) is a perfect example of what may happen when diesel subsidies are removed. The policy pushed prices up and forced many farmers either to revert to rain-fed agriculture or stop agriculture altogether (de Châtel 2014). Diesel prices increased from seven Syrian pounds to 25 pounds per liter for agriculture (Saade-Sbeih 2011).

In Yemen in 1995 the new national Water Resource Authority decided to increase diesel prices as a disincentive to pumping to conserve groundwater. However, the policy had a negative effect on poor smallholders, who still needed diesel to pump water from shallow wells. Despite demonstrations and riots, leading to the deaths of twenty people, the price of diesel was doubled in 1995. Further increases in diesel prices during the 2010s did not meet as strong opposition from large landowners as before due to the fact that they benefited from other measures, such as subsidies for the introduction of modern irrigation techniques (e.g. drip irrigation). According to Al-Weshali et al. (2015), due to changes in diesel subsidies after 2011 and shortages due to a lack of supply and conflict, some farmers in poor households had to abandon agriculture, while others adapted their cropping patterns, abandoning the farming of irrigated crops and practicing deficit irrigation for fruits and vegetables.

In Morocco the removal of subsidies for diesel reinforced the shift towards subsidized domestic gas (butane), with farmers adapting their engines, and even to solar energy. In Yemen high diesel prices also meant that landowners who could afford it switched to gas or solar energy (Lackner 2014). Differential energy prices can also generate technical shifts or a change in the source of water. In Punjab, Pakistan, for instance, an increase in electricity rates for groundwater pumps of 126% between 1989 and 1993 caused a shift towards locally manufactured and cheaper high-speed diesel engines (Steenbergen and Oliemans 2002). The governments of Punjab and Sindh provinces removed subsidies on electricity tariffs, but farmers quickly adopted diesel pumps, relegating electric pumps to only 10% of the total (Qureshi et al. 2010). Although this meant additional costs for farmers, meeting the water demands of their crops and ensuring household food security remained vital objectives.

The full cost of pumping with diesel engines is generally higher than with electricity, but this of course depends on the technology and the depth of the well. In the Azraq area of Jordan, for example, Demilecamps (2010) found that farms connected to the electricity grid would spend between 9 and 22% of their total production costs on energy, against between 40 and 82% when using diesel.

Groundwater real-price policies also have the potential to negatively impact collective wells/pumps, as in Tunisia and Turkey. The main problem faced by groundwater irrigation cooperatives in Turkey (as with irrigation WUAs in general) is financial sustainability, on account of the relatively expensive cost of water abstraction. The government is now trying to divest itself of the cost of supporting these cooperatives by making them more autonomous and directly responsible for paying electricity to a now-privatized operator. The privatization of electricity services in 2013 came with a 22% increase in prices. According to one DSI official in the Izmir region, only 10% of the cooperatives in the region would be fully financially autonomous (Le Visage 2015).

Structure of electricity tariffs

Altering electricity tariffs and their structure can have an effect on groundwater abstraction as well as on water markets. In West Bengal a decision to shift from a flat-rate to a pro-rata tariff altered the cost and incentive structure for pump owners and affected their pumping behavior (Mukherji et al. 2010). Initially, tubewell owners were under pressure to sell water to other farmers to recover what they had spent on their (high) electricity bills. Given the fact that their plots of land were not large enough to justify the cost of electricity at flat rates, the bargaining power was on the side of small and marginal farmers turned water buyers (ibid.). Between 1991 and 2006 electricity tariffs rose 10-fold with the intent to keep them in line with increasing electricity generation and supply costs. Meanwhile water prices only rose by three times (Mukherji et al. 2009). The introduction of meters and the reform of the electricity sector changed the incentive structure for water sellers, as they now pay only for the amount pumped. The lack of incentive to sell caused an increase in the sale price of water of 30% to 50%, affecting water buyers, as they came to face adverse conditions for buying water (e.g. advance payments) (Mukherji et al. 2010).

In Mexico a reduced 'nighttime stimulus tariff' introduced in 2003 applied to pumping between midnight and 8am caused an increase in groundwater withdrawals as farmers over-pumped at night in order to maximize the benefit from the tariff (around 20% below daytime tariffs) (Scott 2013; Scott and Shah 2004).

Even in countries where electricity is only lightly subsidized or not subsidized at all, it is often too cheap to affect behavior. In Tunisia (Ghazouani and Mekki 2016) there is a debate surrounding the possibility of establishing an electricity-based pricing system for private bore wells – an idea negotiated between the Ministry of Agriculture and the Tunisian Society of Electricity and Gas, according to Frija et al. (2014). Elloumi (2016) notes that local officials have tended to refrain from expanding rural electricity for fear of encouraging groundwater use.

In Andhra Pradesh the 2004 elections brought some changes in the free electricity subsidy scheme, as 5% of farmers were excluded from it (based on criteria such as large landholdings or having more than one pump set). The government also aimed to promote power-saving by making it compulsory to use energy-saving devices (capacitors) for pump owners (farmers who failed to install them by March 2006 would not be eligible for the free-power scheme) (Birner et al. 2011).

Another, possibly gentler, way of controlling groundwater abstraction through energy use is through quotas rather than prices, controlling either the total operation time or the level of consumption by pump stations. The most famous example is that of Gujarat, India (since followed by seven other states, Grönwall 2014; Shah 2009). Until the electricity reforms of 1987, Gujarat had one of the highest electricity subsidies in India. With heavy losses in the electricity-supply infrastructure, the poor power supply in the state affected the quality of life in rural areas (World Bank 2013). In the face of opposition from farmers, the government decided not to meter tubewells but to separate agricultural from non-agricultural electricity feeders. Under this so-called Jyotirgram Yojana scheme (Shah 2009), electricity for agriculture was rationed to eight hours per day delivered as three-phase power, on which only tubewells could run, whilst electricity for households was supplied 24 hours a day (using a different metered connection per household). Meters were also installed on each feeder (especially agricultural feeders, so the electric company could identify the source of any abnormal peak in demand) (Mukherji et al. 2010). However, this system was only implemented for new tubewells or old tubewells with meters (a small minority).

The system proved to be neither flawless nor popular (Grönwall 2014). The Jyotirgram Yojana scheme also affected small, marginal, and landless farmers as the market for groundwater shrank and prices soared (World Bank 2013). The dependence on electricity for pumping led to the creation of powerful farmer lobbies, which campaigned to keep the beneficial power tariff structure and were unwilling to see access to electricity reduced or subsidies limited (Grönwall 2014; Shah et al. 2012). The implementation of the reforms was therefore challenged by a culture of non-compliance, bribery, theft, vandalism by users directed at the electricity board, and threats to staff (reluctant to venture into villages for fear of violence). Farmers easily circumvented the rationing scheme by illegally converting single-phase into three-phase power, thereby completely paralyzing the rural domestic electricity supply (Water Governance Facility 2013). Local politicians backed the farmers' violent opposition to the scheme and dedicated police stations had to be set up, with 500 former-military personnel deployed to enforce the rules and control the violence in villages (the 'electricity police' filed cases against 100,000 farmers) (Grönwall 2014; Water Governance Facility 2013).

3.2.7.2 Influencing cropping patterns

The banning of 'thirsty' crops is a means to reduce water abstraction, but the use of incentives is a more common strategy. These can involve making alternative crops and/or markets attractive or decreasing the profitability of undesirable crops through intervention in input or output markets. Governments may choose to influence cropping patterns with the aim of reducing water demand, but it must be noted that farmers often already do this out of self-interest. A few possible measures include:

Banning crops: Imposing restrictions on, or banning, the types of crop that can be grown, for example thirsty crops such as rice, banana or sugarcane, is a way to reduce water abstraction. In practice it is problematic to apply such measures if the country had formerly imposed cropping patterns (in public irrigation schemes) but then deregulated crop choice (e.g. Egypt or Morocco). Faced with the depletion of some of its coastal aquifers, Saudi Arabia enforced a ban on banana cultivation. Interestingly, this triggered the cultivation of banana with groundwater in neighboring coastal Yemen, where no such regulation was enforced (Chevalking et al. 2008). A similar phenomenon occurred when Gulf countries placed restrictions on alfalfa, which spurred its cultivation in areas such as Azraq, in Jordan. In Andhra Pradesh, India, the government tried to establish that farmers would be ineligible for the free electricity subsidy scheme if they grew paddy during the winter season, but, in the face of stiff opposition, the measure was revoked (Birner et al. 2011).

Changing agricultural subsidies: The phasing-out of subsidies for the cultivation of crops with high water consumption, most particularly Rhodes grass, was implemented in Abu Dhabi, where the 2009 Master Water Plan showed that it consumed more that 59% of water used in agriculture. Its cultivation was stopped or greatly reduced on some 15,500 farms, with an overall reduction of nearly 80% in the area cultivated (Fragaszy and McDonnell 2016).

Regulation of import/export of thirsty crops: Crops such as banana (Jordan), rice (Punjab and Pakistan), citrus (Morocco), almond trees (California) often give rise to discussion as to how much (virtual) water is exported, or whether they should be limited or replaced by other crops. However, in part because they are also often the most profitable options and are supported by powerful lobbies, it is rare that tariffs are established *because* of their impact on water use.

Paying farmers not to grow certain crops: In Abu Dhabi, as a 'carrot' extended to mitigate the economic impact of the 'stick' used against Rhodes grass, farmers are now paid (7,500 AED approximately $2000 per month) not to grow this crop on more than 10% of their land (Fragaszy and McDonnell 2016).

Alternative crops: Extension and agricultural research services may promote alternative crops as a replacement for undesirable crops, including those tolerant to salinity and drought (in the Gulf) or cash crops with niche markets (for example medicinal plants in Egypt). In France farmers may be entitled to a subsidy for substituting legume crops for maize in some rotations (Loubier et al. 2017).

Influencing cropping practices: Financial compensation/incentives can also be paid to farmers to induce them to alter their land-use practices. Water utilities in Denmark use this mechanism when they face a risk of pollution of groundwater resources by agricultural land use. Agreements can include restrictions on the use of pesticides, reduced use of fertilizer and manure, and re-forestation. Abildtrup et al. (2012) found 18 water utilities or supply companies having engaged with farmers through this type of process. In the case of a farmer rejecting a reasonable offer for compensation in these areas, compulsory purchase (expropriation) is considered according to the law. In France, too, there are several well-known cases of mineral water companies (such as Evian) paying farmers not to engage in practices that may pollute groundwater.

3.2.7.3 Others tools to limit water use

Aside from action on energy prices or cropping patterns, water conservation can be incentivized by other indirect measures.

In France irrigators who do not comply with the terms of their abstraction authorization have their main European aid (Single Payment Entitlements, DPU) lowered by 3%, and by an additional 1% if they do not have a volumetric control system (Loubier et al. 2017).

In Oman water sales were strictly controlled. Unlike other countries in the region, water trading amongst farmers was not permitted (McDonnell 2016). For example, while a farmer cannot sell water to his neighbors for agricultural purposes, he can for drinking purposes (ICBA 2012). In Jordan transferring or selling water from outside the plot specified in the well license is also prohibited, whatever the intended use.

Jordan has deployed very original indirect tools to force farmers to pay their water bills. Officials claim the unpaid amount from the well owners and give them a period of 15 days to pay. After that the ministry publishes the names of the well owners and the unpaid amount in the newspapers (including the official gazette) and gives them an additional period of 60 days to settle the bills. If the owner still refuses to pay the amount, the minister has the power to seize the account of the well owner (Alwakeelnews 2015; Khaberni 2014). By the end of 2015 the ministry had already published a first list of 70 well owners in the official newspapers. Unsurprisingly, some are well known and influential people in Jordan (certain of them owing more than 200,000 JD) (Mbayden 2013; Khaberni 2014).

Another novel measure is the interconnection of public data, and making any governmental procedure (purchase transaction, passport or driving license request, etc.) conditional upon proof of due payment of water bills. It is hard to assess the impact of this policy, and the extent to which it is hampered by influence and power relations, but it has the potential to discourage low-production farmers, as well as investors willing to drill new wells and reluctant to run the risk of illegality.

Many countries implement public campaigns to raise awareness of water scarcity in general, and groundwater in particular. By way of illustration, the Turkish government has carried out a National Awareness Campaign, with posters and television broadcasting, a Water Saving Campaign with popular artists on television programs, education of students about the importance of water, and the gathering of local governmental officials to inform them of water challenges, etc. (Doğdu 2013). In Peru the National Water Authority developed a Groundwater Management Plan for the Ica Valley (Ministerio de Agricultura 2012), aiming to inform and raise awareness about the state of groundwater and the need to sustainably manage and preserve groundwater resources, as well as to train and improve institutional capacities and coordination (with a budget of 3.4 million USD) (ibid.).

In Nebraska Natural Resource Districts preferred a combination of approaches to manage groundwater resources, mostly focused on educational and voluntary efforts (Aiken 1980; LPSNRD 1995). The Lower Platte South NRD, for example, has primarily resorted to non-regulatory approaches since 1995, "including: public education; encouragement of voluntary use of best management practices; governmental inter-agency coordination; monitoring to identify water quality and quantity problems; and inspection and demonstration (training) programs". Nebraska is also noteworthy for its 'Groundwater Foundation' which, since 1985, "has offered a variety of programs and projects for youth, individuals, and communities to learn more about groundwater and how they can help protect it" (www.groundwater.org).

In Jordan the ministry has been using public debates, publishing a series of articles highlighting the water problem in the country, and public awareness-raising campaigns and school programs (Subeh 2006). Such campaigns have also been directed at judges and imams. Actions such as seizing rigs, sealing illegal wells, fining people for illegal fixtures on mains have been repeatedly and insistently publicized in the newspapers since 2013; the Minister of Water and Irrigation makes frequent television appearances (El Naser 2013). In 2014 there were more than 15,000 cases of groundwater-related offenses reported by the WAJ, some for tampering meters, others for digging illegal wells or sabotage of WAJ's water distribution pipes (Jordannews 2015). The

King also formed a Royal Commission on Water Resources in 2008, which issues frequent reports describing the country's water situation and the strategies required to conserve water (PM 2008) directed at the public and also to members of parliament.

In the literature there is only anecdotal reference to such campaigns, and very little evaluation of their effectiveness. An exception is the five-year Water Efficiency and Public Information for Action (WEPIA) program, funded by USAID in 2001 in Jordan. It used religion as a basis to raise awareness about water conservation (Zietlow et al. 2016).

3.3 Supply augmentation options

As in the case of river basins that undergo a process of closure (Molle et al. 2008), the depletion of aquifers is often addressed through the implementation of supply side solutions. These include bringing surface water from outside of the groundwater basin, water harvesting, intended to capture runoff in order to enhance local infiltration, artificially injecting/impounding surface water (including wastewater), and, in a few cases, desalination.

3.3.1 Transfers or storage of surface water

Many countries favor the option of 'bringing more water in' by partly replacing the existing demand for groundwater with surface water via infrastructure projects. Morocco's Water Strategy for 2030 has planned a large 'water highway' from the north of the country to the south, expected to transfer around 800 Mm^3 of water per year. New water could relieve pressure in particular on the coastal aquifer south of Casablanca and on the Haouz aquifer by supplying Marrakech with drinking water.

In Egypt new investors in the West Delta area have been expanding groundwater-based high-value agri-businesses since the 1990s. The West Delta Canal project was conceptualized to complement or replace dwindling groundwater stocks by surface water from the Nile, via a water transfer (Barnes 2012). So far, however, the project has failed to be implemented due to bidding and procurement issues, and later to the 2011 revolution.

Tunisia has established several safeguarding measures to protect irrigated agriculture in the Cap Bon, such as a water transfer from the Medjerda basin (north-east) to Sfax (western Tunisia). The transfer provides water for cities as well as agriculture, and serves the western (Grombalia) and southern parts of the Cap Bon region, where 15,000 ha of citrus represent an important part of the region's economy. At present, for example, 60 Mm^3 are transferred from the north to the Cap Bon to make for falling aquifers and 'safeguard' fruit trees. Initially this additional water amounted to 30% of the requirement, but in some areas, such as the Grombalia citrus orchards, the percentage rose to 90% (Tayeb 2016). 'Safeguard schemes' can be found along the coast all the way down to Souss.

The Souss Massa basin, in southern Morocco, is home to a famous transfer project, whereby the Guerdane groundwater irrigated area (10,000 ha of citrus plantation spread over an actual area of 30,000 ha) is now provided with surface water derived from a reservoir upstream in the basin in order to make up for declining groundwater resources (Houdret 2012). The current River Basin plan for the Souss-Massa basin, with 2030 as its planning horizon, includes the mobilization of additional water resources via new dams, sea-water desalination, wastewater reuse, and rainwater harvesting. These new resources should increase supply by 20% according to the River Basin Agency (from 901 Mm^3 per year to 1,171 Mm^3 per year).The Saïss River Basin in the north of the country will also receive water by a transfer from the Mdez dam on the Sebou river, aiming to reduce aquifer over-abstraction and stop groundwater pumping for drinking water altogether in 2030 (Del Vecchio 2013).

In Alicante and Murcia provinces, Spain, groundwater extraction on the high lands near the sea began in the 1960s and has never abated (Custodio 2010). Partly due to the high profitability of the cash crops grown there and exported to Europe, overdraft remains very high and unsustainable, as in the Vianalopo area. The region's hopes are pinned on the Tajge-Seguro interbasin transfer, which is under construction. Here again the solution is provided by bringing more water in.

In the Ica-Villacury area of Peru a transfer from the Pisco River is expected to relieve the pressure on the Villacury aquifer, with large-scale investors pressuring the government to invest in a project in tandem with the private sector, and even to consider a transfer from the Pampas River, which flows on the other slope of the Andes toward the Amazon (James 2015a). The general groundwater user association asked for an increase in surface water transfer from the Choclococha lagoon to the Ica Valley, an option they see as the only viable long-term solution to reduce agriculture's dependency on groundwater (Cardenas Panduro 2012)[32].

In India the Sarovar Project diverts water from the Narmada River to downstream Gujarat state and is meant to relieve the situation of critically depleted aquifers in north Gujarat (Shah 2005). Last the western US also offers numerous cases of surface water transfers, which either substitute/supplement groundwater, or are impounded and infiltrated (Colorado water to Los Angeles Metropolitan area or to Arizona) (more on these cases later). Likewise, in Florida the reduction of the impact of groundwater pumping on the Tampa Bay ecosystem and watershed was obtained via the development of new alternative surface water supply sources.

Transfers can even be set up for environmental purposes. In the Guadiana Basin, Spain, many wetlands depend at times on surface water alone and occasionally on imported water, which maintain them artificially during a drought period (Custodio 2010).

An alternative to transferring water from other basins is to store water locally in seasons where water is abundant, as can be seen in England (Holman and Trawick 2011) or in France, for example. OUGC are organizations of users in the south-west of France which are given collective water entitlements and have to propose allocation and monitoring plans to the administration. Where this entitlement has been restrictive and forced users to decrease abstraction, OUGCs have negotiated subsidies for winter local storage (small on-farm dams) as compensation (and a substitution of resources) (Loubier 2017).

3.3.2 Managed aquifer recharge

Managed aquifer recharge or storage seeks to enhance the infiltration of local runoff through various means and techniques, including: 1) traditional water harvesting (e.g. North Africa, India); 2) infiltration basins filled with imported surface water (e.g. Arizona; Raymond aquifer, California); 3) through well pits (Gujarat); or 4) injection under pressure (e.g. US, Spain, Emirates) (Tuinhof and Heederik 2002; van Steenbergen and Tuinhof 2009; Chevalking and al. 2008). A more complete classification is offered by IGRAC (2008) (Figure 10).

While artificial recharge is an attractive option, it comes with several prerequisites that are often hard to meet (Arreguín-Cortés and Chávez-Guillén 2002). They include having sufficient water for recharging purposes, good quality or pretreatment of the water in order to avoid contamination or public health issues, land availability for recharging facilities and/or a sustainable stream of funding to pay for energy costs in the case of recharge by injection; easy recovery of the

[32] This project was however stopped by the Latin-American Tribunal of Water after a community of users using surface water from the Choclococha appealed the ministerial decree that would have allowed the water transfer project to go through (Oré et al. 2012).

recharged water. Although climate variability and future climate conditions increase the need for more water security, and existing cases of the use of water resources through recharge, retention and reuse (3R) are promising, this potential is still far from realized (van Steenbergen and Tuinhof 2009).

Figure 10. Overview of MAR techniques and sub techniques (IGRAC 2008)

	Technology	Sub type	
Techniques referring primarily to getting water infiltrated	Spreading methods	infiltration ponds & basins	
		flooding	
		ditch, furrow, drains	
		irrigation	
	Induced bank infiltration		
	Well, shaft and borehole recharge	deep well injection	AS(TR)
			ASR
		shallow well/ shaft/ pit infiltration	
Techniques referring primarily to intercepting the water	In-channel modifications	recharge dams	
		sub surface dams	
		sand dams	
		channel spreading	
	Runoff harvesting	barriers and bunds	
		trenches	

Traditional water harvesting techniques have been deployed in North Africa and the Middle East (Oweis et al. 2001), and most famously in India[33]: there, the density of such works on the ground has sometimes become so high as to generate substantial reductions in runoff, therefore impacting downstream users. This was observed, for example, in the Krishna basin (Venot et al. 2007), Karnataka (Batchelor et al. 2003), and in Maharashtra, with the construction of many small check dams and weirs (Phansalkar and Kher 2006). Likewise, in Tunisia, in the upper Merguellil basin, massive development of such structures caused a drop of 41-50% in the runoff to downstream areas (Lacombe 2007; Nasri 2007).

In the Saurashtra Peninsula in Gujarat, 15 years of aquifer recharge through dug wells have created common pool recharge structures benefiting the whole community (Shah 2009).[34] In 2007 some half a million wells had been modified for recharge and more than 100,000 check structures had been built (ibid.). This has allowed farmers to increase cropping intensity. Bahrain also applies aquifer recharge technology, using gravity-fed aquifer recharge through gulleys, pits, chambers, and recharge wells to direct urban runoff from storms to the Khobar aquifer (Klingbeil 2014). Treated effluent has also been recharging this aquifer since 1986 (ibid.).

Tunisia has been using aquifer recharge since the 1970s (Bouri and Ben Dhia 2010). Wastewater represents around 30% of the country's agricultural water supply, and aquifer recharge with wastewater has helped prevent coastal aquifer salinization caused by groundwater over-abstraction (e.g. in the Korba plain in the Cap Bon peninsula in North-East Tunisia) (El Hedi Louati

[33] For an inventory of water harvesting traditional techniques in India, see George et al., 2015; and Agarwal 2000.

[34] In Saurashtra monsoon rain and floodwaters are seen by many farmers as a resource rather than a nuisance, as floodwaters are de-silted and diverted into the dug well. In hard-rock Saurashtra, the stimulus was given by spiritual leaders who played a crucial role in encouraging the population to modify dug wells to receive floodwaters and building small check structures after a bad drought in 1987 (Shah 2009).

and Bucknall 2009; Ouelhazi et al. 2013). In 2012 in Abu Dhabi, 17 Mm^3 of desalinated water, excess supplies from summer co-generation activities, were injected into the Liwa groundwater Aquifer, increasing the capacity to supply Abu Dhabi's emergency water needs (Fragaszy and McDonnell 2016). Perth, in western Australia, has also started increasing recharge with treated wastewater. It is an option increasingly planned/implemented in many coastal aquifers, as in Lebanon, where aquifer recharge is being contemplated to fight seawater intrusion, and also because managed aquifer recharge can be used to remove colloid and pathogen removal from injected water (Masciopinto 2013).

The APFAMGS (Andhra Pradesh Farmer Managed Groundwater Systems Project), in Andhra Pradesh, India, has sought to combat the vicious circle involving the drying-up of wells, reduced irrigation, increased migration, declining employment opportunities, low and variable agricultural productivity, water shortages, landlessness, and the deepening of wells by those who can afford it. An integrated program of Managed Aquifer Recharge (MAR) has involved hydrological monitoring by the communities and the development of water harvesting structures in the form of check dams, *kuntas*, farm ponds, rock fill dams, percolation tanks and refilling with runoff of defunct wells.

The US West Coast has long experimented with artificial recharge, such as the Orange County Water District, which used the Colorado River as early as the 1950s. However, this experience also serves to illustrate the unpredictability of the technique. While recharge raised the average groundwater level, albeit unevenly, some inland areas became swampy while water levels near the coast failed to rise as expected (Endo 2015).

Since 2007 in the Llobregat Delta, near Barcelona, a well barrier has been injecting municipal waste water treated through reverse osmosis, successfully controlling seawater intrusion. The same system has been in place in Orange County, California, since 1977, where treated water mixed with groundwater is injected into the 23 wells of the Coastal Barrier Project. A much larger plant now only uses municipal effluent treated through reverse osmosis to be injected in the seawater intrusion control hydraulic barrier (Custodio 2010). In 2012 the Californian Department of Water Resources counted at least 89 agencies engaging in groundwater recharge programs.

3.3.3 Desalination

The increasing use of desalination as an economically viable option for supplying drinking water to urban centers has allowed a reduction in dependency on groundwater resources in the Middle East. Half of the world's desalination capacity is found in the Arab world. Saudi Arabia and the UAE jointly produce more than 30% of the world's desalinated water (UNDP 2013; UNESCO 2012). Although desalinated water contributes around 1.8% of the region's total water supply, some countries are heavily dependent on this resource (UNDP 2013). More than 55% of water supplied to urban areas in the Gulf comes from desalinated water, used directly or mixed with groundwater (UNDP 2013). It is also estimated that 8.5% of the Arab region's total supply will be from desalination plants by 2025 (with an estimated investment cost of 38 billion USD) (UNDP 2013).

Desalination can be construed as a means of stabilizing/reducing groundwater use and meet growing needs (as in Spain or Perth, Australia: Bennett and Gardner 2014) or to substitute groundwater used by cities so it can return to agriculture and/or other uses, as in Bahrain and Algeria, where desalination plants have been ensuring the supply of drinking water in coastal areas since the inauguration in 2008 of the Hamma desalination plant near Algiers (a second plant built near Oran was inaugurated in 2014). Countries with less intensive use of desalination, such as Tunisia, are already considering expanding the sector.

However, this increase in desalination capacity has various implications, the first of which is with regard to energy consumption. Desalination plants are energy-hungry (costs per delivered desalinated water can vary between 0.50 and 4 US$ per cubic meter in the Arab region depending on the level of subsidies) (UNDP 2013). The most serious environmental impact of such dependency can be the discharge of the end product (e.g. brine) into the sea, affecting the surrounding ecosystems, the emission of pollutants, and the carbon footprint of these plants (Lattemann and Hopner 2008).

In southern Morocco's Chtouka region, a groundwater-dependent area of 13,600 ha will be supplied with desalinated seawater via by a PPP scheme[35]. With an estimated cost per cubic meter supplied of 1.3€, the government will subsidize half of it, in addition to footing the bill for the infrastructure.

In Jordan the Red Sea-Dead Sea project envisages connecting the Red Sea to the Dead Sea and supplying desalinated water to Jordan, Israel, and the Palestinian Authority. The project also aims to replenish the Dead Sea and save it from further environmental degradation (Coyne et Bellier et al. 2012). It was expected to pump up to 2,000 Mm^3 of sea water annually a distance of over 190 km in order to produce hydroelectricity with the downward flow from the Red Sea towards the Dead Sea that would power a desalination plant providing up to 850 Mm^3 of water to the region (ERM et al. 2012). The project has since been scaled back[36] (Fanack 2015).

Lastly, there are a few cases of the desalination of brackish groundwater by individual private units. Around 40 can be found in the south of the Jordan Valley, while this technology – associated with solar energy – is now developing in the oases of eastern Morocco.

3.4 Trading in groundwater licenses/rights

The trade of groundwater entitlements has been made legal in a number of places, such as Maharashtra, India, Spain, the US, Australia, and China. In Qingxu the volumetric quotas allocated to villages or wells may be traded up to a maximum price threshold of twice the official price[37] (Guisheng et al. 2013; Li He 2011). Trading in itself is not a means to reduce abstraction but, aside from raising the economic productivity of water, it paves the way for governments or conservation groups to buy entitlements, possibly releasing water to nature. A few aspects of groundwater trading are briefly analyzed here.

One difficulty of trading groundwater permits associated with wells is whether the point of abstraction will be able to be changed. In Ica, Peru, this is not the case and investors buying (often defective or too shallow) wells located at a distance from their properties will have to carry water via pipes or aqueducts to their irrigation fields. The most striking example of this is a 580 hectare farm with an allocated abstraction volume of 0.5 Mm^3 per year via three official permits but which actually owns 20 wells and is pumping 9.3 Mm^3 per year (ibid.). Another possibility is to allow one specific (bought) well to be replaced by another equivalent well. In Mendoza, Argentina, for example, a system of purchase and sealing of wells coupled with the opening of a replacement well (although such trading is not permitted under provincial laws) has

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[35] http://ormvasm.ma/index.php/fr/projets/ppp/dessalement-de-l-eau-de-mer.html

[36] www.jva.gov.jo/sites/en-us/RSDS/SiteAssets/rsds%20phase1.aspx?PageView=Shared

[37] It has been observed, however, that farmers share rather than trade their unused 'excess water' with other family members and neighbors.

been implemented so that groundwater resources may be reallocated to investors with high-value production (the purchase price having exceeded US$ 10,000) (Foster and Garduño 2015).

Of course, in such a situation the administration has to ensure that the initial well is sealed, which is often not the case in places like Toluca Valley in Mexico, where farmers are allowed to transfer/sell all or part of their concessions but in practice continue to use the same volume, which increases abstraction (Reis 2014). Or in the Copiapó basin, Chile, where, in contradiction to the need to regulate a groundwater-right market, wells are recorded without coordinates; transactions are not centrally registered; abstraction is not metered (since the right is defined by the – maximum – capacity of the well at the time of drilling); and officials do not have the right to enter private property to check whether the well that was sold is still in use (Chilean water expert 2016).

A second major flaw appeared in Chile: agricultural users pump water eight hours a day for four months and therefore use only around 20% of their water right, defined as the capacity of the well (Bitran et al. 2014; RedAgricola 2015). Since these agricultural rights were seen not to be fully exploited, further water rights were allocated. The problem arose when those rights were transferred to mines, which would pump water constantly. Further, the consumption of water was calculated on the basis of a return flow (to the river and to the aquifer) from agricultural use, but those calculations remained based on conditions of gravity irrigation, failing to estimate the increase in irrigation technology efficiency (drip-irrigation), which generated "a systematic reduction in the recharge levels, since less excess irrigation water percolated into the aquifer" (Bitran et al. 2014: 858).

In Mexico the creation of an illegal water rights market was an unintended consequence of policy reform in the 1990s, which had sought to cap abstraction by defining/limiting authorization to use water (concessions) in prohibition zones. It now has powerful interests associated with it since 'trading' generates significant financial gains for powerful people as well as to the administration (Reis 2014).

Water entitlements can be traded for a season only, as in the Nebraska Central Platte NRD Pilot project (Bergin 2016; Nebraska Central Platte NRD Pilot 2016), which seeks to offer more flexibility for farmers ready to relinquish their entitlements for a season against payment, while hoping to see the state, natural resources districts, and conservation groups buying irrigation rights just to let it into the system and enhance baseflow in the Platte River. Temporary trading has become popular with the experience of 'groundwater banking' in California, a practice that involves the storage of surface water in aquifers during wet years for use during dry years by the entity that stored the water (Christian-Smith 2013). The trade can happen between different management entities, such as urban and agricultural water districts and other local entities, and also between farmers and other users within the same district. In the San Joaquin River Basin in the Central Valley groundwater users have been selling groundwater to agencies outside the district since 2000 for an estimated value of 140 million USD.[38] The Merced irrigation district not only pumped 56,714 acre feet of groundwater to satisfy its own demand but even sold over 7.2 million dollars' worth of surplus water to other water districts.[39] Groundwater banking and water markets in California also allow irrigation districts to sell surface water entitlements at a very profitable price and shift to groundwater pumping to compensate for the surface water sold.

[38] The Modesto Bee, www.modbee.com/2014/03/15/3242022/irrigation-district-selling-water.html (accessed March 18, 2014).
[39] Ibid.

The ability to transfer groundwater between the users of local agencies depends on local regulations, which can limit groundwater exports in order to prevent harm to local users or avoid damage to local economies. Due to the interconnectedness of surface and groundwater, the California Department of Water Resources developed a set of guidelines in 2012 as part of a draft White Paper on groundwater transfers in the Sacramento Valley. It restricted the locations of wells to be used for transfers and set up pumping ratios taking into account the loss of surface water incurred by pumping.

In the Murrumbidgee basin, Australia, two local 'management areas' were formally gazetted in 2007 and restrictions were placed on spatial trading (NSW Government 2009). This was in response to concerns that abstraction licenses would migrate from outlying areas with poorer groundwater availability to core areas with better availability, whose resource would therefore be compromised (under normal conditions shifting rights from one location to another within the same aquifer is allowed). All trading is subject to hydrogeological assessments of the potential impact on neighboring boreholes.

