TEC BACKGROUND PAPERS NO. 19

Groundwater Governance and Irrigated Agriculture

By Tushaar Shah

Global Water Partnership
Technical Committee (TEC)

Global Water Partnership, (GWP), established in 1996, is an international network open to all organisations involved in water resources management: developed and developing country government institutions, agencies of the United Nations, bi- and multilateral development banks, professional associations, research institutions, non-governmental organisations, and the private sector. GWP was created to foster Integrated Water Resources Management (IWRM), which aims to ensure the co-ordinated development and management of water, land, and related resources by maximising economic and social welfare without compromising the sustainability of vital environmental systems.

GWP promotes IWRM by creating fora at global, regional, and national levels, designed to support stakeholders in the practical implementation of IWRM. The Partnership's governance includes the Technical Committee (TEC), a group of internationally recognised professionals and scientists skilled in the different aspects of water management. This committee, whose members come from different regions of the world, provides technical support and advice to the other governance arms and to the Partnership as a whole. The Technical Committee has been charged with developing an analytical framework of the water sector and proposing actions that will promote sustainable water resources management. The Technical Committee maintains an open channel with the GWP Regional Water Partnerships (RWPs) around the world to facilitate application of IWRM regionally and nationally.

Worldwide adoption and application of IWRM requires changing the way business is conducted by the international water resources community, particularly the way investments are made. To effect changes of this nature and scope, new ways to address the global, regional, and conceptual aspects and agendas of implementing actions are required.

This series, published by the GWP Global Secretariat in Stockholm, has been created to disseminate the papers written and commissioned by the Technical Committee to address the conceptual agenda. See the inside back cover for a list of publications in this series.

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FOREWORD

Groundwater irrigation has grown rapidly over the past 50 years and now supplies over one-third of the world's irrigated area. It makes a major contribution to water and food security for many millions of impoverished people across the world. Groundwater has emerged as a strategic resource, not only in many arid and semi-arid countries, but also in humid climates, because of its capacity to support intensive land use, and high-value agriculture. As a result, effective governance of groundwater is a critical and urgent challenge. But because of the complexity, variability, and uncertainty surrounding groundwater systems they have proved far less amenable to effective governance than other natural resource systems.

This GWP Background Paper is unique. It provides an excellent overview of the global groundwater economy and assesses the opportunities it offers for irrigated agriculture and also the risks it poses for depleting and degrading aquifer systems. It critically examines the various approaches that different countries have adopted for governing groundwater and assesses their wider applicability to global groundwater 'hotspots' where the need for promoting responsible groundwater use and management is urgent and critical for productivity, equity, and sustainability.

This review demonstrates that context is critical to finding solutions and each country will need to evolve an integrated groundwater governance regime appropriate to its own unique set of socio-ecological, economic, and political circumstances. It offers a three-stage approach to achieving this. The first stage is to focus on reforming perverse incentives. The second is to build governance and rule enforcement capacities. Once these are in place, the final stage is to introduce the various tried and tested administrative instruments of governance.

I am grateful to the author, Tushaar Shah, for this excellent publication. My thanks go also to the other GWP Technical Committee members and to Stephen Foster, GWP Senior Adviser, for their invaluable comments and suggestions during the drafting stages.

Dr Mohamed AIT KADI
Chair, GWP Technical Committee

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Acronyms

APFMGS – Andhra Pradesh Farmer Managed Groundwater System
BMDA – Barind Multipurpose Development Authority
CNA – Comisión Nacional del Agua (Federal Water Agency)
COTAS – Comités técnicos de aguas subterráneas (Technical water councils)
DWR – Division of Water Resources
FAO – Food and Agriculture Organization of the United Nations
GMC – Groundwater monitoring committees
GMD – Groundwater management districts
GWP – Global Water Partnership
HUN – Hydrological unit network
IBIS – Indus Basin Irrigation System
IGUCA – Intensive groundwater use control areas
IWMI – International Water Management Institute
KWAA – Kansas Water Appropriation Act
MENA – Middle East and North Africa
MT – Metric tonne
RBA – River Basin Authority (Confederacions Hidrograficas)
WfW – Working for Water
USGS – United States Geological Survey

EXECUTIVE SUMMARY

Groundwater irrigation has grown rapidly over the past 50 years and now supplies over one-third of the world's irrigated area. About 70% of this is in Asia where groundwater irrigation is making a substantial contribution to agriculture and food security, and has lifted many millions of households out of poverty. It can stabilise smallholder farming by buffering droughts, intensifying cropping, and allowing farmers to diversify and access markets for high-value crops that require year-round on-farm water control. As a result, Bangladesh is now a net exporter of rice and Viet Nam is one of the largest exporters of pepper and robusta coffee. In India, well-owning families substantially increased their income from the sale of milk, eggs, chickens, and livestock.

Growth in groundwater irrigation stems from the innovative developments in tubewell and pumping technology since the 1950s. Traditionally, groundwater use was thought to be limited to arid regions and to rechargeable shallow alluvial aquifers, such as the Ganga river basin. But it spread rapidly into more humid countries in Asia and into hard-rock areas in India's peninsular and northern and eastern Sri Lanka, where aquifer storage and yields are low. Growth has now peaked in Mexico, Spain, North Africa, and the USA. It is beginning to plateau in South Asia where it is driven more by increasing population pressure than by water scarcity. In sub-Saharan Africa, south-east Asia (in Indonesia, Viet Nam, Laos, Myanmar, and Cambodia), and Latin America groundwater use is just beginning to grow.

But this success has the seeds of potential failure built in. Unlike major public sector irrigation schemes, most groundwater irrigation is in the hands of the private, or informal, sector and is largely unregulated. There is already growing evidence in many countries of overexploitation, and irreparable environmental damage to aquifers. Shallow wells run dry, pumping costs increase, wetlands dry out, streams and river flows decline, and contamination increases, which also threatens drinking water sources. Thus concerns are growing over the long-term sustainability of this resource on which many people have come to depend.

There is no easy answer to this problem and each country faces a unique and complex mix of hydro-geological and socio-ecological circumstances that determine a nation's pathway towards sustainable groundwater development. In such circumstances, looking at the way others are dealing with this problem can be an invaluable source of support. But care is needed when transferring ideas from one situation to another.

This paper reviews this growing body of documented experience, it provides an overview of the global groundwater economy, and assesses the opportunities for groundwater irrigation and the risks it poses to aquifer systems. It surveys various approaches to groundwater governance and examines their wider application to global groundwater 'hotspots' where the need for responsible groundwater use and management is urgent and critical for productivity, equity, and sustainability. Several case studies illustrate local drivers and institutional innovations.

Groundwater has always proved difficult to manage. Management 'best practices' largely evolved in the industrialised countries, such as Australia, Italy, Spain, Mexico, and the USA, which have the scientific resources and institutional capacity. But over the past 20 years, these 'groundwater governance models', were advocated as 'blueprint' solutions for low-income countries without much regard for the vast differences in contexts. Many have taken up the various legislative and administrative instruments, but results so far are mixed and most countries have paid little attention to enforcing the rules among their farmer communities.

A review of the various 'groundwater governance models' suggests that while each has merit, none can claim to have achieved the sustainable use of groundwater. Moreover, there is little evidence to suggest that models that work in the USA or Australia will work in low-income countries, such as Bangladesh, Myanmar, and Pakistan.

What is clear, however, is that the socio-ecological and political environment is critical in determining the elements of an appropriate groundwater governance regime. What is also clear is that there is no 'one best way' to organise and govern a country's groundwater irrigation economy simply because of the many different socio-economic and political circumstances that exist. Groundwater governance is thus less about groundwater and aquifers and more about social systems, stage of economic evolution, and the society's political organisation. The governance of groundwater irrigation in South Asia is particularly complex because it involves serving many millions of smallholder, private sector farmers.

This helps to explain why different countries choose different policy instruments to govern their groundwater economies. In Mexico and the USA, only a small proportion of the population depends on groundwater for their livelihoods and so governments find it easier to impose a tough regulatory regime. In South Asia though, where over half the population directly or indirectly depend on groundwater, political and administrative leadership is reluctant to legislate and bring in tough regulatory measures. In China, strong local authority structures enable officials to experiment with pilot administrative procedures in a way that Pakistan, which has no such village governance structures, would find hard to emulate.

But many countries still pursue perverse and contradictory policies, often for political reasons, such as one arm of government offering subsidies to farmers to make groundwater abstraction lucrative while another arm is saying that groundwater use for irrigation must be curtailed.

This review highlights the futility of recommending any one way as the best way to achieve groundwater sustainability. Rather it offers a three-stage approach to evolving an integrated groundwater governance regime that fits well with a nation's hydro-geological and socio-ecological reality. The first stage is to focus on reforming perverse subsidies and policies that exacerbate resource depletion and deterioration and to look for indirect approaches to change. There are good examples of this in Barind in Bangladesh and in Gujarat in India. The second stage is to build governance and rule enforcement capacities both in government agencies and in communities. The final stage is to introduce various administrative instruments like those described in this paper. But the first and second stages must be completed before this is done. Taking account of the enabling and disabling contingencies is crucial for this stage. What may suit China may not be appropriate for Nepal or Pakistan, and the elaborate institutional groundwater management regime in Kansas may be too costly for India.

GROUNDWATER AND GLOBAL AGRICULTURE

Rapid growth in groundwater use is a central aspect of the world's water story. Shallow wells and muscle-driven lifting devices have been used in many parts of the world for centuries. In British India (which today includes Bangladesh, India, and Pakistan), shallow wells accounted for more than 30 percent of irrigated land as early as 1903, when only 14 percent of the cropped area was irrigated[1]. Groundwater is also the principal source of domestic water in towns and villages. The groundwater footprint of towns and cities increases directly with increasing population density until a threshold is reached beyond which cities are obliged to source water from distant reservoirs and aquifers. However, agriculture is by far the largest user of groundwater and as towns and cities grow, agriculture will be expected to release groundwater for servicing urban demand and other high-value uses. Agriculture will have to produce more food, fibre, and livelihoods with less water and so the future challenge will be to step up agricultural groundwater productivity.

