www.water-alternatives.org Volume 11 | Issue 3

Molle, F.; López-Gunn, E. and van Steenbergen, F. 2018.
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Water Alternatives 11(3): 445-457

The Local and National Politics of Groundwater Overexploitation

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ABSTRACT: Groundwater overexploitation is a worldwide phenomenon with important consequences and as yet few effective solutions. Work on groundwater governance often emphasises the roles of both formal state-centred policies and tools on the one hand, and self-governance and collective action on the other. Yet, empirically grounded work is limited and scattered, making it difficult to identify and characterise key emerging trends. Groundwater policy making is frequently premised on an overestimation of the power of the state, which is often seen as incapable or unwilling to act and constrained by a myriad of logistical, political and legal issues. Actors on the ground either find many ways to circumvent regulations or develop their own bricolage of patched, often uncoordinated, solutions; whereas in other cases corruption and capture occur, for example in water right trading rules, sometimes with the complicity – even bribing – of officials. Failed regulation has a continued impact on the environment and the crowding out of those lacking the financial means to continue the race to the bottom. Groundwater governance systems vary widely according to the situation, from state-centred governance to co-management and rare instances of community-centred management. The collection of papers in this issue illustrates the diversity of situations, the key role of the state, the political intricacies of achieving sustainability and establishing a mode of governance that can account for the externalities of groundwater overdraft, and the opportunities to establish cooperative arrangements.

KEYWORDS: Groundwater overexploitation, groundwater governance, water politics, water policy, wells, common-pool resources, co-management, permits, allocation

INTRODUCTION

Groundwater overexploitation is a worldwide phenomenon with worrying consequences, particularly for the environment and the most vulnerable people in society, and as yet few effective solutions. A total of 1.7 billion people are believed to live in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat from overexploitation (Gleeson et al., 2012). The advent of modern and cheaper drilling techniques and pumps has allowed irrigators to make up the shortfall in surface water or to expand irrigation in areas hitherto cultivated under rainfed conditions or even semi-arid to desert. Groundwater has also been the preferred resource of industries seeking good quality water and reliable supply, of cities, and of under-served communities. It has shifted from 'a reserve resource', strategically tapped in times of scarcity, to one that is now systematically abstracted in an uncontrolled or unregulated manner. Groundwater contributes as much as 43% of agricultural water needs (Dalin et al., 2017) and much more in arid and semi-arid regions. The magnitude of

groundwater use can be illustrated by the fact that the net amount of water withdrawn from aquifers is even contributing to rising sea levels (Wada et al., 2016).

The impacts of groundwater overexploitation are well known and well documented: they include the drying up of qanats, springs, wetlands and river base flows, saline intrusion along the coast and salinisation of aquifers, land compaction and subsidence, dropping water tables and increased abstraction costs, and growing social divides between farmers/users with the capital to deepen their wells and those without. Groundwater overdraft alters water pathways within the hydrological cycle and redistributes costs and benefits temporally, spatially and socially.

In the past 15 years or so, groundwater has emerged as a global issue, prompting several global studies and research undertakings (van der Gun, 2007), including the Groundwater-MATE project supported by the World Bank and the Groundwater Governance Project supported by several multilateral organisations (www.groundwatergovernance.org). Various volumes have compiled case studies, syntheses and reflections on cross-cutting themes (see for example Llamas and Custodio, 2002; Giordano and Villholth, 2007; De Stefano and Llamas, 2012; Wijnen et al., 2012; Margat and van der Gun, 2013; Jakeman et al., 2016; Molle and Closas, 2017; Villholth et al., 2017). Yet, 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".

Directing our focus on the process of groundwater overexploitation begs the question of how we define overexploitation. *How much is too much*? The commonplace answer hinges around the (contested) concept of 'safe yield' – an abstraction value below which the aquifer is supposed to be sustainable. This issue has been the object of many scholarly debates (Bredehoeft, 1997, 2002; Sophocleous, 1997, 1998; Alley and Leake, 2004; Kalf and Wolley, 2005; Zhou, 2009). Although hydrogeologists have raised the alarm about the '[ground]water budget myth' (Bredehoeft, 1997), unsustainable 'safe yields' (Sophocleous, 1997) and 'bathtub thinking', these scientists also admit that such misconceptions are conspicuously enduring, even within their own community (Bredehoeft, 2002). To the layman 'overexploitation' may mean ever-dropping aquifers; to those with some technical knowledge it is often (mistakenly) understood as a situation where 'abstraction exceeds aquifer recharge' – a definition taken for granted and reiterated in countless official and scientific documents.[1]

Although the diversity of aquifers makes it hard to have one single line of reasoning, aquifer systems can be characterised as underground reservoirs that exchange water between each other, with surface water bodies or the sea. They gain water through 'recharge' from percolating rainfall and seepage from canals, rivers and other water bodies. But they return water to the surface of the earth (mainly) through springs, uptake by vegetation and 'base flow' to riverbeds and wetlands (or the sea in coastal areas). In an idealised, 'undisturbed' situation the average total outflow is equal to the average inflow, with fluctuations reflecting hydrological variability. Water abstraction by humans, whether through qanats (horizontal galleries that act as 'artificial springs') or more commonly through wells (dug or drilled), disrupts this balance.