Lastly, it is necessary to address what are commonly termed *groundwater markets* in South Asia, China, and other parts of the world. The misnomer describes situations where certain farmers or other well owners have an extra abstraction capacity that they use to sell water to neighboring farmers who do not have a functioning well. This 'market' is more akin to a service market (e.g. renting a tractor or paying for land preparation or harvesting), since well owners do not own water formally. This situation is discussed in Chapter 5, which describes groundwater management mechanisms within communities.

3.5 Assessing state-centered regulation

Following this detailed review of the diversity of policy tools available in the regulation of wells and groundwater abstraction, we move on to an overview of state-centered governance. Firstly, we consider a number of key points emerging from the review and then focus on specific cases showing a degree of success and offering valuable lessons. We then briefly attempt to identify contexts and drivers that may be associated with successful policies.

3.5.1 Hydrogeological blindness

One difficulty for the state in its management of groundwater resources is the uncertainty surrounding the resource itself. As alluded to earlier, this firstly has to do with the complexity of hydrological processes, especially when it comes to its hidden part: groundwater. It is extremely difficult to estimate how much water percolates in different ways into the subsoil. As a result the level of aquifer recharge is often a case of 'best guess'. In the Altar-Pitiquito area of Mexico, for example, recharge (natural and induced) was estimated at around 300 Mm^3 in the 1970s and later at 213 Mm^3, with an annual water extraction at about 308 Mm^3, leaving a deficit of 94.7 Mm^3. More recently recharge was estimated at only 118 Mm^3 (indicating that over-exploitation is much higher than believed), while others estimate it at 70 Mm^3 (Wilder 2008).

A further difficulty is the fluctuating nature of the hydrological process, and occasionally the long-term shifts associated with climate change. Places such as Morocco and the Colorado River basin in the US are already showing a clear decline in rainfall, with implications for both surface runoff and groundwater recharge. The south-west of Australia has been experiencing a significant drying trend over recent decades, with winter rainfall down by 17% since 1970 and an associated dramatic decline in streamflow to reservoirs (more than 50%) and groundwater recharge (Bennett and Gardner 2014).

One particular area of uncertainty relates to the pathways of groundwater back to the surface (or the sea). In many watersheds in hard-rock regions in central and peninsular India outflows from groundwater to surface water bodies and streams are significant; yet estimates are based only on "simplistic consideration of only the 'recharge' and 'abstraction'" (Kumar et al. 2011). In South Africa accurate quantification of groundwater contributions to ecosystems is challenging due to the country's heterogeneous and anisotropic fractured rocks (Wright and Xu 2000). This lack of knowledge and data about some aquifers constrains the current registration of rights, and in certain regions of the country water use licenses can take up to 30 months to be processed (Anderson et al. 2007).

A classic example of oversight of the groundwater/surface water interactions is provided by Denmark, where the 1926 Water Law stated that groundwater ought to be distributed via rights based on the water balance, with the idea that abstraction was not to exceed the amount of infiltration of precipitation into the aquifer (Thorn and Conallin 2005). This common misconception (discussed in the first chapter) led to a reduction of surface water flow in the area and local drying up (in the summer) of springs, streams, and wetlands. In the Murray-Darling basin, Australia, it took until the early 2000s before the management of hydraulically connected surface and groundwater was fully addressed, in order to remove 'double allocation' of water (Turral and Fullagar 2007).

In 1998 Kansas filed a complaint with the United States Supreme Court to maintain its share of the Republican River, claiming "that Nebraska had violated the compact between the two states by allowing the development of thousands of groundwater wells in hydraulic connection with the Republican River and thereby using more water than its allocation under the Compact" (Zellmer 2008: 400).[40] At the same time Nebraska claimed that the compact covered groundwater pumping in the allocation scheme (Sophocleous 2010). The Supreme Court ruled that groundwater was to be included within the allocation and consumptive use calculations under the compact "because of its close hydrological connection to the river" (Zellmer 2008: 400). This decision provoked both parties to reach an agreement ratified by the Supreme Court in 2003. Key provisions under the agreement include the joint determination by a committee of the amount, timing, and location of depletions from groundwater pumping to the river (Sophocleous 2010; Zellmer 2008). The settlement also recognized the impact of groundwater withdrawals on surface water flows, as well as a moratorium on the construction of new wells and regulation of existing ones (Sophocleous 2010). Nebraska Law 108 of 1996 recognized for the first time the conjunctive use and "connection of surface and groundwater" but only in 2004 did Law 962 provide for the effective management of these two hydrologically connected resources through the designation of fully and over-appropriated areas (Goeke n.d.).

It is clear that hydrological blindness is partly due to the fact that the notion of determining and imposing a 'safe yield' is always hotly contested. As mentioned in Section 2.20, while the determination of recharge is in itself a thorny technical issue, agreeing on the percentage of recharge that is available for pumping becomes a political question. It involves value-laden judgments on the values of groundwater uses and functions, and on the level of externalities that is deemed 'acceptable'. The definition used by the Australian National Groundwater Commission, for example, is directly derived from that of IWRM ("the groundwater extraction regime, measured over a specified planning time frame, which allows *acceptable* levels of stress and protects dependent economic, social, and environmental values"). But, as Turral and Fullagar (2007) elaborate, taking the Namoi basin as an example, determining allocable volumes is a long and continual process. In 1991 it was proposed to allocate 220 Mm^3, that is, the average

[40] See following section for more information on the Republican River Compact.

recharge plus 10%, acknowledging that the economic life of the aquifer would then be 30 years. The discussion was made more complex by the fact that many 'dozers and sleepers' were using their licenses only in case of drought, and allowances were more than double the recharge (Ross and Martínez-Santos 2010).

The limits of hydrological knowledge also appear when one tries to define (minimum) environmental flows, largely generated by groundwater discharge. In some flat sedimentary settings, such as the Beauce aquifer in France, Eastern La Mancha in Spain, or Nebraska, it is possible to establish relationships between this base flow and the level of the water table, and therefore to determine a range within which the water table should be maintained, but this is not possible for more complex fractured aquifers, for example. In South Africa, the Water Act establishes a so-called 'reserve' to protect human needs and aquatic ecosystems, but the 'bucket analogy' used to quantify and manage groundwater does not specify the threshold between acceptable and unacceptable management and abstraction, creating the "false impression, however, that everything that is left over once water is allocated for the ecological and basic human need Reserves can be allocated for 'consumptive use' without impacting the Reserve" (Seward 2010: 242). The difficulty of considering hydrologic complexity when allocating groundwater rights is illustrated by the case of Oregon, US, where a system intended to 'mitigate' the impact of new groundwater permits on streamflows in the Deschutes Basin was dismissed by a court because "the rules wrongly emphasized average annual water volumes in the river and failed to take into account the need to maintain flows at the specific times needed for fish spawning and rearing."[41]

Blindness to hydrological realities can often be the result of a necessity or will to disregard facts that have unpalatable implications in terms of their political or financial cost. Although Danish authorities knew as early as 1952 that recharge into the Copenhagen aquifer was only 50% of what was initially believed, they allowed the legal limits for groundwater abstraction to be exceeded until the late 1980s. Another way around is to change established hydrological limits: despite the EAA setting the pumping cap for the Edwards Aquifer in Texas at around 550 Mm^3 per year in 2004 (in order to protect plant and animal species dependent on aquifer levels and spring outflow) 881 groundwater permits were issued by the authority, totaling 677 Mm^3 of groundwater abstraction per year. The discrepancy led the Texas legislature to raise the permitted abstraction level to 705 Mm^3 in 2008 – 5% higher than the total groundwater withdrawals registered in 1989. It also necessitated a recalculation of the minimum spring flow requirements (Charbeneau and Kreitler 2011; Debaere et al. 2014).

In Copiapó, Chile, water rights were granted "without knowledge of the capacity of the aquifer; laws, decrees and resolutions did not have hydrological basis or tried to obscure mistakes without solving them; [there are] multiple existing hydrologic models, none of which fully accepted by all actors" (RedAgricola 2014). Furthermore, since "studies are contracted out to private companies and since information is generated by consultants nobody is in a position to assess whether it is correct or not" (ibid).

Another way to "play with limits" is to alter the delineation of areas formally designated as over-abstracted. The over-allocation of rights to the Copiapó aquifer was assessed by the DGA in 1993 (Resolution No.193, May 27, 1993), where the level of abstraction permitted was found to be five times that of the average recharge rate of the aquifer. The resolution declared the entire aquifer to be a "prohibition zone" and ruled that no new groundwater rights be granted (Montero Moraleda 2012). In 1994, however, the decision was modified and the "prohibition

[41] www.oregon.sierraclub.org/tracker/HB3494.html (Accessed March 19, 2014); http://crag.org/content/news/wa20050519.pdf, (Accessed March 19, 2014).

zone" altered to allow new groundwater rights to be granted to certain sectors of the aquifer (the recharge area and lateral valleys of tributaries of the Copiapó). A similar strategy can be seen in the Ica valley, Peru, where Ocucaje district was part of the "zone de veda" declared in 2008, from which it was excluded six months later, reincorporated in 2011, and excluded again in 2014 (Guevara Gil 2015).

3.5.2 The monitoring and enforcement conundrum

It is all too common to hear officials say, "in our country we have all the best laws and regulations, but the problem is implementation and enforcement." The implicit or alleged reason is often that it is costly and strenuous to apply regulations (and that with more means, funding, and capacity building this could be possible). But there are also recurrent mentions of the "lack of political will," which is shorthand to express that the private interests of those in positions of power may not be aligned with the public policies required (this point is discussed in the following section). We elaborate here on the various dimensions and causes of weak regulation enforcement.

It was apparent from earlier sections that lax enforcement of groundwater regulation is the norm. This can be briefly illustrated again. In Mexico surveillance by CONAGUA is said to be weak to nil (OECD 2013). In the Valley of Toluca, for example, most water extraction is unmetered, and thorough monitoring of water extraction (notably by farmers) is deficient (Reis 2014). In the Kairouan Plain, Tunisia, restrictive regulation is not implemented and the CRDA’s staff is unable to enforce the law (Le Goulven et al. 2009). Even in South Africa, where water legislation has been described as 'forward' and 'progressive' in theory, its tangible implementation is seen by some observers as poor to nonexistent (Seward et al. 2015), and enforcement and respect of formal regulatory tools and laws are weak (Beckh 2013). In Turkey, despite recent DSI regulation putting emphasis on the installation of meters, monitoring of actual water use by both individuals and cooperatives is weak to nonexistent (Apaydin 2011; Le Visage 2015).

Good indicators of enforcement are the number/percentage of unregistered wells, and the growth rate of illegal wells, to the extent that such numbers are known. As discussed in the section on well registration, a common situation is that illustrated by Italy (estimates of about 1.5 million illegal wells), Cyprus (50,000 illegal boreholes), Spain (a minister acknowledging around 510,000 illegal wells in 2005) (Dworak et al. 2010), and the Languedoc Roussillon Region in France, with only 5-10% of wells being declared (Montginoul and Rinaudo 2014).

3.5.2.1 Insufficient means

The primary difficulty faced by the administration when enforcing groundwater regulation is related to what was described earlier as a logistical nightmare (see Section 3.1.1.4). To recap, managers and regulators are not given the necessary means (in terms of staff, vehicles, budget, incentives, etc.) to monitor a situation that involves (tens or hundreds of) thousands of dispersed points of use.

In Mexico the water authority lacks the personnel to control abstracted volumes or the drilling and exploitation of illegal wells (OECD 2013). According to the World Bank (2009), the number of groundwater users controlled in 2004 was only about 1% of those listed in the Public Registry. Likewise, the enforcement of prohibition zones ('vedas') was poorly maintained, as the water authority did not monitor groundwater withdrawals from individual wells (Wolfe 2013). In Morocco the Souss Massa River Basin Agency has only two agents acting as water police and the provisions aimed at involving regular police officers as part of this force have not been implemented (BRLi and Agro-Concept 2012.). In Abu Dhabi a need was identified for enforcement officials to check individuals’ compliance in addition to the issuing of permits and licenses. Not only does this require a large workforce of compliance officers but also the support of the farmers for the required checks to take place (McDonnell 2016). In Lebanon the Department of Water Rights and Expropriation (in charge of issuing permits, registering notifications for all drilled wells and following up on enforcement) only has 10 field staff against an estimated need of 100. The Department of Groundwater and Hydrogeology has 49 positions in its flowchart but currently has only nine employees, none of whom is a hydrogeologist (Nassif 2016).

In Spain the Guadiana Water Authority has a small number of guards, with only four for the 550,000 ha of the Western Mancha aquifer (López-Gunn 2003). In South Africa monitoring of licenses barely takes place (it should be done every five years) "due to capacity constraints and the review process is mainly an administrative 'paper' monitoring process" (Movik and de Jong 2011: 72). People "deliberately take advantage of the weak formal governance" as they "try their luck [o]r they know that there are not a lot of knowledgeable people in the department [DWA] or in government or whatever" (Beckh 2013: 13).

In Spain various factors, such as the water basin authority's lack of financial and human resources, the self-interested attitude of farmers, and the lack of advice and information, explain why most water rights inventories are incomplete (Rica et al. 2012). The story of the PEAG program in La Mancha alluded to earlier is a perfect illustration of the discrepancy between ambitious information-intensive regulation policies intended and the lack of capacity to implement them: farmers could sell their full abstraction rights (in which case the River Basin Agency would have to ascertain if they were no longer used) or a portion of them. This meant the agency would have to install a meter in the well and monitor/control it to know the actual groundwater consumption and limit the remaining abstraction right to the permitted level (Calleja 2014). The remaining water could not be used on an expanded area, even if improvement in water application efficiency made that possible, which required monitoring of actual irrigated areas. Other measures in the program depended on the crop type, which meant this information also had to be collected. Yet, visits by officials are reported to be infrequent and there was no increase in visits by guards from the River Basin Authority to land plots having purchased or sold rights since the beginning of the PEAG (Fernandez Lop 2014).

A similar situation is found in several states of India. In Andhra Pradesh, Aguilar (2011: 647) found that, despite the law's good intentions, the authority is unequipped with databases, machinery, and staff, depriving it of any "meaningful implementation." In Bangalore the water distribution board was charged with monitoring all wells and expressed that it did not have a plan to check on existing wells nor sufficient staff. The Water Authority of Jordan, meanwhile, reported more than 15,000 cases of groundwater-related offenses in 2014, some for tampering with meters, others for digging illegal wells, or sabotage of WAJ's water distribution pipes (Jordannews 2015), which gives a measure of the numbers of staff that would have to be mobilized to act on all these offenses. In Texas, US, local groundwater agencies "are required to monitor the elevation of their groundwater basins, though there is no requirement for monitoring or tracking groundwater pumping" (Little Hoover Commission 2010: vii).

3.5.2.2 Ineffectiveness of sanctions

The conventional way for a state to elicit compliance with regulations and laws is to count on the power of penalties to dissuade against any violation. For example, the state of Karnataka in India announced that any person drilling or digging a well without a permit would be liable to a fine of up to 5,000 Rs[42], could face up to six months in prison, and risks seizure of the well. Any user

[42] Around 83 USD.

continuing to abstract water from an unregistered well is liable to a fine of 2,000 Rs and/or up to three months in prison (Water Governance Facility 2013). In France the failure to declare a well can result in a fine of up to €15,000 (Montginoul and Rinaudo 2014). In Western Australia the penalty for taking water without a license or for breaching the conditions of a license is a maximum fine of $10,000 ($50,000 for corporations) plus a daily penalty of up to $1,000 ($5,000 for corporations) (Bennett and Gardner 2014). In the Mancha Occidental aquifer, Spain, penalties are not taken seriously since farmers know by experience that fines of €30,000 for the drilling of illegal wells are eventually reduced to €1,800, which is considered to be worth it (López-Gunn 2009).

Faced with the widespread violation of groundwater regulations, many countries choose to toughen the punishment. Yet this is often tantamount to an admission of failure and misguided adherence to the idea that the fear of increased penalties will discourage people from infringing the law. In Egypt, for example, toughening of the provisions of the Irrigation and Drainage Law of 1984 are routinely recommended, which can only partly be explained by the fact that the penalties it outlines are negated by inflation (IRG et al. 2001). The proposed law (yet to be approved) identifies punishments for various types of violation, entitling the police to take action against the accused in addition to fines of up to EGP 25,000 (US$ 3,100). The well owner must install a meter measuring groundwater use. Failure to comply, or leaving a meter out of order for over a week without informing the ministry, incurs a fine of EGP 5,000 (US$ 620) (El Arabi 2012).

In Jordan a 2014 amendment to Law No.18 of 1988 states that "any user or owner who does not follow the established provisions for obtaining a well license, rules for drilling or replacing, cleaning or deepening a well will face prison (for a period of time of no less than a year and not more than three) and have to pay a fine between 1,000 JD and 5,000 JD [1,200-5,000 US$]." The penalty for illegal well drilling is prison for one to five years and a payment of not less than 2,000 JD and not more than 7,000 JD. In Syria, too, the 2005 Water Law imposed harsh fines and prison sentences in case of infringement (Saade-Sbeih 2011).

In Mexico new regulation demands groundwater users install water meters in their wells, with administrative and financial sanctions for non-compliance. The system is, however, perceived by users to be ineffective, and the high fines for violating concession limits are criticized as unfair and unrealistic (OECD 2013).

Excessively raising the level of penalties has two counterproductive consequences. First, the sanctions become 'non-credible,' in that their application would create such social protest or upheaval that nobody really believes they could be enforced. This further undermines the possibility of enforcing regulations. This may well be the case with the block tariffs recently imposed for illegal wells in Jordan. Second, they provide a bigger 'stick' to local officials, who can then extract larger bribes from illegal groundwater users.

3.5.2.3 Fraud, bribery, and corruption

Numerous and dispersed groundwater abstraction points often pose a challenge to state control, especially in frontier areas where the authority of the state may be drastically reduced. Direct monitoring of the existence and actual use of wells is fraught with the logistical nightmare alluded to earlier and generally involves a large number of field staff who are in direct contact with groundwater users. Water fees or reports of violations depend on the information they collect and send to the upper levels of the administration. This obviously opens space for 'arrangements,' bribery, and selective application of the law, whether the initiative comes from the farmer or from the field staff.

This stark reality was recognized in 1974 by a Gujarat chief minister who refused to sign a bill into law (Shah et al. 2000). He failed to see how the law could be effectively enforced against a million small, private well operators scattered across a huge countryside. He also saw that it would become yet another instrument of rent seeking for the local bureaucracy (Mukherji et al. 2012). But such understanding is the exception rather than the rule.

Indeed, in Indian states with set tariffs and meter reading, staff were found to be cogs in a system riddled by endemic corruption (Shah et al. 2012). Aguilar (2011) refers to a 2004 study that reported that more than 40% of individuals polled had bribed state water officials in order to alter meter figures and decrease their bill. In the same study 12% of those surveyed had paid a bribe to speed up the installation of a water connection. In West Bengal, following the Groundwater Act of 2005 requiring permits for wells, 64% of applications were rejected, with evidence of likely rent-seeking behavior on the part of the administration (Buisson 2015).

Bangladesh is known for its corruption problem within state-controlled schemes (Zaman 2015). Each and every step offers room for corruption – by pump operators, scheme managers, group leaders, technical support staff, and even by one farmer over others. As there are different levels of technical staff, if the system is not properly designed "the farmers can find the appropriate level and get their work done through payment of unofficial fees, or in other words bribery" (ibid). Instances of corruption within the regulatory system of water management are also found in China (WIN 2011), in Algeria, where the granting of loans or well permits in prohibited areas fuelled clientelism and corruption (Amichi et al. 2015), and in Mexico, where falsified well concession licenses and permits are common (OECD 2013). In the state of Jalisco, for example, politically connected well owners can obtain new concessions despite a general ban on drilling (World Bank 2009). The lack of political will combined with the corruption of local government officials and the distance from the capital play against the enforcement of regulations (ibid.). In Lebanon the Directorate of Internal Security Forces (ISF) is the only body with authority against violations of the law observed on the ground, but it is widely reported to use its power to accept payment in exchange for not acting on infringements (Nassif 2016).

The reading of meters is also prone to bribing practices, such as in Syria and Jordan, where it is believed to be a major reason behind the large under-reporting of actual groundwater use (Al Naber and Molle 2017; USAID 2014). In Yemen influential ministers, sheikhs, wealthy farmers, and army and security officials continue to drill wells without permits due to their connections and ability to pay bribes (Zeitoun et al. 2012).

The level of corruption is generally regulated by the fact that both administration staff and groundwater users try to keep a balanced, that is not overly confrontational, relationship. In some authoritarian settings, where the exercise of power by government agents is more brutal, this rent seeking can come closer to racketeering. In Syria the government toughened its regulations, demanding the annual renewal of well licenses, in order to monitor groundwater levels. De Châtel (2014: 12) notes that "this engendered widespread corruption as security personnel or officials forced farmers to pay bribes for new licenses, which in turn triggered strong resentment in rural areas." As described by Wendle (2016), well drillers had connections and trusted contacts with local government officials on whom they could count "to look the other way" if they bent the rules (Wendle 2016: 44): "if you bring the money, you get the permissions you need fast […]; if you don't have the money, you can wait three to five months. You have to have friends" (Wendle 2016: 46).

Other forms of corruption associated with groundwater regulation include low-level exaction at road checkpoints in Yemen, which supposedly should stop any drilling rig without registration from the NWRA. They may spill over to related sectors and activities, such as the energy sector and its diesel subsidies (Al-Weshali et al. 2015). An intricate web of corruption and vested interests benefits from the allocation of subsidies for diesel, the transportation of fuel, and re-shipping and export to other countries (as far as South Africa) (FMWEY 2015).

3.5.2.4 Lack of management target

The level of enforcement can also depend on whether the administration or stakeholders more broadly try to achieve a specified target. In some contexts, stakeholders aim to reduce abstraction to a certain level, or to maintain the water table between agreed limits. This provides a benchmark against which efforts can be judged and therefore incentives to comply. This is the case, for example, in the Beauce aquifer, in France, and in some places in Spain and the US. It is also the driver behind institutional changes in Texas, where stakeholders in each aquifer are compelled by law to define their "desired future conditions."

This lies in contrast to places such as Andhra Pradesh, where "there are no enumerated guidelines in the statute for what constitutes 'damage to the level of groundwater' or 'deterioration or damage to the natural resources or environment' (Aguilar 2011: 643)." Enforcement of the rules and the suspension of pumping rights are at the discretion of the officer from the authority granted by the board (Aguilar 2011). With no clear definition of what is acceptable, stakeholders have limited incentive to make the effort to comply.

3.5.2.5 Meters and tampering

Water use is generally computed based on meter readings (other methods involving remote sensing are discussed at the end of this section). But as indicated in Section 3.2.2, meters are costly, users often fail to install them, and when installed they are frequently broken or tampered with. This is partly why, in Tunisia, meters have never been made compulsory in tubewells: it was recognized that they would be tampered with and that the administration would not have the capacity to handle them (Hamdane 2014). In Bangalore the regulation of groundwater was problematic as board officials lacked enthusiasm, knowing the "various ways in which well owners tend to tamper with irrigation pump meters and refuse to adhere to binding regulations" (Grönwall 2008: 356). Farmers have indeed been creative in finding ways to tamper with meters and alter measurements, as illustrated earlier by the case of Jordan (Al Naber and Molle 2017).

It is understandable that the monitoring and enforcement of well regulation will be limited where meters are costly and often broken or nonexistent, as for agricultural wells in Mexico (Wolfe 2013), where accessing private property is complicated, and the number of wells causes logistical problems. In such cases virtually all attempts at volumetric regulation are undermined.

3.5.2.6 Lack of awareness of regulation

Weak enforcement of regulation can be linked with limited efforts by the government to inform the public, which translates into a lack of knowledge of the law and hence noncompliance. This was found to be the case in Mexico (Wolfe 2013) and in Egypt, where most farmers interviewed in a case study in the Nile Delta were ignorant of legal requirements (El Agha et al. 2015).

Poor awareness of the rules was also reported in India, for example in Karnataka, where the Groundwater Act does not appear to be well known, "at least in the urban environment, maybe because it comes under the Department of Rural Development and Panchayat Raj" (Grönwall 2008). In Spain it was found that the ambitious process of converting private rights into a register of public concessions was not accompanied by an adequate information campaign, so the users' frequent lack of awareness of the regulations, their individualistic views about the resource, combined with the lack of advice and information, meant that the process was far from complete, even 30 years after having been initiated (Rica et al. 2012).

3.5.2.7 Legal constraints

In a number of cases, legal constraints hamper or even preclude proper monitoring of the situation on the ground or the enforcement of penalties. The South African Department of Water Affairs and Forestry has no power to act against past lawful users who exceed their water entitlement until they become licensed users – a process that has been sluggish (Movik and de Jong 2011).

In Texas GCDs (groundwater districts) struggle to enforce the regulation as they, "do not have the financial capacity to adequately deal with the legal battles that face them" (Cardenas Panduro, A.I. 2012, 2014). Despite having regulatory enforcement on 'point source' issues, such as improper drilling, drought restrictions, illegal dumping sites, and direct contamination, GCDs have 'no teeth'. Groundwater users can sue if they feel that the GCD is either lowering the value of their property or over-regulating the use of groundwater[43]. Facing such litigation, GCDs either run the risk of going bankrupt or "simply concede to the permit request" (GCD staff 2015).

In a medium-sized GCD, a member of staff acknowledges that well owners have a certain amount of immunity to centralized control of groundwater pumping due to Texas' basing groundwater law on private property (GCD staff 2015). Additionally, while it is sometimes required to submit meter record updates for permitted wells, this is reliant on the good will of users. The district, it would seem, does not verify the accuracy of recordings. According to the staff member, the submission of meter readings is based "on an honor code." The District does not "go out and check that they are recording the true amount they are pumping" (ibid.).

The situation is even more extreme in Chile, where the protection of individual property rights enshrined in the 1964 Water Law prohibits anyone from entering a private property to check the status and use of wells (Chilean water expert 2015).

3.5.2.8 Personal relationships, legitimacy

Enforcement and monitoring of regulation on the ground requires interaction between individuals, be they users or the staff of various bodies, leaving the possibility that those involved have personal relationships. This can bring a degree of flexibility in the application of overly general laws and regulation that ignores local heterogeneity, but it can also lead to favoritism, bribery, and corruption.

Officials who have family or social links with local users are not inclined to enforce tough regulation, especially when they do not sense clear support for it in the higher echelons or, perhaps more significantly, from local state representatives. This has been observed in Jordan (field staff are sometimes recruited from local families) and in Lebanon, where municipalities hardly report infringements to the ministry and consider themselves unable to intervene because of their social proximity to farmers and residents (Nassif 2016).

In Morocco local authorities under the Ministry of Interior are more inclined to protect the livelihoods of their local populations than commit to long-term environmental sustainability. A similar situation can be witnessed in Tunisia, where, "the provisions of the water code relating to the protection of the aquifers do not attract much attention from local or regional authorities [which display] often only weak support for their enforcement duties and the application of

[43] As seen in the Edwards Aquifer Authority vs. Day law suit, which established how far conservation districts can modify and regulate open access, setting a precedent for the San Antonio Fourth Court of Appeal ruling in 2013.

administrative sanctions" (Hamdane 2014). In such a context, social tolerance can create a disincentive to compliance with regulation because in a system where non-compliance is the norm breaking the law can seem the most rational thing to do (López-Gunn and Martínez-Cortina 2006).

A similar situation can be found in Maharashtra, where individual violations of the Groundwater Act should be officially registered and processed by the local Gram Panchayat. Although violations are known to take place, farmers usually consider such reporting to be vengeful (Phansalkar and Kher 2006). Legislation lacks social legitimacy since groundwater abstraction is believed to be a farmer's right, and there is also sympathy for the view that people would want to use groundwater to improve their lives (ibid.). Such disdain for the law means the Gram Panchayat are reluctant to take the necessary action against offenders. Users also rely on compromises instead of applying the regulation rigorously.[44]

The relationship between groundwater users and the state can be affected by social movements. In Gujarat, India, top-level political backing for the Jyotigram scheme (establishing dedicated power lines for groundwater pumps), all the way to the Chief Minister, was "necessary but not sufficient to control the anarchy" on the ground: staff members were reluctant to venture into villages for fear of violence from irate mobs; they were often taken hostage (Shah et al. 2012: 6). The practical solution was to set up dedicated police stations and employ 500 retired army personnel to keep violence in check, but the scheme lost much of its legitimacy.

Powerful groundwater users, such as large-scale producers and investors producing for export markets, often have close political connections: and politicians themselves are known to invest in such ventures (as in Guanajuato state in Mexico, Hoogesteger 2016). Reis (2014) has shown how, in Mexico, industrialists knew how to stay "on good terms" with the administration (CONAGUA) in order to secure their leniency in reading meters. In the Ica Valley, Peru, investors quickly obtain permission to link their wells to the power grid, which small farmers often struggle to do (James 2015a). In Abu Dhabi one agriculture official explained that, "here there is no such thing as 'illegal' for a local who has good connections" (Fragaszy and McDonnell 2016).

An issue pertinent to the gaining of compliance with regulation is that of social capital (Pretty and Ward 2001). Water users often distrust the authorities, which can lead to decreased legitimacy of official decisions and regulations (López-Gunn and Martínez-Cortina 2006). The reasons for this lack of trust are diverse and might include a past history of inefficiency or ineffectiveness, political meddling in cooperatives or Water User Associations (e.g. Tunisia), or perceived unfairness or arbitrary decision-making on the part of the public administration. (In Jordan's Highland Water Forum, farmers forcefully asked the ministry to implement the bylaw fairly for all well owners with no exceptions.) In some extreme situations bordering on predatory systems, such as in Syria, where tough regulations demand groundwater users install water meters in their wells, administrative and financial penalties for non-compliance are used as threats to exact bribes from users. Needless to say, in such situations the legitimacy of law and sanctions is extremely low.

3.5.2.9 Facing raw power

Monitoring and enforcement sometimes face the raw power of high-profile groundwater users. In the Souss, in southern Morocco, the social and relational capital of some well-connected

[44] Phansalkar and Kher (2006) refer to a case where a compromise was reached between local officials and farmers. In one instance the offender was told he could continue irrigating his orchards if he also supplied his village with drinking water during stipulated hours each day. The matter was then closed without going to court or even formally registering the offence under the Act.

larger abstractors prevents the 'water police' from interfering and controlling groundwater abstractions (Del Vecchio 2013), despite the River Basin Agency officially having the right to close down wells without authorization (BRLi and Agro-Concept 2012). The suggestion that government officials could enter the farms of powerful investors around Marrakech was met with incredulity and laughter by some of these officials (interviews in Marrakech, 2014). In Abu Dhabi there has been anecdotal evidence of agency staff being prevented from entering the land of irate farmers (Fragaszy and McDonnell 2016).

Turral (2015) reports problems with monitoring and verification by the authorities during the pumping ban imposed in 2007-08 in the Werribee Irrigation District (west of Melbourne) during a seven- to eight-year drought episode, with users threatening officials with guns on occasion.

In the Ica valley of Peru the association of groundwater users' monitoring tasks are made difficult by the fact that many properties being guarded and landowners not allowing association representatives access to their farms (Cardenas Panduro 2012; Oré et al. 2013). James' (2015a) investigation in the area revealed confrontation between villagers struggling to preserve what they see as 'their' resource and thugs paid by investors. In Jordan there were several instances of water authority staff being barred from entering private properties, including that of a prominent sheikh in Azraq, which was guarded by armed men. As illustrated by a local commenting on a Bedouin farmer, "it is a tribe and the tribe has power; the small government employee cannot say no to the big tribe" (Al Naber and Molle 2016). In Azraq a case was reported of three farmers attacking WAJ staff during a field inspection, opening fire and injuring one (fieldwork). Abbadi (2003) recorded eight similar attacks in Jordan but without injury.

3.5.2.10 Are there exceptions to lax enforcement?

Although all the factors listed above contribute to explaining why monitoring and enforcement are generally lax, it is also possible to identify situations where conditions promote stricter enforcement. Instances of an administration taking action (although usually with little or no result) have been identified as relating to:

Tip-offs. In Ica, Peru, in May 2014 the National Water Agency issued a fine close to US$ 130,000 to the company Agricola Miranda for having drilled wells within the banned area and proceeded to close the 10 wells irrigating 400 ha. A representative of the farmers in Villacuri had reported the existence of the wells to the Water Agency. In Marrakech, Morocco, a farmer reported his neighbor's illegal drilling of a well because it was directly affecting his own nearby. In the Eastern Mancha, Spain, the Groundwater Association was officially made the only interlocutor of the Water Authority and farmers report violations such as illegal well drilling or use by outsiders. In the province Tiaret, Algeria, the drop in the water table is threatening the sustainability of farming and well drilling has been prohibited: farmers readily report any illegal drilling to the authorities (Daoudi et al. 2017). In the Lower Murrumbidgee, Australia, groundwater users are asked to report suspected unauthorized pumping or water theft to a Compliance Unit (by email or telephone; all reports remain confidential).

Threats to higher-level priorities. The state may be compelled to act when the drilling of wells clearly affects public wells that are used for the domestic supply of cities (as happened in Oran, Algeria, in 2006, for example) or when illegal wells are drilled on public land.