Since the 1950s, thanks to the advent of affordable tubewell and pump technology, agricultural groundwater use has grown significantly in many arid, semi-arid, and even humid regions of the world. In Spain, between 1960 and 2000 annual groundwater use increased from 2 km^3 to 6 km^3 before it stabilised (Martinez-Cortina and Hernandez-Mora, 2003). In the USA, irrigation wells increased from 17,000 in 1900 to 407,000 in 2010[2]. Groundwater irrigation increased from 23 percent of the total irrigated area in 1950 to 42 percent in 2000[3]. In the Indian sub-continent, annual groundwater use soared from about 10–20 km^3 before 1950 to 240–260 km^3 in 2009 (Shah, 2009).

Data on groundwater use are scarce; however, Figure 1 presents a back-cast of the probable trajectories of growth in groundwater use in selected countries (Shah, 2009). In the USA, Spain, Mexico, and north African countries, like Morocco and Tunisia, total groundwater use peaked during the 1980s. In South Asia and the north China plains, the upward trend began during the 1970s and is just plateauing now in 2014. A third wave of growth in

[1] http://dsal.uchicago.edu/statistics/1894_excel (table 119) Accessed 11 September 2013
[2] http://www.ngwa.org/Fundamentals/use/Pages/Groundwater-facts.aspx Accessed 5 May 2014
[3] http://water.usgs.gov/ pubs/circ/2004/circ1268/ Accessed 11 September 2013

groundwater irrigation is now taking place in many parts of sub-Saharan Africa and in some south and south-east Asian countries, such as Cambodia, Indonesia, Viet Nam, Laos, Myanmar, and Sri Lanka (Barker and Molle, 2002; Giordano, 2006; Shah, 2009).

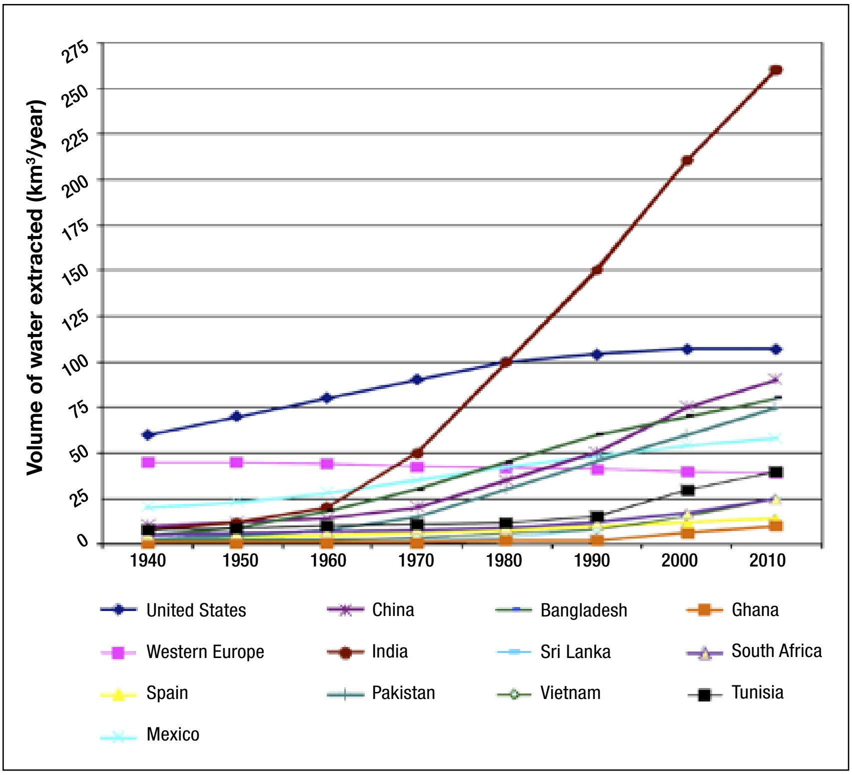

Figure 1. Growth trends in global groundwater use

The FAO estimates that more than one-third of the world's 303 million ha irrigated area is served by groundwater; over 70 percent of this is in Asia (Table 1). These estimates are based on data provided by governments of member countries. But governments often underestimate groundwater irrigation. In South Asia, it is common knowledge that groundwater-irrigated areas are seriously underestimated, and surface-irrigated areas are seriously over-estimated. For example, the 2006–2007 census of minor irrigation structures by the Government of India showed over 60 million ha irrigated using groundwater in India alone. In China, another major groundwater irrigating country, estimates of groundwater-irrigated areas are being constantly revised upwards (Shah, 2009). These data suggest that the groundwater-irrigated area in Asia is significantly greater than FAO estimates suggest. In much of Africa also, informal groundwater irrigation is booming while many public irrigation systems are stagnant (Giordano, 2006). The conclusion is that, in terms of irrigated area, groundwater is likely to be more important in global agriculture today than official FAO data suggest.

Table 1. Area equipped for groundwater irrigation

	Total irrigated area (000 ha)	Area irrigated with groundwater (000 ha)	Groundwater area (% of total)	World groundwater-irrigated area (% of total)
World	300,895	112,936	37.5	100
Africa	13,576	2,506	18.5	2.3
Americas	48,904	21,548	44.1	19.3
Asia	211,796	80,582	38.0	70.8
Europe	22,652	7,350	32.4	6.6
Oceania	3,967	950	23.9	0.8

Source: Siebert et al., 2010

THE GLOBAL GROUNDWATER ECONOMY

While globally, groundwater use in agriculture is growing, the drivers of growth differ from place to place with different implications for resource productivity and governance regimes. Recent groundwater developments have demolished the long-held belief that groundwater irrigation would only intensify in arid or semi-arid regions, such as California, Spain, and the north China plains, which, except for a shortage of rainfall and surface water, have ideal agro-climatic conditions. But the booming groundwater irrigation in humid Bangladesh, eastern India, Nepal terai, Myanmar, and Viet Nam, suggests that it has little to do with rainfall and surface-water endowments. It was also thought that intensive groundwater irrigation was sustainable only in alluvial aquifers that are constantly recharged by floods (e.g. the Ganga basin) or seepage from canal irrigation (e.g. the Indus Basin Irrigation System) and not in hard-rock aquifers with low storage and yield. But rapid expansion of groundwater irrigation in India's hard-rock peninsular, and in northern and eastern Sri Lanka has demonstrated this view is no longer valid. Henry Vaux, an American groundwater economist, has argued that in the USA "sustained depletion of groundwater aquifers is self-terminating" because rising pumping costs would make groundwater use unsustainable in economic terms. But in Bangladesh, India, Jordan, Mexico, Morocco, and Saudi Arabia, farmers organised into powerful political-interest groups and extracted energy subsidies for groundwater pumping (Shah, 2009). Overall groundwater irrigation has grown and changed in keeping with the changing socio-ecology.

There are four recognisable groundwater socio-ecologies – arid agrarian systems, industrial agricultural systems, smallholder intensive farming systems, and groundwater-supported extensive agro-pastoralism (Figure 2 and Table 2). These differ in hydro-climatic and demographic characteristics, land-use patterns, organisation of agriculture, and the relative importance of irrigated and rainfed farming. Also different are the drivers of growth and the nature and level of these societies' stake in their groundwater-irrigated agriculture.

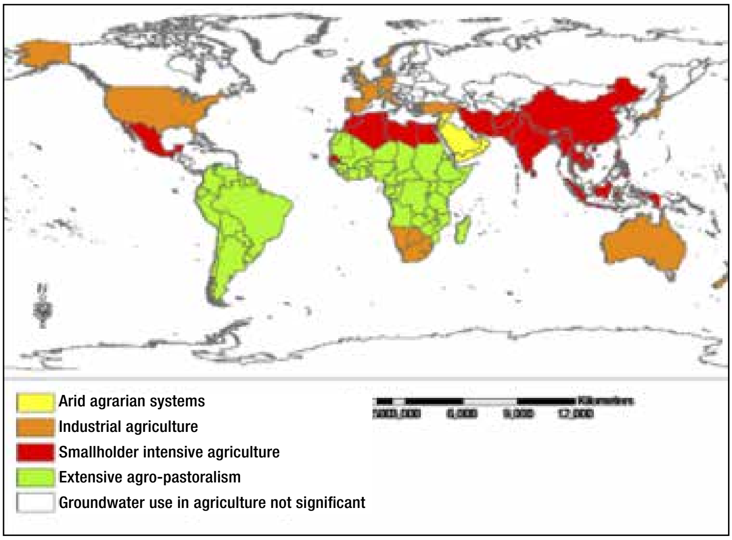

Figure 2. Groundwater socio-ecologies in agriculture

Table 2. Typology of socio-ecologies of groundwater use in agriculture

	Arid agrarian systems	Industrial agriculture	Smallholder intensive farming	Extensive pastoralism
	Jordan, Iran	California, Australia	South Asia, north China	Sub-Saharan Africa
Area served by groundwater	6 million ha irrigation	~ 15 million ha irrigation	> 7 0–100 million ha irrigation	> 500 million ha grazing area
Agrarian population/km^2 of farm land	40-50	< 1–5	300–800	10–20
Cultivated area (% of geographic area)	1–5	5–15	40–60	5–15
Irrigated area (% of cultivated area)	30–90	2–15	40–70	~5
Groundwater-irrigated area (% of geographic area)	0.1–0.4	0.001–1.5	5–25	< 0.001
Driver of agricultural groundwater use	Only source	Wealth creation	Intensive diversification	Stock watering
Groundwater contribution to poverty alleviation	Low	Very low	Very high	High

Source: adapted from Shah, 2009, p. 54

In the arid Middle East and North Africa (MENA), water scarcity is the key driver of groundwater irrigation. The challenge here is striking a balance between present versus future needs and irrigation versus urban uses of what is mostly non-renewable groundwater. In industrialised countries, such as Australia, Italy, Spain, Mexico, and the USA, groundwater in some areas suffers from depletion as well as pollution from agriculture, but it supports high-value export agriculture. These countries bring together vast financial and scientific resources and institutional capacities to agricultural groundwater management; as a result, it is here that much of today's scientific and institutional knowledge base for groundwater management has evolved and been tested. In sub-Saharan Africa and Latin America, agro-pastoral groundwater use is low both in absolute terms and relative to the available (known) potential. However, in both regions groundwater is increasingly used to support commercial and smallholder subsistence agriculture and the livestock economy (Shah et al., 2013).