The net withdrawal results in an equivalent drop in both the outflow and the volume stored (in proportions dependent on the characteristics of the aquifer and the abstraction effort). In other words, the benefits of this net withdrawal (that accrue to abstractors) are accompanied by commensurate losses or costs: the 'losers' include the appropriators of the springs and (now reduced) river flows; the environment (wetlands, the vegetation fed by superficial aquifers, biodiversity when environmental flows cannot be sustained); shallow-well owners (who see their well run dry) and future generations (who must suffer dwindling storage and also storage capacity, as land becomes compacted). To this could be added a variety of changes in water quality and their corresponding externalities.

[1] See for example Wada et al. (2010), who state that, "if groundwater abstraction exceeds the natural groundwater recharge for extensive areas and long times, overexploitation or persistent groundwater depletion occurs".

This summary serves as a reminder that, generally speaking, *any* withdrawal actually potentially generates (mostly negative) impacts.[2] While this does not mean, of course, that no abstraction should take place, it does raise the question of 'how much is too much?', translating into the question of when do the benefits to groundwater abstractors cease to offset induced negative impacts? One must then ask who will *assess* these costs and benefits that are sometimes incommensurable[3] and often difficult to grasp due to the complexity and fluctuating nature of hydrological processes. The costs and benefits are inevitably weighed by the values and the social or political power of those concerned, which explains why costs tend to concentrate on weaker constituencies while benefits tend to accrue to more powerful actors. In other words, what is often considered a *technical* question in fact becomes a highly *political* question. We therefore loosely define 'overabstraction' here as *a situation where the benefits of groundwater abstraction and the negative externalities generated onto the environment or specific constituencies cannot be ignored and define a trade-off that warrants a deliberative process whereby costs and benefits can be weighed in a balanced way, and the decisions made are explicit and transparent.*

Our definition correlates to a warning from Custodio (2002), who pointed out the impossibility of giving a clear-cut definition of groundwater overexploitation due to the complexities highlighted above and the economic, social and political ramifications of groundwater use. He also warns that while insufficient data and understanding of hydrogeology can impair judgement, and that an emotional reaction to the word 'overabstraction' may prompt groundwater conservation policies that are not warranted. Although this is true, it is hard to find examples of countries that have overreacted to dropping aquifers, the overwhelming situation being one of passivity and laxness, and reaction only after the situation has already gone from bad to worse. The costs and implications of this inaction are in many cases hard to ignore, as water tables in many groundwater-dependent economies have dropped dramatically, making their use for certain purposes impossible, while in some semi-arid areas aquifers have simply run dry or become saline.

Arguably, the words 'warrant', 'deliberative' or 'balanced' open the way for further discussion on how they are qualitatively or quantitatively defined. But we argue that it is not possible to avoid 'interpretive' or 'qualitative' words. This is also reflected in the definitions of 'sustainable yield'[4] adopted in Australia, after prolonged discussions, of sustainable groundwater management in California's recent Sustainable Groundwater Management Act (SGMA),[5] or in India and several African countries where the safe (sustainable) yield is defined as "the amount of water which may be abstracted from an aquifer at a rate that shall not reduce the supply to such an extent as may render such abstraction harmful to the aquifer, to the quality of water or the environment". This means that 'safe yields', 'annual quotas', 'red lines' and other limits will have to be addressed and defined through political processes.

[2] Of course in a situation where outflows are abundant and little appropriated no impact is visible. Underground storage also provides a buffer that can be tapped in dry years/seasons and is replenished in wet years/seasons, when water is very (or even too) abundant. Yet in situations of overexploitation with long-term declining trends in storage the zero-sum nature of the hydrological becomes increasingly evident. Increasing evapotranspiration by using groundwater will reduce outflows/stocks and the likelihood of third-party impacts will also increase.

[3] This is despite efforts by economists to give monetary value to benefits, such as recreation, aesthetic amenities or spiritual values.