Conflicting relationships with officials. Anecdotal evidence suggests authorities would take action against particular individuals who have fallen out with them for a variety of reasons, ranging from repeated and outright challenges to the law to refusal to pay bribes, or any kind of interpersonal conflict.

Cases showing more systematic and convincing enforcement of regulations include situations where users are able to exert more balanced peer pressure on one another. Van Steenbergen et al. (2012) report that in the area of Wadi Qarada in Yemen's Sana'a region, two user associations have established mutual checks and balances and implement tasks of monitoring and control of illegal abstraction for each other, lodging complaints to the government if one association discovers that the other has engaged in unlicensed drilling. In south-east Australia, if individual users notice any irregular activity on the part of their neighbors, they can report it to the authorities (Turral 2015). This is a case were enforcement by the authority is stringent enough to make free riding behavior by some individuals unacceptable to others.

In Bangladesh, according to Mukherji et al. (2009), offenders can be imprisoned for up to five years or fined up to 50,000 Rupees. From 2002 to 2003, 2,000 raids were carried out and 73 arrests made. Additionally, power theft and meter tampering were made punishable offences under the Indian Electricity Act of 2001.

State authorities are more likely to be able to keep use to a reasonable level in contexts where major users are domestic water providers or industries and/or where agricultural sector users are limited in number and in terms of total abstraction. These conditions are typically met in Japan (Endo 2015), coastal California, and Denmark, where the bulk of abstraction for water supply is carried out by around 2,500 companies. These are more easily monitored in terms of volume (since a comparison is also made between declared abstraction and billed volumes, with companies paying if losses are greater than 10%) (Jørgensen and Villholth 2015; ECOTEC 2001). In the Lower Murrumbidgee, Australia, there are only 314 groundwater licenses for the deep aquifer source. The number of bulk users is even more limited in the coastal aquifers of California. (Cases where groundwater abstraction has been by and large controlled are discussed in more detail in Section 3.5.8.)

One manifestation of stricter enforcement is the issuing of fines and penalties in accordance with the law. In the case of illegal pumping/drilling during the drought in south-east Australia reported by Turral (2015) and mentioned above, illegal wells were eventually forcefully decommissioned and dismantled and users prosecuted. In Jordan the vested interests of large farmers in the south with licenses to farm in Disi until 2011 resisted the new Groundwater Bylaw (Yorke 2013). It was only as a result of a Supreme Court ruling that they later paid for water consumed above the permitted volumetric limit.

In Eastern Mancha, Spain, the Groundwater User Community charges between €100 and €600 for groundwater volumes abstracted over the authorized cap (between 0 and 30,000 m^3 per year), requesting the return of those volumes (plus an additional 10%) in the following irrigation campaign (JCRMO 2014). The amount paid is on top of a fine by the River Basin Authority (of up to €10,000). If the excess amount abstracted is over 30,000 m^3 (in one year), then the River Basin Authority intervenes and will enforce more drastic sanctions (fines between €10,000 and €500,000). During the 2013 irrigation campaign the Irrigation Court of Spain's Eastern Mancha Groundwater User Community launched five disciplinary procedures against its members (JCRMO 2014).

3.5.2.11 The promise of technology

As discussed earlier, the cost of monitoring both land and water use in situations of numerous and dispersed small agricultural users is often prohibitive and prone to all kinds of data manipulation and corruption. Technology is often proposed as a way to bypass human intervention and data collection. A promising advance has been recorded regarding both the monitoring of groundwater use (metering) and the assessment of irrigated areas (agricultural land use).

Metering is bedeviled by myriad technological problems and deviant behaviors (see Section 3.2.2). As mentioned earlier, the government of West Bengal has adopted a system whereby meters can be read remotely from more than 100 feet, and readings are transferred in real time to the regional and central commercial offices of the electricity supplier (Mukherji et al. 2009). Villagers and groundwater users can no longer intimidate or bribe meter readers.

The Barind Multipurpose Development Authority in Bangladesh oversees 15,054 deep tubewells (2014) providing groundwater for irrigation and drinking water for 292,000 ha of irrigated land. The Authority has so far issued 29,611 prepaid smart cards. The system offers transparency with checks and balances to counter fraud, as water cannot be delivered free of charge by pump operators under coercion from users (Zaman 2015, 2015a). Water savings are said to represent 40% since the introduction of the pre-paid meter and smart card system (Zaman 2015).

Similar successes in linking groundwater abstraction and energy costing were recorded in China. In Shanxi province, the Qingxu County defined annual quotas for all water users from a total of 1,473 wells (Guisheng et al. 2013, Li He 2011). The wells are operated by farmers through a 'smart system' using swipe cards to activate water pumps. The quota is centrally determined for each of the 197 villages and then for each farmer within each village. In the Minqin County in north-central China, (Aarnoudse 2010; Aarnoudse et al. 2012) smart systems to control groundwater were introduced in some villages. Users would activate a well by swiping a prepaid card, and each well has a card kept by the community leader. In these cases, however, prepaid card technologies are firstly deployed to ensure cost recovery and long-term maintenance. Yet, by establishing a direct relationship between what is paid and what is used they constitute a powerful monitoring tool, as well as one to enforce quotas. Wang et al. (2017) provide an updated view on the current situation and development of prepaid-card smart systems in the past 15 years in Northern China. While problems with implementation costs (covered by the state), maintenance of the technology or unregistered individual wells have weakened the system, there is a clear potential for improving it in the future.

Monitoring can be hampered by inaccuracies in official statistics about areas irrigated with groundwater. As an example, statistics for the state of Guanajuato show that there are 250,000 ha irrigated with wells. However, alternative methods used by the Secretariat for Agriculture (aerial photography and on-site visits) have quantified the irrigated area at around 326,000 ha (ibid.). This demonstrates the potential of technologies such as remote sensing and satellite imagery for monitoring well expansion or existing abstraction levels. Jordan's Ministry of Water was using this technology 15 years ago, but it is only recently that, with the availability of cheap and frequent images as well as data-processing facilities, satellite imagery is used to identify land with irrigation and locate illegal wells. Recent studies have shown that actual abstraction in the highlands of Mafraq and Azraq, as estimated from land-use maps, was between two and three times higher than per official data (Al-Bakri 2015; USAID 2014). These results produced a shockwave within the ministry, and the technology is to be fully adopted. In Portugal's Algarve region, the water administration has a GIS system in support of the licensing process (Rinaudo et al. 2012).

Another advanced experiment in the use of satellite data, obtained in real time, was carried out by stakeholders of the Eastern Mancha aquifer in Spain, with the help of a local university (Sanz et al. 2015). Maps indicate discrepancies between images and the annual operating plan (AOP) agreed by farmers, making field review more effective. This helps to ensure strict compliance with the Plan since all stakeholders, including the Groundwater User Association, have access to these data and can point to inaccuracies at any time. A recent judgment by the Spanish Supreme Court stated that remote sensing cropland maps are admissible as proof in court proceedings as they allow for real-time results, reliability, and reproducibility, and can be validated by other methods (Sanz et al. 2015). Likewise, amendments to the groundwater bylaw in Jordan validate the use of water consumption estimates through indirect means. Interestingly, Sanz and colleagues (2015) have come up with an estimate of the budget needed for detailed monitoring of land and water use through remote sensing: €150,000 per year for a typical area of 150 km x 150 km.

Managers in the Murray Darling basin in Australia have also resorted to satellite imagery, including aerial photographic inspection of rice areas (routinely for the last 20 years) with the aim of enforcing limits on groundwater recharge (in shallow saline aquifers especially). Water use audits are, however, less of a routine compliance mechanism and more a one-off control (Turral 2015).

3.5.3 The infamous "lack of political will"

The ineffectiveness of groundwater regulation, aside from the many difficulties described above regarding monitoring and enforcement, is commonly blamed on a "lack of political will." In other words, it is believed that all the means of control are sound and generally sufficient but they are not implemented because the 'government', that is, the bureaucracies in charge of groundwater as well as councilors associated with those in power, are ultimately unwilling to make use of the 'sticks' at their disposal. As a result, the government is more inclined to resort to 'carrots' (extending positive incentives at public cost) and to supply augmentation options. We examine here three major reasons for the ubiquitous "lack of political will."

3.5.3.1 Vested private interests

First it is often the case that the government officials and political leaders responsible for the voting in and application of regulations are the primary beneficiaries of the groundwater economy. Nowhere is this clearer than in Yemen, where sheikhs and landlords command considerable power in the parliament and the government. It has been reported (Alhamdi 2012) that on the very day a law was passed to ban wells in the Sana’a basin the Minister of the Interior was drilling an illegal well on his property. Al-Zubari (2012) notes the lack of political will in Arab countries "to enforce legal regimes that contradict local institutional regimes as well as the vested interest of political and economic elites".

In Jordan and Morocco too investors in groundwater-based agriculture are often powerful figures or corporations, sometimes close to the king. In Azraq oasis, in the highlands of Jordan, most of the farms belong to investors, around 90% of whom reside in Amman or other large cities, or even in foreign countries (Iraq, Kuwait). Among them feature powerful figures, such as former ministers, heads of the public security and intelligence apparatus, senators, members of parliament, and large investors such as shopping mall owners (Al Naber and Molle 2016).

In Morocco the investment boom into the groundwater economy is partly associated with the financial interests of large local and foreign investors. Through different means and for various reasons, these investors are reportedly powerful enough to help maintain the *status quo* regarding groundwater regulation. In León, the capital of the state of Guanajuato, Mexico, the influence and power of specific policy networks, oriented towards the representation of strong local business interests (tanning and shoe-making industries), ensured the control of water management policies by these groups (Caldera-Ortega 2013).

In Algeria subsidies chiefly benefited investors with capital or land deeds who could get as much as 100% subsidies for their micro-irrigation systems, while opportunities for the personalized granting of favors (accessing loans without the required land titles, permits for wells in prohibited areas) fueled clientelism and corruption (Amichi et al. 2015).

In the Liwa Oasis, United Arab Emirates, government officials described the conundrum in this way: increased monitoring and metering of abstraction could begin, but as soon as one well-connected and powerful individual gets upset and begins airing grievances, the entire program may be in jeopardy (Fragaszy and McDonnell 2016). The personal interests at stake can sometimes be political. In the Medina Zayed section nearly 1.8 million trees are planted on an area of almost 10,000 ha and utilize 1,122 wells. This represents the 'desert greening' project launched by Sheikh Zayed with the idea of transforming the desert into greenscape (Fragaszy and McDonnell 2016). Although the 'desert greening' project is known to be damaging to groundwater resources, it remains politically sensitive as it was a core feature of late Sheikh Zayed's agenda.

3.5.3.2 Conflict with higher-level state priorities

Second, the need to conserve groundwater resources (but this is also true for surface water) often comes second to higher-levels state priorities. Any action by the authorities responsible for groundwater management is therefore subordinate to, or negated by, policies implemented by other sectors and ministries. In other cases, the contradiction is between the policies designed by the ministry and local administrations which have to take into consideration developmental or other objectives of the provinces or regions in which they are located (e.g. Morocco).

In Mexico, for example, the introduction of 50 'zonas de veda' between 1948 and 1963 had no effect, since the development of groundwater resources was considered as key to the expansion of commercial agriculture at the time, and extraction was not monitored (Wolfe 2013: 17). In Western Australia it is difficult to address groundwater over-allocation through the use of license amendments since there have been deliberate policy decisions to allow continued over-allocation "in order to facilitate the ongoing operation of coal mining and coal-fired electricity generation in the area" (Bennett and Gardner 2014: 61). Likewise, in Chile water extracted from an aquifer during mining excavation is not considered water use.

In Turkey monitoring of actual water use by both individuals and cooperatives is weak to nonexistent, partly on account of the very high number of wells but also because of the crucial importance of groundwater in making agriculture competitive – a high-priority government policy objective (Apaydin 2011; Le Visage 2015). Pakistan faces the pressure of producing sufficient food to feed the population and reduce poverty in rural areas where more than 70% of the population lives. This explains why the government has been reluctant to enforce groundwater regulation, when the resource has come to cover more than 50% of the total crop water requirements (Qureshi et al. 2010).

To date no specific area in Morocco has been declared a groundwater prohibition zone (despite legal provision for it). In the south the Souss Massa Basin Organization prepared the necessary files and made such a request in 2009 but the central administration has so far failed to take any action on that request. The Tensift Basin Organization issued a memorandum in 2008 banning the drilling of new wells, but with no willingness to constrain the expansion of tourism in the Marrakech region its enforcement has remained elusive, overridden by higher political players. In northern Algeria the state administration has tended to turn a blind eye to the proliferation of wells in part because surface water was being redirected from agriculture to cities, and farmers were therefore being dispossessed of their water resources. A similar situation can be found in

Maharashtra, where local Gram Panchayat are reluctant to register violations and take action against offenders as they sympathize with the hardship they have to face in their daily lives.

In Tunisia local and regional authorities pay little attention to the *Code des Eaux*, which provides for the establishment of protection or prohibition areas (Hamdane 2014). The wali (provincial governor) retains the power to apply or filter central regulations from the ministry. Groundwater use in non-agricultural sectors is often planned and developed without coordination with the CRDA. Industries are planned and their water needs are then transformed into requests to the CRDA. Walis commonly approach the central government to militate against control of groundwater use and request support for industrial and tourist development in their provinces (Interview with CRDA staff 2015).

3.5.3.3 Consolidating political power and clienteles

Choosing the degree of implementation or disregard of groundwater regulation is also one aspect of power-building and creating or sustaining clienteles. As long as little effective regulation/reduction of abstraction is possible without using heavy sticks, implementing those regulations is often tantamount to political suicide (at least in terms of threatening the result of forthcoming elections), or in some cases to generating serious social unrest and upheaval. Obviously neither of these prospects is attractive to politicians, who predictably adopt procrastination strategies. "Sweeping under the carpet" is all the easier because the consequences of overexploitation do not dramatically change within the timeframe of the next election, meaning tough decisions can be postponed. Only in times of dramatic drought (like those undergone by Australia in the last decade and the recent one in California), are these consequences made vivid enough to trigger policy responses and make them unavoidable.

In Yemen the tensions underlying water management and water politics are derived from the contest between traditional power structures and a relatively young Yemeni state system, trying to establish itself and find its own legitimacy amongst the country's various tribal allegiances (Zeitoun 2009). The state sought, in particular, to strengthen its power and legitimacy by co-opting rural elites in crucial rural constituencies through preferential access to irrigation, public investment in new wells, and also diesel subsidies (Al-Weshali et al. 2015; Moore 2011). In many tribal rural areas tubewells came to be seen as a sign of wealth and prestige, and financing groundwater abstraction amongst tribal elites became an effective patronage mechanism. Indeed, wells were used as political gifts through which local leaders could be co-opted into power.

The regulation of electricity connections is also subject to the will of local and partisan politics. In West Bengal local village councils control new electricity connections for submersible pumps. The issuing of new permits is co-opted by local elites, such as village council heads refusing to forward new applications either because the applicant did not adhere to their party or a new permit would harm the interests of party supporters. Villages with stronger representatives also obtained disproportionately higher numbers of permits (Mukherji 2006). In Lebanon, too, cases are reported of local political leaders from the Bekaa Valley petitioning the ministry to issue permits to their electors (Nassif 2016).

In Gujarat, in 2013, the proposal of a bill to make compulsory the licensing of groundwater abstraction beyond a certain depth, with penalties for non-compliance, provoked strong reactions at the assembly, as opposition parties deemed it 'anti-farmer'. Notwithstanding the vocal opposition, it was passed in February 2013. However, with the country's general election looming, the governing party in Gujarat (with India's president-to-be as its leader), decided to shelve the irrigation bill in February 2014 "for fear of irking farmers," and as a message of "good governance to the people."[45]

Phansalkar and Kher (2006) found that nominated leaders who fear not being re-elected as much as they fear for their social standing are reluctant to implement laws restricting the digging or drilling of new wells. Ultimately, as Lundqvist and Falkenmark (2010) argue, the political will to do "the right thing" – and the skill to do so in a proper and effective manner – is conditioned by the political will to stay in power, which presumes social acceptance. As Cullet (2012a: 65) notes, until recently "state governments often preferred opening up their coffers to ensure that sufficient groundwater could be pumped up in a context of falling water tables rather than tackling the issue upfront by starting to allocate, restrict, and take a broader view of groundwater governance."

In Morocco, in 2004, the Souss Massa River Basin Agency decided to close two wells drilled without authorization. Different agricultural unions saw the event as a potential precedent and a risk for many wells without authorization. After they staged several protests the wali of the region suspended the decision, approaching the problem instead by creating a commission incorporating representatives of the agricultural unions in order to find a solution. To date the Souss aquifer has not been officially declared as overexploited. In Mexico, too, the declaration of overuse has been heavily influenced politically, since a restriction in water use has socioeconomic impacts in the area of application. Out of 77 aquifers with problems of overuse (Instituto Tecnológico Minero de España (ITGE) 1997), only 15 were legally declared as overused (Rica et al. 2012).

In India the social fabric of the rural economy is in constant flux. Although the agricultural elite exercises its power, small and medium farmers have also been able to increasingly exert pressure on local authorities and governments via their political voice, whether by voting or through agrarian movements (Birner et al. 2007; Mukherji 2006). As the case of Andhra Pradesh shows, political parties frequently change their position towards reform (as with the Congress Party) and their positions can also vary in different states depending on strategic considerations. Policy discourses are also important as the debate around farmers' suicides helped farmers establish themselves as a group that needs and deserves subsidies (Birner et al. 2007).

In Jordan the enforcement of the Groundwater Control Bylaw of 2002 (which established quotas and water prices) proved difficult according to Yorke (2013). Initial tariff reforms in 1994 had also met with opposition, leading to the occupation of the parliament floor and intervention by the king in the matter (Venot et al. 2007b).

Political considerations explain why some of the instruments have been lacking 'teeth' (for example, the overly generous 'free block' of the water tariff, the leniency towards illegal well drilling or meter tampering, land encroachment, etc.). The country largely holds thanks to the support of tribes and investors, both being the main actors of land and water development. The tribal politics of Jordan, and their constitutive role in state-building, have long been the subject of much scholarship (Alon 2007; Kark and Frantzman 2012). In order to win the support of local tribes, the Hashemite regime has always engaged in a give-and-take relationship – a crucial balancing act for its sustainability. Settlers, smaller scale farmers, and rural populations more generally often suffer from the political and economic situation, making it politically costly to antagonize them. This is especially true in the wake of the Arab Spring: the weakening of

[45] The India Express, 'Non-populist' irrigation bill shelved for fear of irking farmers, February 5, 2014 http://indianexpress.com/article/cities/ahmedabad/non-populist-irrigation-bill-shelved-for-fear-of-irking-farmers/ (Accessed August 17, 2014).

authority (and therefore of the willingness and capacity to enforce the law) is now extremely clear in Tunisia, Morocco, and Egypt.

In Abu Dhabi, too, the prevailing and overriding concern is the maintaining of security and stability, especially after the Arab Spring. This brings difficulties of introducing metering in rural areas where the Emirati cultural and heritage ties to the land are pronounced. "The owning of land and the farming therein is a sign of prestige and moves to control this are met with resistance. Anecdotal evidence of water meters being disconnected and thrown down into wells on the few attempts made to enforce this measure are just one of a number of signs of non-compliance exhibited by the landowners" (Fragaszy and McDonnell 2016).

3.5.4 Groundwater use and inequity

The negative effects on smaller farmers of groundwater over-abstraction have been examined for example by Hoogesteger and Wester (2015) and Petit et al. (2017). Drops in the water table due to the continuous over-abstraction of groundwater can hinder future agriculture developments (or dent the sustainability of the sector or other economic activities related to groundwater, such as groundwater-dependent industries). The decrease in agriculture following the depletion of groundwater reserves in certain areas can create limited availability of production factors (capital, labor) (Petit et al. 2017). Water table drops and the depletion of aquifers can cause a decrease of agricultural output for farmers and the loss of livelihoods. James (2015b) documented the case of the severely overpumped Souss-Massa region in Morocco and showed how the need to dig as deep as 250 m in order to access groundwater was driving small farmers out of business and out of agriculture, one of them explaining that "Everybody is out of work in this area (…) Moving on is better than staying there and suffering". Reyes Martínez and Quintero Soto (2009) have described a similar situation in Sonora, Mexico, where small farmers and members of *ejidos* are being displaced by agribusiness.

Groundwater abstraction through modern individual wells can disrupt social relations and cause or compound socioeconomic inequalities. The race to the bottom is suffered more intensively by small farmers as their economic and financial security can be precarious (Mukherji 2006; Reddy 2003). This can be due to the lack of land ownership, an additional limiting factor in the raising of capital to invest in improved groundwater abstraction techniques (new pumps, the cleaning of wells, or deepening them). This has pushed farmers in India for example to seek additional capital to deepen their shallow tubewells (from banks or informal money lenders, sometimes at extortionate rates). Those facing long-term mortgages and the inability to pay interest or repay their loans have abandoned agriculture altogether while others have committed suicide (Taylor 2013). Further, the inequality in places such as Gujarat results in a growing concentration of tubewell ownership and control over groundwater, driving social polarization between casts and socioeconomic groups (Dubash 2002).

Access to groundwater can be linked to the social and political capital some farmers can accumulate. As reported in India, some administrations require permits and authorizations to pump or obtain subsidies (e.g. for electricity); some well-connected farmers can bypass legal procedures and obtain permits more quickly by calling in personal favors or paying bribes (Aguilar 2011; Davis 2004; Mukherji 2009; Nayak 2009). Facing groundwater depletion or policy reforms, larger and wealthier farmers or investors can develop alternative sources of income whereas small farmers have limited options. Some larger farmers have also the capacity to tap into international markets and export their produce more easily than small farmers with limited access to local markets (e.g. in the Souss in Morocco). Also, the level of organization and professionalization of large farmers can be an advantage in the accessing of state subsidies for improvements to irrigation technology. Meanwhile, small farmers' lack of organization and association can restrict their access to these same subsidies (as seen in the Souss, Morocco) (Closas and Villholth 2016; Houdret 2012).

The socioeconomic differentiation of farmers in Iqaddar in the Saïss, Morocco, has been driven by the unequal access to groundwater and substantially higher net incomes of landowners (Ameur et al. 2017). The intensification of agriculture is partly linked to the security of land ownership allowing further investment. Seeing the depletion of groundwater resources and using privileged information and contacts, larger investors have been able to negotiate directly with the state for the provision of additional water (e.g. surface water from a nearby dam under construction) (ibid.).

Social conflict can arise over access to groundwater and its appropriation for different uses, as seen in Rajasthan and Kerala in India between beverage bottling plants and neighboring communities (Bloomberg 2014; Karnani 2013; The Guardian 2006). In the Ica Valley, Peru, land and groundwater are concentrated in the hands of a relatively small group of landowners. There, the state will grant priority to water users with a water-efficiency certificate when it comes to issuing new abstraction rights. This benefits landowners and agri-businesses who can afford to invest in better irrigation techniques (Cardenas Panduro 2012). The lengthy administrative process to obtain new permits and drill new wells also favors larger farmers as they possess the financial means to employ lawyers to carry out the paperwork and to rent equipment to drill new wells (ibid.). Conflicts have arisen in the Ica Valley between small and large landowners, as small farmers resist the expansion of agri-businesses by refusing to sell land or confronting international donors supporting the expansion of intensive agriculture in the area (CAO 2011).

In Chile conflicts have also arisen regarding the allocation of groundwater rights. In the La Ligua River Basin, agricultural expansion and increasing groundwater use have become a contentious issue among farmers (particularly established large farmers) (Budds 2009). The majority of requests for new water abstraction rights are submitted by commercial farmers with the economic means to submit the applications (i.e. to pay a lawyer to undertake the process), raising questions of access and procedural equity (ibid.). Acquiring groundwater abstraction rights also grants access to irrigation subsidies from the state and thus further differentiation amongst users, as access to groundwater by users without rights is being reduced (ibid.).

In Karnataka, India, the use of tubewells and deep wells has affected local traditions, such as community-managed irrigation tanks (Chandrakanth and Romm 1990). Administrative and political changes promoting the rapid exploitation of groundwater benefit farmers with the capital to invest in private wells, creating individualism and discouraging the maintenance of the shared tank systems that had sustained the vital groundwater resource in the past. Needless to say, it is the small farmers depending on these traditional structures who suffer most from their lack of use and maintenance (Shah 2012).

Local and national lobbies can affect the enforcement of policies and regulations destined to improve groundwater management and control, or at least limit over-abstraction as found in Almeria, Spain (Petit et al. 2017) and in Guanajuato state, Mexico (Caldera-Ortega 2013). Political connections at the national level between local leaders and large landowners and politicians can affect the ability of governments to develop effective legislation, further increasing the negative effects on small farmers. This has been documented in countries including India (Mukherji 2008), Yemen (Moore 2011; The Hague Institute for Global Justice 2014), and Jordan (Al Naber and Molle 2016; Richards 1993), where, through tribal networks or contacts, local leaders and wealthy farmers can reach influential members of parliament or higher (in the case of Yemen, the deposed president). In Guanajuato, Mexico, the influence and power of specific political interests oriented towards the representation of strong local businesses (tanning and shoe-making industries) ensured the control of local water management by these groups (Caldera-Ortega 2013).

In Rajasthan and Gujarat in India the accumulation of wealth and power can be established via the proxy of groundwater control, social and economic capital and land ownership (Bhatia 1992; Birkenholtz 2009). Moreover, the current legal provisions for groundwater management in India, linking groundwater rights to landownership, indirectly assume that only landowners have a stake in groundwater management thereby excluding more than 30% of the population (who do not own land) from the purview of groundwater rights (Cullet 2014).

Until 1994 groundwater access in South Africa was linked to racial divides associated with the ownership of land (only for whites). The 1998 Water Act brought a new groundwater authorization system. However, making water available to black farmers still depends on how much water white farmers are willing to give back. This is due to the fact that a large part of the expertise and knowledge of local water management and commercial farming issues continues to reside within the irrigation boards and the white farming sector (Woodhouse and Chhotray 2005). Complying with the law and regulation regarding groundwater permits is difficult for illiterate users, who also have to shoulder the administrative costs and burden (van Koppen and Schreiner 2014a).

Inequalities arise from informal groundwater 'markets' found in Pakistan and India. Meinzen-Dick (1996) documented how in Punjab, Pakistan, large landowners are more likely to own tubewells and pumps and that smaller landowners and tenants are more likely to purchase groundwater from other farmers' tubewells. These markets have high entry barriers, as documented by Jacoby et al. (2001), as they depend on land ownership and high installation costs, not easily affordable by small farmers. The exchange of water in these informal markets according to Jacoby et al. (2001) tends to be between a monopolistic tubewell owner selling groundwater to his own share tenants as well as to other cultivators. A lower price is charged to tenants since they share their output (ibid.). This is also the case in Punjab, India, where farmers' access to groundwater varies by size. Large farmers control access to groundwater as they control larger portions of land (Sarkar 2012).

Gender inequalities have also been exacerbated by the development of groundwater-based agriculture. In the most patriarchal societies women continue to be excluded from agriculture and money-generating activities, while men dominate access to and control over production and technology (manufacture, repair, training, land ownership, etc.) (van Koppen et al. 2013). Women are usually constrained and limited to domestic subsistence agriculture, although the dynamics can be more complex and multifaceted (ibid.). In Tunisia, for example, women can provide manual labor during the harvest and additional services surrounding the preparation of some agricultural inputs (plant seeds) or as part of the value chain (preparation of produce, selling in local markets) (Ghazouani and Mekki 2016). In Rajasthan intermittent access to electricity can affect the gender division of labor in agriculture (Birkenholtz 2009). Women usually have to stay awake at night in the event that electricity becomes operational after power cuts so that the groundwater pump can be switched on. Females in these families have to work in the fields and also for other farmers, and daughters do not attend school beyond fifth grade (ibid.).

Even in the extreme case of Syria inequality arose from a combination of policy changes (the liberalization of agriculture with a decrease in agricultural subsidies) and the depletion of groundwater resources. Accentuated by a prolonged drought, this created an exodus of farmers to urban areas, which acted as an underlying factor in the escalation of tension and conflict in the country (de Châtel 2014; Kelley et al. 2015) and demonstrated the vulnerability of groundwater economies.

3.5.5 Bureaucratic competition and sectoral contradictions

Despite universal standard calls for the application of IWRM principles, there is ample evidence that decision-making regarding water issues is frequently fragmented. In the groundwater subsector this is clearly illustrated by contradictory if not antagonistic actions and policies on the part of different administrations and ministries, such as those in charge of agriculture, water, public works, or the environment.

The main contradiction, as identified in Sections 1.2 and 3.5.3.2, is that between water managers, striving to achieve a degree of control over groundwater (over-)abstraction, and administrations in charge of promoting agricultural development, which are concerned with expanding cropping areas and enhancing production.

A clear illustration is provided by Morocco's *Plan Maroc Vert* for massive investment in and subsidizing of agriculture and provisions for the bypassing of groundwater restrictions to subsidize well drilling and drip irrigation, associated with an intensification of agriculture which often results in higher consumption of water (see Section 3.2.5). Private and political interests around the promotion and expansion of agriculture are gaining the upper hand over resource or environmental conservation (Molle 2017). Tunisia still extends substantial subsidies to private investment in water mobilization. The government covers 25% of investment in well drilling and associated irrigation facilities (pump set, on-farm reservoir, filters, pipes, etc.). This subsidy rises to 40-60% for investments in micro-irrigation, to which must be added tax-free diesel and reduced electricity tariffs (mainly available at off-peak times) (Hamdane 2015). Algeria has also been fully subsidizing the expansion of date palm and other agricultural activities in oases and desert areas of the country, with scant regard for the availability of the resource.

In Yemen the long process of developing and drafting a new Water Law for the country (2002) revealed two factions within the government: the irrigation specialists in the Ministry of Agriculture, with their goal to maximize production, and the hydrologists and environmentalists concerned about sustainability (FMWEY 2015). Lasting several years, this antagonism was further fuelled by a lack of political leadership and vested interests, "in favor of the short-term benefit" and "to please the land owner, and the tribes, and farmers, especially qat farmers" (ibid.).

In Bahrain fragmented water authorities offer little coordination (there are four different agencies responsible for water) and there is no clear comprehensive national water policy. Groundwater regulation authority is 'weak' as it is attached to agriculture and suffers from a lack of legislation enforcement. In general, the policy emphasis for the country remains supply management and augmentation (Al-Zubari 2012). In Turkey DSI is said to be the only authority for water management, municipalities having to go through it to obtain authorization and licenses for well drilling. But this gives rise to conflict, and municipalities frequently fail to communicate information about their wells (Apaydin 2011).

In Abu Dhabi the provision of water for agriculture is largely controlled by the Abu Dhabi Food Control Authority (ADFCA), although water is under the control of the Environment Agency Abu Dhabi (EAD). Policy objectives between the two organizations are clearly not aligned, since the drive for agricultural expansion and increased food security conflicts with the requirement to manage the groundwater resources more sustainably. Farmers can still purchase pumps for wells at half the market price and even have drilling paid by the government in some areas (Fragaszy and McDonnell 2016).

The core principle of regulation, whereby the authority holding the regulatory power over water resources must be located outside of line ministries and sectoral administrations, is rarely implemented. Where this is the case this regulator (often located under the ministry of environment) is invariably weak. In many cases the regulator is located within the most powerful ministry in charge of water[46], which is sometimes even responsible for agriculture, as in Peru, where the National Water Authority (*Autoridad Nacional del Agua*) was set up in 2008 to act as the regulator for water management while being dependent on the Ministry of Agriculture and Irrigation. This represented a problem as the ANA is located within the Ministry of Agriculture and therefore prone to subordination to the interests of agribusiness and dominated by irrigation engineers (Lynch 2013). In Tunisia the idea of a regulator for the water sector independent of the Ministry of Agriculture (responsible for water resources) was removed from early drafts of the new Water Code currently under consideration by the parliament (Hamdane 2016). Groundwater management has also long suffered from lying in the grey zone between the mandates of two General Directorates (that of Water Resources and that of Rural Engineering and Water Exploitation) (ibid.).

Other common cases of policy contradictions include a lack of coordination between electricity providers and those in charge of water and agriculture. This not only potentially fuels groundwater abstraction (as in Biskra, Algeria, where the electricity provider is independent of water administrations and not concerned with groundwater sustainability) but also forgoes policy options where electricity supply can be used to regulate groundwater abstraction (see Section 0).

Nebraska, and the Ogallala aquifer generally, has seen irrigated agriculture driven by the ethanol/biofuel craze (Zellmer 2008), which poured targeted subsidies into the encouragement of soy-based biodiesel, followed in 2005 by larger subsidies for the production of grain crops for ethanol (Jones 2012). This resulted from a desire to minimize the country's reliance on unstable oil supplies from the Middle East, as well as to minimize greenhouse gas emissions from fossil fuels (Zellmer 2008). The surge was also driven by the 2007 Energy Bill, which sought a fivefold increase in the use of biofuels (with the declared goal of 133 Mm^3 of biofuel being produced per year by 2017). This boosted the demand for maize, causing prices to rise, as well as the package of subsidies included in the 2007 Farm Bill, continuing long-standing financial aid for maize farmers.