All these regions face governance challenges in achieving sustainable use of aquifers. This challenge is more complex and overwhelming in monsoon Asia where groundwater is used for intensive farming by smallholders. The explosive growth in groundwater irrigation in South Asia and China is driven not so much by water scarcity, but by the relentless increase in population pressure, which has driven smallholders to intensify their land use and protect their livelihoods. India, Pakistan, Bangladesh, Nepal, and China account for more than 70 percent of the global annual groundwater diversion of around 1,000 km^3; and it is here that some of the worst consequences of groundwater over-abstraction are visible. The rise of 'water-scavenging atomistic' irrigation by millions of private tubewell owners defines the resource management challenge. Supply-side factors, such as government subsidies for pumps and electricity, have helped to promote intensive groundwater irrigation. But arguably the primary driver of expansion is the increasing population pressure on farmland, which has made intensive diversification a precondition for smallholder subsistence – something unlikely to occur in the other three socio-ecologies.

In all four groundwater socio-ecologies, intensifying groundwater use has many wider environmental and economic impacts. Where there is intensive farming by smallholders these impacts are the norm rather than the exception and cover large areas. The most common outcome is alluvial and hard-rock aquifer depletion and falling groundwater levels. This causes shallow wells to run dry and users, who share the same aquifer, must compete to deepen their tubewells, interfering with each other if they are close together, and pumping costs increase. As groundwater levels fall, there is evidence of large-scale impact as wetlands dry out, river and stream flows decline, and secondary salinisation occurs. In some cases, this increases concentrations of geo-genic contaminants, such as fluoride, arsenic, and nitrates in groundwater which many people use untreated, as their main source of drinking water. Fluoride is emerging as a major public health risk in large areas of South Asia, China, and sub-Saharan Africa. All these issues put into bold relief the urgent need for effective groundwater governance regimes that minimise these adverse conditions while, at the same time, sustain the massive poverty-reduction benefits that groundwater has produced in Asia.

ECONOMIC SIGNIFICANCE OF GROUNDWATER IRRIGATION

The boom in groundwater irrigation is the result of a strong 'demand-pull' from farmers because of the significant value added that groundwater offers over dryland and irrigation farming based on surface water. The value added comes from its 'stabilising effect' (Tsur, 1990), its 'intensification effect', and its 'diversification effect'.

The stabilising effect is groundwater's buffer role during droughts and dry spells when surface supplies run dry. The intensification effect, important in smallholder farming systems in Asia and sub-Saharan Africa, refers to the capacity of groundwater users to intensify land use by cultivating two, three, or more crops each year. The diversification effect refers to smallholders being able to access high-value markets or export crops that require year-round, on-farm water control, which groundwater wells offer. All these effects play a role in most countries. In South Asia and China, the economic value of groundwater irrigation comes from intensifying land use (Shah, 2009). In Bangladesh, groundwater irrigation enabled an additional pre-summer (boro) rice crop to be grown, which transformed the country from a perennial food importer into a rice exporter (Palmer-Jones, 1999). In many south and south-east Asian countries, groundwater irrigation made possible a new dry season crop, mostly vegetables for the market (Barker and Molle, 2002). Viet Nam became the largest exporter of pepper and robusta coffee through groundwater irrigation (Zhu et al., 2007). In India, a survey in 2004 of over 17,000 farmers showed that, compared to others, including surface-water irrigators, households with wells had, on average, 35 percent higher land use intensity, and 35 percent more milch cattle and buffaloes. Well-owning households derived 61 percent more income from the sale of milk and eggs and 86 percent more from the sale of chickens and livestock compared to those who did not own wells.

Groundwater irrigation is economically important in many high-income countries. In the USA, 67 percent of groundwater withdrawals is used for irrigation and constitutes more than 40 percent of total irrigation water supplies. The Ogalalla aquifer, accounting for a third of the USA's irrigated agriculture, is estimated to produce US$20 billion/year in food and fibre[4].

In 2004, the total annual value of the groundwater draft (for agriculture and other sectors) in the USA was valued at US$20.9 billion[5]. In 2013 in Australia, the estimated annual economic value of the groundwater draft was US$3.85 billion. The US$3.47 billion from irrigation contributed US$6.4 billion to GDP (National Centre for Groundwater Research and Training, 2013).

Groundwater is generally associated with cultivating high-value market crops. In China, a large-scale survey of farmers found that groundwater is a major source of irrigation for cash crops, accounting for 70 percent of the cotton crop, 62 percent of the oil crop, and 67 percent of the vegetable crop (Wang et al., 2009). The value added to farming from groundwater use is best demonstrated in the Mediterranean countries. In Andalusia, Spain, groundwater users applied less water per hectare compared to surface-water irrigators – 3,900 m^3 vs. 5,000 m^3. They achieved higher gross water productivity – US$3.24/$m^3$ vs. US$0.97, and increased farm output value per cubic metre of water – US$9.94 vs. US$4.6 (Hernandez-Mora et al., 2010). Another study in Spain in 2006 claimed that groundwater productivity can be as high as US$5.52/$m^3$ for peppers and tomatoes compared to US$0.28/$m^3$ for field crops like corn, sunflower, and cereals (Garrido et al., 2006). Labour can be 300 man-days/ha for groundwater-irrigated export crops and the gross value of the output as high as US$55,000/ha for irrigated strawberries and citrus. Many Spanish glasshouse growers generate upward of US$95,000/ha from groundwater-irrigated tomato production (Ramon Llamas, personal communication).

In 2008, farmers in the Jordan River valley earned net revenues from groundwater-irrigated farming of up to US$14,000–16,000/ha (Venot and Molle, 2008). In Morocco, the area irrigated by groundwater is just over a third of the area under irrigation, but it contributes nearly 75 percent of the country's exports of high-value orchard and vegetable crops. These are shipped mostly to the European Union and account for more than half of the total value added from all sources of irrigation (FAO, 2009a). However, 80 percent of Morocco's vegetable and fruit production comes from areas where groundwater levels are falling at 2–3 metres annually (Ait Kadi, personal communication. 2013).

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[4] http://www.ngwa.org/Fundamentals/use/Pages/Groundwater-facts.aspx
[5] http://water.epa.gov/action/importanceofwater/upload/21-Uddameri.pdf

Higher economic productivity of groundwater in agriculture readily converts into greater market valuation of groundwater-irrigated land. Farmers in the USA during the early 1970s, found that access to groundwater irrigation increased the value of land from US$187/ha to US$415–427/ha (Lee and Bagley, 1973). In Spain, access to groundwater rights multiplies the value of land by a factor of 1.5 for vineyards and 2 for olive trees, representing an implicit groundwater value of US$2.8–5.5/$m^3$ (Garrido et al., 2006). An earlier study claimed that Spain needed 50,000m^3 of surface water to create a farm job in rice or cotton, but only 5,000m^3 of groundwater to do so in greenhouse agriculture for export (Corominas, 2004).

Groundwater availability can add value to farm land, but depletion or deterioration can easily take away value. Groundwater irrigation across the High Plains overlying the Ogallala aquifer in the USA changed the land from marginal agricultural productivity at the beginning of the 20th century into one of the world's most productive areas. But unchecked groundwater depletion over the past century – estimated to be 800 billion m^3 – is now raising questions about the sustainability of agriculture (Konikow, 2011). Hornbeck and Keskin (2011) compared land values in Ogallala counties with neighbouring counties and estimated that sustained aquifer depletion reduced capitalised land values from US$26 billion in 1974 to US$9 billion in 2002.

Figure 3 provides a broad 'picture' of prominent groundwater-irrigation economies based on estimates of the proportion of the population dependent on groundwater irrigation for their livelihoods, the annual volume of groundwater used, and the value of groundwater-irrigated agricultural output (in US$) produced per cubic metre of water.

There are three distinct groups. First are the many low-income developing countries (such as India) where the marginal value product of groundwater is modest, but it is the basis of livelihoods for large sections of the population. Second, includes regions (like California, Morocco, and Spain), where groundwater-value productivity is high and groundwater irrigation continues because it has a large impact on commercial farming incomes and on agricultural exports. The third includes regions (like Jordan) where groundwater is often the only source of irrigation. This economic dynamic is critical to success in eliciting farmer participation in the sustainable management of aquifers. Technical interventions that fail to factor in this dynamic will have little chance of success.

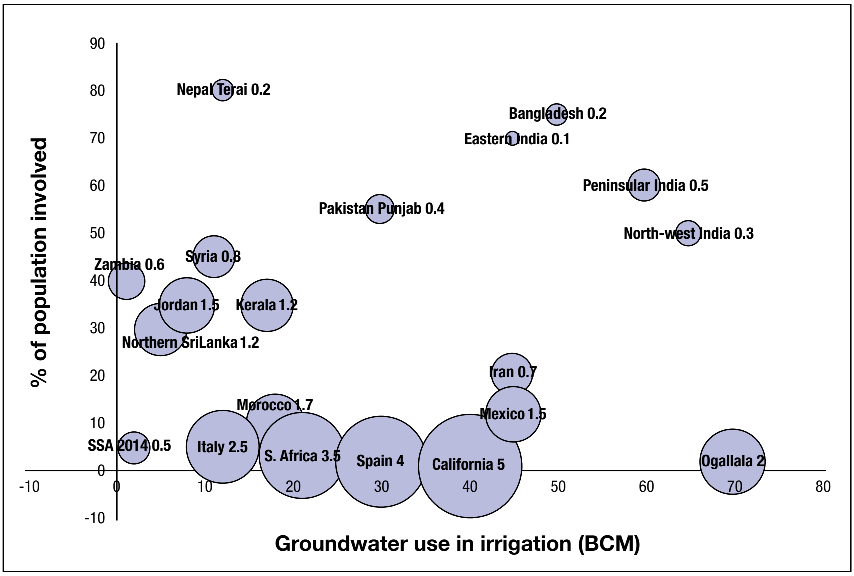

Figure 3. Prominent groundwater-irrigation economies: Volume of groundwater use (billion m³/year), proportion of the population dependent on groundwater-irrigation (%); and value of groundwater-irrigated farm output (US$/m³)

INSTRUMENTS OF GROUNDWATER GOVERNANCE

Groundwater governance discourse worldwide is a product of the growing threat of water scarcity, which has put into bold relief the critical transition from resource *development* mode to resource *management* mode. Groundwater has proved to be particularly difficult to manage relative to other natural resources. Although the western USA, Spain, Mexico, and other countries offer lessons about how to craft groundwater governance regimes, nowhere are the outcomes fully satisfactory. So groundwater governance around the world is still a work in progress.