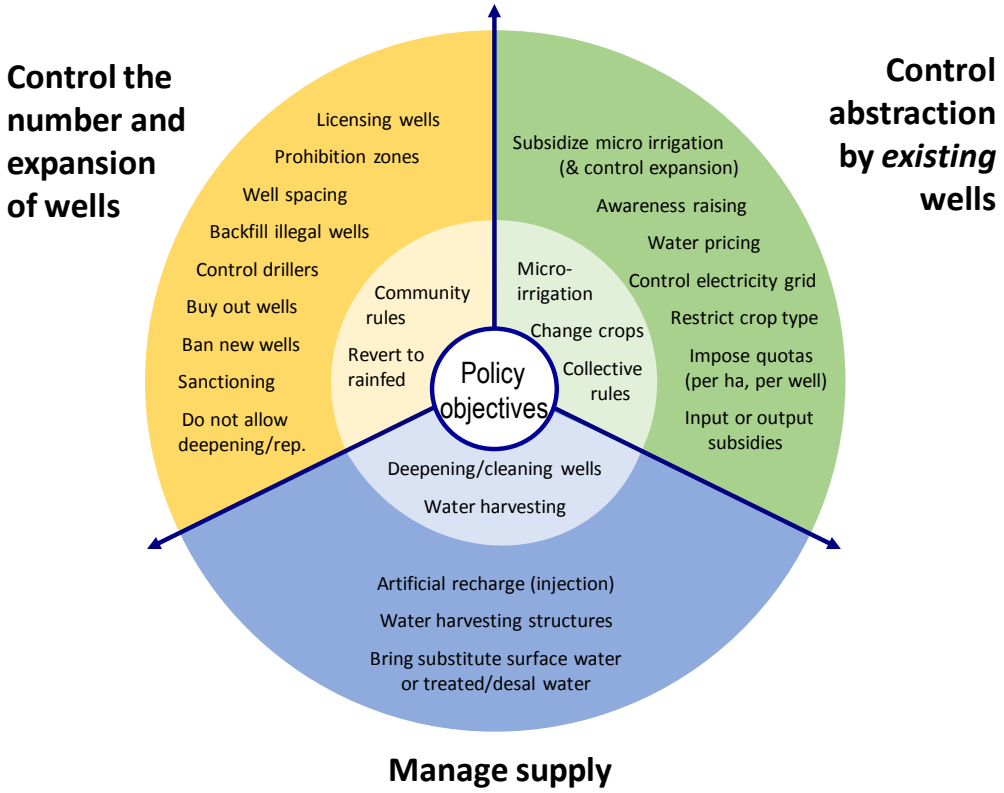
[4] "The amount of water which can be taken out of the aquifer for consumptive use while leaving enough water in the aquifer to maintain the integrity of the resource and the dependent environmental, social and cultural values. The sustainable yield is calculated as an annual rate of abstraction that could be taken over the long term and is referred to as the 'long-term sustainable yield'". www.water.wa.gov.au/__data/assets/pdf_file/0011/4601/94392.pdf

[5] "The management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results".

This political question leads directly to an examination of the governance of groundwater development and abstraction. Is the state, as the putative guardian of the public interest, better placed to establish guidelines and policies that offer ways to solve the trade-off? Are the concerned 'users', ideally together with the affected constituencies, more likely to be able to address the trade-off? Or does a form of co-management between the state and citizens have the potential to combine the strengths of the two sides? Is groundwater overabstraction a local issue or do the spatial (via the hydrologic cycle) or temporal (inter-generational) forms of externality call for its treatment at much larger scales?

This Special Issue first reflects on the politics of groundwater policy making and how state policies, laws and regulations shape the access to and use of groundwater resources. It investigates how the state – as a groundwater user but also as the confluence of various private financial and political interests – mediates and handles the conflicting interests of a diversity of actors. The state is confronted with three major challenges (Figure 1): the first is to control the digging/drilling of wells so that the abstraction capacity stays in line with the available resource.[6] This is notoriously difficult due to the diffuse and stealthy nature of digging/drilling, with ever-cheaper, more efficient and mobile technologies. The second challenge is to control abstraction by existing wells, either to make sure that it stays in line with what is expected or has been permitted or to impose reductions in abstraction when circumstances demand. The third policy objective, of a more technical nature, is to enhance supply and recharge so that the imbalance is reduced.

Figure 1. Main groundwater policy objectives and tools (Molle and Closas, 2017).



[6] This, of course, directly poses the question 'how much is too much?' discussed above.

The papers in this Special Issue also address 'policies in action' and provide evidence on implementation problems and how local actors ignore, circumvent, deflect, appropriate, cope with or adjust to state policies. What does this reveal about state-community relationships and the limits of state power? Who is impacted and how/to whom is water reallocated? What are the implications of these dynamics for policy making?

Last, a few papers shed light on various governance arrangements, ranging from co-management by the state and local stakeholders to community-based rules and institutions, as well as market mechanisms. Despite a majority of cases/countries where governance is state-centred and akin to command-and-control, instances of co-management and polycentric configurations shed light on whether and how state regulations can 'enable' local management – both in regulating access to existing groundwater resources or in promoting groundwater recharge.

THE STATE AND THE POLITICS OF GROUNDWATER POLICY MAKING

States worldwide have been slow to wake up to the challenges posed by poorly or unregulated groundwater development (Molle and Closas, 2017). They have even frequently incentivised and subsidised this development in various ways, as groundwater was seen as a means to distribute a livelihood-enhancing resource to the rural poor, with limited outlay by the state.