Policy conflicts have also been noted in Europe. Contradictions between the goals of European environmental programs and the Common Agricultural Policy (CAP) meant that while the former were trying to reduce groundwater stress, agricultural funds were incentivizing groundwater abstraction, through subsidies to irrigated agriculture and water-intensive crops, such as corn, beetroot, and alfalfa (Martínez-Santos et al. 2008). After 2003, although most agricultural subsidies were unified into a single farm payment separate from agricultural production, linked subsidies were maintained for specific crops, such as grapes, as part of the 1999 reform of the European Common Market for Wine (Sanjuan 2013). These subsidies and restructuring programs for vineyards had an adverse effect as they represented an incentive to increase the total area cultivated with vines, offsetting any water savings by this substitution of crops. In addition, most

[46] See Molle and Hoanh (2011) for the case of Vietnam.

grapes are now grown in espalier, a cultivation technique requiring more water than conventional vines (between 2,000 and 3,000 m^3/ha) (Ruiz Pulpon 2013; Sanjuan 2013). Between 2003 and 2009 the Regional Government of Castilla-La Mancha invested around €65 million per year for the transformation of vineyards.

3.5.6 The over-allocation syndrome

The usual laissez-faire attitude, which prevails at the beginning of groundwater development, invariably results in use outstripping the available resource. When the pressure to rationalize abstraction increases, management often shifts to defining water entitlements or rights (see Section 3.1.3). The question then arises as to exactly how much of the resource can be shared (see 'how much is too much' in Section 2.2)0. This has been shown to be a political question that is frequently answered inadequately, partly due to the 'hydrological blindness' discussed in Section 3.5.1.

The tendency to over-allocate resources, that is, to be overoptimistic about the availability of the resource, has been documented for surface water allocation (see illustrations in Molle and Wester 2009). In the Colorado basin, for example, allocation of water among riparian states has been based on optimistic average hydrological data, without considering either evaporation losses in reservoirs to be built years later (now totaling 2 Bm^3) or the rights of native communities. In the Murray–Darling basin, Australia, interstate water shares across the basin were agreed in 1915 (without much knowledge of the actual river flows or science). These limits "were not tested by water resource developments until it was realized (in the late 1970s) that the licensed volume exceeded the available resource" (Turral and Fullagar 2007: 324). Additionally, notably in New South Wales, licenses have been granted despite recognition of the ticking time bomb represented by large contingents of 'dozers and sleepers' who only use their rights occasionally or pay their fees without using water. In the Olifants basin, South Africa, all water was allocated, making it virtually impossible to grant new rights to black communities. In the Lerma–Chapala basin, Mexico, the 1991 treaty on surface water allocation was based on an optimistic assessment of annual water availability (with two dry periods excluded from the hydrological model underlying the treaty) (Molle and Wester 2009).

Defining the total amount of groundwater that can be sustainably utilized every year is no easier task, on account of the heterogeneity of aquifers and the complexity of groundwater flows.

On balance, only a few countries have arrived at the point of setting an overall entitlement for a given aquifer. It is a fairly surprising conclusion in that it is hard to speak of management if one does not eventually come down to quantitative numbers and limits. But this is also understandable, as the definition of quantitative quotas theoretically puts an end to the otherwise comfortable fuzziness preferred by politicians, which always allows for an increment in abstraction and for delaying tough decisions. Reluctance to define and fix quantitative limits is evident in countries such as Morocco, Egypt, Turkey, and Mexico. In the Murray Darling basin, in Australia, the 1994 cap on surface water abstraction was tellingly not paralleled by a similar cap on groundwater. While it is true that the limits of hydrologic knowledge at the time made an assessment difficult, it is also clear that groundwater was left as an additional resource for farmers to resort to once surface water was restricted (indeed, they largely shifted to groundwater). In Western Australia, too, over-allocation is widespread and has not been effectively addressed to date. On the Gnangara system, for example, 27 management areas were over-allocated in 2009; by 2014, 26 management areas remained over-allocated (Bennett and Gardner 2015).

In the Toluca Valley, Mexico, to establish volumetric concessions officers used information such as the characteristics of the construction and operation of the well, the number of hectares irrigated, (e.g. 6,000 m^3/year), and so on. But it also surfaced that agricultural users could state any volume they wanted during regularization and acquire the concession. As a result most agricultural users are "over-concessioned," possessing rights to higher volumes than they actually use, which partly explains the current over-allocation of the aquifer level (Reis 2014). Similarly, in South Africa, the Department of Water Affairs has "very limited capacity to evaluate and judge each application on its own merits, check on-site or enforce the licensing process. Administrative pressure, and the proven threat that vested applicants can report any delays to the Water Tribunal, pushes officials towards allocating whatever is being asked for" (Funke and Jacobs 2011: 90).

One cause of groundwater over-abstraction in the Copiapó basin, Chile, was the over-estimation of aquifer recharge (4.85 m^3/s) levels in 1987 by the DGA by almost 1 m^3/s (re-evaluated at 3.5 m^3/s) (Bitran et al. 2014). These estimates were overoptimistic as they used the unusually humid period of 1980-1990 as their baseline data. A second major cause was that agricultural users pump water eight hours a day for four months, therefore using only a fraction (around 20%) of their water right, defined as the capacity of the well (Bitran et al. 2014; RedAgricola 2015). When transferred to mines, which pump water constantly, these water rights translated into much higher abstraction.

The variety of cases shows that the allotting of entitlements and rights has not taken into consideration the specificity of each use and locale (especially when transfers are possible) and that hydrologic estimates tend to be optimistic. Just as with projects' cost-benefit ratios, while the estimation of available resources errs on the generous side, that of use is conservative. (A rare exception[47] was the Raymond aquifer in California, which was allocated by a court in 1950 based on the availability of an estimated 27 Mm^3 and re-assessed in 1955 at 38 Mm^3 [Steed 2010].) This suggests that flawed assessments reflect not only uncertainty in hydrologic knowledge but also political interests. Although it would be understandably difficult to find a straight acknowledgment of this fact, the hypothesis that groundwater authorities are slow to set allocation limits and quotas because of the unpalatable consequences of such definitions, and that when they do it is always on the optimistic side, is consistent with what has been said earlier about hydrological blindness and the reasons for the observed "lack of political will." As noted by Nevill (2009), in the case of the Murray Darling basin, abstraction should have been reduced in some areas, rather than the introduction of a mere cap, given the level of over-allocation and over-use. The cap, however, represented the politically acceptable, if not a scientifically or environmentally sound, solution (ibid.).

3.5.7 The attractiveness of licensing (and the overestimating of state power)

Regulations address the conditions under which drilling rigs can be owned and used, wells can be dug or drilled, and water can be abstracted and metered. While these approaches are generally sound and straightforward on paper, in practice they are bedeviled by a number of practical, logistical, financial, and political difficulties that have been abundantly illustrated in Sections 3.1 and 3.5.2.

Although groundwater rights/licenses seem, at face value, to be easier to establish and control than those for surface water (since the points of use and users are potentially easier to identify), this assumption proves to be wrong. Yet, the pervasiveness of the licensing approach, narrowly

[47] It might not be by chance that the overstatement came from a court and not a state body.

associated with state ownership or custodianship of groundwater, as well as with the conventional 'best practices' of IWRM, clearly pertains to the "instrumental myth [which] assumes that the intended changes in water management can be made only by formulating and legislating official rules" (Boelens et al. 2002). The persistence of the command-and-control paradigm can also be explained by the fact that it fits the engineering ethos of technical departments; it flatters politicians' sense of "taking charge"; and it speaks to the illusion that power can be exerted through clean paperwork, without "muddying boots on the ground."

The model has therefore been highly attractive. Even in India, by far the world leader in its number of wells, and a political economy which has produced free-electricity policies for rural areas rather than strict regulations, most states officially embraced licensing policies. The latest (2011) Groundwater Model bill proposed by the federal government extends the need to apply for permits for all uses (which are granted for an indefinite rather than a limited time). Half the Indian states have passed laws by and large inspired by the 2005 Model Bill, with common features such as the prohibition of drilling in 'notified' areas, licensing, regulation of the depth and spacing of wells, and the blanket regularization of existing wells/uses (not allowing re-allocation) (Water Governance Facility 2013). Likewise, the installation of water meters was a priority in the Indian National Water Policy adopted in 2002 (Grönwall 2008). The 2002 Andhra Pradesh Water, Land and Trees Act (WLATA) established a permit and registration system for wells, mandating that well owners (including those not fitted with power-driven pumps) register their well with the authority and establish well spacing rules (Taylor 2013). Drilling-equipment and rig owners are also to register with the authority. In Maharashtra, Phansalkar, and Kher (2006) note the "exaggerated and erroneous impression about the power of the Collector[48] to ban construction of new wells and to take over existing wells for the purpose of protecting drinking water sources" (Phansalkar and Kher 2006: 75).

It is arguable that in many settings (but perhaps not all), such regulations are *necessary*. It is abundantly clear, however, that they are never *sufficient* in their own right. There is a need to acknowledge that *the capacity* of the state to control and reorder the use of groundwater is overstated, which speaks both to its *ability* to deploy regulatory power on the ground and its *willingness* to do so, as discussed earlier. This echoes Elinor Ostrom's (2000) warning that "the worst of all worlds may be one where external authorities impose rules but are only able to achieve weak monitoring and sanctioning." The severity of the penalties for violations is often proportional to the helplessness of the state in the face of the problem it seeks to solve. But raising this severity to non-credible levels only serves to undermine further the efficacy of the regulations. It also has the unintended effect of bolstering bribery, since the money given to evade or avoid a threat can be increased proportionally.

Yet reforms and regulations do not only fail; they severely dent the trust between citizens and state agencies and expose the weakness of the state. Strong declarations and regulations are often undermined by shifting deadlines and give the wide impression that there are no repercussions when wells are not declared or new illegal wells are dug. As Thomas and Grindle (1990) have observed, "reforms have been attempted when the administrative or political resources to implement them did not exist. The result has generally been misallocated resources, wasted political capital, and frustration."

3.5.8 Searching for success stories

At this stage, having demonstrated the difficulties faced by state-centered policies and governance, it is appropriate to ask whether any specific success stories could be identified.

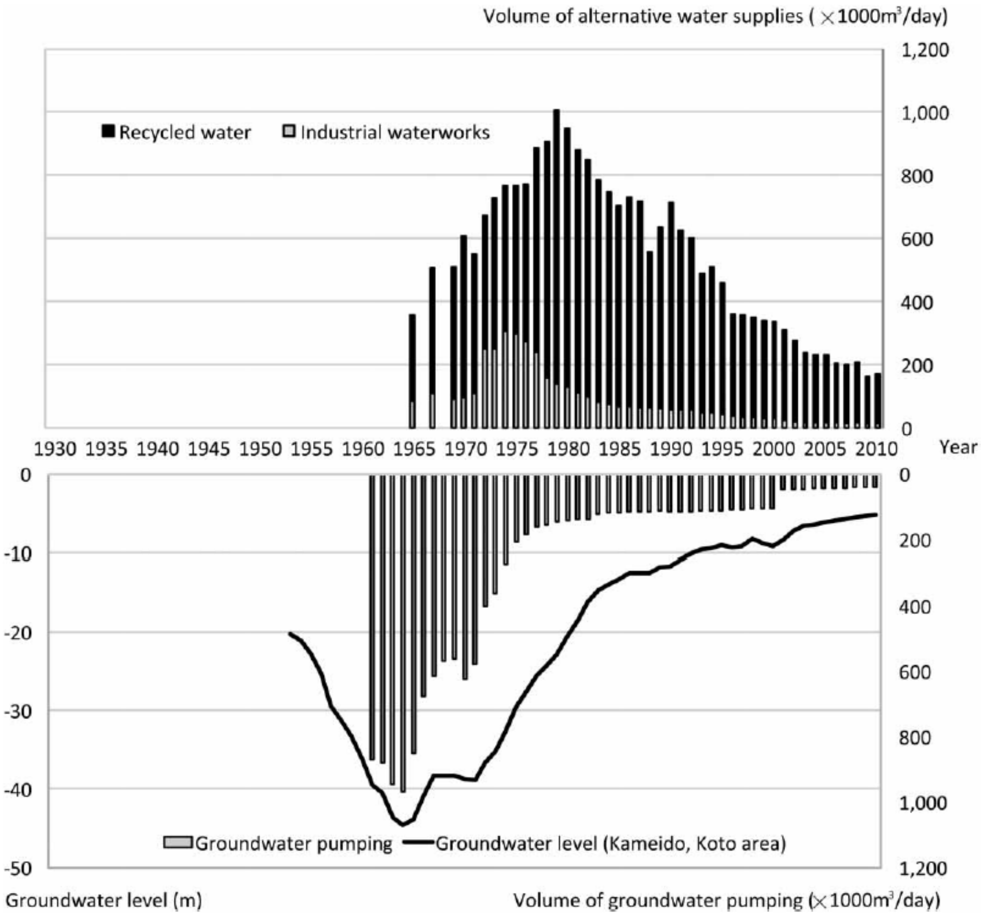
[48] The Collector is the chief administrative and revenue officer of an Indian district.

These could serve as models to determine the particular circumstances that are associated with the effectiveness of state regulation (understood as a situation where abstraction is stabilized at a sustainable level). We limit ourselves here to cases where governance can by and large be identified with state action and decision-making, although, arguably, the agency of other actors can never be fully discounted. Cases of co-management showing a degree of effectiveness or affording interesting lessons are considered in Section 0.

3.5.8.1 Japan

Japan has successfully stabilized abstraction from coastal aquifers (and controlled salinity intrusion). The regulation in 'designated areas' made it necessary to obtain a permit from the appropriate prefecture, which would constrain drilling in terms of well diameter and depth. For example, in Koto Ward (Tokyo), well outlet size was to be between 21 and 46 cm^2 and depth longer than 250 m (Endo 2015a). In 1962 only wells with outlet under 21 cm^2 and deeper than 650 m would be allowed, which made virtually any pumping uneconomical and impossible (Endo 2015a). Such technical constraints, however, were made acceptable/effective thanks to the government's development of surface water networks (which delivered subsidized water as a substitute), recycling domestic and industrial wastewater, improving cooling and other industrial processes as well as domestic use efficiency, and also of artificial recharge (Endo 2015; Tanaka n.d). Savings in groundwater resources were also due to substantial wastewater fees, whereby industries had to pay for any water released into the drainage system, prompting efficiency gains and recycling. This eventually led to a huge public deficit when industries turned away from costly surface water and shifted to using recycled water for cooling (Endo 2005b). It is useful to note that users are mainly utilities and factories, with agricultural use being negligible to nil.

Figure 11. Changes in groundwater pumping, groundwater level, and alternative water supplies in Tokyo (Endo 2015)



3.5.8.2 California

Southern California[49] has been credited with effectively regulating abstraction in coastal aquifers (Blomquist 1192). The West Coast basin is an example of an aquifer from which pumping has been controlled and even reduced. As Lipson (1978) wrote, the adjudication of the basin which involved a cut back in pumping through the agreement of all parties, rested on the availability and possibility of a massive import of surface water (four to five times the amount of groundwater used) and also some recycling of wastewater, as well as desalination and recharge. But even the overall use is declining slightly. Agriculture is minimal and decreasing because the area is largely if not fully urbanized; in addition per-capita consumption may have gone down thanks to more efficient appliances. Another side to the story is corruption and the interests that were associated with the oversizing of infrastructure and overestimated projections for use (Steed 2010).

The Orange County Water District (OCWD) has reached a balance between demand and supply. Demand has decreased with the shift from agricultural to urban use and the increased efficiency

[49] Groundwater governance in California is generally described as pertaining to polycentric governance. As such most would object to seeing it treated as a case of state-centered governance, particularly as it was one of the iconic cases studied by Vincent and Elinor Ostrom in the past. Yet, because stakeholders are mostly local administrations and regulated entities such as bulk water supply providers (as opposed to cases with a large number of mainly agricultural users), we are considering Southern California in this section (it will however be recalled in Chapter 5 on co-management).

of domestic appliances and industrial processes; supply has been increased through water and flood harvesting and infiltration structures in the local Santa Ana River. They also import Colorado water bought from the Metropolitan Water District (either used directly or infiltrated into the riverbed). All wells must be registered and fitted with a meter, except those with an outlet diameter of less than one inch. Seawater intrusion has been controlled by injecting recycled water into the coastal area (Endo 2015). OCWD promotes mutual checks by publishing the annual pumping volume of the major groundwater users (non-irrigation users over 25 acre-feet per year).

In the (small) Raymond aquifer the stabilization of groundwater abstraction was achieved by an increasing dependency on imported water, with up to 60% of that used in the basin originating in the Colorado River, as well as the regulation of wells and the control of pumped volumes. Users are in fact bulk-users, which numbered 30 in 1944 and 16 at present (Steed 2010).

The stabilization of groundwater abstraction levels in Los Angeles was ultimately made possible by the tapping of new sources of water from inside and outside the basin. Such technological fixes – the increasing proportion of imported and recycled water in the overall water production balance of Los Angeles – suggests that the political and financial capacity to increase water production within the basin is paramount in solving internal institutional issues. Endo (2015) points to the financial requirements of implementing supply augmentation options. In the case of Japan it was the government that financed the bringing in of substitute surface water. In the US shared or local financing demanded more sophisticated arrangements to collect fees from users to fund such measures. In Japan the fact that groundwater is regarded as included in land ownership made it difficult to establish the tax on groundwater use. Efficiency gains were therefore obtained through the establishment of a wastewater tax. In OCWD no subsidies were available from local or federal government, so a pumping tax was introduced to pay for the securing of sufficient water supply to accommodate growing urbanization. Prices, however, are set at a level which keeps the cost of groundwater below that of imported water. To avoid overreliance on groundwater a Basin Percentage Production is defined depending on the status of the resource, so that bulk suppliers purchase both types of water, while keeping the system in balance.

3.5.8.3 Florida

In Florida a reduction in the impact of groundwater pumping on the Tampa Bay ecosystem and watershed was largely obtained via the development of alternative surface-water-supply sources. The abstraction of groundwater from 11 well fields was brought down from 158 to 90 million gallons per day by the end of 2008 (Yates et al. 2011). There was an accompanying increase in the re-use of treated effluent for irrigation and industry, and the implementation of aquifer storage.

3.5.8.4 China

An interesting (and rather exceptional) case is provided by China's Minqin district, where 3,000 wells out of 7,000 have been closed and their owners paid compensation (Aarnoudse 2012). The central government's keen interest in controlling groundwater abstraction and desertification in Minqin arose from the fact that if the oases were to disappear, the two surrounding deserts would join to form the largest source of sandstorm threatening the populated east, including the capital (Aarnoudse 2010). In 2007 the "Shiyang River Basin Management Plan" was designed with the main aim of reducing groundwater abstraction in Minqin from 500 Mm^3 to 90 Mm^3 by 2010. Over the past two decades measures to re-establish a balance between supply and demand have included: surface water transfers from the Yellow River (50 Mm^3 for Minqin), increasingly tough procedures to obtain permits for well drilling, prohibiting the acquisition of wastelands by farmers, subsidies for drip irrigation and greenhouses, establishing groundwater user associations, defining individual crop-and-area-based quotas (adjustable according to the quantity of surface water available), water pricing, cutting electricity to private wells outside the community, using pre-paid cards to implement quotas at each well, and buying back wells.

In 2012, 3,000 of the 7,000 existing wells had reportedly been closed down (filled in with cement and disconnected from the grid), although it seems some of them were no longer in use. This measure was mediated by the water user associations which were instrumental in determining which wells would be closed and in what order, based on criteria such as well density, the quality of groundwater, and the fertility of surrounding lands. This very rare instance of well closure can be explained by factors including: the determination of the central government (explained above), the fact that the wells had been drilled under government funding and control (and were, therefore, not individually owned), the fact that the land was also in public ownership, allowing its redistribution between farmers and avoiding impact on individuals, the village authorities' involvement in the process of selecting the wells to be closed, the transparent and equitable plan for reallocation making it acceptable to users, the compensation (between US$ 800 and US$ 5,000) paid to farm groups using the wells, and the aging population with a declining interest in farming. Yet, according to official statistics, 32,000 people left Minqin as "ecological refugees," and 35% of the total farmland was abandoned (Aarnoudse 2010; Aarnoudse et al. 2012). Minqin remains an exceptional case, and elsewhere in China "the implementation of the quota policy is very poor," according to one expert (Wang 2015). Even since the 2011 policy push improvements have remained only incremental with regards to licensing and metering (ibid.).

3.5.8.5 Jordan

Since the first ban on agricultural wells in 1992 Jordan has experimented with a wide range of regulations and policies aimed at controlling groundwater abstraction in the country, most notably in the highlands (Al Naber and Molle 2016, 2017). The 2002 bylaw was seen as watershed legislation in reinstating the licensing of all existing wells, establishing annual quotas for each well, limiting the number of well licenses to one per plot of land, and introducing a block tariff pricing system. But its practical implementation has been lax, and the drilling of new wells has continued unabated, fueled by the profitability of irrigated agriculture as well as land speculation (ibid.). It became apparent that the implementation of the legislation was bedeviled by the costs of meter readings, monitoring the existence and dimensions of wells, and extracting payment, not to mention the limited capacity and material means available to the Water Authority field staff. Such constraining factors are associated with the social proximity of field staff and farmers, incentives to bribery, and the feeling that the degree of resolve of higher-level authorities to enforce the law is unclear (ibid.).

To deal with lingering problems of illegal well drilling, meter tampering, and unpaid water bills the Ministry of Water Resources and Irrigation has recently implemented new measures, including cracking down on illegal wells (even destroying them with dynamite) and drilling companies, increasing the water tariff for unlicensed wells, limiting the granting of labor permits, publishing the names of violators in newspapers with the sum of their unpaid bills, using satellite imagery to estimate and charge water consumption, and improving inter-departmental coordination to make users pay their bills before embarking on other administrative procedures (passport applications, renewing driver's licenses, purchasing assets, etc.). Having experimented with a groundwater co-management option through the establishment of a Highland Water Forum, Jordan is now retreating to a full-blown command and control approach. It is too early to make a definitive assessment of this move, but the combination of (creative) measures is showing signs of success. Everything hinges around the ability of the state to raise and sustain pressure on users amid a volatile political context where access to land and water resources is part of a crucial balancing act on which partly depends the sustainability of the regime. It remains to be seen whether the ministry's current resolve, buttressed by a growing sense of urgency in the throes of a water crisis, can succeed in harmonizing private interests (ibid.).

3.5.8.6 Denmark

In Denmark groundwater provides 99% of water supply, but overall abstraction is limited (400 Mm^3 – 50% less than 25 years ago). Agriculture accounts for 25% of abstractions (as an order of magnitude because this varies between basins and from one year to the next). The reduction in use is partly ascribed to water pricing although half this reduction occurred prior to price increases. Due to the pollution by nitrates and pesticides, public awareness of the need to protect groundwater is fairly high. Municipalities, who are close to users, are responsible for licensing and monitoring. Further, around 2,500 companies carry out the bulk of abstraction for water supply, meaning it is more easily monitored in terms of volume (since, in addition, a comparison is made between declared abstraction and billed volumes, with companies having to pay if losses are more than 10%) (Jørgensen et al. 2016; Villholth 2015; ECOTEC 2001). Although many aquifers are sustainably exploited, some areas, including the Copenhagen region, still show substantial levels of overdraft.

3.5.8.7 Edwards Aquifer, Texas

Fifteen years ago the city of San Antonio, Texas relied on the Edwards aquifer for 99% of its needs (Glennon 2002); this dependence is now down to 90%. Early settlers above the aquifer drilled artesian wells for domestic and irrigation purposes, drying up the San Antonio creek, which was feeding downtown's famed River Walk – a tourist hotspot. In 1911 San Antonio began pumping water from the Edwards aquifer into the river to sustain River Walk artificially. The year 1959 saw the creation of the Edwards Underground Water District, which in turn spawned the Edwards Aquifer Authority (EAA) after the stress caused by over-abstraction of the aquifer culminated in a lawsuit in 1991 finding in favor of the Sierra Club against the US Fish and Wildlife Service for failing to enforce the Endangered Species Act and protect those species depending on adequate flows in springs and rivers (Boadu et al. 2007; Gulley 2015). In May 1993 the Texas Legislature passed Senate Bill 1477 creating the EAA, not only to preserve and protect the aquifer but also to avoid federal intervention (Dupnik 2012; Gulley 2015). The Edwards Aquifer Authority Act (the EAA Act) was historic in that it replaced the rule of capture with a permit system administered by the EAA, installed meters on wells, and limited the total amount of groundwater withdrawals to 450,000 acre-feet per year (in time to be reduced to 400,000 acre-feet). These quantities were based on "extensive scientific analysis of minimum aquifer levels and associated spring flows to support the endangered species" (Debaere et al. 2014).

However, a substantial disparity was to appear between the imposed caps and the total volume of water rights issued. After many legal challenges, a total of 881 groundwater permits were issued, amounting to 549,000 acre-feet (677 Mm^3) – far higher than the cap. This carried considerable environmental risk, particularly if people were to use their rights fully. Texas could have bought back some of the excess water rights, but the public funding was not available. Instead, it passed a bill in 2007 that relaxed the cap on total water rights (increasing it by 5% to 705 Mm^3, or 572,000 acre-feet), while at the same time shifting from a cap on permanent water rights towards a cap on water allocations during drought periods. The system, which came into effect at the end of 2012 (Debaere et al. 2014), follows a table that defines five successive stages (corresponding to drought severity based on specific levels of flow at two major springs and aquifer levels in reference wells), to which are associated coefficients that reduce entitlements between 20 and 44% (Boadu et al. 2007; Charbeneau and Kreitler 2011, Debaere et al. 2014).

The law requires that all wells tapping the Edwards aquifer be registered with the EAA, regardless of their age or purpose. (This can be done by mail and carries a fee of $10.) Water users must report their use annually as standard and monthly when restrictions are in place. (This applies to permit holders using more than three acre-feet/year.) EAA staff are expected to visit and inspect wells every ten years. The EAA has been promoting the use of remotely sensed meters and meter-tampering detectors. Domestic use makes up 67% of groundwater abstractions (800 licenses) against 26% for irrigation (930 licenses) and 7% for industrial use (405 licenses). The EAA maintains a website that is remarkable in terms of transparency, providing in particular a list of all license-holders and hydrological data. Although River Walk still relies entirely on groundwater but after it has been used, since this water is recycled wastewater. The overall reduction in groundwater abstraction was accomplished through investment in improved agricultural irrigation efficiency, conservation measures in the city and in industrial processes, the recycling of wastewater, and thanks to the under-utilization of water rights (Debaere et al. 2014; www.edwardsaquifer.org).

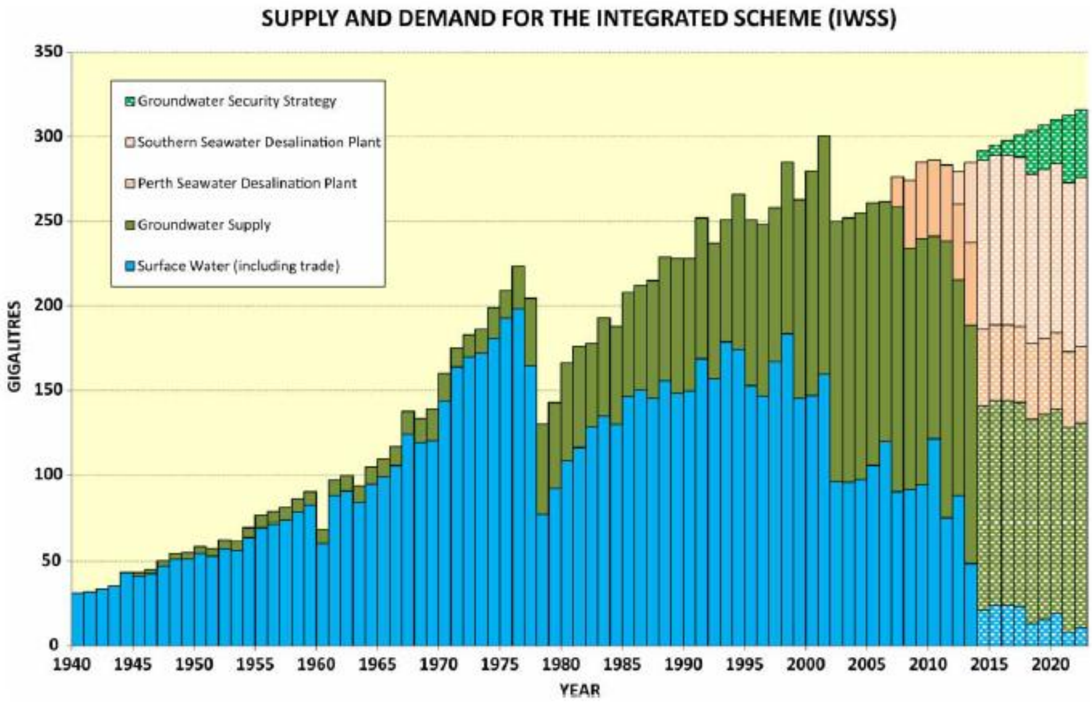
The EAA is a rare example of a body that has acted more on demand management than supply augmentation (aside from wastewater reuse) and that, notwithstanding little stakeholder involvement, has established a system of volumetric management that appears to work (as tested in 2015).

3.5.8.8 Western Australia

Perth, Western Australia, illustrates how the need to stabilize groundwater abstraction can drive massive desalination plants, in the face of growth in demand and a dramatic decline in surface water (Figure 12). The city's water utility established a "Groundwater Security Strategy" in 2013, which includes the development of groundwater recharge projects with treated wastewater (with the goal of recharging 14 Mm^3 per year), allowing it to continue abstracting groundwater at the same rate for its water supply (Water Corporation 2013). The plan transferred groundwater abstraction to the deeper aquifers surrounding the city to protect groundwater-dependent ecosystems and secure groundwater supply. Since 2006 desalination has been used to compensate for the lack of surface water and relieve pressure on groundwater resources, with a first plant producing 45 Mm^3 (soon be expanded to 145 Mm^3/year).

This is a history of water-supply augmentation but it is paralleled by legislative reforms (2004) that mainstream environmental objectives, systematize the licensing and metering of wells, establish conditions under which entitlements can be temporarily curtailed, and introduce trading (Bennett and Gardner 2014).

Figure 12. Evolution in the sources of water used in Perth, and projections



3.5.9 Favorable drivers and contexts

The examples above pertain to very different physical and political contexts. However, together with the many observations presented in this Chapter, they can be used to identify an array of conditions and situations that would seem to be associated with a higher likelihood of success. (It goes without saying that although several will be found in association with the various cases, alone they are neither necessary nor sufficient.)

- A limited number of institutional bulk users. This is typically true of the aquifers in the Los Angeles area.
- Limited or negligible agriculture, as illustrated by the case of South California or Japan.
- The possibility of substituting groundwater use with imports/transfers of surface water, often from a different river basin.
- The possibility of reusing treated wastewater or desalinated seawater (e.g. Gulf countries, Western Australia, southern Morocco, Tunisia, etc.) and therefore to provide an alternative source of water to relieve local aquifers.
- The possibility of enhancing aquifer recharge by impoundment or artificial injection.
- The financial capacity to fund such supply-augmentation options.
- A strong state, with a vertical structure down to the village level, with the coercive power to impose tough decisions (as in the Chinese case, although the measures implemented were mediated by village councils and involved compensation).
- A political economy where administrative and political bodies have sufficient legitimacy to rein in individual strategies.
- A legal framework that provides sufficient power to the state to implement command and control measures (in particular where the legal background may be a constraint).
- Coastal aquifers threatened by salinity intrusion, where the consequences of current use are deemed unacceptable.
- Cities and/or industries threatened by salinity and land subsidence.

- A governance framework in which sectoral policies are (relatively) harmonized and do not pursue antagonistic objectives.
- Situations of crisis which allow the passing of tougher regulations and policies, and institutional change in general.

While most of these points have been discussed earlier a few comments must be made on this list. First, it is clear that in most cases several supply-side policy options tend to be jointly implemented, since none may be sufficient on its own, while demand-side options appear to be limited in scope and more difficult to implement. As explained in Section 3.3.1, many regions are currently hopeful that their salvation lies in surface water transfers. These include: Alicante and Murcia provinces, Spain, the Haouz of Marrakech or the Saïss Plain in Morocco, and the Ica Valley in Peru.

Second, it is a well recognized fact that situations of crisis open windows of opportunity for politicians and decision-makers to pass more restrictive regulations (Birkmann et al. 2010). Aiken (1980) and Kepfield's (1993) research on groundwater policy in Nebraska confirms that drought has been a major driver of irrigation innovation, groundwater abstraction, and groundwater legislation in the state. The 'sharing rule' in Nebraska, which informed the state's 'correlative rights' doctrine for groundwater access, was first codified in 1933 during the Dust Bowl years (Mossman 1996). In Texas the Edwards Aquifer Authority Act was passed in 1993 after a court ruling called for immediate state action under the threat of federal intervention in the matter (Gulley 2015). The current drought in California provides a graphic illustration of institutional change induced by critical circumstances. The 2014 bill required water agencies to develop management plans and the 127 groundwater basins with the highest water use to manage the resource (23 adjudicated basins are exempt). The bill gave local officials until 2017 to form a management agency, with that agency having to submit a plan by 2020 to address the monitoring of water levels, the prevention of sea-water intrusion, and the collection of data.[50] Groundwater sustainability agencies benefited from greater powers of enforcement, as the bill authorized them to conduct well inspections. Groundwater management plans will have to address the halting of groundwater overdraft, and each basin will have two decades to comply with the new limits.[51]

The situation in Jordan is extremely critical, particularly given the influx of 1.5 million Syrian refugees, and is motivating the government to maintain a rigid stance. Contrastingly, although the water situation in many parts of Yemen is also dramatic, the political structure and situation, not to mention the severe recent disruptions, have not helped politicians to seize the window of opportunity.