The Global Water Partnership (GWP) defines water governance in very broad terms as 'the range of political, social, economic, and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society' (Rogers and Hall, 2003). This view explicitly recognises that the water sector is part of broader social, political, and economic development and is thus also affected by decision-making outside the water sector[6]. Worldwide, governments have used a variety of instruments to govern agricultural groundwater use. Here we briefly review the experiences with major groundwater governance instruments, each of which seeks to directly influence the actions and behaviour of users.

Administrative regulation

Governments in many countries, notably Iran, Israel, Oman, Saudi Arabia, and countries in South Asia, have often used laws and administrative regulation to control the agricultural groundwater draft. These have worked when the State is strong, has monitoring and enforcement capacity, and there are a small number of groundwater users, as in Oman. However, elsewhere, administrative regulation of agricultural groundwater use has suffered from a lack of popular support, political will, and enforcement capacity. A good example is Jordan, where from 1962 onward the government tried to regulate the groundwater draft for irrigation through a programme of licensing agricultural wells and issuing each farmer with a groundwater quota. However, the quotas were never enforced (Venot and Molle, 2008). A 2002

[6] http://www.watergovernance.org/whatiswatergovernance

by-law introduced a penalty for abstraction above the sanctioned quota, but that remained unenforced partly because of strong opposition from farmer interest groups and partly because of a lack of administrative capacity and political will. China, under the 1988 National Water Law, tried to introduce a system of permits. However, a 2005 study found these remained unenforced in most villages (Wang et al., 2009). In South Asian countries, especially India, a plethora of groundwater laws and regulations has for decades remained unenforced (Planning Commission 2007).

Economic instruments

Groundwater is a quintessential common property resource which, in the absence of appropriate governance, is liable to meet the 'tragedy of the commons'. Left to themselves, groundwater abstractors tend to increase abstraction until its marginal private productivity exceeds the marginal private cost of abstraction. But since the marginal social cost of the groundwater draft is higher than the private cost, far more groundwater will be used than is socially desirable. Volumetric pricing of groundwater is generally considered a superior method of promoting efficient groundwater use rather than using coercion or invoking compulsory purchase. In China, pricing is important for managing urban groundwater demand. Pricing works best when it is easy to measure and monitors groundwater abstractions; this is typically the case where abstractors are few and large and where the culture of a metered water supply has formed deep roots. Where groundwater abstractions are small, numerous, and dispersed, groundwater pricing becomes difficult to administer without the awkward use of force. Jordan has struggled to enforce well metering and volumetric pricing for fifty years, even though they created a 'water police'. Hence, while the principle of 'scarcity pricing' of groundwater is widely accepted, it has proved difficult to put into practice in agriculture even in the developed world. Even in southern Europe, where groundwater use for irrigation is far greater than in northern Europe, individual metering/monitoring of underground water abstraction has proved very costly and almost impossible to implement (Zoumides and Zachariadis, 2009).

A practical method is to use energy prices as a surrogate for groundwater pricing. Since the electricity used to pump groundwater is subject to government influence, it is possible to discourage groundwater overdraft by manipulating electricity prices. However, in China, India, and Iran, electricity prices are heavily subsidised, either to protect livelihoods, food security, or both. These subsidies are often the prime drivers of the groundwater overdraft. Chinese farmers in many provinces are charged only 25 percent of the normal electricity rates for pumping water (COWI 2013). In Iran, farmers pay only 20 percent of the actual cost of electricity (FAO 2009b; Soltani and Saboohi 2008). Mexico offers farmers a 20 percent discount on electricity used for pumping groundwater during the night-time. In most Indian states, farmers are charged a flat rate for electricity regardless of use, thus the marginal pumping cost of energy is zero (Shah, 2009). In all these situations, using energy prices as a surrogate for groundwater prices is likely to encounter much resistance from farmers.

In contrast, in the Mediterranean region energy prices are easier to manipulate. However, they are unlikely to have much impact, unless raised several-fold, because the value productivity of groundwater irrigation at the margin is several times higher than the cost of producing groundwater (Zoumides and Zachariadis 2009). In Cyprus, Italy, Spain, Turkey, and even Morocco and Jordan, groundwater value productivity is €1–4/m^3, making groundwater demand too price-inelastic to respond to small increases in the energy price (Garrido et al., 2006). In the Dong Nai river basin of Viet Nam a survey of 397 groundwater irrigators showed their average energy cost for pumping groundwater was high. But as it stood at 3.4–6.6 percent of the total cultivation costs, it was unlikely to have much impact on pumping (Zhu et al., 2007); the elasticity of groundwater demand with respect to irrigation pumping costs was only 0.38–0.59. Badiani and Jessoe (2010)[7], using data from 372 districts in India, found that a 25 percent increase in electricity price would reduce groundwater use by only 1.6–3.3 percent, yielding an even smaller value of elasticity than that estimated for Viet Nam (Zhu et al., 2007). However, in the USA High Plains aquifer, where groundwater is used for intensive irrigation of corn, alfalfa, sorghum, wheat, and soybeans, and pumping uses highly subsidised or free natural gas, the situation is the opposite. Here, groundwater irrigation was hyper-sensitive to energy costs. Pfeiffer and Lin (2013) estimated that a US$0.01/1000 btu increase in the price (i.e. 2.6 percent of the mean natural gas price) would force farmers to change their cropping patterns and cropped areas and decrease annual groundwater abstraction per farmer by over 127,000 m^3 – 63 percent of the average annual amount pumped. According to this study, the energy-price elasticity of groundwater demand for agriculture in the High Plains aquifer is over 24!

[7] http://www.researchgate.net/publication/228835889_Electricity_Subsidies_Elections_Groundwater_Extraction_and_Industrial_Growth_in_India

Water-saving technologies

Using water-saving technologies, such as piped water and pressurised micro-irrigation, to replace flood irrigation are the most widely accepted means of promoting sustainable groundwater use. The advantage claimed is that delivering water on-demand to the root-zone of plants can improve application efficiency by saving water lost to evaporation and the seepage associated with other methods. Whether these save groundwater in real terms at the basin scale is a subject of some controversy. At the basin scale, it is argued that only water saved by reducing evaporation and flows to 'sinks' qualifies as a real saving and that much micro-irrigation produces little real water saving in this sense. Researchers argue that micro-irrigation often delivers the same total volume of water in more frequent, but smaller, doses, thus reducing seepage which curtails return flows which can be used further downstream. Farmers often use the water they 'save' to increase their irrigated areas and so the result of using water-saving technologies has little impact on reducing the groundwater overdraft at the basin scale. This important argument draws on an old debate in economics well-known as Jevon's Paradox[8] which claims that energy-saving technologies end up achieving the opposite of what they were intended to do. Pfeifer and Lin (2013) analysed panel data for over 20,000 groundwater-irrigated fields in western Kansas from 1996 to 2005 and concluded that the shift to more efficient dropped-nozzle irrigation technology increased the amount of groundwater used[9]. The Ogallala Aquifer Initiative, which successfully reduced the groundwater draft by 1,850 million m^3 attributed 60 percent of this saving to converting irrigated land to rainfed cropping and only 33 percent to water-saving technologies (Gollehon and Winston, 2013). Despite such counter-intuitive evidence, promoting water-saving technologies is still a popular policy instrument of groundwater governance in China, India, Mexico, Spain, and the USA. There is little denying the claim that micro-irrigation can save energy and labour, reduce salt-load, and improve crop yield and quality. However, most governments have substantial budgets to subsidise the adoption of micro-irrigation, mainly inspired by the widely held belief that it can save groundwater. This, in many cases, is the figleaf used to cover tough demand-management policies.

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[8] Stanley Jevons, a 19th century economist who argued that energy saving policies end up increasing energy consumption. "It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth."

[9] See also http://www.nytimes.com/2013/06/07/us/irrigation-subsidies-leading-to-more-water-use.html?_r=0

Tradable property rights or entitlements

In the 18th and 19th centuries, 'new world' countries like Australia, New Zealand, and USA used secure property rights to encourage settlers to make private investment in land and water development. Groundwater governance evolved from the premise that users, with the help of the courts, can evolve regimes for self-governance of water resources with the state providing an overarching regulatory and facilitative legal framework. Tradable property rights in water are the basis for such self-governance. The experience of the USA in the 1990s led to aggressive promotion of tradable groundwater rights as a 'one-stop' solution for resolving the problems of groundwater mal-governance (Rosegrant and Binswanger, 1994; Rosegrant and Gazmuri, 1995; Thobani, 1996). The impact of this however, is by no means clear in the USA or elsewhere. Many observers argue that Kansas, with its well-designed institutional governance, and Texas, where groundwater is treated nearly as an open access resource, are both over-exploiting the Ogallala aquifer. The consequence of introducing tradable water rights in Chile was vigorously lauded and also roundly criticised (Bitran et al., 2014)[10]. The principle of tradable property rights can result in the better allocation of scarce groundwater. But the real deterrent is the transaction costs of enforcement, which rise in line with the number of users. Because transaction costs matter, groundwater institutions in the USA and Australia carefully exempt numerous *de minimis* users in order to reduce them to manageable levels.

If India or China were to exempt *de minimis* users following the USA or Australian criteria more than 95 percent of groundwater users would fall outside the legislation. Yet, recent experience in some counties in China to use tradable rights as an approach to groundwater governance raises new avenues for thinking about adapting this approach for a developing country (Box 4).

[10] http://ourwaterisnotforsale.com/wp-content/uploads/2013/02/ChileWaterMarkets.pdf Accessed 26 March2014.

Box 1. Groundwater governance in Kansas and Texas: two contrasting approaches

Both Kansas and Texas have large land areas, known as the High Plains, overlying the Ogallala aquifer, but each state approaches groundwater governance in different ways. Kansas has set up an elaborate regime for institutional groundwater management whereas Texas has adopted a 'rule of capture' approach.