Tetreault and McCulligh,[7] for example, recall how during the 1960s and 70s hundreds of wells were drilled for the purpose of irrigation with subsidised credit from Mexican government banks. Taking the state of Guanajuato as an example, Hoogesteger reports that 16,500 tube wells abstract as much as 4 billion m^3 each year, with average aquifer levels falling by 2 m a year and major users deepening their wells to between 250 and 500 m and sometimes 700 m. Nabavi describes how in the 1980s, during the war between Iran and Iraq, the Iranian government began using subsidies to assist those producing food, covering between 93 and 97% of the water-pumping costs. After the revolution groundwater was seen to belong to the nation, rather than just those with enough money to drill deep wells, and access to resources was prioritised, contributing to a water crisis that is arguably reaching epic and threatening proportions. Saadé-Sbeih and colleagues refer to the Syrian agricultural policy and populist 'social contract', whereby tolerating unplanned groundwater development helped to achieve self-sufficiency in wheat and production targets that would not otherwise be met. They describe the expansion of groundwater-fed irrigation in the Orontes Basin and how most qanats dried out as early as the 1960s in the eastern part of the basin, while the springs at the eastern edge of Al Ghab Plain dried up in the 1990s, and only then did the state attempt to enforce regulations. Shrestha and colleagues discuss the drastic decline in the groundwater level in the deep aquifers of Kathmandu Valley, ranging from 1 to 4 m per year since 1984, with an extraction rate in 2001 20 times higher than the recharge.

In the face of groundwater overexploitation, states typically establish systems of permits with volumetric specifications on how a well can be used. While knowing 'who is abstracting what' seems a straightforward prerequisite to any kind of quantitative management, these policies have tended to be established without a clear understanding or anticipation of the costs and the logistical or legal difficulties involved (Molle and Closas, 2017). In Syria the first law on irrigation water, passed as early as 1958, required prior authorisation for the digging of new wells. In 1972 a law requiring a licence to use surface or groundwater was reaffirmed in 1996 and in the 2005 water law (Saadé-Sbeih et al.). In Kathmandu Valley the Supreme Court of Nepal issued an order in 2009 enforcing a licensing system to control the illegal exploitation of groundwater. Guidelines for licensing the extraction and use of groundwater specify the need for a permit, except for domestic uses of shallow groundwater. But the

[7] In what follows, authors referred to without specific date are to be understood as contributors to this Special Issue.

local Water and Sanitation Management Board has only licensed deep groundwater extractors and implementation has remained weak.

In Iran the 1983 water law repealed the former prohibition of well drilling in some regions, empowered local authorities and paved the way for the unlicensed deep wells dug during the early years of the revolution (1979-1983) to be legalised (Nabavi). One of the main rationales for issuing permits was to promote fairness of access to water. In 2006 regional water authorities attempted to stop the unabated growth of illegal wells and took to closing them. Social resistance led the parliament to terminate the programme and issue a new law in 2010, again calling for abstraction permits to be issued to illegal active wells dug before 2005. The Ministry of Energy was also made responsible for installing meters on all agricultural wells, but this failed to be implemented.

In Tanzania the 2009 Water Resources Management Act dictates that anyone wanting to "construct, sink, enlarge or deepen a well or borehole in a Groundwater Controlled Area or any other area" needs to obtain a groundwater permit from the relevant Basin Water Board (Komakech and de Bont). But the full cost of registering one well is much higher than the informal drilling of a deep borehole, and way beyond the financial capacity of most users. Only those with large abstractions and deep boreholes can afford to register, but they are sure to be granted an authorisation since permits are the main source of revenue for the Basin Water Board.

Hoogesteger has found a similar situation in Mexico, where non-agricultural large users not only need to register but pay a fee for their water use, which is also a major source of revenue for the administration. Other well-users officially have maximum water abstraction volumes, but these are not monitored or checked by the water agency (CONAGUA). In Guanajuato CONAGUA has the logistical capacity to carry out 280-320 inspections annually while the number of existing wells is estimated at 20,000. As in Iran (Nabavi) and Morocco (Del Vecchio and Barone), illegal wells have been legalised several times by politicians and bureaucrats willing to appease citizens.

The case of the Taparacá Aquifer in Chile, addressed by Lictevout and Faysse, reveals a system of water rights based on limited hydrological knowledge of the resource, a registry of water rights that is not updated, and a lack of monitoring of water right transactions, of actual use, of the type of water use and whether right holders cease to use water after selling their rights. Interventions by the administration are limited and mostly follow denunciations of alleged violations.

In other settings, such as New Zealand (Boone and Fragaszy), California (Langridge et al.) and Idaho (Du Bray et al.), Texas/New Mexico (De Stefano et al.), wells are generally known and registered, but the over-allocation and monitoring of actual use are problematic. This is even truer for the Texas High Plains, where self-regulation by districts under state pressure is only just starting to change behaviours in a region where the rule of capture prevails, few wells are metered, and the rate of overdraft is about six times the recharge (Closas and Molle).