Third, an interesting finding is the greater mobilization in cities on coastal aquifers in developed countries. This can be explained by the fact that the threat to domestic water supply as well as that of land subsidence are perceived as particularly serious by urban elites and constituencies who also have the political power to support and/or implement capital-intensive supply-augmentation solutions.[52] While it is easier to envisage the slow but gradual drop of deep aquifers, such as the Ogallala in the US, the negative consequences of overexploiting a coastal aquifer tend to materialize more quickly and forcefully (including potentially irreversible salinization of the aquifer).

[50] "California lawmakers move to protect the state's collapsing groundwater supply," The Circle of Blue, August 20, 2014, www.circleofblue.org/waternews/2014/world/california-lawmakers-move-protect-states-collapsing-groundwater-supply/ (Accessed August 21, 2014).
[51] Ibid.
[52] Of course, many large coastal cities remain unable to address the problem of sea intrusion despite its consequences.

Fourth, while it is rare to achieve substantial improvement without a combination of a crisis situation (e.g. severe drought), political leadership, and several of the conditions listed above, it is even harder to find instances of pure and successful state-centered governance. Whether out of necessity or conviction, state administrations are often led to acknowledge the importance of a degree of co-management with users (although this is clearly insufficient in itself). Several examples given in this chapter have hinted at the role of non-state actors or at cases of polycentric governance (US). Before exploring the co-management spectrum, the next chapter will analyze the (opposite) paradigm of community-centered governance.

4 Community-centered governance

This section reviews a series of cases found across the world where communities are in sole charge of groundwater management, with minimal or no involvement by the state. We examine how communities can be directly included in groundwater management, distinguishing between how communities can manage irrigation structures and systems (e.g. khettaras and collective wells) and aquifers. These community management systems can arise either from the community itself (e.g. Bolivia and the traditional use of groundwater through springs and wells in oases in Morocco and Algeria) or be transferred from total state control to the community wholesale (e.g. Algeria and India). The extent to which these communities have been able to locally control groundwater resources has allowed them to develop agriculture through irrigation and sustain livelihoods. As this section puts forward, the presence of 'pure' community-based institutions and organizations to manage groundwater, wells, or aquifers is rare, due to various limitations (physical, social, economic) and exists predominantly in self-contained management systems, based on specific community characteristics. Instances of communities taking a prominent role in, or even total control of, managing groundwater or aquifers are rare.

Environmental factors can enable community organization (e.g. specific climatic events, such as droughts, pushing individual users to act together, as in Yemen or India). To that effect, Emel et al. (1992: 45) have stated that historical evidence suggests that water-stressed environments seem "to generate non-individualistic ideologies, whether expressed through a strong centralized authority, […] or through much smaller, decentralized communities."

4.1 Community management of *qanats*

A prominent instance of community management involving groundwater is the traditional system of *khettaras* in Morocco, *foggara* in Algeria, *karez* in Central Asia, *qanat* in Iran, and *aflaj* in Oman found in the Middle East and North Africa region (Lightfoot 1996; Wilkinson 1977). Despite the different names, these are all essentially underground drainage galleries dug to collect and convey groundwater. In some areas they are in decay and limited to relatively small rural communities and oases (e.g. Morocco, Algeria), whereas in others many still function and are widely used (e.g. Oman, Iran).

In the Togha valley in south-east Morocco, khettaras are part of the 'social capital' of the community, and, despite recent changes in oasis society (e.g. unemployment, rural exodus), these systems remain the geographical and symbolic centers of the villages (Rondier 2012). Daily life is marked by irrigation, and the village councils and elders' authority over it remains. Traditional ruling bodies retain considerable weight in the management of water – an important symbolic role due to their seniority and legitimacy.

Communities establish rules to control the access to and use of groundwater by their members. In some Moroccan oases norms limiting groundwater use and well drilling still exist in traditional systems linked to the historical rights of these communities to harvest and manage groundwater and to protect the catchment areas of the khettaras (Faysse et al. 2011). In El Figuig oasis the traditional system of access to water emanating from the khettara is established as a private system and rights can be inherited, sold, or bought (El Jamali 2013; Janty 2014; Jilali 2014). The oasis is governed by an autonomous central authority, headed by elders, which appoints local people to govern on the basis of community management rules (Janty 2014; Jilali 2014). The system of government in the oasis is characterized by family lineage and roots rather than by wealth.

In Oman the *aflaj* provide not only a distribution system for water but also a system of association between users with rules that have been in operation for hundreds of years. They are run by a *wakil*, chosen by the owners, who is in charge of water distribution, expenditure, and solving disputes between farmers (USAID 2010). Despite the advent of modern drilling techniques and the physical threats to these constructions posed by flash floods, the aflaj system still represents 38% of the total water consumed by agriculture (FAO 2009b). Users of the aflaj system engage in exchanges of water rights (Zekri and Al-Marshudi 2008). These markets concern either the sale and purchase of permanent water rights or their temporary lease. The unit used is the '*athar*', which corresponds to half an hour per water cycle rather than volume (ibid.). Exchanges are made through auctions usually held in the village. Auctions of temporary rights are the main source of income for aflaj communities, and are usually conducted within the same community.

Spanning from Morocco to Pakistan, the private ownership of water rights, and the associated communal management and trading rules, is remarkably robust, being linked to initial investment in labor or capital in collective water infrastructure. With few exceptions, however, these systems have been undermined or destroyed by the spread of tubewells.

4.2 Collective community-managed wells

Communities have also sometimes been able to establish and manage collective wells. In many regions, such as Morocco (Molle and Tanouti 2017), Iran (Hoogesteger 2005; Molle et al. 2004), and the Nile Delta, Egypt (El-Agha et al. 2017), farmers come together to invest in a well which will be collectively managed. In some cases even the pumping equipment is collectively owned. The main reason for such joint investment is to achieve economies of scale, especially when farmers have several small and scattered plots. Demand may be relatively limited (where the well is only a complementary source of water), but the well can also be a sine qua non of the survival of the activity (Haouz, Morocco). When the overall demand is unmanageable and collective management generates conflict, investment in wells tends to be on an individual basis (Egypt), unless the cost is too high (Morocco). Where investment is limited (in shallow aquifers or easily dug soil) farmers usually directly opt for individual wells (e.g. oases along the western border of Algeria; Salem 2016). Where groundwater is only a complementary source the well often operates on a first-come-first-served basis. If demand is higher, some rotations can be organized (e.g. Iran). The role of the state is merely regulatory, since farmers must often theoretically apply for permits (which they fail to do in most cases).

Cases in Yemen reported by Bruns and Taher (2009), where community-well management has succeeded, show solid local institutions and community consensus, providing farmers with the confidence to mobilize substantial funding to drill wells, manage them communally, and control the use of water. The ownership of communal wells in the Wadi Dhelaa, Sana'a, is divided into shares of half a day's water supply (Van Steenbergen et al. 2012; Taher et al. 2012). These are given to families, who may own shares in different wells. Users have also connected the irrigation systems fed by each of the wells in order to be able to switch source when a temporary drop in water level occurs in one of the wells. The role of tribal leaders was essential in this area as they introduced the water sharing rules for the system of inter-connected pipes and wells. As there is no user association for farmers and local councils in this case study, security forces or members of parliament can be called upon to settle conflicts (Taher et al. 2012). Molle et al. (2004) have reported a similar situation in Central Iran.

In Cochabamba's upper valley, Bolivia, villagers have come together to form cooperatives. Stallings (2006) analyzed the emergence of institutional arrangements, infrastructure maintenance, allotment and distribution of water, conflict resolution, and the monitoring and enforcement of rules at the local level, albeit with varying degrees of success depending on the cooperative. The interference of the state is basically nil, but the legal status of the cooperative allows them to open bank accounts and grant loans and other services to members.

In each of the cooperatives, the operation of the pump is rotated weekly amongst community members so that all users are invested in the management of the infrastructure. Some of the cooperatives provide informal loans for poor farmers to pay the entrance fee, ensuring their access to groundwater. The general assembly of each cooperative appoints the board, and penalties are decided monthly by the assembly based on existing rules or on new ones created on a case-by-case basis. Groundwater irrigation practices revolve around the flow of finances as money is required to become a member of the cooperative, maintain infrastructure, and access water. These groundwater cooperatives have therefore become arenas for economic activities and emerged as important providers of financial services to their members (e.g. small loans). They also help maintain the cohesion of the community through the provision of community facilities (e.g. public toilets). Conflict resolution tends to have low transaction costs and members usually work together to resolve issues.

In India, according to the 2010 census by the Ministry of Water Resources, 16% of dug wells and 12% of deep tubewells are owned by farming cooperatives (Ministry of Water Resources 2010). Andhra Pradesh is considered a pioneer state when it comes to community-based groundwater management (e.g. Das and Burke 2013; Garduño et al. 2009; Ratnakar and Das 2006)[53]. In 2010 groundwater-stressed areas in Anantapur district developed a system of borewell networking to secure rain-fed crops irrespective of ownership (Dasgupta 2016). Wells are connected by a network of pipes and outlets, and farmers sign a sharing agreement in the presence of district officials to ensure compliance (ibid.). A committee is appointed to oversee well drilling, set up the borewell networks, and collect equal contributions towards share capital and an annual contribution to the maintenance fund (ibid.). The state provided financial support for the pipeline network and regulators connecting existing wells and other irrigation infrastructure.

In Punjab, India, Tiwary and Sabatier (2009) found that of the 44 tubewells in the village 40 are shared by more than one household and all of them are kinship-based, started as shared wells by immediate ancestors. Water is shared according to the land ratio and is allocated by turns, reflecting the right of the shareholder (ibid.). In Rajasthan Birkenholtz (2009) has observed farmer partnerships organized around the ownership of wells and following patrilineal relationships where the eldest member is usually the decision-maker (for crop decision, rotation, and conflict resolution).

In Andhra Pradesh similar inherited wells shared amongst family members or close neighbors (up to eight sharing one well) have been found (Aggarwal 2000). The sharing of management duties was greatly facilitated by proximity (i.e. neighbor relations and kinship ties). Water is allocated in these groups prior to each crop season. Agreement is reached on the crops each member will grow and the amount of water to be pumped (the number of hours for which the pump is operated). Access to the well and groundwater is linked to the area of land owned. Well maintenance (e.g. silt removal) is ensured collectively. Equality amongst users (land plot size) and family connections ensure the well's successful management; improvement costs, such as well deepening, are equally shared (ibid.).

Oases in central Algeria, such as Ziban, El Oued Mzab, and El Goléa, flourished in the late nineteenth century thanks to collective deep artesian wells (Bouzaher 1990). As early as 1909 Beadnell observed artesian wells in the Kharga oasis, Egypt, owned collectively with

[53] See also www.thewaterchannel.tv/media-gallery/5911-sharing-borewells-and-groundwater?category_id=769

arrangements allowing the proprietors to utilize groundwater flows "for periods corresponding to the extent of their holdings in the well. Individual shares may amount to as much as one third or one half of the well, or be only the merest fraction: in the latter case the small holders combine so as to obtain control of the flow for an appreciable period" (Beadnell 1909: 10).

Other wells are collectively managed having been partially or totally handed over by the state to the farmers using them. This particular case is examined in Section 5.1.

4.3 Community management of aquifers

The shared management of aquifers presents a different set of challenges given the (often) larger number of users involved, the scale and complex physical features of aquifers, and the varying degrees of homogeneity of users that would participate in the management of the system. The wide distribution of low-intensity investments (i.e. private wells) makes the transaction costs linked to the common management of aquifers somewhat high (Moench et al. 2012). Nevertheless, some groundwater systems and aquifers can be managed communally by establishing rules and regulations aimed at controlling groundwater access, abstraction, and volumes.

As expressed above, however, it is hard to find 'pure' community-based aquifer management systems without the imprint or support (or meddling) of state agencies or international donors. As an example, the oft-quoted case of community-based aquifer recharge systems in Andhra Pradesh (e.g. Reddy et al. 2014) remains linked to significant external investment, with the promotion of these management systems dependent and driven by state and international donor funds.

Communities often react sporadically to undesired drilling that may affect the aquifer and their own wells. In Sidi Bouzid, Tunisia, for example, local people have mobilized to block the drilling of wells by a wealthy investor from Sfax, who was threatening their own resource (El Amami 2016). In Ica, Peru, the construction of new infrastructure to carry water from abstraction points to other distant irrigation areas by some large agri-businesses has resulted in social mobilization attempting to stop the works, and subsequent clashes with the police (Cardenas Panduro 2012; James 2015a).

There are rare cases of communities succeeding in establishing rules to control or ban the expansion of wells within the community-controlled area, prohibiting the export of water from the abstraction area via tankers, and preventing harm to existing users (e.g. Yemen and Morocco) (Van Steenbergen et al. 2012; Faysse et al. 2011). Rules can also be established to improve resource conservation and availability directly, such as the development of recharge structures by communities in Yemen and India (Rajasthan), as mentioned below, to increase aquifer recharge during rainfall events and store it for future use.

In Yemen community rules allow for the allocation of groundwater, access, and compensation mechanisms to be established between groundwater users (Bruns and Taher 2009; Taher et al. 2012; Van Steenbergen et al. 2012)[54]. A large array of rules is found, including those for well spacing, spring protection with well zoning, the closure of disputed wells, agreements on reservoir operation, and user associations to regulate the development of new wells. For example, Bruns and Taher (2009) and Taher (2016) describe how some communities have begun to regulate groundwater abstraction by restricting well drilling (to protect domestic water supply, which is a priority often motivating local initiatives) and have established rules to reduce

[54] Collective Action in Groundwater Management in Yemen. http://www.thewaterchannel.tv/media-gallery/994-collective-action-in-groundwater-management-in-yemen-english?category_id=769

conflict and provide more reliable access to water. Such initiatives arise, in part, from the fact that formal state regulations to control and reduce groundwater abstraction are not applied at the local level (despite national legislation and efforts by formal institutions and courts) (ibid.).

In Taiz governorate the Al-Sinah cooperative has been in existence since the 1960s and stands as an example of long-term institutionalized local resource management.[55] The cooperative owns three wells and provides approximately 1,900 homes with drinking water. It is forbidden to use water for agriculture, and any plan to drill a new well must be approved by the cooperative. Its board is elected every three years from 12 local assemblies. The cooperative has also sought support from public agencies for part of its investment program. It bought up fields in a neighboring hamlet in order to drill wells for drinking water. Additionally, between 2005 and 2008 public agencies in the area (the Taiz governorate branch of the National Water Resources Authority) issued no permits for well-drilling without obtaining authorization from the cooperative. No drilling permits have been issued since 2008 (Taher et al. 2012).

In Rajasthan communities have organized themselves to manage shared aquifer recharge structures (Everard 2015). Under the auspices of donor programs (and therefore not purely as community-based initiatives), groundwater recharge projects carried out by a local NGO have rebuilt traditional governance structures and user participation in community-designed and maintained water harvesting structures for aquifer recharge. These interventions were, however, suggested and directed by local communities, requesting the reconstruction and local management of these harvesting systems and the resurrection of village-based bodies with decisive power over water management (ibid.). The various participating communities are able to overcome issues of scale and boundaries to develop cohesion and coherence through participation in a water parliament established in 1998 that meets twice a year to determine water sharing and management matters across the catchment.

In Japan an already defunct case of community-based aquifer management remains relevant for this section: the Kabu-Ido system, which ensured the management of groundwater abstraction and recharge by communities in poldered areas in the Noubi Plain (Endo 2014). The system dates from the middle of the nineteenth century, when farmers began using artesian wells to cope with occasional water shortages. The flowing groundwater would accumulate in the lowlands, creating drainage and flooding problems (especially in the rainy season, with excess water to be drained out of the polder). The Kabu-Ido system established well permits in the polder, restricting well-drilling and instituting a system whereby well owners paid a fee which was used to build and maintain drainage gates (ibid.). Villagers from the upper and lower areas would periodically renegotiate well permits and the payment of fees based on an observation of the water status within the polder, as well as during extreme events (ibid.). Some degree of transparency was established by labeling all wells with a number visible to all. The system was discontinued at the turn of the century, when modern pump stations resolved the drainage problem (ibid.).

Enforcement is an important component of the sustainability and effective functioning of community management systems, and violations must be punished accordingly. Most of the community-based groundwater management systems reviewed here rely on conflict-resolution mechanisms to prevent or at least limit the risk of conflict erupting between users. The authority to make decisions, enforce regulations, and punish transgressions usually resides with a collective, such as the well cooperative in Cochabamba (Stallings 2006) or an existing institution, such as an assembly of tribal leaders or elders in Yemen (Ward 2015). The community's access to

[55] Also see www.thewaterchannel.tv/media-gallery/2031-al-sinah-the-remarkable-groundwater-story-of-a-co-operative-society-english?category_id=769

information and voting rights helps to ensure the transparency of decision-making processes. This is seen in Bolivia with assemblies of well cooperatives. Group homogeneity, such as that found in the villages of Yemen (Van Steenbergen et al. 2012), or in Andhra Pradesh (Aggarwal 2000), can allow rules to be more widely accepted and therefore enforced. A sense of belonging to the community and that the rules are applied to everyone equally are paramount factors.

In Yemen community-based conflict management structures are often relied upon and water conflicts are rarely brought to civil court. The community authority facilitates the negotiation of local rules and mediates conflicts, helping for example to close disputed wells (Taher et al. 2012). This is due to the existence of legal pluralism in Yemen and limited faith in the fairness of court trials due to the corruption and politicization of officials (The Hague Institute for Global Justice 2014). The high cost of court arbitration also outweighs that of traditional channels, prohibiting plaintiffs from seeking justice through the official legal system (The Hague Institute for Global Justice 2014). Some of the customary conflict resolution rules were drafted centuries ago, and, although they can be specific to the type of water source (spate, groundwater, surface water), they are generally consistent with Islamic law and approved and upheld by local sheikhs (Ward 2009).

4.4 Groundwater and CPR theory

The study of community-based groundwater management is often underpinned by Hardin's (1968) "tragedy of the commons." The exhaustion of a common pool of natural resources is explained by the behavior of individual rational users within an often dispersed and relatively vast territory trying to maximize their self-interest by accessing the resource and resulting, ultimately, in its depletion (Schlager 2007).

Following Ostrom's (1990) work, Schlager and López-Gunn (2007) remind us of the specific features that are believed to favor collective action in the efficient management of a common-pool resource (CPR) system: 1) clearly defined boundaries of the service area and individuals or households with water use rights, 2) agreements that include most individuals affected by operational rules so that these rules can be modified, 3) monitoring of rule implementation that is also accountable to users, 4) a system of sanctions for users violating operational rules, their severity in line with the seriousness of the offence, 5) conflict resolution mechanisms, 6) recognition of the right to organize, which is not challenged by governmental authorities, 7) these structures organized in multiple layers of nested enterprises. Building on these factors, much of the literature focuses on the constraints and potential of harnessing local initiatives and community management to improve the allocation of the resource and overcome the 'invisible' and common characteristics of groundwater.

Critics of CPR, such as Cleaver (2002), consider that the theory misrepresents the multiplicity of people's identities and the different ways they interact and are involved with various aspects of the social mesh. Such complex processes are difficult to delineate formally following the standard categories found in Ostrom's approach. Studies often tend to be apolitical, propounding a simplistic view of the community devoid of its intrinsic contradictions, and thereby avoid peering inside the 'dirty black box' of day-to-day politics and institutions. Such analyses give little weight to the cultural, social, historical, political, and environmental contexts within which communal resources are used (Stallings 2006). As Agrawal and Gibson (1999: 629) pinpoint, "the concept of community is rarely defined or carefully examined by those concerned with resource use and management", and the forces at play at the local level and their traditional systems are misunderstood and undervalued. Following Mosse (1998: 2), "ideas of community [in irrigation] are sociologically naïve and inaccurate in their assumptions of homogeneity, co-operation, autonomy from the state [etc.]." As Agrawal and Gibson (1999: 633) also wrote, "such representations of community ignore the critical interests and processes within communities, and between communities and other social actors." There is sometimes only a limited grasp of the reality behind power structures, hampering the effective implementation of participatory management narratives.

Agrawal (2001: 1650-1651) has further noted that CPR studies suffer from a lack of focus on how aspects of the resource system, user group membership, "and the external social, physical, and institutional environment affect institutional durability and long-term management at the local level." Reality is more complex and therefore requires a more adaptive and potentially accurate way of looking at social interaction. Moench (2007), meanwhile, highlights the limits of conventional approaches to groundwater governance. He refers to a disjuncture between CPR and the nature of groundwater use that leads to the recommendations from CPR analysis not generally to be met in specific groundwater management contexts (too many caveats and imperfections surrounding the users). Formal institutional theory would attribute particular identities and emphasize specific roles within communities. For Cleaver, this "may not just reproduce but reinforce or amplify social divisions," following more static interpretations of culture and society (Cleaver 2002: 18).

Furthermore, many CPR studies draw from the same pool of case studies and successful examples, building on common pool theory, rational models, and collective action theory to develop arguments for replicating those best practices. The same plethora of factors (up to 35) highlighted as critical for the organization, adaptability, and sustainability of common property use undermines replicability due to its varying degrees of complexity and lack of overarching theory (Agrawal 2001). Theories of resource use and sustainability are too tightly linked to specific cases and the intrinsic variables and parameters found in those examples, meaning conclusions sometimes seem far-fetched. As Agrawal (2001: 1651) pointed out, "it is likely that many conclusions from case studies of common-pool resource management and even from comparative studies of the commons are relevant primarily for the sample under consideration, rather than applying more generally."

The striking paucity of cases of pure community-based aquifer management in the pool of 'success stories' is probably worth pondering. The use of CPR in reviewing cases of community-based groundwater management usually underplays the role of the state or external actors (e.g. donor funds) in setting up and maintaining community structures. This is introduced in the following section (Section 5) of this report, where we review a series of cases of groundwater co-management, and establish the linkages and shared roles of communities and the state.

4.5 The case of unregulated local 'groundwater markets'

In fully groundwater-dependent economies, such as Punjab, Pakistan, families who do not own a tubewell are forced to buy irrigation water from those who do (Sarkar 2011). Community groundwater 'markets' can arise out of the necessity for small farmers to secure access to water for their crops. Groundwater exchange arrangements studied by Sarkar (ibid.) led to sellers devoting a larger area to more profitable (and more water-intensive) crops, such as rice, than buyers, who would grow less water-intensive and far less productive crops (i.e. maize). This would support the theory by Ballabh (2003 in Sarkar 2011) that these types of arrangements (or markets) can create 'water lords', who appropriate agricultural surplus from the poor based on their reliable access to groundwater, control of production inputs, and larger landholdings. Meinzen-Dick’s (1996) original research in Pakistan supports this, as she found out that large landowners are more likely to own tubewells and pumps and that smaller landowners and tenants are more likely to rely on purchases from other farmers’ tubewells to access groundwater.

Since the study by Meinzen-Dick (1996) groundwater markets have continued to grow in Pakistan and can be found across all four provinces (Khair et al. 2012; Qureshi et al. 2003). Where the cost of well drilling is prohibitive, small farmers resort to these markets, either directly buying groundwater from a (sometimes neighboring) well owner or – in most cases – renting pump services or paying for the use of a well. In Baluchistan, Pakistan, payment in informal groundwater markets can be established as a flat-rate (defined as an hourly rate for the use of the pump), increasing as the exchanges occur at higher altitude in response to the relative scarcity of water and smaller farm size (Khair et al. 2012). In Pakistan these informal markets have emerged as a practical option for the management of increasing seasonal water scarcity. They provide a cushion against declining water tables, reduce the risk of losing high-value crops, and enhance water-use efficiency (as the sale of surplus irrigation water allows the reallocation of the resource to other users) (ibid.).

In West Bengal, India, Mukherji (2007) found a large number of people benefiting from groundwater through informal exchanges between well owners and buyers. According to her estimates, based on data from 1999, of the 6.1 million households in West Bengal only 1.1 million had reported owning water-abstraction devices, whilst over 3 million said they hired irrigation services from other farmers. Marginal farmers cultivating up to 1 hectare of land own most of these shallow wells (54% of all farmers) (ibid.).

4.6 Limits to and scope for community-centered management

For users solely dependent on groundwater supplied by a community-managed system, variations in water quantity or quality are a risk to livelihoods. This variability can challenge access and allocation rules for local users. A prolonged decrease in groundwater flow or the erosion of community structures can provoke users to adopt 'exit strategies' and abandon the community-run system after drilling private wells (e.g. Andhra Pradesh after several years of drought). These 'exit strategies’ are dependent on the user’s individual capacity to access additional resources (e.g. financial, through credit for drilling a well, or political contacts to obtain a license). This is seen in some oases in North Africa (e.g. in Biskra or Adrar, Algeria, and in the Jerid, Tunisia) where traditional users have moved outside the historically irrigated area and drilled individual wells (Amichi 2015; Battesti 2012, 2013). Users can either become free-riders depending solely on private tubewells or exit the system altogether and abandon agriculture.

The increasing abstraction of groundwater through deep tubewells and the related water table declines have had a severe impact on the number of underground water galleries (qanats). In northern Tafilalat, Morocco, the number of active khettaras declined from 80 (historically) to 27 in 1970, irrigating 1,750 ha, to 19 irrigating less than 900 ha by the mid-1990s (Lightfoot 1996 in Goes et al. 2017). In the Tensift the first victims of newly drilled groundwater wells in the 1980s were the traditional khettaras. More than 500 were to be found there in 1974 and none survives today (Tanouti and Molle 2013). In Iran more than 38,000 qanats were reported to be active in 1966; this dropped to around 18,000 in 2009 (Ahmadi et al. 2010 in Goes et al. 2017). In Helmand province, Afghanistan, more than half the karezes have dried out due to a lack of maintenance, an increase in the number of boreholes and tubewells since the 1990s, and a prolonged reduction in precipitation since 1998 (Goes et al. 2017).

The small size of some of these communities and their level of exposure to outside forces can affect their ability to "fend off invasive actions by outsiders," exposing a need for national or regional government involvement or arbitration (Agrawal and Gibson 1999: 638). In Yemen disputes have escalated into armed skirmishes and fights, with casualties, requiring police intervention (Ward 2015). In the Upper Souss Basin new farmers appeared from the lower Souss, who were able to invest in tubewells, sometimes buying land upstream from the khettaras and, as in the case of Tamast, investing in intensive fruit farms with sophisticated groundwater abstraction technology (Boujnikh 2008). In Cochabamba (Stallings 2006) the success of groundwater cooperatives remains localized given the fact that they are fairly socio-demographically homogenous and that no external actors have developed other wells.

Competition from tubewells, the fragmentation of family assets, and the development of pluriactivity and other livelihood opportunities have all taken their toll on community systems and social cohesion. In Yemen traditional social structures have been eroded and weakened over recent decades due to the boom of individual well-fueled irrigation, threatening inherited communal norms and values, and traditional authority (sheikhs) (FMWEY 2015). In Afghanistan a similar story unfolded, accentuated by decades of war, which have altered the social cohesion of the communities dependent on karezes and affected the traditional maintenance of these structures (Goes et al. 2017). The prolonged drought suffered by Afghanistan reduced the number of flowing karezes and also affected the availability of skilled technical laborers to undertake maintenance and repair tasks, as these people moved to areas with better job prospects (ibid.).

In Oman contemporary changes have had a negative impact on the traditional aflaj. The level of shareholder participation in the management system of the aflaj has been reduced as well as its role in agriculture following dropping water table levels due to groundwater over-abstraction and frequent drought (Bosi 2009). Access to private wells also reduced farmers' incentive to participate in public water auctions to allocate remaining or additional flow to other users run by the aflaj communities (ibid.).

In the palm groves of Ait Aissa OuBrahim in the Togha valley in south-eastern Morocco the abstraction of groundwater via several khettara by the Ait Atta tribe was essential for irrigation (Rondier 2012). However, over several generations, water access rights and land property in the oasis have become fragmented, contributing to a lack of interest in agriculture on the part of the younger generations who see no point in working hard for the right to only a few minutes of water to irrigate a narrow patch of land (ibid.).

In Andhra Pradesh a rich tradition of family-shared wells has been eroded by modern well-drilling techniques and irrigation expansion. According to Aggarwal's (2000) study of community-organized wells, their presence has been decreasing mainly due to persistent drought conditions (Deb et al. 2014). In Dokur the number of community-based wells has also decreased due to the splitting of households and formation of nuclear families (Deb et al. 2014).

Community-based management systems can be prone to elite control aiming to sustain particular forms of privilege (social, political, or economic), as in Yemen. These systems can be affected by corrupt practices and rent-seeking behaviors of the local elites or be used to manipulate and control degrees of political and social power. Community structures are particularly at risk of being taken over by politics between community factions or groups. The government's use of the tribal system for its political gain has also undermined its roots within the community as they ended up being seen as serving their own self-interest. Former president Abdullah Saleh "deliberately co-opted sheikhs to secure tribal loyalty, which increased the dependency of sheikhs on the government," and fostered conflicts between tribes by appointing as sheikhs local individuals without status or experience in tribal traditions (The Hague Institute for Global Justice 2014: 2-3). This had the express aim of undermining the authority of authentic sheikhs to create tribal divisions (The Hague Institute for Global Justice 2014).

5 The co-management spectrum

Co-management is defined here as management involving both users and the state, the latter sometimes intervening through municipalities or more or less decentralized agricultural/water services. In the literature co-management is often used to refer to situations of collaborative management, generally between public (or corporate) institutions, or representatives of water users, NGOs or civic groups, whereby "the responsibilities for allocating and using resources are shared among multiple parties" (Conley and Moote 2003; Plummer and FitzGibbon 2004; Berkes 2007; Plummer and Armitage 2007; Plummer and Armitage 2017). As clarified in the introduction, we focus here on the relationships between the state and (numerous) agricultural groundwater users, organized or not, and possible other users.

Before analyzing in some detail a number of cases that can be considered as instances of co-management of aquifers, we briefly examine the case of collective wells, which displays similar dimensions of collective action and interplay between users and state actors.

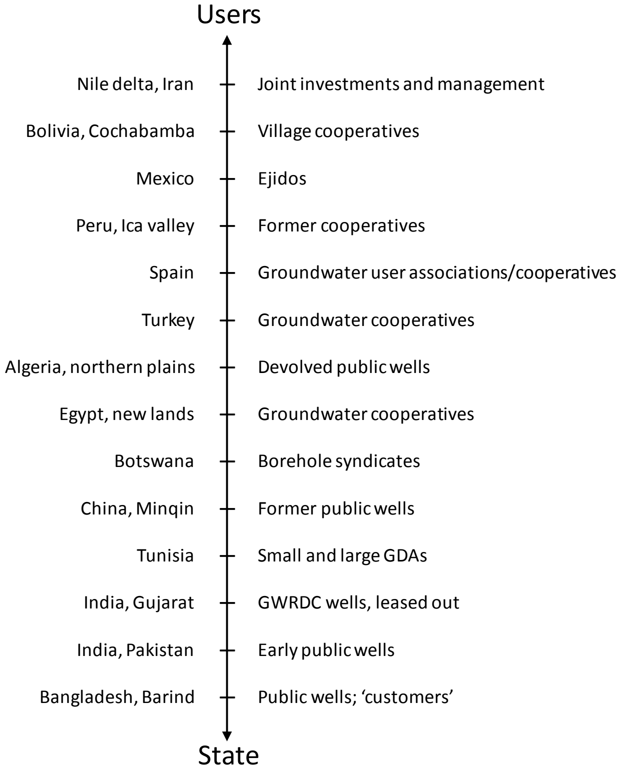
5.1 The case of collective wells/pumps

There is one particular situation where the balance between the users' and the state's prerogatives influences the management and governance of groundwater use: that of collective wells and/or pump stations. The collective management of a well poses questions of collective action and social arrangements for investing in the well, managing and maintaining pumping equipment, and sharing the abstracted water. These issues are clearly distinct from the problem of collectively managing an aquifer (the shared resource) but shed some light on the extreme diversity of user-state relationships and possible roles in a co-management arrangement. Examples are presented here around the continuum showed in Figure 13.

At one extreme, that closest to (pure) user-based management, we find situations described earlier (Section 4.2), such as those observed in the Nile Delta, Egypt (El-Agha et al. 2015a, 2015b), in Iran (Hoogesteger 2005; Molle et al. 2004), and Morocco (Molle and Tanouti 2017), where farmers come together to invest in a collective well which will be collectively managed. We also referred to the case of the groundwater cooperatives in Cochabamba, which qualifies as an example of an endogenous process of self-organization, despite external financial help. Other examples of groundwater cooperatives can be found, with the state and/or the imposed legal framework playing varying roles.