Kansas has three institutions responsible groundwater management – the Division of Water Resources (DWR), Groundwater Management Districts (GMDs), and Intensive groundwater use control areas (IGUCA). Since 1927, DWR, through its Chief Engineer, has been the custodian of the state's waters. Until 1945, they operated on the doctrine of reasonable-use riparian groundwater rights. But in 1945, under the new Kansas Water Appropriation Act (KWAA), the state switched to a prior appropriation doctrine. This involved users applying for 'vested rights' and new rights through a water-use permit. This created real property rights for groundwater with DWR assuming the responsibility for protecting existing investments in diversion works. A 1957 amendment de-linked the property right to in groundwater from the land and made it tradable. Since then, Kansas has issued 30,000 water rights, each carrying an entitlement to withdraw a specified volume from a particular source for use for a specific purpose at a pre-specified location. This property right can be sold, but only within a radius of between 425–790 m (1400-2600 feet) from the specified location. Since 1978, unauthorised appropriation of water became a criminal offence. Five Groundwater Management Districts (GMDs) were created under the 1972 Act as membership organisations. These organisations were designed 'to allow local water users to shape their destiny with respect to the use of groundwater, as long as they do not violate the state law'. The Chief Engineer and GMDs share several powers although the former dominates the groundwater scene. GMDs intervene in a variety of ways, such as issuing moratoria on new permits, specifying and enforcing well-spacing rules, determining allowable depletion criteria, recommending to the Chief Engineer specific regulations for their domain, declaring and managing IGUCAs, and undertaking aquifer storage and recovery projects as on the Victoria aquifer.

Kansas DWR has evolved a sophisticated GIS-based system for groundwater monitoring the resource and its use. In the USA. Kansas DWR boasts of having evolved the best water reporting system based on annual returns on water-use data filed by all its permit holders. A civil penalty of US$250 is levied for failure to report. US$40,000 is collected every year in fines; and the compliance rate is as high as 99 percent. The DWR also carries out regular quality checks at various locations with support from GMDs.

The Kansas part of the High Plains aquifer, which provides 70 percent of the state's water, is being depleted annually by an average of 0.4 5m. The sustainability notion advice to developing countries is zero depletion in net terms, by limiting abstractions to the 'safe yields' of the aquifers. But in Kansas, and elsewhere in the USA, depletion and the eventual drying up of the High Plains aquifer is taken as a fait accompli; the central debate is about how fast is the aquifer is to be depleted. In regions overlying the Ogallala, managed depletion is the key goal.

Box 1. Cont.

Several questions arise from the Kansas experience. But the most critical is, "Is the elaborate institutional management worthwhile if all it does is enforce a 'depletion formula'?" Is Kansas trying to do administratively what the economics of groundwater depletion would do anyway?

Texas has a far less vigorous groundwater governance regime, but is it in any worse condition because of it? Texas has vast areas where groundwater is being depleted. It embraces the 'rule of capture', which means that a land-owner can pump at will without having liability for the consequences to other users provided: [a] there is no malice or waste; [b] it does not cause land subsidence; [c] there are no slant wells; [d] pumping does not affect the underflow of a river (but the statute does not define the underflow); and [e] pumping is not done in a Groundwater Conservation District. The consequences of the rule of capture are that the biggest pump wins, mining is encouraged, and so is water transfer out of agriculture. It has also given stimulus to political discord and led to neglect of community impacts.

Kansas, and also California and Colorado, are depleting aquifers in a 'managed' manner. Texas is doing the same in an 'unmanaged manner', and is saving the substantial management costs. Legislative response to depletion in Texas is – let the locals figure it out, except, as in Edwards Aquifer Authority, Huston Harrows County Subsidence District, or Kinney Country, where serious externalities necessitate state intervention. In Edwards Aquifer Authority 844 permits were issued for 672 million m^3 of water. These permits are enforced and water police can be called in by a farmer to prevent illegal pumping by neighbours.

The Kansas model is often recommended to developing countries. Quite aside from the fact that the success of this model within the USA itself is a subject of some debate, there is also the question of transaction costs. That these costs matter is evident in that Kansas' 1978 law exempts small users who [a] only divert up to 18,500 m^3 of groundwater annually; [b] draw water for domestic needs ; and [c] divert water for cattle herds. If these rules were applied to India, over 99 percent of the 20 million groundwater diversion points would be exempt leaving only large industrial and municipal users within the legislation, and these are already regulated. In China it would exempt 7.5 million small abstractors. If India and China were to adopt the Kansas approach significant financial and manpower resources would be needed. Clearly groundwater governance in South Asia is a fundamentally different situation from institutional groundwater management in the USA.

Community aquifer management

Mexico and Spain have adapted the USA experience of tradable water rights and groundwater districts to promote groundwater management through farmers' organisations. In Spain, the 1985 Water Act made basin-level groundwater federations responsible for resource planning and management. Similarly, Mexico's 1992 Law of the Nation's Water created aquifer management councils, known as comités técnicos de aguas subterráneas (technical water councils – COTAS) (Box 2). While the idea has great merit, the implementation of this mandate has proved to be difficult in Spain as well as in Mexico. While Mexican COTAS have played a useful role in generating information and educating farmers, their effectiveness in managing groundwater overdraft needs improvement. In Andhra Pradesh, India, the FAO-supported Andhra Pradesh Farmer Managed Groundwater Systems (APFMGS) project experimented with community management of groundwater. The project involved over 700 village communities in participatory monitoring of groundwater behaviour, in collective farm planning, and by creating an 'information-rich' local environment in the hope that awareness would influence the actions of tubewell owners. But now that the project has ended the future sustainability of the community management regime is open to question (Box 8).

Box 2. Groundwater governance in Mexico: hiatus between regulation and populism

Agriculture is the largest user of groundwater in Mexico – 18.91 km^3/year of a total of 31.2 km^3/year. By 2000, 100 of the 653 aquifers assessed were declared overexploited. Rapid expansion since the 1960s of poultry, beef, and fresh and processed fruit and vegetables for exports has led to rapid expansion in groundwater irrigation in states like Guanahuato, often with heavily subsidised groundwater pumping for the poor. All the aquifers in the state are overexploited with abstraction some 40 percent greater than annual recharge, leading to sustained annual falls in groundwater levels of 1.22–3.30 m. Well depths of 200–400 m are now common, while depths up to 500–1,000 m are reported. Pumps range from 75 to 300 HP. Annual land subsidence of 2–3 cm is reported in Bahio as a result.

In 1948 Mexico introduced a law to restrict groundwater overdraft and the number of wells in prohibited areas, called vedas, in which drilling permits were required. This law was further strengthened in 1972. But its enforcement remained lax. Moreover, illegal well owners were repeatedly reprieved by regular amnesties decreed by the Mexican president. Between 1948 and 1962, ten veda decrees were issued in Guanahuato and in 1983, the entire state was put under a strict veda. Yet, the number of wells increased from 2,000 in 1960 to 19,600 by 2000. There was an on-going battle between the need to physically control groundwater abstraction and the politicians' need to attract the farming vote. As a result, veda decrees were announced at the same time as subsidies and credit for drilling, equipment, and electricity for new tubewells. Around 2000, the electricity tariff covered just one-third of the cost, implying an annual subsidy of US$592 million. A major subsidy programme to fund land-levelling, sprinkler and drip irrigation systems, and fertigation improved the field efficiency of water use, but did nothing to reduce the pressure on aquifers, because farmers used the water 'saved' to expand the irrigated area. In 1992, the new Law of the Nation's Waters mandated a National Water Registry of newly created private

Box 2. Cont.

property rights in water. A user could not impound or divert more than 1,080 m^3 of water annually, except by obtaining a 'concession' from the Comisión Nacional del Agua (CNA – the federal water agency). All existing and new tubewells were to be registered and assigned a quantitative water right in the form of a concession. In theory, this was to give teeth to the veda, but in reality illegal tubewells proliferated.

Against this backdrop, Mexico turned to community-based self-governance through the formation of technical water councils of farmers (COTAS). COTAS were to implement a strong programme of reducing abstractions through modernising irrigation systems, relocating wells, and using treated wastewater. In formal terms, the first COTAS formed in Queretaro was to *"favour, promote, and organise inter-institutional coordination and user participation to carry out actions and programmes aimed at efficient use of water and the preservation of the Queretaro aquifer."* The CNA envisaged COTAS as institutions that would organise the participation of aquifer users to form and enforce agreements to reduce groundwater abstraction. Although COTAS were government funded they had no legal or official status or authority, or a clear mandate or structure. When Vincente Fox became governor of Guanahuato he saw COTAS as the vehicle to create a 'new water culture' by amending the relationship between the user and the resource. By 2000, 14 COTAS had been formed and the election of Fox as president of Mexico raised high hopes about COTAS charting a new course in Mexico's water governance.

During the early 2000s, Guanahauto's COTAS grew in membership. They formed 20 aquifer management committees, trained several thousand aquifer users, created a well database, identified irregular wells, and became a useful service window to access government assistance, especially groundwater concession titles and 'technification' subsidies. However, the COTAS role in groundwater governance or reducing overdraft was very limited. They were embroiled in political infighting between states and the federal government. Their representative structure was uneven; large abstractors, like municipalities and large companies, preferred to deal directly with the CNA. Since agriculture, which accounted for 80 percent of groundwater use, was not adequately represented, the COTAS had little hope of reducing abstractions. They had no authority or resources and no 'buy-in' from all aquifer users. The only support came from state funding, which meant that years after their formation, they failed to emerge into genuine, autonomous, user organisations and were overly influenced by the government water agencies.

It was only in 2002, under the new Rural Energy Law, when the National Electricity Commission began insisting on concessions before granting new electricity connections for wells, that the increase in the number of illegal wells declined. Not having concessions now meant forgoing two-thirds of the electricity subsidy. Existing tubewell owners were eligible for subsidised electricity (about 65 percent of the commercial rate) only if they obtained a concession. This pressured existing tubewell owners to secure concessions and made it very difficult, if not impossible, to drill new tubewells in areas covered by the ban. But given the impracticality of monitoring actual groundwater abstractions by farmers,

Box 2. Cont.

using 'concessions' to restrict pumping was difficult to implement. However, groundwater volumes are now translated into electricity-equivalents and electricity used above the 'concession equivalent' is charged at commercial rates. This creates a powerful incentive to reduce excess pumping beyond concessional volumes.