South African legislation requires groundwater abstraction licences for quantities of water in excess of domestic or subsistence agricultural use. Cobbing and Rose-Innes explain that in the Grootfontein Aquifer combined irrigation abstraction licences significantly exceed the available annual groundwater resource. The verification and validation of water-use licences and actual use are said to be a priority but action on the ground has been very limited, in part for fear of legal action. Komakech and de Bont report that in Arusha, Tanzania, the lack of capacity to monitor compliance with the conditions attached to the water permits means that users can pump as much as they want – a situation also observed in Mexico (Hoogesteger).

In all cases where governance is centred on the state its regulation and enforcement are found to be lax. In Nepal unregulated use has continued unabated even after the formulation of regulatory mechanisms. Nabavi stresses that in Iran the reluctance to impose regulations can be understood by the state's desire to boost food production and support rural incomes and its lack of appetite to punish illegal water pumping or close wells, which come with high political costs. Iran's new plan to protect

and rehabilitate groundwater resources, while mentioning 'soft' measures such as a water market and water user associations, reinforces command and control measures (smart-metering systems on wells, GPSs on drilling machines, staff to patrol and inspect).

Governance is also about understanding the physical status of the resource. Shrestha et al. note that, in Kathmandu Valley, a lack of scientific knowledge of groundwater has adversely affected its development, management and protection. De Stefano et al. show the crucial importance of data and modelling in decision making and adjustment to legal requirements and agreements (between states, and between US and Mexico), and echo du Bray et al.'s study on Idaho to emphasize the complexities brought about by surface water/groundwater relationships. Mirnezami et al. refer to a study showing how the lack of data has led to multiple and opportunistic readings and interpretations of the water balance in the Rafsanjan Plain, Iran, by the state. Tetreault and McCully report on another telling case of the opportunistic 'adjustment' of the natural recharge of an aquifer, which was multiplied by five prior to the installation of a huge open-pit mine, one author describing an "amazing, even magical, creati[on of] water by government decree"! Saadé-Sbeih et al. describe how in the Orontes Basin hydrogeological studies justified the reduction of water consumption in the marginalised eastern dry areas rather than in the politically sensitive core areas of the basin. Lictevout and Faysse reveal how hydrological reports were heavily biased in order to justify maintaining existing water use and granting the entitlements that had been requested, while establishing a restricted area to avoid competition by possible newcomers. A high level of uncertainty in all terms of the groundwater balance, notably actual use, not only seriously compromises the implementation of a management system based on water rights but also opens the way for the opportunistic use of data. This applies more widely to many of the cases presented.

In the face of the logistical and political difficulties in effectively controlling groundwater abstraction, states have favoured capital-intensive, technological/infrastructural responses. 'Saving water' or supplying more of it have the potential to relieve pressure in the short run without having to curtail access to resources.

Drip irrigation has all the features of a 'modern' panacea against the alleged wastage resulting from the adherence to 'traditional agricultural methods of irrigation' (flood or furrow irrigation) (Venot et al., 2017; Molle and Tanouti, 2017). Del Vecchio and Barone recall that, in Morocco, the promotion of drip has been accompanied by changes in cropping patterns that tend to increase consumption and that the volume of water 'saved' by the technology is frequently used to expand the irrigated area or reallocated to other uses – a well-known counter-effect also noted by Tetreault and McCulligh in the case of Zacatecas, Mexico. Hoogesteger found that, in Guanajuato, the subsidies extended since 1996 to modernise groundwater irrigation systems have allowed an intensification of agriculture (with higher yields and incomes), but this has not led to lower pumping volumes.

The attractiveness of a 'technological fix' can sometimes have more profound ideological roots, as in the case of Iran. Nabavi underscores the "country's fascination with technology" and notes that Iranian universities rank very high globally in terms of water-related 'hard' science publications. Substantial outlays have been made to 'improving irrigation efficiency' and convert gravity irrigation systems to pressurised systems. Whether this is conducive to real water savings (in terms of reduced consumption) is the subject of debate in water policy circles.

Infrastructural solutions invariably remain the preferred option. In Iran the water-diversion tunnels from the Karoun River to the Zayandeh-Rood River have been controversial. Mirnezami et al. describe how transfer from the upper Karoun River has also been envisaged as a supply-augmentation solution for Rafsanjan Plain. Also on the agenda are the transfer of desalinated water from the Caspian Sea to Semnan in central Iran, cloud-seeding and the extraction of deep water.

Surface water transfers are the central policy response in Zacatecas, Mexico, where Tetreault and McCulligh show how dams and aqueducts not only shift benefits and costs spatially but also create

monopolies and rents over 'produced water' through the 'public-private partnerships' that introduce build, operate and transfer schemes (BOTs). The transfer is justified by the objective to restore water-table levels to 'satisfactory conditions', but it is doubtful whether this could occur while abstraction is uncontrolled. A very similar situation is described by Del Vecchio and Barone with regard to the Saïss Plain in Morocco. There, too, a new dam on the Sébou River and a transfer to the plain are presented as a means to relieve pressure on the aquifer. In other cases, such as the Pájaro District in California described by Langridge and Ansell, the technological solution is the treatment of wastewater that is meant to 'replace' groundwater abstraction. Transfers of surface water may work if abstraction is locally controlled. This is unusual but has been attempted in New Zealand, where the Central Plains Water Organisation described by Boone and Fragaszy has the capacity to enforce agreed management rules after the transfer of surface water.