In Mexico, *ejidos* (settlements of the agrarian reform) have been subject to the management transfer policies carried out in the late 1980s. In the ejidos supplied with groundwater by (initially) public wells, the wells have been transferred to users together with long-term concessions. In the Altar-Pitiquito-Caborca scheme, in Sonora state, there is one well for every 27 ejidatarios, on average. Although user associations are fully autonomous in the technical and financial management, the transfer of the well was accompanied by a contract specifying that water abstraction be reduced (under the state's supervision) and by an annual fee payable to the national water authority. People tend to leave agriculture because of debts, unpaid electricity bills that result in power being cut off, dwindling water and increased production costs, a lack of interest in farming, turning to other activities (including drug trafficking), or the appeal of a windfall for selling water rights (or land) or leasing them out (Wilder 2008). As a result, 86% of the wells in the Caborca irrigation district are now in private ownership (with 80% of the asparagus area farmed by foreign companies).

Figure 13. Cases illustrating the user-state continuum in the management of collective wells



In Ica, Peru, some small irrigators have had access to groundwater since the 1980s, when farm cooperatives were divided and groundwater wells were allocated to private farmers. Some farmers formed associations to use the wells for irrigation, share the operation and maintenance costs, and establish tariffs for other irrigators wishing to purchase water from the collectively owned well (Cardenas Panduro 2012). The association of irrigators of the Pachacutec wells, for example, owns six wells and irrigates 600 ha of cotton with an annual allocation of groundwater of 2.3 Mm^3 shared between 237 users (Cardenas Panduro 2012).

In Spain it is common to see farmers clubbing together to invest in collective wells. In the Vall d'Uixó, for example, 5,500 farms are grouped into 12 associations that manage one or several wells (Ortega Reig 2015; García-Molla et al. 2013; Sanchís-Ibor 2016). Collective wells have been dug either by individuals or by cooperatives, which have then offered shares to individual farmers, with the right to irrigate a given area of land from a specific well. Since farmers have many plots in different locations they are frequently shareholders in several wells. Such cooperatives have legal status and obligations.

In Turkey Groundwater Irrigation Cooperatives have been established since 1966 in accordance with the cooperatives Code 1163. DSİ has "to prepare technical and economic feasibility reports concerning the facilities to be constructed by DSİ, to drill groundwater wells, to erect the electrification installations to these wells, to determine right motor-pumps and procure them for the wells" (DSI 2002). The "Transfer Contract" prepared by DSİ includes the reimbursement of the initial investment over a period of 30 years. In 2010 an area of 452,238 ha was irrigated by 11,235 deep wells (10,380 of which transferred to Groundwater Irrigation Cooperatives) by a total of 1.8 million farmers. A minimum of seven farmers must come together as a group to submit a request to the government. Financing is arranged with the Agricultural Bank (Fayrap and Sargın 2015).

Cooperatives, like other irrigation organizations (WUAs), establish water charges that are calculated to cover O&M cost, most particularly electricity costs and staff salaries, and are proportional to the area irrigated, varying occasionally depending on the crop cultivated (Çakmak 2010). The main problem faced by groundwater irrigation cooperatives (as with irrigation WUAs in general) is financial sustainability, on account of the relatively high cost of water abstraction, the possible lack of leadership of the management board and its weakness in collecting fees, or more recently the privatization of electricity services, with an increase in the price of electricity of 22% in 2013 (Le Visage 2015). Interestingly, the state does not deliver individual well drilling authorizations in the area under the purview of the cooperatives without checking with them if this is acceptable (Kuper 2016).

In Algeria collective wells arose from the transfer of former public wells, which had been dug in the coastal-plain areas irrigated with surface water to serve as a supplementary resource in the face of dwindling supply. In the 'pioneer front' of Biskra, at the southern foot of the Atlas, some wells were drilled by the government in response to political or social demand, but these were later transferred to individuals or groups with long-term concessions (Kuper et al. 2016).

In Egypt the expansion of irrigated agriculture on the margins of the Nile Delta, although mostly the result of individual private investment, has included a few cooperatives initially set up by the state. In the Western Delta, for example, 20 cooperatives have been established since the mid-1990s.[56] Would-be members were allowed to buy an area of between 5 and 30 feddan (one feddan = 0.4 ha) (at the cost of EP 4000/feddan, to be repaid in 20 years, after which the cooperative member may sell his share). One cooperative had 230 members and was managing 43 wells (originally 23, but additional wells were drilled to address the dwindling discharge). A well would initially allow the irrigation of 100 feddan, shared by between 4 and 20 farmers, which would be granted an annual quota of 5,200 m^3/feddan. It is difficult to assess the degree of independence of the cooperatives, but it is clear that they receive some subsidized input, such as fertilizers, and two government officials, paid by members, work within the cooperative.

In Botswana there are an estimated 21,000 boreholes. Many are disused or capped, and many are not registered. Half of the registered boreholes are owned by the government, the rest by private individuals (Colman 2013). As a result of borehole drilling in the 1930s, syndicates of cattle owners with existing grazing boreholes were entrusted by the administration to run the new boreholes under a new community structure: the borehole syndicate. Even though this structure grew out of state intervention, it was developed as an institutional form to partially self-fund, manage, and maintain boreholes for traditional grazing and livestock-owning communities, becoming a new type of private group ownership of the resource (Manzungu et al. 2009; Peters 1994). The activities involved in the daily management and organization of a borehole syndicate are mainly financial, especially the assessment and collection of rental fees and members’ contributions for fuel and repair costs (Peters 1994). Borehole syndicates were initially transparent, and organized around a managing committee with regular meetings and a defined quorum (ibid.).

In China the decentralization of the formerly state-controlled mode of governance generated a large diversity of institutional arrangements and property rights (Shah et al. 2004a; Bluemling et al. 2010; Wang et al. 2005, 2006, 2013), including situations where:

- the Village Committee controls the (public) well, and funds O&M through different sources (farmers and others);

[56] Information obtained from authors' fieldwork in 2015.

- The running of the well is contracted out by the Village Committee (often to the earlier technicians who were running it, or a specific farmer, who pays a fee against delivery of electricity);
- Formerly public wells are turned over to the farmers using them (often the 'production team' associated with the wells in the past); this is tantamount to shared ownership;
- Shared ownership of new privately owned wells (a group of farmers pooling resources for this investment) or of a formerly public well (sold to the group); the government has extended special loans and subsidies for such investments;
- Individual ownership (a single individual investing in his own well).

As a result, the degree of state control and involvement varies but unless the wells were funded by private individuals they fall under the direct control of the village committee and/or the township water bureau, in particular with regard to determining the irrigation fee or fixing quotas. This is the case in Minqin and Qingxu counties, where 'smart systems', using swipe cards to activate water pumps, were put in place. In Qingxu overdraft is tackled by defining annual quotas for each of the 1,473 wells, but there is some flexibility to exceed the quota by paying a far higher price for the water (The Water Channel 2012; Guisheng et al. 2013; Li He 2011). In Minqin county, by contrast, each well has a card kept by the community leader, while restrictive quotas are imposed.

In Tunisia GDA (*Groupements de Développement Agricoles*) were created as associations of irrigators that can either operate within a large public irrigation scheme (receiving bulk water supply at the secondary canal level, at a cost) or be independently managed by the users themselves (smaller GDAs, such as those managing one or more wells, for domestic use and/or irrigation). In large schemes/GDAs the role of the state remains important, in part because of the value and complexity of the infrastructure, whereas small GDAs are much more autonomous. The initial investment is fully covered by the state and the infrastructure is then leased to the association for an indefinite time. The contract between the state and the association specifies their respective roles. In large GDAs the state may retain control of the main waterworks, while for small ones their operation and maintenance is the responsibility of the association. When a critical or costly maintenance problem arises the association may approach the government for financial help if they can demonstrate that the level of the water fees charged to each user is reasonably high (and that, therefore, there are no delayed maintenance issues) (Hamdane 2016).

The 2004 law affecting GDAs put them in control of their own management procedures and salary rates (Mekki and Ghazouani 2012; Sghaier 2010). This added to their pre-existing water management activities (selling water to their users, collecting fees), the establishing of their own specific management rules, and having to devise and submit action plans, as well as providing financial projections. Large GDAs must be audited yearly by a private audit company, while smaller ones are audited by the Ministry of Finance. The law stipulated that GDAs act as intermediaries between the Ministry of Agriculture (via the CRDAs) and the users, channeling subsidies to the users. Despite official objectives expressed in terms of participatory management, it has long been recognized that GDAs were often under the influence of local authorities and politicians who would meddle in different ways (such as in the selection of board members and hired staff, the use of the associations as political springboards, the financial takings, etc.) (Mekki and Ghazouani 2012). Since the revolution, however, such interference has substantially decreased, while freedom of expression and demands have soared (Marlet 2013).

As early as the 1970s India and Pakistan encouraged the use of modern mechanical pump technology as a means of ensuring more widespread access to irrigation (Shah 2009). The system and design of the new public tubewells were developed by a World Bank Project between 1980 and 1983 in Uttar Pradesh. By 1993, 547 public tubewells had been dug and 328 rehabilitated or modernized (Alberts 1998). The Indo-Dutch Tubewell Project started in 1988 with similar objectives. Despite initial success, and notwithstanding the demonstration of the productive value of modern private tubewell irrigation for neighboring farmers, the unreliability and politicization of these schemes ultimately spelled their failure (Shah 2001). According to Alberts (1998), public tubewells in Uttar Pradesh were often out of order because of break downs and defects caused by voltage fluctuations. Additionally, the operation and maintenance division of the Department of Irrigation was not able to repair them in time due to small budgets and lack of planning. Moreover, the arising competition with smaller tubewells owned privately and markets selling superior irrigation services to their neighbors contributed to the undermining of these public programs and led to an era of 'atomistic irrigation' with private wells (Shah 2001).

Most of the over one million wells in Gujarat are individually owned, but around 30,000 belong to groups of farmers who pull resources together in order to overcome the costs of deep drilling. A few thousand are also owned by the local district *panchayat*, cooperative societies, or by the government.

The state-owned Gujarat Water Resources Development Corporation (GWRDC) invested heavily in the drilling, digging and construction of some 4,000 tubewells. However, problems with collecting fees, maintaining the infrastructure, and declining yields led the state to consider transferring those wells (Kolavalli and Raju 1995). Most have now been successfully handed over to farmers through a simplified transfer process that set targets for each section office (Mukherji and Kishore 2003). When tubewells are in poor condition no user or group of users comes forward to take over. When tubewells are in very good condition the transfer to users is still difficult as different users or groups of users will lay claim to the tubewell, making it difficult for the GWRDC to hand them over (Mukherji and Kishore 2003).

The transfer system involved wells irrigating an average of 17 ha, served by a network of several hydrants, being devolved to groups of at least five farmers (*juth*) or to at least 11 individual farmers promising to form a cooperative, which means maintaining a compulsory bank account and being subject to a regular financial audit by a government auditor. But since farmers had to pay a fee (Rs 5000/year), request a permit to alter the well or pump in any way, and return the infrastructure in the same state they received it, it amounted to an annual lease. Initially the water fee was fixed by the corporation (this was later dropped). Although transferred tubewells performed better than those managed by the state, there is a lack of incentive to maintain them in the long term (due to short leases). The major objective of the turn-over program was to reduce the huge financial losses incurred by the GWRDC, but it is not yet clear how maintenance costs will be handled by the users in the long term (Mukherji and Kishore 2003).

Early public tubewell-transfer programs in the 1990s in the states of Haryana and Bihar have been relatively unsuccessful in turning over public tubewells to village panchayats (Brewer et al. 1999) which were not willing to take over; many were eventually sold to individuals.

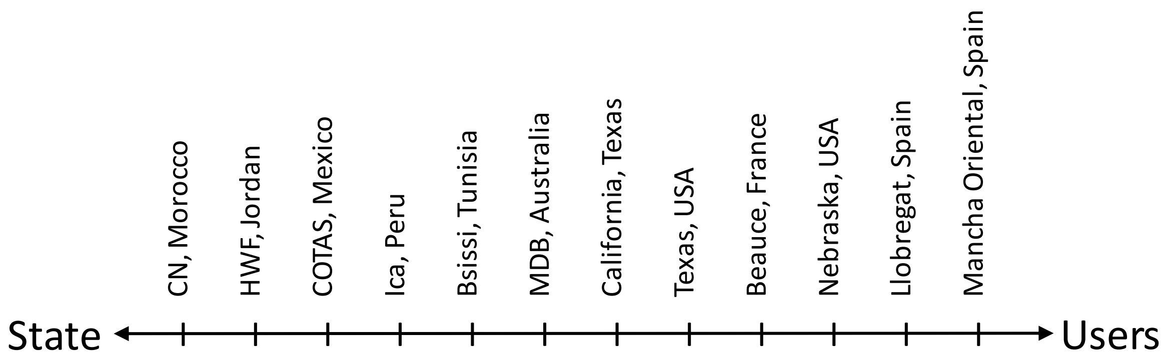
It is common for public wells, such as those in India, to perform poorly. Many, such as those found in Spain or Tunisia, have incorporated users into the scheme's management. But the extreme end of our continuum – collective schemes fully managed by a state agency – can still be found. For example, the Barind project in Bangladesh is considered to be a success story of financial sustainability, with farmers as mere 'customers' of the corporation.

A few important points emerge from this review of collective wells. First, there has been historical decline in state systems distributing water abstracted from one or several interconnected public wells to beneficiaries. This has to do with the difficulty of maintaining such systems and overall financial difficulties. Notwithstanding the example of the Barind project, and perhaps the case of Abu Dhabi[57], very few countries are still developing public wells for public irrigation. Second, while in some countries farmers are able to come together to make shared investments in wells (e.g. Egypt, Iran, Spain, China…), such collaborative arrangements are not always popular (e.g. Tunisia or Algeria) for reasons that need further inquiry. Third, water user groups or cooperatives that have taken over formerly state-run wells almost invariably face problems of financial sustainability, especially where energy prices tend to increase (e.g. Mexico, Turkey, India). Finally, it seems that single collective wells are more sustainable than larger networks of interconnected wells (generally inherited from the state).

5.2 A mix of top-down and bottom-up processes

As mentioned earlier there is probably no such thing as purely state-centered or community-centered governance, given that in all cases the decision-making processes span various scales, constituencies, and organizations. Consequently, 'co-management' applies in fact to a very 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 which can tentatively be placed in a continuum between the ideal-types of state and community governance (Figure 14).

Figure 14. Examples of situations along the co-management continuum



5.2.1 *The Highland Water Forum in Jordan*

Azraq Basin is a closed basin covering an area of 12,710 km^2 located 120 km north east of Amman, where surface and groundwater naturally flow to a central wetland, a Ramsar site of major importance. Due to the shallow nature of groundwater, irrigated agriculture as well as the abstraction of water for Amman developed to the point that water use exceeded the available resource, resulting in a drawdown of the water table by 0.3-0.8 m/year (Mesnil and Habjoka 2012). As a result local springs and the wetland altogether dried up in the early 1990s. The wetland is currently sustained by a public well (at only 10% of its original area). According to the Ministry of Agriculture, around 104,285 du of land are cultivated in Azraq district, the main crops being winter vegetables, bersim (alfalfa), fruit trees, olive trees, and grape vines (MoA 2010). Via a series of well-fields, the government abstracts about 23 Mm^3 of groundwater from the Azraq basin for drinking purposes annually, while agriculture abstracts around 28 Mm^3 – almost the equivalent of the basin's safe yield (24 Mm^3 per year) (MWI 2009). All shallow wells have now

[57] "In areas where access to new groundwater is required and approved, the preference is to create government well fields to supply farms with the appropriate volumes of water, rather than providing wells on farms. Only where a government well field is not feasible should a new or replacement well be drilled on the farm. In these cases the wells should have permits with volumetric limits, and meters, which EAD will regulate" (Fragaszy and McDonnell 2016).

been closed or turned into boreholes. The number of working wells in 2015 had reached 420 (the majority of which only have permits and are subject to higher tariffs), to which should be added unregistered/unknown illegal wells. Studies conducted recently in the Azraq basin have found that actual groundwater use for agriculture in the basin exceeds twice the officially recorded data (Al Bakri 2015; USAID 2014).

The Azraq basin has been the beneficiary of various local, regional, and international initiatives to promote sustainable water management and preserve groundwater resources, including the UNDP-supported Azraq Oasis Conservation Project in the 1990s, the Azraq National Dialogue Initiative steered by IUCN/InWEnt in the late 2000s, and the Highland Water Forum, a GIZ-funded project which ran from 2010 to 2013. This last project established a forum in the Azraq basin, bringing together water users of all levels 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".[58] The final task of the forum was to come up with an action plan towards the sustainable management of groundwater, which would tackle the issue of overdraft in particular. The process of developing the action plan followed several meetings with different actors in the basin from the lowest to the highest level. The plan was presented to the Minister of Water and Irrigation but most of its points remain to be implemented.

At the start of the forum, farmers were optimistic about its aims and the idea of having an open dialogue with policy makers from different administrations, such as WAJ, the Ministry of Water and Irrigation, the Ministry of Agriculture, and the Azraq and Mafraq municipalities (Al-Naber and Molle 2016b). The resulting action plan included the following points: revision of the 2002 bylaw with, in particular, a fair and transparent water pricing system, improving well-owners' access to the procedures and regulations related to wells, cross-sector coordination, with, in particular, a joint national water and agriculture strategy, setting up a reliable repository of data and information, institutionalizing the Highland Water Forum as a consultative entity and a strategic partner to MWI, allocating water by sector, finding cropping patterns to reduce water demand, improving the efficiency of irrigation on farms, promoting the reuse of grey water, establishing a compensation mechanism to buy out wells on a voluntary basis, developing alternative income sources to replace agriculture (energy farming, salt industry, tourism, etc.), awareness programs/ activities, and rainwater harvesting programs.

It is remarkable that the ministry did not accept the idea of a freeze on well drilling against in exchange of the full legalizing of existing wells, including illegal ones. It must be noted that the devolution of decision-making powers to local authorities and/or to users is not supported by sectoral policies that affirm the centralized and overriding power of the ministry. The elaboration of the action plan was also constrained by the necessity of making it compatible with the National Water Strategy (BRLi and AFD 2015b). At the end of the support by GIZ, the HWF was institutionalized and now appears in the organization chart of the ministry. Studies have recently been carried out to find ways of generating a steady and secure source of revenue for the Forum, but the dominant feeling of most stakeholders is that the Forum's 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.

[58] Source: https://highlandwaterforum.wordpress.com/about/ (Accessed April 2017).

5.2.2 'Aquifer contracts' in Morocco

Over recent years Morocco has been trying to implement an aquifer management model loosely based on France's '*contrats de nappes*' (aquifer contracts). These 'contracts' are presented by the Ministry of Water as a groundwater management tool based on a collective process of dialogue about the shared problems within an aquifer. They are signed by the various public administrations and user associations and incorporate the measures that need to be implemented in order to protect water resources and sustain groundwater demand. With the contracts the government aims to prioritize these measures and establish a plan of action, while defining sustainable water management policies involving all users (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). Groundwater represents 95% of its total water use. In 2004 the Souss Massa River Basin Agency ran an awareness campaign about the new water law and proceeded to close illegal wells. This triggered social unrest, so the wali of the region suspended the regulation, deciding instead to approach the problem by creating a commission to incorporate representatives from 20 institutional partners (including the governorate of the region, the Souss-Massa 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*, and by three large agricultural unions (vegetable and fruit exporters, the largest producers in the Souss Massa region). It encapsulated the discussions that took place during the commission's sessions and included: freezing the expansion of irrigated areas for citrus and vegetables, the conversion of gravity irrigation into drip irrigation (financially backed by the region and also by a fund derived from fees levied on farmers' groundwater abstraction), an increase in the fees for groundwater use, the completion by the state of several surface-water infrastructure projects (22 small and 5 large dams), carrying out studies on the feasibility of irrigation with desalinated water in the Chtouka region, and registering 'illegal' wells. The agreement also stipulated the enforcement of rules and allowing the 'water police' to fulfill its mission. This led to the closure of 40 illegal wells, the confiscation of drilling equipment, and requiring drilling companies to possess permits, as well as purchasing three cars for surveillance patrols.

Once signed, subsidiary agreements would also be signed in order to implement the various provisions and plans. Thus, the terms for the registration of wells or the installation of meters would be negotiated between the River Basin Agency and the farmer associations under the supervision of the Monitoring Committee. User participation and consultation for these contracts was going to be based on the concept of 'participative planning'. The contract would then be drawn up, identifying common problems and the potential measures to be adopted based on feedback from user working groups. An institutional, monitoring, and supervisory structure was meant to be created as well as indicators regarding the completion of the 'contrat' (BRLi and Agro-Concept 2012).

The issue of limiting the expansion of irrigated areas became one of the most controversial points. Groundwater users argued that groundwater could be saved with drip irrigation and augmented by the supply of surface water from the new infrastructure projects. Following further discussion an agreement was made on the areas to be included, with a commitment by the regional office to follow up these cultivated areas through a GIS system, in addition to a commitment by the River Basin Agency to register wells and authorize new ones in the areas specified in the convention as being irrigable, should well discharge become insufficient (BRLi and Agro-Concept 2012).

Eight years since the signing of the *contrat de nappe* and despite a much better collective awareness of the problem, the situation has not really changed. The contract was undermined by a general laisser-faire attitude, the failure of the government to deliver on the supply augmentation projects, and the event of a few good hydrologic years that displaced the prevailing sense of urgency. Efforts to design *contrats de nappe* in the Haouz Plain (Marrakech) and the Saïss Plain never reached the point of launching a new co-management dynamic (Tanouti and Molle 2013; Del Vecchio 2013). In 2014, however, the government put the *contrat de nappe* in the limelight again by declaring a policy to establish such contracts in all major aquifers (later reduced to three) in Morocco by 2016 (L'Economiste 2014) in compliance with the conditionality of a World Bank loan.

5.2.3 COTAS in Mexico

In Mexico the experience with water user communities began in the 1980s with the emergence of multi-stakeholder platforms pushed forward by the federal government after more than 100 years of centralized policies. It saw the creation of new water management coordination bodies, such as River Basin Councils and technical committees for groundwater management, or COTAS (Marañon Pimentel 2010; Wester et al. 2007).

Following previously unsuccessful experiences, and in view of the continuous depletion of groundwater, in 1995 the National Water Commission started to promote the formation of COTAS. It organized users so that they could establish mutual agreements to reverse groundwater depletion in selected aquifers of the Lerma-Chapala basin (Pérez Fuentes 2010; Wester et al. 2007). To date 82 COTAS have been created with the officially stated objective of restoring and protecting groundwater bodies and reaching a balance between abstraction and recharge (OECD 2013). Several studies (Wester et al. 2007, 2011; Valdés Barrera 2014; Pérez Fuentes 2010; Marañon Pimentel 2010; OECD 2013) have identified several commonalities across the experiences with COTAS.

First, despite being created to enhance user participation, COTAS retained a consultative role without creating the necessary space to make decisions and devolve powers to the users (Castellan 2000, in Valdés Barrera 2014). Moreover, the Basin Council does not concede any formal decision-making power to the COTAS. The water law describes them as existing merely for the purposes of consultation and policy coordination rather than possessing any authority, and then only participating if invited by the CONAGUA (Valdés Barrera 2014). 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). User participation remained 'consultative' with no responsibility in management decisions (Pérez Fuentes 2010). Indeed, the federal state displayed pervasive resistance to the decentralization of the appropriate decision-making powers, investment funds, or technical and managerial resources.

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; Marañon Pimentel 2010), and expertise to deal with the technical issues and hydrogeological data to make informed decisions (OECD 2013). In addition, COTAS depend financially on the CONAGUA (Valdés Barrera 2014). Members received limited/poor training and never on methods to improve the participation of groundwater users in their COTAS.

Third, the COTAS' ability to reach agreements on the reduction of groundwater extraction was undermined by the fact that only a small group of community representatives was invited to participate (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 (along with one from industry, one for drinking water and another from the service sector) (Caldera-Ortega 2013; Pérez Fuentes 2010). The agricultural sector was represented by commercial farmers but no members of the peasant sector (despite most small farmers producing alfalfa, maize, and other fodder crops being responsible for the majority of aquifer depletion).

The creation of COTAS in León (Guanajuato), for example, did not represent a substantial increase in stakeholder participation but, rather, the formalization of previously existing links between water agencies at the federal and state level and organized user groups. The latter would often benefit from state and federal programs (such as the use of improved technology to increase water efficiency) (Caldera-Ortega 2013; Maranon Pimentel 2010). Caldera-Ortega (2013) has shown the influence and power of specific policy networks in León, oriented towards the representation of strong local business interests (tanning and shoe-making industries) and the enforcement of water management policies by these groups.

Fourth, this lack of representation due to a poor democratic process of selection and representation within the COTAS (Valdés Barrera 2014) also created the perception amongst users that COTAS were merely an 'appendix' organization of the state government (Wester et al. 2011). The lack of trust and interest from users (as they do not see the benefits of the COTAS' tasks and missions) undermines their role within the community (only 10% of users attend the meetings and assemblies) (ibid.). This lack of legitimacy is also driven by the perception amongst users that the COTAS are in place to denounce illegal wells and abstractions.

Fifth, COTAS are curtailed by the superiority of other government agencies and have no power to control groundwater abstraction. Instead they must rely on the good will of users and on the National Water Commission, the only government agency with the power to issue pumping permits and responsible for the enforcement of aquifer regulations (Pérez Fuentes 2010; Wester et al. 2007). As a result no mechanism to significantly reduce groundwater abstraction can be jointly devised and agreed upon (Pérez Fuentes 2010; Wester et al. 2007).

The state's grip on participative processes is still pervasive, and in most instances the effectiveness of these processes is dependent on government intervention (Marañon Pimentel 2010). The legacy of Mexico's highly centralized and bureaucratic state makes it difficult for regional and local agencies to play the role of facilitator and enforcer of rules. This is because decision-making processes by basin authorities are still politicized and dominated by unilateral actions by the federal water agency (Marañon Pimentel 2010; Wester et al. 2007). The democratization process that has been taking place in water management, which reflects wider changes in Mexican society, is a fragile one that can be easily derailed by interest groups and politics blocking the aspirations of water users to negotiate agreements (Wester et al. 2007). To date COTAS have failed to live up to expectations, signaling the pervasiveness of water politics and the slow pace of democratization in Mexico.

5.2.4 Lockyer Valley, Queensland

In Queensland 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 a search for self-governing institutional arrangements. This is consistent with Australia's water reform agenda of 1994 and the Australian National Water Initiative of 2004. The latter aimed to restore environmentally sustainable extraction levels in overused ecosystems and use community partnerships to promote transparency and ensure access to information for decision-making (Sarker et al. 2009). The Lockyer Water Users Forum is a group of users created 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-catchment (Baldwin 2008). Following the 2004 policy initiative, the Lockyer Water Users 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).

Lockyer irrigators were attempting to "manage [the] decreasing availability of water on an individual basis with little scientific information." In their co-management plan they proposed "to supplement State government data acquisition with funding for additional groundwater monitoring of use (through meters) and aquifer levels and three-dimensional aquifer modeling in conjunction with irrigators to produce credible independent data on groundwater use and its impacts" (Balwin 2008: 119). After 10 years of discussion between the government of Queensland and the Lockyer Water Users Forum a co-management proposal for the sustainable management of Lockyer Valley surface and groundwater was developed. This effort lapsed, however, as the Australian government "was not forthcoming" (partly due to its lasting perception that the Forum was merely a lobbying structure for farmers). This failure saw progress in the implementation of groundwater management slow down and be overtaken by the implementation of pricing reforms (SEQWater 2013: 9). The government's current plan to fix and reduce allocations is viewed with deep concern, giving rise to calls for consultation and further socioeconomic studies on potential impacts. "Until the necessary in-depth studies are done, we will stand by the testimony of our growers as representing the best understanding of the system. We will hold the government to account to ensure that decisions are truly based on science and that every effort has been made to ensure the producers are in fact the true beneficiaries of any management changes."[59] In summary, the co-management proposed by groundwater users was more akin to a lobbying activity towards securing public support for supply augmentation than the reflect of an interest in more demand management-oriented policies.

5.2.5 Vall d'Uixó, Valencia, Spain

The municipality of Vall d'Uixó, near Valencia, Spain, has been credited with reducing abstraction (Custodio 2010). A General Community of Groundwater Users was formed in 1989, following a 1985 law and a declaration that the area was overexploited (and threatened by salinity intrusion). The General Community includes 3,996 farmers representing 5,500 farms grouped under 12 associations managing one or more wells (Ortega Reig 2015; García-Molla et al. 2013; Sanchís-Ibor 2016). Collective wells were dug either by individuals or cooperatives, which then offered shares to individual farmers, that is, the right to irrigate a given area of land from a given well. Since farmers have several plots in different locations they often hold shares in several wells, to which they are connected by an increasingly intricate and extensive network of pipes and ditches. The associations can increase the number of shares (and therefore reduce the per-hectare fixed cost) as long as the capacity of the well is not exceeded.

Several major changes have been witnessed over the past 15 years: the rationalization of the irrigation network (concentrating extractions in a selected number of wells and simplifying the distribution network; the number of associations has now been reduced from 18 to 12), a shift

[59] Source: www.queenslandcountrylife.com.au/story/3713906/lockyer-changes-studies-essential/?cs=4785 (Accessed April 2017).

to a new collective (drip) irrigation network (now covering 93% of the area, subsidized at 60%), land retirement due to an orange crisis, farmer ageing, urbanization, groundwater becoming saline (of the 2,932 ha with irrigation rights only 2,395 ha are irrigated at present), increasing electricity prices, the provision of treated wastewater, and higher-than-average rainfall over the past 15 years (Ortega Reig 2015; García-Molla et al. 2013; Sanchís-Ibor 2016). Although abstraction has been reduced as a result of all these changes, it is less clear what happened to the water table (since the return flow from gravity irrigation has also decreased). The reduction in abstraction was not associated with a reduction in quotas, or an administrative decision, but was a consequence of a combination of the changes highlighted above.

5.2.6 Bsissi, Tunisia

The experience of the Bsissi-Oued El Akarit area, near Gabes, Tunisia provides several interesting lessons (Frija et al. 2013, 2016; Leghrissi 2012; Hamdane 2015; Loubier 2017; Montginoul et al. 2017). The area covers 5,122 ha, of which 1,619 are irrigated by 138 farmers relying on 213 boreholes. Until the 1980s the upper aquifer had long been exposed to a proliferation of wells. Farmers then realized that drilling boreholes allowed them to tap the deeper aquifer providing artesian water. 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; farmers were denied access to their farms; and protests were taken to the national government. This led the local administration (CRDA) to change its strategy and propose 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 concerned) and representatives from trade unions, CRDA, and local authorities.

Farmers and the CRDA agreed upon a series of give-and-take measures to control both the drilling of new wells and consumption by existing wells. Farmers becoming members of the association would have a number of benefits on condition that they respect certain rules: limiting total abstraction to 6.3 Mm^3/year (to be shared among members according to rules to be decided by the association and a written commitment by each farmer); to pay the annual fee (already) dictated by the law for all water users in Tunisia; to report any illegal drilling witnessed; 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. (Later the CRDA showed a willingness to assist farmers further with water and soil analyses and the registration of land tenure so that they could access credit. It also created a cooperative selling agricultural inputs twinned with the association, so that it could use the additional income to pay for a permanent member of staff.) The GDA committed to assist the CRDA in closing disused or abandoned wells. This saw the backfilling of 46 tubewells that belonged to farmers refusing 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.

Restrictions on abstraction, as well as problems with groundwater salinity and marketing of products, have 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. 2013, 2016; Leghrissi 2012; Hamdane 2015; Loubier 2017).

5.2.7 Beauce, France

The Beauce aquifer is a calcareous aquifer shared between six '*départements*' and two administrative regions in France (Centre and Ile-de-France). It is located between the Seine and Loire rivers, south-west of Paris. At around 10,000 square kilometers, it has a natural storage capacity of 20,000 Mm^3 (Petit 2009). Agriculture is the main user of groundwater (around 420 Mm^3 per year) and groundwater is abstracted for irrigation through 2,138 wells on around 3,600 farms (declared since 1993 and recorded on a database) (Chauvet 2014; Lejars et al. 2012). Concern for the aquifer's conservation first arose in the 1990s when the wetland of La Conie, fed by the aquifer's high water table, began receding as a result of increased irrigation during a series of droughts between 1989 and 1992. An association for the protection of the ecology and environment of La Conie complained to the state between 1995 and 1997 about the weakness of the measures put 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 irrigators' representatives. The charter set volumetric measures for the limiting of groundwater abstraction for irrigation. This followed an aquifer monitoring system and the establishment of three alert thresholds associated with increasingly restrictive measures (prohibiting irrigation for 24 or 48 hours on certain days of the week) (Petit 2009) established in order to maintain environmental flows in the basin's rivers (Deruyver 2014). 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 as well as introducing a new system of abstraction quotas. It established the total annual average for volumetric abstractions for irrigation at 525 Mm^3, to be shared between farms (with variations according to crop). With the 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 (Beauce Centrale, Blesois, Montargois basin and Fusain basin) (Petit 2009). In 2010 a reduction coefficient of 0.8 was applied to all farms (to reach a total of 420 Mm^3).