This powerful effect was, however, greatly diluted in 2004 when the government offered a heavily subsidised night-tariff for groundwater pumping. As a result, electricity for groundwater pumping, which is already subsidised, received an additional 20 percent subsidy for night-time pumping. This encouraged a switch to night-time pumping and significantly increased groundwater withdrawals. On paper, between 2009 and 2013, agricultural groundwater concessions in Mexico decreased by 1.96 km^3 annually, but in reality, this was not the case. In Chihuahua state, electricity use for groundwater pumping grew annually at 9.6 percent from 2004 to 2012 compared to only 4 percent from 1996 to 2004. Chihuahua continued to add new tubewell connections at a compounded rate of 3.3 percent each year from 2004. To add to this problem, the government wrote-off over US$200 million of farmers' unpaid electricity bills to mitigate drought conditions. Thus in 2009, estimated groundwater pumping across the country was 1.36 times greater than the entitled annual volumes.

The federal government also tried to create a market in groundwater rights by buying up concession titles from willing sellers. However, this only added to the problem. Many farmers with dry wells sold their titles and used the money to deepen their wells and many others sold part of their concession, but kept pumping as before. Urban developers bought farmers' concessions and drilled in the same aquifer; but farmers continued to pump their wells too. Without real-time monitoring of groundwater withdrawals by title-holders, the market in titles has only served to increase the groundwater overdraft.

Supply augmentation

Developing alternative water sources or augmenting groundwater recharge are effective and time-tested approaches for easing pressures on stressed aquifers. In the western USA, imported surface water, supplied in lieu of groundwater pumping, was a central feature of groundwater governance for decades. The central Arizona approach is one example, but there are many other federally-supported projects that import surface water to ease the pressure on and/or recharge groundwater aquifers. Spain's much-proposed water transfer project from the Ebro River, China's south-to-north water transfer project, and India's proposed project to link Himalayan rivers with peninsular rivers are all inspired in part by groundwater depletion and stress. The fact that this supply-side initiative is used more widely signifies the huge difficulties in implementing demand management of groundwater in developing countries.

India has experienced 'mass movements' as a powerful response among people to recharging groundwater depletion in some hard-rock aquifers where rainfall is reasonably good. In the Saurashtra-Kutch region of Gujarat, covering some 99,000 km^2, spiritual preachers and gurus with mass followings exhorted rural people to take their destiny in their own hands and divert floodwater, after filtering, into their large open wells. "You quench the thirst of mother Earth; and she will quench yours." (Shah, 2000). Some faithful disciples followed the gurus' advice and benefited. In the following years, decentralised groundwater recharge through new check dams, percolation ponds, underground dykes, and open well recharge, developed into a mass movement. The government actively supported this, industry contributed by offering free cement, and Foundations offered free earth-moving equipment. Studies showed that the total addition to groundwater resources was modest; but its socio-economic impact was dramatic because it ensured the main monsoon crop and, in years of a good monsoon, it also offered winter and summer irrigation (Shah, 2009). Eastern Rajasthan had a similar mass movement with similar results (Shah, 2009).

In Morocco, a recent innovation used supply augmentation as the basis for introducing demand-side management (Box 3). In the Souss region, groundwater depletion and repeated droughts forced farmers to uproot high-value citrus orchards, especially in the Elguerdane area. The government responded with an innovative project, under a public-private partnership with a 30-year 'build-operate-transfer' contract, to transfer 45 million m^3 of imported surface water for conjunctive use with groundwater. The project will supply 50–70 percent of crop water requirements through piped distribution. The farmers will share 40 percent of the capital cost and pay volumetric water charges. In addition, an aquifer management contract, based on wide consultations, will also control new wells and boreholes, the expansion of orchards, adoption of micro-irrigation, irrigation scheduling, and awareness building. The intervention involves three innovative ideas. First, it combines aquifer management with importing surface water. Second, it seeks voluntary compliance in place of policing. Third, it adopts an integrated approach to agriculture and water management by combining several regional initiatives (Ait Kadi, personal communication, 2013).

Box 3. Groundwater governance in Morocco: the crisis in a coastal aquifer

Morocco's 1,200 km^2 coastal Chaouia region has emerged as a zone of tension between farmers' survival and the sustainability of aquifers. Groundwater irrigation has grown three-fold between 1970 and 1996. Many farmers rented or purchased land and drilled boreholes while some set up partnerships with neighbours who owned a usable borehole. As result, groundwater overdraft is growing in Souss, Tadla, Berrchid, and Saiss. In the Chaouia aquifer, the overdraft has led to saline intrusion and fresh groundwater has become increasingly scarce making irrigation difficult. The annual groundwater deficit in the aquifer is some 10 million m^3 and to date there is no sign of this easing. Some farmers have installed pipelines to draw water from the Oum Rbia River some distance away to try and augment the supply. One farmer installed a distillation plant to clean up saline groundwater to irrigate cut-flowers for export.

During the 1980s, and as recently as 2010, local authorities have tried to control excessive borehole drilling. However, a series of droughts so threatened the local economy that the regulations were abandoned. Two catchment management agencies are responsible for managing the aquifer. But in reality all these agencies can do is to monitor piezometric and salinity levels. Supporting adaptation of the aquifer economy to a groundwater crisis has persisted as a 'wicked problem' with no perfect problem formulation or a clear-cut first-best solution.

Box 4. Experiments in groundwater governance in China: government-directed community management[11]

Attempts at direct regulation of groundwater demand through administrative measures, bans, licensing and permit systems, pricing, and other means have been tried, but faced major implementation problems. However, researchers have documented recent experiments in direct regulation by some local governments in the north China plains that appear to have met with success. Aarnoudse et al (2012) documented a pilot in Minqin county in Gansu province. Zhimin and Baojun (no date) documented a pilot in Zhonggao Village in Taocheng District of Hengshui City (Hebei) which was expanded to 21 villages and showed that groundwater draft was reduced by 20 percent in one year. He and Perret (2012) reported a similar experiment in Quinxu county in Shanxi province. Both involved similar institutional innovations in which strong local governments successfully implemented government-directed community groundwater governance involving fixing groundwater quotas (akin to Mexican concessions), using pre-paid smart cards, and progressively increasing electricity prices as a surrogate for groundwater price.

These pilots imposed a regime in which farmers are faced with high and steeply rising marginal social costs of groundwater withdrawal. Normally, for common property natural resources, like groundwater, private users would expand groundwater use until the private marginal benefit becomes equal to the private marginal cost of producing the resource. However, the marginal social cost of groundwater withdrawal is much higher than the mar-

[11] Case study based on Aarnoudse et al. (2012), He and Perret (2012), and Zhimin and Baojun (no date)

Box 4. Cont.

ginal private cost. So society can achieve sustainable resource use by imposing a tax on the groundwater draft so that groundwater withdrawal is restricted to what is socially optimal.

In 2002 the Water Law of China declared groundwater a state property; and in 2005, the central government issued 'Suggestions on strengthening the development of water user associations'. In Quinxu county, with 193 villages and 24,500 ha of groundwater irrigation, the overdraft in recent years was 125 percent, resulting in an annual fall in water level of 1.6 m. In order to implement these suggestions, the county government modernised all irrigation wells and equipped them with pre-paid smart card readers. Water quotas were fixed for various sectors, townships, and villages, and within them, for farmers. The village water user committee, with members paid a special honorarium, was responsible for administering, monitoring, and enforcing water quotas, collecting water charges, and the maintenance and upkeep of the irrigation infrastructure. A 'water price ladder' – differentiated for the domestic, industrial, service, and agriculture sectors – was enforced. The price of water increased by 50 percent for up to 30 percent excess withdrawal over the quota, by 100 percent for 30–50 percent excess, and by 200 percent for over 50 percent excess. The quota allocation, the fixing of the water price, and the progressive electricity cost (as a surrogate for the groundwater price) per mu (about one-fifth of a hectare) for different levels of water use in three villages were studied by He and Perret (2012). In addition to the metered electricity costs, farmers are also required to pay the salaries of the O&M staff (IC cards manager, accountant, cashier, and staff maintaining the pipelines and wells) and maintenance charges. In the three villages studied, these annual costs ranged from US$7,500–10,000. In sum, much of the groundwater governance was done by the water user committee and the local government, while farmers paid the bills and accepted the outcomes. He and Perret (2012, p. 11) concluded: "This case is a successful model, but not all …regions …can copy these experiences. Government dominated … in the administration domain, but also in market and civil society domains. Government helped to establish the market mechanism through pricing… and helped to establish the self-governance …at village level."

In all three pilots significant investment in modernising groundwater irrigation preceded institutional reform. In the Zhonggao village of Taocheng, farmers were provided US$120–240 (RMB750–1,500) per ha to invest in a piped water supply, land levelling, and making some 300 furrows per ha for efficient irrigation. In Minquin, 3,000 of the 7,000 wells were closed by sealing and de-electrification; the remaining 4,000 were modernised and fitted with smart card readers. Aarnoudse et al. (2012) found that not all wells were fitted with card readers. For wells without card readers, access was controlled though keys that were kept with the committee.

In Hebei, where a 20 percent decline in groundwater draft was reported, 1 million m^3 of groundwater and US$40,000 (RMB250,000) of electricity were saved and the rate of decline in the water table fell from 2 m/year to 1 m/year (Zhimin and Baojun, no date). In Minquin the new groundwater regime served to expand the growing army of 'ecological refugees' who had begun leaving their farms for towns and cities to escape the groundwater crisis, reducing the farming area by 40 percent from the 2007 levels. In keeping

Box 4. Cont.

with the government policy of 'close the wells, abandon the land', farmers moved on to non-farming livelihoods. The farmers surveyed had lost an average of 0.231 ha/household of farm land (Aarnoudse et al, 2012).

Progressive pricing of groundwater irrigation in three villages of Qinxu county, Shanxi

	Unit	Oingdepu	Xihuaiyuan	Xiaowang
Quota for village	10,000 m^3	70	98	50
Quota/mu (ha)	m^3	240 (3,582)	240 (3,582)	180 (2,687)
Groundwater lifted/kWh	m^3	1.4	1.8	1.5
Price within quota	US$/kWh	0.091	0.072	0.101
Irrigation cost/mu1 with allocated quota	US$	21.8	17.3	18.2
Irrigation cost/mu1 with 125% of allocated quota	US$	36.9	28.8	24.5
Irrigation cost/mu1 with 145% of allocated quota	US$	45.6	39.0	33.41
Price for withdrawals < quota + 30m^3/mu	US$/kWh	0.123	0.0	0.109
Price for withdrawals < 1 quota + 30m^3/mu	US$/kWh	0.131	0.121	0.128

1 1 mu is approximately one-fifth of a hectare

Conjunctive-use management

Different approaches to groundwater governance are needed for 'groundwater-only' irrigation and 'conjunctive-use' irrigation. GWP (2012)[12] explores the technical options. Here, the focus is on approaches to groundwater governance to improve conjunctive management of surface water, groundwater, and salinity.