Managed aquifer recharge programs are also a common supply-augmentation option that facilitates agreements as found by du Bray et al. in Idaho or discussed by Richard-Ferroudji for India. They contrast the consensual view on Managed Aquifer Recharge (MAR) in India and its strong shortcomings when it comes to implementation: a lack of communication to, consultation with, and involvement of, local communities, no preparatory technical surveys, such as risk analysis, high public cost, a lack of monitoring and impact assessment, inadequate organisation of maintenance, etc. MAR implementation may either centralise groundwater governance or open the way for more community-based management. But in many ways, MAR replicates in a new guise previous top-down approaches and collusions of interest, and "in some areas MAR structures can be seen as new pieces in the system of administrative and political corruption that already involves other water infrastructures (canal irrigation, tanks)". By placing the emphasis on a 'technical fix' it also deflects attention from political issues, such as encroaching urbanisation and illegal settlement on the recharge areas.

In sum, the case studies suggest that states have underperformed in their attempt to regulate groundwater (over)abstraction for a mix of reasons. These include poor hydrological knowledge about the characteristics and capacity of aquifers, a lack of financial and human resources to monitor actual use and control illegal drilling, legal challenges and – more crucially – a reluctance to face the political cost of antagonising rural constituencies by curtailing their access to groundwater resources. To this can be added the interests of specific, economically powerful and politically connected users, legal complexities and obstacles (e.g. South Africa, Texas and Chile) and the extraction of bribes by the administration. But not all states are the same: they differ with respect to their political capacity to act (van Steenbergen et al., 2015). Some have a broad capacity to initiate the instruments described in Figure 1; some have a tradition of effective enforcement and their presence extends to the village level, but many have neither.

POLICY IMPLEMENTATION AND LOCAL DYNAMICS

Our case studies highlight local responses and the social dynamics resulting from policies and their implementation (or lack thereof). In the great majority of the cases farmers have tried to elude regulation and circumvent constraints.

A common way to avoid punishment for illegal drilling or use is to bribe the authorities. Nabavi comments on the problem of arbitrary law enforcement and bureaucratic inconsistency in dealing with illegal water abstraction in Iran, with farmers complaining about unfairness in law enforcement and having to bribe officials or use forged licences to be able to use their illegal well. Mirnezami et al. report that, in the Rafsanjan Plain, the monitoring of wells by officials was "totally symbolic, and bribing officials was regarded as a natural phenomenon by pistachio growers". Hoogesteger also finds bribery to be a widespread practice in Mexico, along with meter tampering. Instances of abductions of inspectors by angry farmers demonstrate a perceived lack of legitimacy of state control. Tetreault and McCulligh even talk of 'institutionalised corruption', when unpacking the shoddy data and specious

arguments advanced by actors in favour of the Milpillas Dam, or documenting practices such as "granting concessions for the extraction of additional volumes of water where it is banned, tolerance of partial transfers of water concessions to cover up higher extraction rates in practice, low levels of enforcement on metering requirements and on limiting extraction rates, and on-paper changes of water availability in order to circumvent drilling bans where large investments in extractive activities are at stake". In Chile loopholes in the technical and legal apparatus organising water rights and trading have allowed practices such as the splitting/multiplication of existing water concessions through partial transfers of titles (Lictevout and Faysse).

Farmers have also implemented a series of on-farm technical solutions, including buried tubes in Rafsanjan, where some high-income growers have even resorted to desalination (Mirzenami et al.). But the most ubiquitous coping strategy is, of course, the deepening of wells. Together with the entry of new competing users, such as domestic water suppliers and commercial housing developments in the Kathmandu Valley (Shrestha et al.), this has marginalised users of shallow wells. In Yemen large farmers (often including tribal leaders) capture benefit from water access through landownership and deep tubewell drilling, further entrenching inequality (Morris-Iveson and Alderwish). In Mexico the *ejidos* and rural communities are losing access to water in the race to the bottom of the aquifers, pushing many out of production (Hoogesteger). In Syria's Ghab Valley the Agropolis project (stalled by the war) relied on the private sector for the development of the agro-industrial and tourism sectors and raised fears about land and water resources being reallocated (Saadé-Sbeih et al.). In the Pangani Basin, Tanzania, by contrast, the reduced availability of surface water resources generates competition between large-scale (foreign) commercial users and local smallholder communities and large-scale agribusinesses are pushed towards (costly) groundwater to alleviate pressure on surface water (Komakech and De Bont).