The 2006 Water and Aquatic Ecosystems Law, however, initiated a process of 'disengagement' of the state from groundwater resource management (Montginoul and Rinaudo 2013), whilst introducing the possibility of co-management between the state and users. The state remained responsible for setting the maximum volume of groundwater to be abstracted in each basin declared as overdrawn through the designation of areas of water allocation (*Zone de Repartition des Eaux*). However, it delegated this task to a 'Unitary Body for Collective Management' (*Organisme Unique de Gestion Collective,* or OUGC) (BRGM 2012; Montginoul and Rinaudo 2013; Moreau et al. 2014). Although there should only be one OUGC in Beauce, the administrative and political structures overseeing the aquifer, consisting of two regions and six departments, would have complicated the management of the OUGC.[60] Thus, the decision was made to create one OUGC per *département*.[61] An existing structure or organization (in general, Chambers of Agriculture) can submit an application to become an OUGC. The prefecture considers each application, using criteria such as the hydrological boundaries represented by the organization, its ability to represent irrigators, and its relationship with the state (BRGM 2012).

Some analysts have found the OUGCs' degree of collective management to be limited, however (Figureau et al. 2013; Lafitte et al. 2008). Notwithstanding the fact that the allocation of the shared groundwater quota is delegated to the OUGC, it has no "strong power entrusted to it and is sometimes considered a simple delegate" (Bourgeois 2011 in Figureau et al. 2013: 4). Moreover, 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. Via the prefect, the state remains in control of key decisions, such as approving the OUGC or authorizing the groundwater abstraction plan. Although OUGCs can impose sanctions onto their members, police functions remain in the hands of the state (BRGM 2012). In the case of a multiannual plan not being approved, the prefect will notify each irrigator individually about the volumes he may abstract (ibid.).

5.2.8 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 in 1975 the community of groundwater users requested a 'special Legal Regime' ('*Regimen Juridico Especial*') in order to protect the groundwater resources of the area, stop groundwater quality degradation due to significant sea-water intrusion, and represent the users vis-à-vis 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). After a long legal procedure, the final statutes of the CUADLL were approved in 1981, the first Community of Groundwater Users created in Spain. It is organized around: a General Assembly of users (each one paying a fee based on the volume abstracted), a Governing Board (eight members), a Court (to resolve any conflicts), a Technical Commission (an advisory body in charge of technical follow up, and formulation of technical projects), a consultative council, and a technical department (carrying out and implementing the technical projects and management of the aquifer). 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 km^2 where groundwater abstraction represents around 60 Mm^3 per year (in 1990 the surface area of the CUADLL was extended by the Catalan Regional Government in response to a change in environmental law and demarcation of aquifer and water bodies). There are 150 users registered with 800 wells. The delta and Llobregat river aquifer groundwater is used to supply drinking water to Barcelona (70%), for industry (24%), and for agriculture (6%). Agriculture irrigated with surface water mainly covers an area of 1,755 ha in the lowlands near the coast.

[60] "L'Irrigation en France: les disponibilités en eau et la gestion par l'organisme unique (OU)", March 19, 2013, www.coordinationrurale.fr/lirrigation-en-france-les-disponibilites-en-eau-et-la-gestion-par-lorganisme-unique-ou.html (Accessed August 26, 2014).
[61] Ibid.

The main problem facing the CUADLL is seawater intrusion affecting groundwater abstraction and drinking water supply. Seawater intrusion 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 largely 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. The same happened with irrigation. The success can also be explained by the absolute necessity to control seawater intrusion in order to protect Barcelona's drinking water supply, as well as the limited number of users and the strong support – and control – of the government.

5.2.9 The San Luis Valley, Colorado, and Sheridan County, Kansas

The San Luis Valley, in southern Colorado, is home to approximately 140,000 ha of irrigated land. Largely relying on groundwater for its supply (~3,500 wells), it grows potatoes, alfalfa, and small grains (Smith et al. 2017). 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 enacted certain measures but was sued by irrigators, resulting in a 1984 verdict that protected existing users but banned new wells. In the 1990s nearby thirsty cities, such as Denver and Colorado Springs, tried to acquire and export water out of the valley, but residents successfully mobilized to ward off that threat (ibid.). The watershed moment was the drought of 2002. The resultant over-pumping exposed the endemic situation of groundwater overexploitation in the valley. This triggered state intervention that started with the organizing of a Basin Roundtable of stakeholders and negotiations through which, between 2006 and 2013, US$9.0 million state funds were secured as subsidies. 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 some wells, in line with the state's obligations under the Rio Grande Compact. Special Groundwater Sub-District 1 (one of the five sub-districts in the valley) was formed in 2009 (65,000 ha with 671 farmers) and, after difficult debates and many users opposing the move, a majority (60%) accepted metering and the establishment of a self-defined and self-enforced mechanism whereby users would be taxed at US$75/AF[62], while people fallowing land would be compensated. Implemented in 2011, the scheme needed external support as the sub-district was able to afford only 20% of the funds. The remainder was granted by the federal Conservation Reserve Enhancement program, which approved US$120 million to help pay farmers in that first sub-district to stop farming land. The goal is to fallow around 80,000 acres of land, which should translate into a 20% reduction in water use (Conran 2013). 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 before the project (HCN 2016). It is therefore apparent that efforts were made at the intensive margin (reducing the amounts of water applied) rather than at the extensive margin (fallowing land), although the details of local dynamics have yet to be documented.

The 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 a realization – triggered by drought

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[62] 1 Acre-foot (AF)= 1,234 m^3.

events – that the entire valley would be likely to go 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 concerned (671 in sub-district 1). Another lesson is that the 'stick' element of the scheme was mitigated by a 'carrot'; the self-imposed tax was not simply lining the state's coffers but also helping to solve the problem. It is apparent, however, that the state subsidy enlarged the carrot and was probably key to the success of the scheme.

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 (a Local Enhanced Management Area) program, where water rights holders in depleted areas would join to implement voluntarily reductions in groundwater use[63]. All counties voted the proposal to reduce use by 20% down[64], except one: 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 two years few years, and although some producers question why they have to use less water when those on the other side of the road do not, after three years the drop in the aquifer has been significantly reduced.[65] 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 to issue legislation enabling the collaborative LEMA concept, a shared sense that farmers' grandchildren should still be able to farm in the area in the future, a limited number of right holders (135), a preference for 'local control'[66] and trust in a process whereby nothing can be imposed without the right-holders' consent, the prospect that restrictions could 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), with the prospect of impacting junior right holders, including a feedlot which is the largest buyer of local farmers' corn… (Lord et al. 2013; Owen 2016).

5.2.10 NRDs in Nebraska

Nebraska's groundwater reserves are very large and only 1% of that storage has been depleted. Nonetheless, there are localized groundwater depletion problems, and these are reducing well discharge and groundwater base flow to some rivers in areas with shallower water tables (Scanlon et al. 2012).

The 'sharing rule' in Nebraska, which informed the 'correlative rights' doctrine ruling groundwater access in the state, was first codified in 1933 during the Dust Bowl years (Mossman 1996). The Nebraska Supreme Court ruled that groundwater was not the sole property of the landowner and that it must be shared by competing users during periods of water scarcity (ibid.). In 1959 Nebraska passed the Groundwater Conservation Act, allowing for the creation of local Natural Resource Districts (NRD). These were authorized to establish corrective measures to "ensure the proper conservation of groundwater" (Aiken 1980: 950). In the 1960s and 1970s new laws reorganized the state's water management by merging and forming districts along

[63] http://kcur.org/post/kansas-plan-conserve-water-looks-combine-carrots-and-sticks#stream/0

[64] http://www.circleofblue.org/2014/world/ogallala-water-conservation-setback-western-kansas/

[65] See www.kansasagland.com/news/stateagnews/no-mincing-words-sheridan-county-s-water-conservation-program-is/article_51cec358-a482-53be-8019-e050044a9a4e.html

[66] http://cjonline.com/news-business/2016-07-23/kansas-leaders-tackle-aquifer-conservation

hydrologic units rather than county lines. This empowered these districts, enabled an integrated management of resources (connecting groundwater to surface water) (Jones 2012), and allowed the establishment of designated 'management areas' where restrictive measures can be put in place. The board governing an NRD is elected for a four-year term from among the citizens living in the district (not only water users) and its size can range from 5 to 21 members, depending on the population and land area (Hoffman and Zellmer 2013). Each district runs a groundwater management plan, supervised by the Department of Natural Resources (DNR).

The Upper Big Blue NRD established a Groundwater Management Area for quantity control purposes in 1977 in response to concerns regarding 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 (expressed in inches of water that can be applied in a year) (Upper Big Blue NRD 2014). In the Upper Republican district the allocation for the 2013-17 period is a total of 65 inches – or 13 inches annually. Water users can spread the use of their allocation over the five-year period as they wish, as long as they do not exceed the 65 inches. Amendments approved in 2013 limit the amount of "carry-forward," or unused allocation from previous periods, to 7.5 inches during an allocation period.[67]

The Central Platte NRD has adopted a "fine-grain" approach, having mapped soils, groundwater depths, and thicknesses and defined 24 groundwater supply management areas. A maximum acceptable decline for each of the management areas was calculated, establishing a margin of safety in each area. In 1987 the board established the Groundwater Management Plan with a phased program to implement controls in a specific management area when needed. The maximum acceptable decline (in relation to the 1982 level) ranges from 10 feet in the eastern end of the district to 30 feet in portions of the western end of the district. If the water table falls to fixed percentages of that maximum decline, successive "phases" can be declared, with increasingly restrictive measures (e.g. reductions in irrigated acres, establishing spacing limits for new irrigation wells).[68] A similar system has been in place in the Lower Platte South NRD since 1995, and considers five separate 'groundwater reservoirs' (LPSNRD 1995). Each of these areas is managed separately with a monitoring network and a fixed amount of aquifer drop serving as a trigger for a specific set of actions to be taken (as judged by the NRD). Upon the establishment of the groundwater management area in the Lower Platte South NRD, the entire NRD was put under Phase 1. Phase 2 would be triggered when the spring static water level elevations in 30% of the monitoring wells fell below the established upper elevation of the saturated thickness to a certain percentage in elevation reduction and remain below that elevation for two consecutive years. (This was set at an 8% reduction for all areas except one where it was set at 15%). Phase 3 is triggered when spring static water level elevations in 50% of the NRD’s monitoring wells in a designated area have fallen below 15% (except for one area, with a trigger set at 30%) (LPSNRD 1995).

Law enforcement is made easier by the fact that it is exercised locally by district staff. In the Upper Republican district, for example, district officials read and service meters and verify their accuracy via electrical use records when necessary. 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 state

[67] Source: www.urnrd.org/programs-regulations/groundwater-management (Accessed April 2017).
[68] Source: http://cpnrd.org/groundwater-quantity (Accessed April 2017).

department DNR, or goes to litigation). Penalties can be financial or in terms of restrictions on irrigation. In an extreme case, a few thousand acres lost the right to irrigate (Fanning 2016).

For Kepfield (1993: 241), the "apparent abundance of groundwater is crucial in explaining the course of Nebraska's groundwater law." In comparison with the Texan part of the Ogallala aquifer, for example, as it receives 750 mm of rainfall, irrigation is only complementary. It also has substantial recharge. This is a point also touched upon by Aiken (1980: 919), who wrote that Nebraska's groundwater law "is not so completely developed because the relative abundance of ground water has postponed many of the user conflicts that are at the basis of legislative or judicial precedents." With the rapid development of irrigation, however, it is more difficult to ignore conflicts between uses and "forcing consideration of ground water policy issues previously ignored" (ibid.). In many cases, the enforcement of restrictive measures has been triggered by overriding legal considerations, in particular those related to the Endangered Species Act, which enforces the maintaining of base flow in rivers, and the Republican River Compact, which governs the sharing of water between Colorado, Nebraska, and Kansas.

Nebraska has succeeded in finding a balance between federal regulations, state laws, and local management. Longo and Miewald (1989: 753) consider Nebraska's groundwater management to be 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 entitlement-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 (Bleed and Hoffman Babbit 2015): a consistent monitoring network, the maintenance of a split hierarchy between state bodies and NRDs, forming "a nested hierarchy with a strong emphasis on local control," the local enforcement of rules thanks to the self-interest in compliance, and graduated sanctions, adequate funding mechanisms with support from the state, and strong political leadership at critical moments. Nebraska is branding its experience a success story. The reasons given for the effectiveness of the NRDs include their possessing greater power than most local water boards, being drawn along river basin rather than county lines, having ample taxing authority to pay for water conservation projects, and allowing anyone eligible for public office to serve (rather than just farmers) (Schulte 2015).

5.2.11 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 Mm^3/yr in 2000 (Sanz et al. 2011), against 320 Mm^3/yr allocated to the area by the Júcar River Basin Plan, pointing to a deficit of 115 Mm^3/yr (López-Gunn 2009), with environmental impacts which fail to be aptly taken into consideration (desertification, springs and base flow drying up, etc.) (López Sanz 2008). The target for 2027, to achieve 'good ecological status', is 260 Mm^3. An additional 33 Mm^3 of surface water were granted by the Plan Hidrológico del Júcar. "The Eastern La Mancha aquifer is an exceptional example of collective action by farmers and, to the best of our knowledge, is the only case in the world of cooperation in a large aquifer" (Esteban and Albiac 2011). 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 Mm^3 (JCRMO 2014).

Several factors have contributed to the emergence of cooperation in Eastern La Mancha (López-Gunn 2009, 2012; Esteban and Albiac 2011, 2012): the credible threat from the Júcar basin authority to declare the basin as over-exploited and establish a far more restrictive system of entitlements (as in the upper Guadiana) should no improvements be made in order to respond to the needs of downstream Júcar users; the relatively limited number of users (around 1,000, although some of these are bulk users); the bottom-up creation of the user association and local social capital (López-Gunn 2009, 2012); the efforts of the water user association, together with the support of the basin's authority (JCRMO) and the state government. Measures taken 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 "*tarifazo eléctrico*");
- the substitution of groundwater by surface water transfers (39 Mm^3 in 2014), "deemed essential to restore the balance of the aquifer" (JCRMO 2014);
- adjustments in cropping patterns and 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 shift towards micro-irrigation, subsidized by the Júcar water authority and the provincial government (Valcárcel 2013), which reduced gravity irrigation to 4% (with 18% of drip-irrigation, 40% by sprinklers, and 38% by central pivot) (JCRMO 2013);
- reduction in abstraction during the 2004-08 drought ordered by the water authority, with reductions of between 20% and 45% and buy-back by the state of entitlements from farms located near the river in order to protect environmental flows (Sanz et al. 2011; Ferrer et al. 2008; JCRMO 2007, 2008). This explains the drop in total abstraction from 379 to 270 Mm^3 between 2005 and 2007.

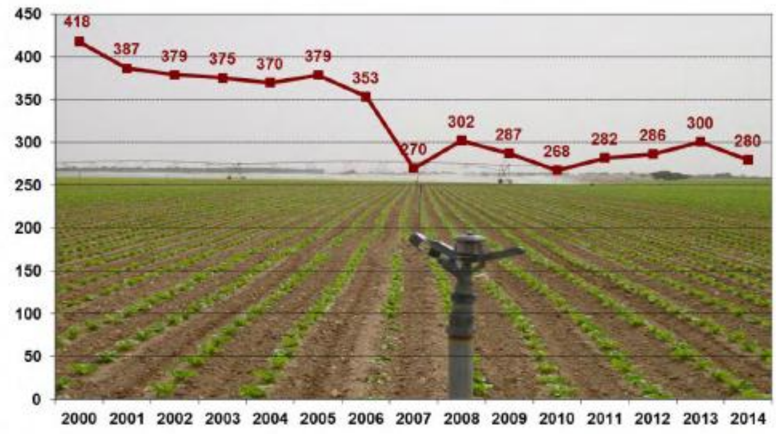
For water rights older than 1986, their allocation was established at 5,800 m^3/ha for summer crops and 4000 m^3 for spring crops. For concessions (valid for 75 years) granted between 1986 and 1997 (year after which no authorization has been delivered) entitlements were established at 4,000 m^3/ha (de Santa Olalla Mañas 2014). Since then allocations have been granted according to crop type, and farmers are able to choose between being charged as per values defined for each crop or by meter (JCRMO 2014).

The JCRMO and the Júcar Water 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 (López-Gunn 2009).

The Groundwater User Community charges between €100 and €600 for groundwater volumes abstracted over the authorized cap (between 0 and 30,000 m^3 per year). They also request the return of those volumes (plus an additional 10%) in the following irrigation campaign (JCRMO 2014). The amount paid is added to a sanction by the River Basin Authority (of up to €10,000). If the excess amount abstracted is above 30,000 m^3 (in one year), then the River Basin Authority intervenes and enforces more drastic sanctions (fines between €10,000 and €500,000). During the 2013 irrigation campaign, the Irrigation Court of the Eastern Mancha Groundwater User Community launched five disciplinary procedures against its members (JCRMO 2014). The JCRMO Water Jury (the association's judicial body) is *not* the Water Authority (López-Gunn, 2009). The regulations applied to farmers are backed up by the Water Authority's rules.

No water meters have been installed or made compulsory. In agreement with the Júcar Water Authority, the JCRMO leaders have secured technical assistance from universities and external projects to develop a system whereby the overall area is divided into 1,400 water Management Units (generally corresponding to the area served by one or several wells). The cumulated water rights for these units are compared (Sanz 2016; Sanz et al. 2015) with theoretical crop requirements (based on crop-based water requirements and land-use maps derived from satellite imagery) (Castaño et al. 2010). Anybody can check whether the information for a particular plot is correct (150 field checks were carried out in 2013) and the transparency associated with this system won the support of members (Sanz et al. 2015).

Figure 15. Evolution of the groundwater volume abstracted in La Mancha Oriental (JCRMO 2014)



5.3 Key contextual elements of co-management

5.3.1 Nature of the user community

There is a large body of literature on the factors associated with a higher likelihood of collective action, beginning with Ostrom's (1990) design criteria and the many authors who have built on them (see Section 4.4). This includes Agrawal (2001) and, to take a few examples related to groundwater, López-Gunn and Martínez Cortina (2006), Schlager and López-Gunn (2006), Schlager (2007), Ross and Martínez-Santos (2010), Rica et al. (2012, 2014), Bleed and Hoffman-Babbitt (2015), and Megdal et al. (2017). We do not explore this issue (see some elements above, in Section 4.4), but merely emphasize here the features of group size, homogeneity, and leadership.

Firstly, co-management is clearly facilitated when the transaction costs of collective organization are lower. The number of groundwater users affected by the future of a given aquifer is of course a key feature.

Some example of numbers involved are: the Namoi (550), the Murray (200), Bsissi (100+), Sheridan County (135), the Lower Murrumbidgee (315 groundwater licenses for the deep aquifer source; Kumar 2013), Llobregat (150), Vall d'Uixó (~4000), Eastern La Mancha (~1000), la Beauce (2000+ wells), and the San Luis Valley (3000+ wells). This suggests that a few hundred, or even thousand farmers might be conducive to collective action for co-management. In contrast, La Mancha aquifer (17,000), the main aquifers in Morocco (several tens of thousands), India or China are understandably harder to manage. Of course, while a smaller number may help, it is not a sufficient characteristic in itself.

A second characteristic is social homogeneity. In Mexico (e.g. Sonora) and Peru (Ica) there are clear distinctions, and antagonism, between investors growing crops for export and local farmers: in Sonora, asparagus farmers are not from the area and can move out after 10 or 15 years if the aquifer runs dry (Reyes Martínez and Quintero Soto 2009). Similar situations can be found in Morocco and Egypt's Nile Delta western fringe. In such cases groundwater users have different means, power, and interests and it will be very hard to reconcile their respective objectives.

In Portugal' Algarve region, past experiences of failed collective action in associations and cooperatives (with leaders often accused of favouring some associates and even of corruption) discouraged farmers from envisioning a self-regulation of the aquifer and indicated that bonding social capital is fairly weak within the community (Rinaudo et al. 2012). In contrast, Bsissi or La Mancha Oriental display a high level of trust and reciprocity amongst users and bonding social capital (López-Gunn and Martínez Cortina 2006; López-Gunn 2012).

The comparison of eight groundwater user associations in Spain by López-Gunn and Martínez Cortina (2006) showed that one of the main reasons for the success of self-regulation of uses and users in Spain is leadership. Even though it is not a homogenous phenomenon across the different user organizations, leadership ensures internal legitimacy and also competence. Leadership can be based on charisma, encompassing intangible attributes binding the community of users together (López-Gunn 2012; López-Gunn and Martínez Cortina 2006).

5.3.2 Credible threat

We can observe that in several instances the groundwater users were encouraged/compelled to organize because of some credible threat to the *status quo*. For example, when the Western La Mancha aquifer was declared over-exploited, this triggered (by law) the necessity for users to establish a Groundwater User Community. But the administration tried to impose specific statutes that irrigators did not want to accept and as a consequence significant social conflict and confrontation occurred (lawyer of GWUA Aquifer Campo de Montiel 2011). In the nearby Eastern La Mancha aquifer, this made credible the threat by the Júcar Basin Authority to declare the basin as over-exploited and establish a far more restrictive system of entitlements (as in the upper Guadiana), if no improvements were made, in order to respond to the needs of downstream Júcar users (López-Gunn, 2009, 2012; Esteban and Albiac 2011, 2012).

In France agricultural users are now obliged to organize themselves as *Organisme Unique de Gestion Collective* (OUGCs), which are granted a quota to be managed and apportioned internally. The OUGC must submit its plan and have it accepted by the prefect (*préfet*), failing which top-down administrative orders can be imposed on users.

Farmers in San Luis Valley, Colorado, also organized themselves and proposed home-grown measures to reduce abstraction under the threat of state intervention (a threat made vividly credible by the shutting down of 440 wells in the nearby South Platte River in 2006).

In the US, state laws and policies have frequently evolved under the pressure of threats. 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, initiating the approach to local groundwater management, still followed today in Texas, with no other reason than to avoid centralized control, granting counties the responsibility to initiate the creation of GCDs (Dupnik 2012). To date the main motivation of farmers to create GCDs is an attempt to develop homegrown regulations and ward off the threat of imposed rules. Likewise, Arizona belatedly adopted groundwater legislation against the threat of not receiving federal funding for the Central Arizona Project (Schlager 2006).

5.3.3 Environmental or legal trigger

In other cases decisive moves towards negotiated (and sometimes top-down) management rules are also linked (at least in northern countries) to degraded environmental conditions generated by over-pumping, which result in third-party impacts and legal challenges.

In California, where in most places people are free to abstract water on their property without reporting it, the protracted drought has led the state to issue a new bill (2015) that empowers local groundwater agencies to "control groundwater extractions" by "regulating, limiting, or suspending extractions," and by "establishing groundwater extraction allocations."[69] Local agencies have five to seven years to develop binding groundwater plans that are overseen and approved by state agencies. This is a common situation in the US, whereby the state is forced to impose, directly or indirectly, constraining measures to respond to a legal or climatic challenge. In Tampa Bay, for example, in order to respond to an impending crisis in 1972, the Florida legislature passed the Florida Water Resources Act, requiring the different water management districts to establish minimum flows and levels for surface water bodies and aquifers to protect ecosystems and livelihoods. This law also required the districts to develop regional management plans to meet water demand over a 20-year planning period, identifying water supply sources and water resource development projects to be implemented to meet those future demands (Yates et al. 2011).

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, which led to the creation of the aquifer authority (Boadu et al. 2007; Gulley 2015). As a result of the court ruling in favor of the Sierra Club, in May 1993, the Texas Legislature passed Senate Bill 1477 creating the Edwards Aquifer Authority that eventually defined volumetric allocation and management rules (Dupnik 2012; Gulley 2015).

The 1950-57 drought affected 244 of 254 counties in Texas (classified as disaster areas), and cost US$ 3.5 billion for each year of drought (Wythe 2011). The High Plains Groundwater Conservation district amended its regulations in 1954 to set up larger minimum distances between wells. It also stipulated that old wells could no longer be replaced with larger ones without obtaining a new permit from the district board. As a reaction to the drought, the legislature created the Texas Water Development Board (TWDB) in 1957, with view to future regulation by the state.

The 1990s saw an increase in the creation of GCDs as well as legislative efforts. Texas Senate Bill 1 was passed in 1997, immediately after a drought in 1995-96 (Wythe 2011). The bill granted more regulatory powers to the districts by allowing requirements for groundwater abstraction permits and by statutorily designating GCDs as the state's medium for groundwater management (Teel 2011). The bill also provided technical support to the GCDs by the Texas Natural Resource Conservation Commission and the Texas Water Development Board. With this increased support, however, more accountability was demanded from the districts as they were required to provide more comprehensive management plans in conjunction with regional water management plans. Districts also became subject to audits on management performance reviews. Amidst another drought (2005-06), causing state-wide losses of US$ 4.1 billion, the Senate of Texas passed House Bill 1763 which represented a 'profound change' in how groundwater availability is determined in Texas (Mace et al. 2008: 1). This bill represented the

[69] Source: http://news.nationalgeographic.com/news/2014/09/140917-california-groundwater-law-drought-central-valley-environment-science/ (Accessed April 2017).

regionalization of decisions on groundwater availability, as well as requiring the fixing of targets and caps for groundwater abstraction, which ultimately affect the rules and plans of individual water districts.

In Spain the Western La Mancha Aquifer was (provisionally) declared to be overexploited in 1987 (confirmed in 1994) after the iconic 'Ojos del Guadiana,' the main 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 with the purpose of overseeing the implementation of the newly established emergency abstraction regime (Closas et al. 2017; Hernández-Mora 1998), as mandated by the 1985 law. Co-management of the Beauce aquifer, France, also started when the wetland of La Conie started to recede as a result of the increase in irrigation during a series of droughts between 1989 and 1992, and after an association for the protection of the ecology and environment of La Conie complained to the state (Petit 2009).

The Nebraskan legislature's initial measures of the 1950s (the registration of large wells, well spacing, etc.) resulted from the Dust Bowl years. The dry period of the 1970s, dropping water tables, and the multiplication of water districts, motivated the 1975 Groundwater Act (Bleed and Hoffman-Babbitt 2015). In the 1980s and 1990s the conflict between Nebraska and Kansas on the Republican River compact (as to whether groundwater was to be included within the allocation, and the consumptive use calculations under the compact) led both parties to reach an agreement ratified by the Supreme Court in 2003. Key provisions under the agreement include the joint determination by a committee of the amount, timing, and location of depletions from groundwater pumping to the river (Sophocleous 2010; Zellmer 2008). This settlement forced the affected groundwater district in Nebraska to enforce restrictions on use. NDRs designated as over-appropriated must also draw up management plans that protect stream flows under the Federal Endangered Species Act. A similar story, reported earlier, was how New Mexico and Texas sued Colorado for violating the Rio Grande compact that defines the sharing of water in that basin (Cody et al. 2015), spurring groundwater conservation policies.

In Australia the "Millennium drought" spurred several changes. The management plan for the Murray-Darling basin was enabled by the Water Act of 2007 approved by the Australian parliament. This piece of legislation redefined the priorities of the basin's water policy and required the preparation of a plan alongside the creation of the Murray-Darling Basin Authority (Weir 2011).

5.3.4 Mobilization of groundwater users

In other cases the impetus towards co-management originates with the users themselves. This often occurs in the face of some threat, as discussed above, or out of a growing collective awareness of the problem, specific local challenges and conflicts, and existing social capital.

In 2005 in Ica, Peru, groundwater users began to mobilize to create groundwater user associations. The first to be created was the JUASVI (*Junta de Usuarios de Aguas Subterraneas del Valle del Ica*) in 2005 by a group of businessmen (Cardenas Panduro 2012). This was mainly driven by the declining levels of the groundwater table, the slow release of groundwater abstraction permits, and the lack of representation of groundwater irrigators in the associations of surface water users (Cardenas Panduro 2012; Oré et al. 2012). The JUASVI represented 59 users over 10,000 ha out of a total of 26,000 ha represented in three associations in total (Cardenas Panduro 2012). The creation of the community of groundwater users in the Ica Valley was sponsored by the regional water administration who recognized the necessity put forward by the users themselves and officially recognized the JUASVI in 2009 (Cardenas Panduro 2012; Oré et al. 2012). In total, 24% of all groundwater users in the Ica valley belong to a groundwater association (Scamarone 2008).

A similar situation occurred in 2006 in the Copiapó Basin, Chile, when the Pascua Lama Mining Project was to be developed by a Canadian mining company. As a result of the pressure of public opinion against the project and a continuous drop of the water table, the regional office of the DGA initiated a process of public-private partnership among users through the creation of a 'water roundtable' (*Mesa del Agua*) in order to improve water governance and the sustainability of water resources (Dourojeanni et al. 2010).

In the Altar-Piriquito District, Mexico, producers of all stripes felt pressed into action because of several mounting threats and uncertainties, including Mexico's entry into several trade agreements, dwindling state support for agriculture, and droughts and water shortages forcing some farmers to take land out of production (Wider 2001).

As noted earlier, several attempts at co-management originated from conflicts between farmers and the state, when the administration started taking drastic measures against illegal well-drilling and over-pumping. This was the case in particular in Bsissi, Tunisia, and in the Souss-Massa, Morocco.

5.3.5 Joint monitoring and transparency

The enforcement of jointly agreed (or imposed) management rules was found to be greatly enhanced by establishing accountability mechanisms, transparency with regard to the rationale behind the measures, and the distribution of costs and benefits.

Ross and Martínez (2010) refer to cases in Spain and Australia showing 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.

In Eastern La Mancha, Spain, theoretical crop requirements are based on land-use maps derived from satellite imagery) (Castaño et al. 2010). Anybody can check whether the information for a particular plot is correct (150 field checks were carried out in 2013) and the transparency associated with this system won the support of members (Sanz et al. 2015).

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

When adherence to rules is not expected, indirect transparency can be obtained through 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, in 2006, some of Colorado's fastest-growing urban communities have hired private investigators to determine which farmers were not abiding by the pumping ban (Cech 2008). In Jordan the Ministry of Water Resources and Irrigation now publishes in newspapers the names of illegal groundwater users and the amount of their unpaid water bills, as well as those responsible for major fixtures on water mains (*naming and shaming*). Satellite imagery is used to estimate and charge water consumption.

5.3.6 Funding

Co-management implies the participation of users at a level that requires funding for their action, and/or for implementing the measures jointly agreed upon.

The Highland Water Forum in Jordan, for example, has produced an action plan without a mechanism having been identified for the self-funding of the forum or any of its activities. The water roundtable for the Copiapó River, Chile, had no independent funding and financially depends on the Water Directorate and the National Water Commission (DGA 2009). In Morocco the Souss-Massa's first '*contrat de nappe*' was reportedly undermined by the fact that the state failed to make the investments (new dams, etc.) that were part of the agreement. A lack of earmarked funding or internal mechanisms to raise funds is in general a sign of a weak and/or transient initiative.

Nebraska's NRDs have the authority to raise funds. In 2013-14 the NRD's budgets for their programs ranged from a low US$900,000 to US$17 million (Edson 2014). NRDs 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. In 2007 the NRDs with an integrated management plan were also given the authority to levy an occupation tax of up to US$10 per acre on irrigated agricultural lands, and production fees are capped at US$1 per acre-foot/year for agricultural use (Hunka 2008). They also benefit from collaborations with the University of Nebraska, which has its own funds. A bill creating a Water Sustainability Fund was introduced into the legislature in 2014, providing a one-time start-up fund of US$21 million, and the dedication of US$11 million per year, with no clause indicating when the funding should end. The goals of the Water Sustainability Fund are to provide financial assistance to programs that increase aquifer recharge, reduce aquifer depletion, increase streamflow, improve drinking water, promote the goals and objectives of integrated management plans, reduce flooding, provide wildlife and recreational benefits, assist municipalities with sewer infrastructure, increase water productivity, enhance water quality, and comply with interstate compacts and agreements (Bleed and Hoffman-Babbitt 2015). Still, many GCDs have faced tough rulemaking and management issues as well as a lack of financial security (Brock and Sanger 2003). Many have low annual budgets as they can only rely on fees (well production fees and administrative fees for well and export permits) and fines rather than a compulsory tax base.

According to John Turnbull, Manager of the Upper Big Blue NRD, "the property tax amounts to about half or 60% of our annual revenue. The rest comes from grants and outside monies working with other agencies for projects. […] The property tax amounts to about one and a half percent of an individual's property tax whether its farmland or property in town" (Ganzel 2006).

In Texas, Groundwater Districts can have limited revenue and operational efficiency due to their insufficient jurisdictional area. Funds from taxes and fees are also a hindrance for the GCDs with taxing authority, as many local communities do not want to hear about rising taxes. Districts therefore have to compromise with a rate that provides limited funding within a potentially hostile constituency opposed to further taxation[70] (Dupnik 2012).

According to Choy et al. (2014), California is characterized by a glaring lack of data, due to 'chronic' underfunding of state-wide groundwater monitoring programs. As Grantham and Viers (2014) state, the chronic underfunding of California's water regulatory agencies is a major constraint to modernizing the state's water rights system. The lack of funding contributes to

[70] The mean tax rate is US$ 0.060 per US$ 100 of land valuation for groundwater users – far less than the statutory cap of US$ 0.5 US$ / US$ 100 USD) (Dupnik 2012).