The Indus Basin Irrigation System (IBIS), encompassing Pakistan Punjab and Sind, and the Indian states of Punjab, Haryana, and Rajasthan, represent a peculiar class of groundwater depletion problems in the midst of canal command areas. From 1850 these dry areas began supporting vibrant irrigated agriculture as vast areas were brought under canal irrigation. In recent decades, massive expansion in private tubewell irrigation has created large and growing pockets of groundwater depletion while other areas face water logging and secondary salinisation. One instrument of sustainable groundwater management lies in curtailing the use of surface-water supplies in water-logged areas and augmenting it in groundwater-depleted areas. A

[12] GWP (2012) Groundwater Resources and Irrigated Agriculture No. 4

major limitation, however, is the salinity in the water and soil (Evans and Evans, 2011). In many saline areas in the IBIS command, farmers demand surface water primarily for blending with saline groundwater (Box 5).

Box 5. Conjunctive management of surface and groundwater: by design rather than default in the Indus Basin Irrigation System

The 14 million ha Indus Basin Irrigation System (IBIS) – the so called 'Indus Food Machine' – is by far the best example of the potential of what planned conjunctive management can achieve in terms of improved land-water productivity and ecological resilience. IBIS produces 9 million MT of rice, 23 million MT of wheat, and 10 million bales of cotton in a landscape that was a desert until 1830. During the 19th and early 20th centuries, water allocations from the Tarbela dam were regulated through a system of canals and by an intricate system of water rights administered through a 'wara-bandi' system. Over time, the wara-bandi system has weakened, as has the everyday operation of canals and the distribution system. The resulting loss of reliability and equity in canal water supplies would normally have seriously impaired the overall socio-economy, food security, and environmental sustainability of the system. However, the growth in groundwater irrigation, with over 1 million shallow tubewells, enabled farmers to minimise the impacts of institutional and managerial decline. Shallow tubewells recycle canal seepage and deliver over half of the water supplied on-demand, thereby countering the unreliability of canal water allocations. Thanks to this spontaneous conjunctive use of canal and groundwater, cropping intensity now exceeds 200 percent turning IBIS into the Indus Food Machine.

There is nothing formal or planned about this development and so the opportunities for expanding basin-wise gains from planned conjunctive management remain untapped. This is particularly true in Sind province at the tail-end of the Indus System where excess canal water has caused water logging, salinity, and loss in productivity. Decades ago, Sind would receive canal water only during the wet season. Now, however, Sind's water allocations are 50–150 percent larger than the Punjab; canal water flows during the wet as well as the dry seasons, and keeps vast areas water-logged. The damage this was doing came into bold relief during the 1998–2000 drought when canal supplies to Sind shrank, groundwater use soared, the water-logged area fell from 2 million ha to 250,000 ha, and Sind farmers harvested record crop yields. No better proof was needed to show that Sind agriculture would boom if only it spread its surface-water allocation on 0.5 million ha of dry land. But as soon as the drought ended, Sind fought for its higher water allocation which increased the water-logged areas and in turn reduced its agricultural water productivity.

The mirror image of Sind is south-west Punjab and Rajasthan on the Indian side. Low-lying pockets in the south-western districts of the Punjab, such as Muktsar, Fazilka, Bhatinda, and Faridkot, irrigated by the Sirhind canal, face severe water logging and secondary soil salinisation. There is too much surface water and too little drainage. A master-plan to tackle the problems includes lining the Sirhind canal and Rajasthan feeder, promoting diversification of farming systems with emphasis on commercial dairying and aquaculture, and bio-drainage through eucalyptus plantations[13].

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[13] http://www.thewaterchannel.tv/index.php/thewaterblog/138-managing-mega-irrigation

Conjunctive use could provide a solution to some of the problems in the vast 800,000 km^2 Ganga-Brahmaputra-Meghna basin, encompassing Bangladesh, India, and Nepal where flooding is the main problem. The basin receives some 1,350 billion m^3 of snow melt and rainwater every year. But over 80 percent of this comes in just four months between June and October with no scope for storage. Every monsoon, overflowing rivers and tributaries flood large parts of eastern India and Bangladesh. But dry season flows in the Ganges system are too small to meet the needs of the basin population. One possible solution, which has been discussed for decades, is to view the basin as the 'Ganges water machine'[14] (Revelle and Lakshiminarayana, 1975). Developing groundwater irrigation would pull down groundwater tables and create space in the deep alluvial aquifers to absorb monsoon floods. In addition, spreading channels in the terai areas, check dams across streams, and a network of 'leaky' canals would recharge the Ganges water machine during the monsoon. This is another side of the conjunctive management of surface and groundwater (Foster and Steenbergen, 2011).

Indirect instruments – energy pricing and rationing

Often, groundwater demand can be more sustainably managed by intervening outside the groundwater economy. The Ogallala Aquifer Initiative reduced aggregate groundwater draft more by providing incentives to convert irrigated lands into grasslands than any other direct measure. In the Canary Islands, the tourism sector was allowed to buy irrigation wells (Garrido et al, 2006). China's new programme to shift 250 million of its rural population to urban areas[15] may do more to ease pressure on groundwater in the north China plains than any amount of groundwater regulation. Likewise, moving India's rice-wheat system eastward by reforming perverse incentives, such as free electricity and artificially high procurement prices of rice and wheat for farmers in the north-west, can do much to alleviate groundwater depletion in Punjab, Haryana, Rajasthan, and western Uttar Pradesh (Rodell et al., 2009). In a bid to improve rural electricity supplies, many Indian states, led by Gujarat, have separated feeders taking subsidised power to tubewells from others that serve non-farm consumers (see Box 10). Such feeder separation has helped governments to ration the power supply to tubewells and thereby put an effective cap on the groundwater draft (Shah and Verma, 2008).

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[14] http://www.khosla.in/pdf/The%20Ganga%20Water%20Machine.pdf Accessed 21 March 2014

[15] http://www.nytimes.com/2013/06/16/world/asia/chinas-great-uprooting-moving-250-million-into-cities.html?_r=0

Indirect instruments – managing land use changes

Land use changes in favour of tree plantations can significantly influence groundwater use. In countries like Australia, tight control over tradable water allocations to various users determines who gets how much water. But an increase in land planted with trees can increase interception, just as farm bunds, boreholes, and structures store overland water flows, and they distort the integrity of the water allocation system. This is because groundwater transpired by deep-rooted trees reduces flows into the river system and the water available for allocation. This has emerged as a major concern in Australia where the government plans to provide incentives to farmers to grow tree plantations to serve as 'carbon sinks'. The proposed incentives may entail a major change in land use that threatens the stability of water allocations. One solution is for farmers, who plant trees, to offset the impact of their plantations by surrendering water entitlements equivalent to the estimated water used by trees or opt out of the allocation system all together (Young and McColl, 2009). To recognise the benefits of forests as carbon sinks, the entitlement to be surrendered should be reduced appropriately by a kind of 'climate change insurance premium'. But this solution will only work in an institutionally advanced water governance regime such as that in Australia.

In many societies, natural wild tree growth can be a major source of 'interception' accounting for a significant portion of total water use. In South Africa, some 200 invasive alien wild tree species transpire groundwater without creating any value. They cover some 10 percent of the land mass and their growth is exponential. They are perceived to 'waste' about 7 percent of South Africa's water annually, impeding farming and irrigation, intensifying floods and fires, causing erosion, destroying rivers, increasing siltation of dams and estuaries, and promoting poor water quality[16]. In 1997, invasive alien tree species reduced mean annual river flows by an estimated 3.3 billion m^3. The country's 25-year Working for Water (WfW) programme, engages over 200,000 people in removing alien trees, and is expected to save water and is considered critical for water security[17].

Rice paddies are seen by some as a problem and a solution by others. In north-western India and Pakistan, rice irrigation supported by perverse output and input subsidies is a major driver of groundwater depletion. These

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[16] http://www.watershedconnect.com/documents/files/working_for_water_pes_in_south_africa.pdf
[17] http://www.dwaf.gov.za/wfw/

regions are advised to wean their farmers away from rice irrigation towards more sustainable agriculture. In contrast, the city of Kumamoto in Japan was awarded the 2013 UN Water-for-Life prize for reviving irrigated rice paddies as a principal means for increasing groundwater recharge (Box 6).

Box 6. Rice paddies and groundwater depletion: a problem as well as a solution?

In Indian and Pakistan Punjab, groundwater depletion is blamed on rice irrigation. Irrigating a hectare of rice can take up to 12,000 m^3 of water in South Asia's hot summers. In 2013, India exported nearly 7 million MT of Basmati rice valued at US$9 billion[18]; the equivalent of exporting 25–30 billion m^3 of groundwater. In 2008, the Punjab government banned the planting of rice nurseries before 10 May and transplanting before 10 June. In 2013 this reduced the annual rate of groundwater decline by 30 cm, 65 percent of the long-term average annual rate of decline, and saved 275 million kWh of electricity (Singh, 2009). Studies suggest that groundwater levels in north-western India can be restored to pre-development levels by weaning the region's farmers away from the rice-wheat system that is depleting its aquifers.

In Kumamoto, Japan, groundwater pumping is a solution which won the UN's Water-for-Life award for best practices in 2013[19]. Kumamoto is a city of 730,000 people and is supplied wholly by groundwater, which today is so clean that it is offered without any treatment as natural spring water. Kumamoto today is known as the 'home of the richest groundwater in Japan'. But this was not always so. Some 400 years ago, a local overlord promoted numerous rice paddies in the alluvial low-lands along Shirakawa River. These became excellent recharge structures for the weathered rock aquifers to a depth of 100 m. Paddy fields in the middle-basin areas of Shirakawa River recharge 5–10 times more than those in other areas. These age-old rice paddies, dried up as rice cultivation became unprofitable and the government began discouraging rice irrigation during the 1970s and 1980s. Moreover, urbanisation covered most spaces in and around the city with concrete and asphalt impeding natural recharge. While recharge declined, rising industrial and household demand increased groundwater withdrawals.