In the Grootfontein Aquifer agriculture is provoking an overexploitation that has reduced yields, in particular in the wells serving the city of Mahikeng, which has been forced to increasingly rely on the polluted Setumo Dam and to face the costs of water treatment (Cobbing and Rose-Innes). In the Texas High Plains overdraft impacts all users, as well as future generations, as Groundwater Districts 'plan' the exhaustion of their resources by agreeing upon 'Future Desired Conditions' (Closas and Molle). In the Rio Grande, groundwater abstraction to make for insufficient surface water allocations has actually further reduced surface water resources (De Stefano et al.). This has provoked tension and legal cases with regard to inter-state compacts and the sharing agreement between Mexico and the US.

GROUNDWATER GOVERNANCE PATTERNS

In addition to instances of state-centred (ground)water governance, our case studies unveil various governance arrangements involving diverse actors.

As indicated above, a theme that runs through most papers is the relative weakness of state intervention in the regulation of groundwater, whether due to a lack of means, judicial constraints, social realities or political calculus. Users are therefore not passive and can even organise to become key players. Hoogesteger reports that in 2000 in Mexico a large group of farmers united in the national *Comité Pro-Mejoramiento del Agro Nacional* (CPAN) to oppose electricity price hikes, refusing to pay their agricultural energy bill. This adds to the exemption of agriculture from paying water fees that is also zealously defended by agricultural lobbies. Aquifer COTAS (user associations supposed to contribute to the co-management of groundwater) have also often become interest groups lobbying for increased water volumes, engaging as brokers in local groundwater markets, or helping to access subsidies to modernise their irrigation systems.

Politics are also apparent in the case of Rafsanjan (Mirnezami et al.), where some local, influential families with close political relationships with the state have used their power to force the government and parliament to act against the interests of the wider public by considering a water transfer. In

Yemen sheikhs and tribal leaders often influence the siting of wells and reap the benefits of deep groundwater use (Morris-Iveson and Alderwish).

Once established free-for-all attitudes are hard to check. According to one head of COTAS in Zacatecas, the lack of oversight by authorities "is so entrenched that if water authorities were to actually attempt to enforce regulations, the result would be social conflict". Attempts to close wells in Iran have led to civil unrest, and the literature provides many similar examples of state incapacity in the face of potential political cost. In Iran (Nabavi), and many other countries,[8] farmers have learned that if they break the law and drill illegal wells, they will be exempted from penalties and their wells will probably be legalised at a later stage.

In several settings the law tends to be protective of users and hamper state action. In Rafsanjan violations are reported by the water authorities, but the judges mostly vote in favour of the violators (Mirnezami et al.). Tetreault and McCulligh report that in Zacatecas most well closures have been successfully challenged in court after inspection visit procedures were shown to be flawed. In the Grootfontein Aquifer in South Africa users may legally challenge adjustments to their water allocation (Cobbing and Rose-Innes). In Texas Groundwater Districts are constrained by the threat of costly legal cases by users that they cannot afford to face (Closas and Molle).

In the Texas High Plains state groundwater regulation and laws must contend with abstraction rights rooted in the rule of capture, a longstanding tradition of governance devolved to the county level, and the crucial importance of groundwater in the farming economy. Rather than dictate what 'sustainable' or 'rational' management means, the state's duty is to ensure that district-based Desired Future Conditions (agreed aquifer status targets by 2060) and management are compatible with objectives set up and shared at the aquifer level, and then with state-wide surface/groundwater supply planning (Closas and Molle). All in all, local groundwater users eventually wield substantial power in preserving their individual interest or maintaining the overall status quo.

Whether the state is seen to have too much power or not enough, co-management is often advanced as a solution. In Morocco the state has decided to establish 'aquifer contracts' in the main overexploited aquifers. Del Vecchio and Barone show, however, that the River Basin Agencies in charge of the initiative are underfunded and lack the authority to impose conservation policies against the Ministry of Agriculture's development drive. Although cloaked in a discourse of co-management and stakeholder participation, aquifer contracts mainly consist of supply augmentation projects. In Chile the Water Code states that a groundwater user association should be set up when an aquifer has been declared a restricted or prohibited area. These associations are expected to define abstraction rules for members, monitor use and report to the administration. However, this is rarely the case: user participation is poor and collective action is hampered by the diversity of users (from mines and commercial farmers to small landholdings) and the perception that responsibility lies with the state (Lictevout and Faysse). The Mexican COTAS are also often found to lack power (Hoogesteger).

Three papers use Ostrom's design principles and self-regulation attributes to analyse collective action or the lack thereof. Cobbing and Rose-Innes show that appropriator groups with a stake in Grootfontein groundwater have none of the 'appropriator attributes' described by Ostrom (2005). Stakeholders are heterogeneous and lack a shared understanding of the aquifer, organisational experience, leadership, trust and reciprocity. "The appropriators see no advantage in changing their current behaviour, even though the situation is in no-one's best interest". They conclude that there is a need for a convening body or organisation with adequate funds, skills, democratic mandate and legal authority to break the stalemate and existing power asymmetries inherited from the years of apartheid.

[8] See, for example, De Stefano and López-Gunn (2012) for Spain, who remark that, "in a system where non-compliance is generalised, breaching the law can seem the most rational thing to do", Al Naber and Molle (2017) on Jordan, Water Governance Facility (2013) on India and Bangalore, and Molle and Tanouti (2017) on Morocco.