"decades-long backlogs in processing water rights applications" and reflects, in part, "political opposition to action by those who benefit from lax enforcement" (Grantham and Viers 2014: 8).

5.4 A balance between carrots and sticks

A seen in Section 3, the capacity of the state to control diffuse groundwater pumping on the ground is limited. This extends to co-management situations, and so does the evidence that 'stick-only' policies are unlikely to work in most settings. Case studies suggest that co-management can only work if a delicate balance between sticks and carrots is struck. Sticks should be brandished and carrots extended only to those who *comply with the constraints.* The constraint side is generally associated with the 'credible threats' discussed above (e.g. in the US, that of state intervention), overriding environmental laws, compacts (US) or treaties (EU), and negative incentives such as water pricing or the sanctioning of illegal practices. The benefit side includes incentives such as compensation for land fallowing, subsidies for irrigation technology or growing certain crops, connection to the grid, the buyback of wells, or water market mechanisms. But tough policies (often unavoidable in many overly degraded situations) generally require substantial state funding. It would be illusory to believe that a severe imbalance in the availability of the resource and its use could be remedied simply by top-down regulatory pressure and decrees. 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. This included the earmarking of A$3.1 billion for the purchase of water entitlements from willing sellers (Grafton 2017).

In the Guadiana Basin, Spain, the aquifer was declared to be over-exploited in 1987. This translated into strictly reduced abstraction quotas established in 1991. Coming as they did during a drought the economic impact on the farming sector was harsh, with unpredictable political consequences. A proposal was put forward by the Spanish government (jointly by the Ministries of Agriculture and Public Works) and the regional government of Castilla-La Mancha to take advantage of the European Union’s 1992 reform of its Common Agricultural Policy. This approved funds for member states to support agro-environmental projects encouraging farmers to reduce water use and preserve natural ecosystems (Regulation CEE 2078/1992) (Rosell and Viladomiu 2000; Viladomiu 2014). An Agro-Environmental Plan was set up in 1992 by the European Commission with the aim of reducing the total volume of groundwater abstracted from the Western La Mancha aquifer to 240 Mm^3 per year, and compensating farmers willing to stop or reduce groundwater abstraction for irrigation (Rosell Foxà 2001). Given the poor state of the Las Tablas de Daimiel national park, Spain coupled its (urgent) need for funds to compensate farmers and alleviate the burden of the measures approved in 1991 with the necessity of protecting the endangered ecosystem (Viladomiu 2014).

In Texas the Senate Bill 1 passed in 1997, immediately after a drought in 1995-96 (Wythe 2011), acknowledged the importance of groundwater not only for agriculture but for individuals, cities, counties, and industries. The bill granted greater regulatory powers to the districts (e.g. groundwater abstraction permits, strengthening well-spacing regulation, etc.) and by statutorily designating GCDs as the state’s preferred means of groundwater management (Teel 2011). It also clarified and increased the authority of the GCDs (Dupnik 2012). The bill provided technical support to the GCDs by the Texas Natural Resource Conservation Commission and the Texas Water Development Board. With their increased power and backing, however, greater accountability was demanded from the districts, which were required to provide more comprehensive management plans in conjunction with regional water management plans. Districts also became subject to audits on management performance reviews, to check they were meeting their planning objectives. The 1950s had seen the creation of the Texas Water

Development Board (TWDB) and the implementation of certain regulatory constraints, associated however with a Water Development Fund totaling $200 million to assist local communities to develop and maintain water supplies.

In 2002 the California Legislature approved Senate Bill 1938 establishing a system of carrots and sticks in requiring local agencies to develop and implement groundwater management plans with specific components in order to be eligible for state funding (Osuji et al. 2003). The funds, provided by the Department of Water Resources, were to be allocated for the construction of groundwater projects or groundwater quality projects. Similar incentive-requirement schemes were associated with the 2015 bill.

In France irrigators have no choice but to form OUGCs and frame mechanisms for the apportioning of the collective abstraction quota granted to them. Yet they also use their status to negotiate benefits against the constraints, such as subsidies for on-farm storage as a substitute source of water (Loubier 2017).

5.5 The state-user balance

The balancing of the roles and power of the state and the user communities varies (widely) according to local socio-political circumstances and dynamics. It becomes a political game in which users have to strike 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, with a view to the resources it can devote to mitigating/solving the problem.

In some instances the initial negotiations over co-management fail to yield results because the state either wants to retain control or does not see the potential of shared responsibilities. This was the case in Jordan, regarding groundwater use in the Highlands, and in Queensland, Australia, where the government was in discussion with the Lockyer Water Users Forum for over 10 years over the supply of water for irrigation (SEQWater 2013: 9).

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" (Leathes et al. 2008; Holman and Trawick 2011). These organizations are expected to be partners in the negotiations to define and enforce a licensing system that respects environmental objectives (and therefore has rules that may reduce annual entitlements or even discontinue licenses).

Tunisia offers a clear illustration of the significant role that can be played by financial and political factors. Its acceptance in 1987 of a Structural Adjustment Program from the World Bank and the IMF came with a new approach to groundwater governance aimed at progressively disengaging the state from local community water management. It sought to implement reforms to increase the role of users and decentralize agricultural development, while shifting towards water demand management. User Associations (GDAs) were indeed strengthened, yet it appeared that the objective was more to divest financial costs onto users rather than empower them. Following the 2011 revolution a new water law under approbation aims at establishing specific GDAs for groundwater management (which will include every well, shallow and deep, within a designated irrigated area), while the government realizes that it no longer has the formal authority to conduct top-down policies. Co-management appears to be the only viable option, whether this is seen as desirable or a necessity.

In tribal societies where local political and symbolic power counterbalances, and sometimes overrides state power, specific arrangements have to be found, even if they tend to favor local elites rather than the public at large. In Botswana centralized political authority over land and water clashed with traditional forms of community organization, dissolving the sub-district authorities. Community structures and institutions evolved and reorganized themselves using existing structures of power and control over non-privileged members of society. Powerful members of the ruling elite in traditional communities became wealthy individuals accumulating power and capital in borehole syndicates controlling access to groundwater. Relatives of ruling families were the ones who benefited from training programs, education or employment around the drilling and maintenance of boreholes in the area. In Yemen co-management is not an option because of distrust in the state, disincentives, and a weak system of rule of law affected by years of internal conflict. Situations of 'weak state/strong society' (Migdal 1988 in Handley 2001) and legal pluralism make community-based management a preferable option.

Co-management processes incorporate the dynamics that exist within the group of users. In Lubbock, Texas, this meant the dissatisfaction of many district members with the rules "requiring users to install new water meters and report their usage to the district or face fines." The race for election in the district saw confrontations between the proponents of a revision of pumping limits to preserve the resource in light of decreasing aquifer levels and its opponents who claimed it would be an infringement of private property rights "and a slippery slope toward socialism" (Lubbock Avalanche-Journal 2014a). In San Luis Valley, Colorado, reaching a majority within Sub-District 1 to pass the proposed regulatory measures "was a struggle, requiring plenty of door-to-door efforts" (Smith et al. 2017).

It is interesting to note that several attempts to find a co-management solution have stemmed from an earlier unsuccessful attempt by the state to enforce the law unilaterally, notably by closing illegal wells. This is what happened in Bsissi, Tunisia (Montginoul et al. 2006), and in the Souss, Morocco, where the social unrest triggered by such measures forced the state into a compromise that saw the setting up of a participatory process, leading to an agreement on the measures and the roles of each party. In the Souss this led to the signing of a contract (which has, however, been largely ignored).

Attempts at co-management may also result from pressure from donors or cooperation agencies that have made up their mind that it is a solution to be pursued and supported. This is clear from the Moroccan case, where the Agence Française de Développement (AFD), the GIZ, and the World Bank have supported the drawing up of 'aquifer contracts', and also from Jordan's Highlands Water Forum, which, with financial support from the German Cooperation Agency (GIZ) as well as French funding in 2008, has attempted to bring together 60 different stakeholders (agricultural water users, government institutions, NGOs, and research institutions) (Mesnil et al. 2012).

When the consequences of groundwater overdraft are high (land subsidence, farmer bankruptcy, environmental destruction) the groundwater economy may be seen as 'too-big-to-fail'. This can see the pressure and the onus of responsibility shifting to the state, and often results in its support for one-shot, capital-intensive technical solutions (wastewater treatment stations, desalination, or inter-basin transfer). These can have the 'advantage' of spreading costs across taxpayers, and providing respite by bringing in more water rather than curtailing supply. In Ica, Peru, the government approved two projects aimed at supporting agro-exporters and avoiding crop losses due to the water crisis through urgent decree laws. The national media and agro-exporter lobbies argued that "Ica agriculture has to be saved;" "we are the main producers of asparagus in the world;" "agro-export offers full employment for the population" and "Ica is the principal agro-export valley in the country" (Boletín de la JUASVI 2011)(Oré et al. 2013).

The Ebro transfer (the key infrastructure of Spain’s National Hydrological Plan of 2001, since repealed) was estimated to cost approximately €380 million and intended to reduce the pressure on around 100,000 ha in the Segura river basin, often irrigated with groundwater from illegal wells (Albiac et al. 2006, in De Stefano and López-Gunn 2012). The negotiation of a mutually agreed settlement can also lead to a PPP, whereby the shares to be paid by the state and the users reflect the local political economy. The Guerdane project in southern Morocco (Houdret 2012) and the West Delta project in Egypt are examples in point.

The spending of public money can also be challenged, however, as demonstrated by the case of Israel (Feitelson 2005, 2006). During a series of drought years in the 1990s the country’s treasury fought the development of new water sources. With concerns about the heavy cost of increased wastewater treatment and seawater desalination, it prevented the capital outlays necessary until full-cost pricing was implemented. Since this needed to be approved by parliamentary committees, where agricultural interests are disproportionately represented, their lobby challenged the move, hoping to prevent higher water rates (ibid.).

An example of the state or private companies being forced to extend benefits to abstractors/polluters so as to meet environmental objectives is that of 'polluter-paid' systems, such as those in France and Denmark, where water utilities establish arrangements with farmers and compensate them for changing their land use practices (e.g. reducing the use of pesticides, fertilizer, and manure, and re-forestation).

Co-management options can be constrained by past legislation, such as in Texas where the state made "Faustian choices […] In adopting the laissez-faire capture rule, the Texas Supreme Court sought to minimize political and legal conflicts over groundwater ownership and management, but it left Texas landowners without a remedy for well-interference disputes, and it left Texas aquifers subject to harmful over-pumping and mining" (Kaiser 2006; Kaiser and Skiller 2001). Against such a background, the state – and GCDs – can make only incremental moves towards a joint framework that would instill a degree of control over groundwater abstraction.

In other cases, such as that of India, politics and the prevailing state-citizenry relationships make co-management an unlikely option. In the late 1990s the ruling party was defeated in parliamentary elections precisely in states with a precarious groundwater situation. Groundwater irrigators in India have emerged as a huge, powerful base of voters which political leaders cannot ignore when discussing energy subsidies or financial support measures for agricultural product markets (Shah et al. 2001). Some states have even approved laws making the electricity used for pumping free.

5.6 The problem of spatial 'fit'

A key question in natural resource management is the determination of the spatial unit(s) considered (Folke et al. 2007; Moss 2012). In the field of water resources the river basin (watershed, catchment) appears to be the ubiquitous prescription, despite the identified limitations of the concept. Groundwater resources are allegedly best managed at the aquifer level, a unit that is not necessarily included in or coterminous with a surface river basin, and which also has its limitations (e.g. several interconnected aquifers).

A constraint shared by both units is that they are frequently too large to be conveniently managed, all the more so when a substantial role is given or expected for local stakeholders. Distant water users may not feel they are part of the same system, especially if the action of one group has no discernible impact on another. It is therefore tempting, for administrative convenience, to fragment these units into smaller, more manageable ones. This is the case, for example, in Chile where river basins are generally segmented into successive sections (Bitran et al. 2014).[71] At first sight, and with regard to groundwater, segmenting an aquifer is somewhat odd because abstractors on both sides of a given limit are likely to impact one another. The case studies reviewed offer a number of important conclusions.

In the case of the Beauce aquifer, France, four sub-aquifers – intersecting six *départements* – were hydrogeologically assessed before being assigned their own threshold and coefficient for reducing allocation. When user-based OUGCs (Organisme Unique de Gestion Collective) were set up to manage abstraction, one should have been formed by sub-aquifer. Because OUGCs are mostly driven by *département*-based Agriculture Chambers, however, six were formed, one for each *département*.

In 1972 Nebraska established 24 Natural Resources Districts (NRDs), consolidating a multitude of single-purpose local natural resource districts governed by a locally elected board (Bleed and Hoffman-Babbitt 2015). Boundaries were drawn according to surface watershed boundaries (due to the central flood concern at the time). The Platte river basin, for example, is split into seven NRDs. Aquifers, however, usually extend across several NRDs and interact with various river systems (ibid.). The joint management of surface and groundwater has given rise to a need for knowledge of surface/groundwater interactions and of which wells should be considered as potentially impacting river flows. It is recognized that "groundwater use or surface water use in one natural resources district may have adverse effects on water supplies in another district or in an adjoining state" (ibid.). NRDs have been able to organize higher-level initiatives in response to basin-wide problems, such as compliance with the Endangered Species Act or inter-state river compacts (e.g. seven NRDs, along with the State DNR, formed the Lower Platte River Basin Water Management Plan Coalition) (ibid.). Since there are more than 112,000 irrigation wells registered in Nebraska it would be a tall order for the state to administrate them. Despite their lack of 'fit' with aquifers, NRDs provide a means of mobilizing actors on a 'manageable scale.'

The history of Texan groundwater is instructive in terms of scales of management. Groundwater Conservation Districts (GCDs) were often based on administrative counties, showing a strong belief in private property rights, a general aversion to outsider interference (whether state or federal), and the related desire to preserve local autonomy (Dupnik 2012). Of the 98 confirmed GCDs 58% encompass a single county or less. The size of these districts also brings the issue of economies of scale and the problem of insufficient funding and areal extent, as the GCDs can have limited revenue and operational efficiency due to their insufficient jurisdictional area.

The 1997 Senate Bill 1 established PGMAs (Priority Groundwater Management Areas). These were locations that the Texas Commission on Environmental Quality deemed to be experiencing, or likely to experience within 50 years, critical groundwater problems. Such problems included shortages of surface water or groundwater, land subsidence resulting from groundwater withdrawal, and contamination of groundwater supplies. In PGMAs citizens have two years to establish a GCD. In 2001 Senate Bill 2 included the establishment of sixteen regional Groundwater Management Areas (GMAs), all composed of GCDs and serving as an administrative and managerial base for future state water management plans (Teel 2011). The state reviewed the status of the aquifers and 16 GMAs, and, by 2013, had declared eight PGMAs. The purpose of Groundwater Management Areas (GMAs) is to carry out joint planning. In 2002 the Texas Water Plan became a way to unify even further the administrative and managerial

[71] The Copiapo basin, for example, was divided into six sections "established for administrative purposes. To facilitate the formation of underground water communities, instead of having one such association for the whole aquifer, the regulator expected that it would be easier to form different water associations that would jointly manage extraction in each section" (Bitran et al. 2014). Sections are considered as separate sources and it turned out that this constrains the trading of water rights within the basin (Izam 2012) and neglects the interactions between sections.

boundaries between the GCDs by following the boundaries of Texas' major aquifers (TCEQ 2011). We can see the gradual approach to regional groundwater management, through a joint process requiring the collaboration of the GCDs belonging to a particular GMA.

In the San Luis Valley, Colorado, Sub-District 1 is located over a well-defined, hydrologically contained portion of the valley. This facilitates cooperation because by focusing on a smaller, relatively homogeneous hydrological region it is easier to model and understand the intricacies of the ground-to-surface water connection. By the same token, grouping together users sharing the same resource (and excluding users of other systems) allows the users to sense their hydrological connection to one another, producing more homogeneous interests (Cody et al. 2015). Similarly, in East Anglia, UK, catchments are divided into water resource management units (WRMUs), "which define the largest subdivision of the aquifer or catchment that can be managed in the same way" (Holman and Trawick 2011), and these units are responsible for abstraction decisions.

In the Lower Murrumbidgee basin, Australia, the aquifer has had to be divided into two local 'management areas' to restrict spatial trading (NSW Government 2009). This was in response to concerns that abstraction licenses would migrate from outlying areas with poorer groundwater availability to core areas with better availability but which would therefore be impacted. Any trading is subject to a hydrogeological assessment of the potential effect on neighboring boreholes.

In conclusion, it is apparent that the number of wells and/or the heterogeneity of the aquifer may militate for a partitioning of the aquifer into manageable and (more) homogenous sub-areas. Hydrogeological research must address relations between the aquifer and rivers (or surface water bodies in general), and possible interaction between sub-management areas. This requires substantial investment in modeling capacity. Administrative units are in principle irrelevant but political and/or pragmatic consideration may give them a role in the overall governance.

5.7 The planning approach

Although the circulation of water in the soil is invisible and more complex than on the surface of the earth, it may be possible, in some clearly delineated areas, to approximate the degree of control established for surface water (Foster et al. 2015; Van der Gun 2010). The resource is monitored quantitatively in real time, and allowable abstraction is attuned to the resource. Thresholds – or 'red lines' – are defined to make explicit the acceptable range within which the system should be maintained. This limit can be expressed in terms of groundwater levels (e.g. Beauce or Nebraska), dam storage and groundwater levels (e.g. La Mancha Oriental), or spring discharge (e.g. Edwards aquifer).

Basing the allocation planning process on such quantitative limits is not a simple matter and demands sophisticated knowledge of groundwater dynamics (Bennett and Garner 2015). As discussed earlier, situations of overexploitation have stemmed from a lack of capacity (and/or willingness) to determine and enforce acceptable limits on groundwater abstraction. The matter may be even more complex where there are different, possibly interconnected, aquifers. In order to maintain base flows, extraction from superficial aquifers could be reduced, and that of deep aquifers increased, in dry years, and the opposite in wet years (ibid.). Water quality issues might complicate the situation even further.

As discussed in Sections 3.5 and 5.2, a few cases illustrate such planning approaches. Since 2012 the Edwards Aquifer Authority has employed a system that uses a table with five successive stages of drought severity characterized by specific levels of spring flow at two major springs and aquifer levels in reference wells), to which are associated certain coefficients that reduce entitlements between 20% and 44% (Boadu et al. 2007; Charbeneau and Kreitler 2011; Debaere et al. 2014).

In the Beauce aquifer, France, a system of thresholds was introduced in 1999, together with a new system of quotas for a total annual average of 525 Mm^3 for volumetric abstractions for irrigation. The quota was divided between farms (with variations based on crop type). An integrated water resource plan for the river basin introduced in 2007 saw four distinct thresholds (ranging from 110.75 to 113.50 m) and corresponding reduction coefficients for each of four newly defined sub-basin units (Petit 2009).

In the Central Platte NRD and Lower Platte South NRD, Nebraska, if the water table falls to fixed percentages of a maximum admissible decline, successive ‘phases’ can be declared, with increasingly restrictive measures (e.g. reductions in irrigated acres, establishing spacing limits for new irrigation wells). The Lower Platte South NRD’s five 'groundwater reservoirs' are managed separately with a monitoring network and a defined drop in the aquifer serving as a trigger for a specific set of actions to be taken (as judged by the NRD) (LPSNRD 1995).

In Eastern La Mancha, Spain, groundwater-based agriculture exceeds sustainable abstraction and environemental flows are only met if surface water is released by the Alarcon dam. When storage is insufficient to allow this as well as supply to downstream areas, yearly entitlements of agriculture can be reduced by 10 to 50%.[72] Measures are triggered by a drought index that takes into consideration water conditions in reservoirs and aquifers (see CHJ 2007).

What is special, if not exceptional, about these cases? They have been made possible by several conditions.

- A legal background, in particular with inter-state sharing agreements or environmental regulations that mandate the maintaining of minimum flows in the river system, and law-enforcement capacity
- A sophisticated knowledge of the resource, relatively straightforward hydrogeology, and credible modeling capacity (in particular of surface-groundwater interactions and flows)
- Unacceptable consequences of a reduction in base flows (or drying up of the river)
- A relative equilibrium between supply and demand: irrigation is a complement to rainfall and its overall requirements can reasonably be met/regulated at a level roughly compatible with the resource (less so in La Mancha though).

[72] www.jcrmo.org/fileadmin/Jcrmo/descargas/noticias/informe_sobre_el_plan_hidrologico_2014.pdf

6 Conclusions

A recent global assessment of groundwater governance (FAO et al. 2015) has found that "legal and regulatory frameworks for groundwater have often been inadequate and their application has proved problematic […]. In many countries, non-compliance is pervasive, and in all regions pollution continues largely unchecked. The problems are weak regulatory capacity and widespread lack of adherence to the objectives and practices of regulation." This report certainly confirms this statement. It also tried to take stock of the diversity and efficacy of the policy instruments used and, while agreeing about the paucity of the "scientific evidence on which mix of policy interventions is most likely to be successful in promoting the goals of economic performance, environmental protection, and sustainability" (Megdal et al. 2015), tried to both open the black box of the 'lack of political will' and to unravel some factors enabling the effective co-management of aquifers.

Too little, too late. This short statement provides a convenient entry point to the vexing problem of groundwater governance worldwide. Unpacking the problem of groundwater overexploitation includes understanding why users and the state invariably wake up to the reality of over-abstraction only when the problem has become so severe that solving it is close to impossible; and why it is so difficult to arrive at policies or management solutions that address the problem effectively.

As with surface water (see Molle et al. 2008), governments invariably over-allocate the groundwater resources available. This may be formally – through the granting of licenses – or by default (remaining passive in the face of exploding private investment in well drilling). In many cases the boom in groundwater use (or at least its initial phase) is encouraged and often subsidized by the state. The passivity is partly due to a lack of scientific data and understanding of hydrogeology as well as to the fact that the cumulative impact of groundwater overdraft manifests itself only incrementally. In contrast with surface water, which can be exploited to the last drop but not beyond, it is almost always possible to deplete groundwater stocks a little further without dramatic short-term effect.

In many cases, however, the lack of capacity is paralleled by a lack of willingness to put an end to the bonanza. Groundwater-based economies present many advantages to the state: unless subsidized, the expansion of wells is funded by the users themselves; the resulting use of groundwater is diffuse and sometimes reaches areas deprived of surface water; operational and maintenance costs are shouldered by well owners; aquifers provide a valuable buffer against climate vagaries which have the potential to destroy livelihoods and generate social unrest. *Once overexploitation has reached a level where its impact on third-party users or the environment can no longer be neglected or ignored it is generally too late to act*. Smallholders have invested in wells to decrease their vulnerability or to intensify; investors have sunk capital into high-tech irrigation and commercial crops. Before enough scientific knowledge has been gathered to make sense of what is happening in quantitative terms, and before the legal challenges have been dealt with, the number of illegal wells has multiplied and the situation has become far worse. The most common situation is one where the unchecked drop in the water table results in diminished (and even reversed) baseflow, with impact on ecological continuity and wetlands, and growing abstraction and well-deepening costs that ultimately put small farmers out of business and reallocate groundwater to richer farmers or agribusiness (with graphic illustration in Morocco, Peru or Mexico). This non-management by default is akin to mining.

This all-too-common situation sees states, and sometimes users, occasionally in tandem, being called upon to take action against a disaster in the making. The diversity of tools in the IWRM toolbox, and (often) standardized policies are mobilized. Our review sheds light on the relative ineffectiveness of such policies, as well as the specificities of the few cases where the aquifer's balance has been more or less restored.

The registration of wells, in order to quantitatively estimate the number of abstraction points and the volume of water pumped from the aquifer, is a sine qua non of groundwater management. However, in most overexploitation situations thousands of wells have been dug or drilled without formal authorization or notification to the administration. It is often assumed that well owners will respond to administrative injunctions and come forward to register their wells. *Experience shows that regularization most often proves to be a logistical nightmare and that the states underestimate not only the time and money required to establish inventories but also the set of incentives that needs to be extended to users to offset the many reasons why they are reluctant to register*. In situations with many thousands, or tens of thousands, of agricultural users this is an *uphill battle, which can only be fought with a substantial outlay on the part of the state*, and a concomitant determination to ban the expansion of new wells. No penalty or constraint can fairly be imposed on those failing to register existing wells if, at the same time, others can drill new wells illegally yet unhindered.

A second classic policy recommendation that was scrutinized is the use of meters. While it is highly desirable to have devices that can provide managers with data on the quantities of water abstracted, meters are even more difficult to impose than compulsory registration. Groundwater users loathe the state knowing how much they abstract, particularly because they (rightly) fear that restrictions and/or taxation wil be imposed upon them. In any case, making meters compulsory is only part of the job. The data on the abstracted volumes need to be collected, which results in very high costs for the administration. If pricing or penalties are to be based on the readings, it will be extremely difficult to avoid meter tampering and/or the bribing of the field staff charged with collecting data.

In some instances it might be desirable to use proxies to estimate the use of water at a lesser cost. Groundwater consumption can sometimes be estimated based on electricity consumption, the area and the type of crops irrigated, the depth or diameter of the wells, or the horsepower of the pump. Remote sensing, especially in dry environments where irrigated crops stand out, can also provide valuable information.

In the face of groundwater overdraft, policymakers and public authorities generally combine *four major policy objectives*: 1) to increase available supply; 2) to limit or control the expansion of wells; 3) to limit or control the amount of water abstracted by existing wells; 4) to avoid the contamination of groundwater resources. *Supply augmentation tends to be the preferred option because it spreads the financial cost more thinly across all taxpayers instead of antagonizing specific constituencies by reducing the amount of water they use*. This often requires some hydrological blindness with regard to the possible impact of mobilizing or transferring additional resource (such as wastewater treatment and reuse, seawater desalination, inter-basin transfers, aquifer recharge, and new reservoirs). When supply augmentation options become prohibitively expensive the problem is increasingly akin to a zero-sum game. Reducing over-abstraction and lessening the drop in the aquifer generally means recognizing that it will be necessary to counter certain private interests, who will have to *reduce* their net abstraction. It is important to recognize the primacy of the second policy option over the third, that is, *it is illusory and nonsensical to devote efforts to curb individual abstraction by a few percent, whatever the means employed, if, at the same time, neighbors are given free rein to continue drilling illegal wells*.

Controlling the expansion of wells requires strong political will and the deployment of field staff, in addition to the capacity to impose gradual and credible sanctions on violators. Where co-management exists local users may be in a position to control expansion, which they might do in a much more effective way. Controlling and licensing drilling companies is also a way forward. *The power of the state to affect the situation on the ground is often overstated*. In many countries officials face raw power, intimidation, and the show of arms, if not violence, when visiting farms.

Reducing the number of wells (in use) can be achieved by buying them back (although this may be a legal problem for illegal wells). It is necessary, however, to ensure the wells that are bought back are backfilled and sealed. In theory, illegal wells can also be backfilled, but it is striking to note that this is only observed in a few very specific cases. *The idea that illegal wells could be closed on a large scale simply because they are illegal should be abandoned*. Further, it should be realized that this could not be done *without some form of compensation* (e.g. substitute water or the payment of a subsidy).

State-centered governance is rarely successful. Situations where groundwater overdraft has been stabilized by state action and policies are generally found in countries with strong law enforcement, where aquifers have a limited number of agricultural users and a predominance of domestic supply or industrial operators, in places where the negative impact of failing to regulate would have unacceptable consequences (typically coastal aquifers tapped for domestic water and under the threat of salinization) and, more importantly, where financial resources have allowed managers to bring in additional/substitute water.

Community-centered aquifer governance is extremely rare. While the collective management of wells can be found in many countries (although individual access to groundwater is always the preferred option, conditions permitting), managing a common-pool groundwater resource is a much taller order. Despite examples in India and Yemen, where people have endeavored to determine and enforce access rules, the more common scenario is illustrated by the destruction of *qanat* and spring systems – from Morocco to Pakistan – by the uncontrolled drilling of tubewells.

Co-management is often touted as the answer but is usually a hasty inference from the widespread failure of state- and community-centered governance rather than a conclusion based on empirical evidence. Here, too, cases of successful aquifer management are relatively rare and seem to be facilitated by an association of (some of) the 11 (non limitative) *following features*:

1) the credible threat of a 'stick measure' being applied in accordance with the law, often linked to environmental safeguards or water sharing agreements/treaties,

2) a severe drought or an environmental crisis that makes state intervention more legitimate and acceptable,

3) a limited number of users (a few thousand at most, preferably tens or hundreds),

4) the relative social homogeneity of users (and possibly bounding social capital),

5) financial means to parallel any cost/constraint with benefits of some sort (i.e. a balance between carrots and sticks),

6) a smart breakdown of the aquifer into smaller manageable parts,

7) the development of a sophisticated modeling capacity to assist negotiations, in particular better taking into consideration surface water-groundwater interactions,

8) transparency in the use and sharing of information on both the status of the available resource and on who uses it,

9) the physical and financial possibility of additional/substitute water,

10) adequate funding of the user-based organization involved in the management of the aquifer,

11) a resource that is not too degraded, where the recovery, or at least a stabilization, of the situation is a credible objective.

Point 6 emphasizes the need *to focus on critical areas and partition the aquifer* into manageable and (more) homogenous sub-areas, especially where the number of wells and/or the heterogeneity of the aquifer are high. Hydrogeological research must address relations between the aquifer and rivers (or surface water bodies in general), and possible interaction between sub-management areas. Administrative units are in principle irrelevant but political and/or pragmatic considerations may give them a role in the overall governance.

Groundwater markets are an attractive option, with only a few cases though where they have worked efficiently and effectively without creating inequalities. They require a degree of control and understanding of the hydrology that is rarely forthcoming (only recently did Australia come to terms with this complexity in the Murray-Darling basin). The more common situation, illustrated by Chile and particularly clearly by Peru and Mexico, is one where groundwater rights are traded with little control over abstracted volumes and in the absence of consistent checks and monitoring of whether sellers are actually discontinuing the use of their wells after the right has been sold. Peru and Mexico also show that the result of this mechanism is that groundwater access becomes concentrated in the hands of investors.

The 'lack of political will' syndrome, conjured up to explain the weak application and enforcement of regulations, has been investigated in some depth. It is indeed apparent that the importance of the groundwater economy in rural livelihoods is such that politicians are reluctant to take unpopular regulatory measures. An '*after me the deluge*' attitude prevails, whereby hydrological realities are ignored, short-term electoral considerations trump longer-term public interests, and political procrastination becomes a viable strategy. Syria was a dramatic case: the cancellation of diesel and fertilizer subsidies, along with continuous years of drought, made groundwater abstraction impossible for many and contributed to 300,000 farmers abandoning their land and migrating to urban areas (de Châtel 2014; Gleick 2014). It helps in understanding the reluctance and cautiousness of politicians in the region, in a post-Arab Spring age.

Yet it was also apparent that claiming to protect the 'small farmer' often served as a fig leaf for investors, corporations, and urban elites (usually close to the centers of power), who were given free rein to pump groundwater. In other cases, we found a glaring contradiction between sectoral policies, with agricultural interests driving intensification and expansion, with little consideration for the resource or environmental degradation. Permitting access to groundwater, turning a blind eye to illegal well-drilling, and bribery can be part and parcel of wider *clientelistic practices*.

Once tough policies have become unavoidable in overly degraded cases, however, substantial state funds will be required. *It is illusory to believe that situations of severe imbalances between the availability of the resource and its use can be remedied simply by top-down regulatory pressure and decrees*.

Some analysts have claimed that direct regulation by the state is ineffective and that indirect incentives and instruments are preferable (see Shah 2007 on South Asia), while others conclude that "adequate management can only be brought about by stakeholder cooperation through the appropriate institutional setting, rather than by using pure economic or command and control instruments that are more difficult to implement in the case of public goods" (Albiac 2009). Still others state that "collective management has generally come late with little or no prospect of reversing trends or stabilizing aquifers" (Moench et al. 2012: 10, on India), aside from certain community programs aimed at recharging aquifers in Peninsular India.

In all cases what is called into question is the capacity of state legislation to control groundwater abstraction. This speaks to the drivers of the infamous 'lack of political will' and to the high cost of controlling diffuse dynamics on the ground, implementing subsidy schemes, or collecting data on wells and abstraction. As a manager in Peru put it,[73] "however strict a law may be, there is always a way out of it […] when the law is made, so is the loophole to evade it."[74] The familiar statement, "we have all the best laws in our country, but the problem is implementation" should perhaps be turned on its head. Are policies 'the best', or even 'good', if they are not suited to the hydrologic and socio-political realities in which users operate? And, is it reasonable to wait for or expect due 'implementation' if practical and political conditions are not met? Acknowledging these weaknesses and shortcomings leaves us with few available options, and certainly no magic bullet.

[73] Cited in Cardenas Panduro, 2012.

[74] The phrase used in English would be "laws are made to be broken." The original quote is: "Una ley por más estricta que quiera parecer siempre deja la posibilidad de sacarle la vuelta. O como se dice, hecha la ley, hecha la trampa."

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