Mirnezami et al. describe the early situation of groundwater management through qanats against Ostrom self-regulation variables and contrast it with the current situation. They emphasise the role of technological change in the deterioration of collective action as well as the concentration of decision-making power in the bureaucracy paralleled with corruption, the abuse of political power, and a perception of inequity. "The failure of the state to fulfil its role as a guardian of rights has annihilated any possible collaboration in resource conservation". They unpack the key challenges to pursuing a community-based management approach.

In New Zealand, by contrast, Boone and Fragaszy have found promise in the Water Management Groups (WMG) that have emerged in recent years to ensure the reliability of irrigation water supply. Local governments have increased "responsibility and authority to address cumulative effects of diffuse resource use and have increased pressure on agricultural communities to farm within environmental constraints". They illustrate how some WMGs have successfully engaged with water quality issues and broader environmental challenges while seeking to ensure members' economic viability. With time, the need for greater formalisation of WMGs and increased authority becomes a necessity. Their 'professionalisation' is also the challenge found by du Bray et al. in Idaho, where groundwater districts do not have paid staff and little enforcement authority, and also by Closas and Molle in Texas High Plains.

Langridge and Ansell examine two Groundwater Districts in California that qualify as belonging to 'polycentric' systems, where governing authorities are "disaggregated and typically composed of multiple centres of semiautonomous decision making, sometimes with overlapping functional or spatial jurisdictions that take each other into account in competitive and cooperative relationships". In the Santa Paula District water rights have been adjudicated by the judiciary and, while this may achieve sustainability, it created a closed club of stakeholders who control an existing pie of groundwater, hindering creativity in designing flexible and robust collective strategies to face evolving challenges. In the Pajaro District self-management is more advanced but it still struggles to halt seawater intrusion. These authors conclude that "the more that self-governing local units are organised as closed private units the less they will engage in wider polycentric arrangements".

Milman et al. address the recent Sustainable Groundwater Management Act (SGMA) by investigating the formation of Groundwater Sustainability Agencies (GSAs) dictated by the Act and the determinants of the choice between single basin-wide organizations or agencies coordinating across multiple organizational structures. They show the diversity of the factors involved (e.g. the weight of agriculture, the number of counties, racial diversity) in the emergence of particular governance structures and the room left by the SGMA for local-level dynamics to influence agency formation.

Du Bray et al.'s paper show the possibility of adaptive governance in Idaho, USA, in the face of 20 years of extensive litigation between surface water and groundwater irrigators and the advent of a drought. In 2015, an agreement was negotiated that led to a new policy that requires groundwater irrigators to reduce their groundwater withdrawals by an average of 13%. They review adaptive governance's attributes (representation, access to scientific and technical information, neutral facilitators, areas of disagreement between the competing parties which are made explicit, and experimentation and collaborative monitoring), stress the importance of credibility, legitimacy and a strong knowledge of the resource system and conclude with a "certain optimism for a collaborative approach to governing groundwater and preventing groundwater overexploitation in the future".

De Stefano et al. demonstrate the necessity of a better understanding of multiscalar politics and show how actions at the local state, federal or international levels are both constrained by high-level rules such as inter-state compacts, international agreements or the Endangered Species Act. But these rules are also undermined by the very local dynamics that they generate due to their insufficient consideration of groundwater-surface water interactions.

Community self-management is often hailed as a way forward, but evidence of successful cases is limited (van Steenbergen, 2006; López-Gunn and Martínez-Cortina, 2006). The paper by Morris-Iveson and Alderwish reports that communities in Yemen have been able to find creative and pragmatic ways to promote equity in the face of water scarcity and dwindling groundwater resources (see also van Steenbergen et al., 2012). They have variously controlled the drilling of boreholes, restricted banana cultivation or the selling of water to irrigate *qat*, developed water-use awareness campaigns, designed fair allocation principles, collectively reduced their irrigation during a drought or decided to prioritise drinking water over irrigation; but they have also deepened their wells, relied on piped water networks through external donor-financed projects or water tankering. Nabavi explains that in Iran the failure of the government's current command-and-control strategy makes groundwater co-management an imperative and detects a few promising examples of NGOs or farmer syndicates acting on illegal abstraction (even setting up a local water market). It highlights the remarkable ingenuity of people when faced with problems but that this ingenuity can either strengthen existing healthy institutions or make opportunistic and extractive use of weak, failing or corrupt state institutions.

In summary, the collection of papers offered in this Special Issue confirms the intractable and 'wicked' nature of groundwater overexploitation, its political and legal ramifications, the importance of accepting hydrogeology as a inherently uncertain yet evolving science, and the need for a far more nuanced and deeper understanding of the key elements promoting the effectiveness of various modes of governance, where one size does not fit all. Despite widely varied situations, an emerging conclusion is that a degree of management autonomy by users, combined with strong state guidance, holds some promise for the achievement of sustainability.

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