Around 2000, Sony operated a groundwater-intensive semi-conductor plant and took the initiative, in collaboration with the municipality and local NGOs, to enhance Kumomoto's aquifer. To enhance recharge, Sony provided incentives to farmers to flood their converted paddy fields with water from the Shirakawa River for up to three months, between May and October, when their land was free of crops. Payment, at a rate of US$110 (JPY11,000) per 1,000 m^2 – was linked to the length of the flooding periods. Since every kilogram of rice was estimated to recharge 20–30 m^3 of groundwater, Sony began buying rice from its partner-farmers at a premium (JPY430 as against a market price of JPY300) and serving it

[18] http://www.airea.net/page/57/statistical-data/rice-export-from-india Accessed 28 March 2014
[19] http://www.un.org/waterforlifedecade/winners2013.shtml Accessed 28 March 2014

Box 6. Cont.

in its cafeteria. Employees were invited to buy partner-farmers' rice, marketed under the brand 'Gift of Water', and thereby contribute to groundwater recharge. By 2009, against its accumulated draft of 9.8 million m^3 of groundwater, Sony had recharged an estimated 11.6 million m^3, thus turning Sony into a groundwater positive company. Besides the ecological service of groundwater recharge, flooding also created other positive externalities, such as limiting weeds, insects, and diseases. Spring waters in Lake Ezu have also shown an upward trend suggesting increasing groundwater levels. Following Sony's success, several other companies joined the effort and Kumamoto city incorporated groundwater recharge as part of its five-year environmental plan.

Sony's schedule of payments to partner-farmers for groundwater recharge

No of days of flooding	Area of the rice paddy (m^2)	Payment for recharge (JPY)
30	1,000	11,000
60	1,000	16,500
90	1,000	22,000

GROUNDWATER GOVERNANCE EXPERIENCES

Countries have evolved their groundwater governance strategies based on their unique combination of social, economic, and environmental circumstances and a blend of the various instruments outlined above.

In the USA

The United States Geological Survey (USGS) defines sustainability in groundwater as the "use of groundwater in the manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences"[20]. The USA has pioneered in facing the environmental fallout of intensive groundwater irrigation as well as in devising ways to minimise or counter its impact. As a result, its experience in groundwater management has held sway over global discussions on how other regions of the world – South Asia, North China, Mexico, Spain,– can rein in their over-exploitative groundwater irrigation economies and make them sustainable in the USGS sense.

Western USA has a 150-year history of extensive groundwater-irrigation development and this has been fertile ground for technological and institutional experiments in groundwater management. Various states have tried a mix of several approaches to respond to groundwater overdraft, including forming groundwater districts; buying-out groundwater rights from farmers; supplying imported surface water in lieu of groundwater pumping; and notifying 'active management areas' where a 'water master' is appointed to undertake direct administrative/legal action by courts.

Reducing groundwater depletion in the western USA has often meant reducing areas irrigated with groundwater. In the mid-1990s, Colorado State forcibly decommissioned about 1,000 irrigation wells, and Idaho purchased water rights from irrigators and closed 2,000 wells. In Colorado, some wealthy irrigators reacted by organising small water management groups, but other irrigators stopped farming or switched to rainfed crops, and supplemented their incomes with non-farm activities. In Idaho, groundwater pumping from increased depths became so expensive that irrigators were

[20] http://wellowner.org/agroundwater/gwsupplyanduse.shtml Accessed 22 December 2013

ready to have their operations bought out. But in both cases it is costing the American taxpayers millions of dollars to buy back water rights that the state had given away for free to begin with (Kendy, personal communication, 2005). Similarly, in California, in areas where overdraft is apparent, mechanisms such as 'water banking', artificial recharge, and water allotments, are used to protect the aquifer. In some of the more affected groundwater basins the courts were asked to decide how groundwater is to be allocated to various users. There is no 'one size fits all' solution to these problems (Reay, John, R.G. personal communication). The states overlying the High Plains aquifer have each adopted different water allocation laws and management tools and yet they face similar issues in dealing with declining groundwater resources.

Groundwater governance varies greatly across the USA. According to Henry Vaux, a senior economist from the University of California, out of 431 groundwater basins in California, only 19 are 'actively managed', implying some restrictions on pumping. Groundwater management is passive in all the others and essentially involves providing federal government grants to build infrastructure to import surface water and supply it to groundwater users in lieu of pumping. In 412 basins, nobody is expected to reduce groundwater use. In Blomquist's 1992 book, Dividing the Waters, he explored eight groundwater basins in California and the somewhat chaotic management of groundwater as a common property resource through so called 'polycentric governance structures'. But seven of the eight basins did not reduce abstractions, rather they imported surface water to ease the pressure on groundwater. Thus it may well be that proactive demand management by decommissioning tubewells or converting irrigated into rainfed farms are exceptions rather than the rule in western USA. Vaux also suggested that active management basins are overlain by highly urbanised areas where governments or municipalities can easily buy water rights to serve high paying urban consumers.

There is a difference between the theory and practice of groundwater management in the USA. In that same debate, John Peck of Kansas University argued: "If a city has purchased the entire water right of a farmer, the farmer will have to shut down with respect to that water right. A city may also be able to take the water against the will of the farmer under the power of 'eminent domain', in which case the city will acquire the water right and will have to pay the farmer the fair market value of the water right. In this case the farmer will also have to shut down." But according to Glennon, in many cases, "… farmers who sell their surface water have continued to farm just as many acres because they have simply drilled groundwater wells and continued pumping. Were this not absurd enough, the groundwater is usually connected to the surface water so, really, they are selling their water, and then pumping it anyway." (Shah, 2006).

In summary, the western USA has seen much institutional and regulatory action to improve groundwater governance. Yet, it is not at all clear that groundwater governance has worked well to the satisfaction of all. The Ogallala aquifer continues to be depleted; and the objective there is not to preserve the use of the aquifer for 'an indefinite time without causing unacceptable environmental, economic, or social consequences' as the USGS would like, but merely to lengthen the life of the aquifer in a planned manner. Once the Ogallala dries up, scientists reckon it will take nature 6,000 years to refill it fully[21]. According to Kalf and Woolly (2005), Kansas experiences "widespread falls in groundwater levels of significant magnitude [that are] non-recoverable in large areas." In Arizona, overexploitation and falling water levels are addressed by legislation that mandates balancing abstraction with recharge; but it is "not clear that targets will be met". In California, the courts have determined "equitable distribution" over large areas, but "it may not lead to sustainable use". All in all, despite intensive governance, sustainable groundwater is still a work in progress in many parts of the USA.

In Mexico

In recent years, Mexico has experimented with a communitarian model of groundwater management. The underlying premise is that if groundwater users are organised and empowered, they will mobilise their collective strength to monitor groundwater behaviour and undertake the steps necessary to protect the resource and ensure its long-term sustainability.

Few countries have reformed their water laws as extensively as Mexico. The 1992 Law of the Nation's Waters entrusted the National Water Commission (CNA) with the responsibility to register water-use concessions. Mexico's water sector reforms declared water as a national property and made it mandatory for existing users to legitimise their rights through procuring concessions. In addition, the CNA was authorised to set up a regulatory structure to enforce and monitor these concessions and also to collect a volumetric water fee from all users, except small-scale irrigators. COTAS

[21] http://www.ngwa.org/Fundamentals/use/Pages/Groundwater-facts.aspx

(technical committees for groundwater) were promoted by CNA as user organisations created to manage groundwater and in some provinces, such as Guanajuato, all water resources (Sandoval, 2004; Shah, 2003; Shat et al., 2004b). While water is administered by the CNA, states like Guanajuato are faced with the challenge of sustaining the region's economy without the means of direct intervention. Being so constrained, Guanajuato, which has severe aquifer overexploitation problems, has followed a two-pronged approach; gathering better-quality scientific data, and promoting water users' associations in canal systems (Sandoval, 2004).

While progress on data collection is commendable, COTAS are yet to function in the form envisaged by the water policy-makers. As Luis Marin, a Mexican researcher, argued: "[In Mexico], the government has tried to give the stakeholders the responsibility for managing aquifers by establishing the COTAS. However, they depend financially on subsidies from either the federal or state governments, and typically, don't have any technical personnel. Under the new law, stakeholders who do not use all of the volume that they have a permit for, stand to lose the unused volume the following year. As a result, stake holders abstract their full volumes, even if much of this water is wasted, so as not have their concessions reduced." (see Shah, 2009).

The CNA adopted three sets of tools – regulatory, economic, and participatory – for groundwater reforms (Burke and Moench, 2000). But response to the reforms is mixed. The large water users (industrial and commercial users) quickly applied for concessions and paid water fees. However, the real challenge is registering the water rights of agricultural users, who together account for at least 80 percent of the total volume pumped, and monitoring their withdrawals. But agricultural users who own tubewells have responded positively to the law and have applied for water concessions. The major reason being the 'carrot' of subsidised electricity promised to those who regularise their connection[22]. This subsidy could reduce annual electricity charges by US$1,000–1,350 making it worthwhile to register (Shah et al., 2004b, p. 365). Thus farmers respond well to direct economic incentives, but monitoring actual abstraction from individual wells has proved nearly

[22] The electricity subsidy did encourage farmers to register water rights with the CNA. However, the challenge was to keep farmers from pumping beyond their concession volume. Since monitoring pumped volumes was difficult, a subsequent change limited electricity subsidies only to the extent of power needed to pump concession volumes. If the extraction exceeds the allotted water right, then the farmer will not receive the subsidy for the portion of water use that exceeds the right. Both the electricity utility service providers and CNA have agreed to use electricity consumption and some well efficiency factors to estimate abstraction for the purpose of determining the amount of subsidy a farmer is entitled to (Scott, 2013).

impossible, even in groundwater-stressed provinces like Guanajuato, which has over 15,000 irrigation wells.

Whenever, a ban was proposed on new tubewells there was an increase in drilling in order to get them registered before the deadline (Figure 4). Thus passing laws and erecting administrative barriers does not always work unless social and economic realities are taken into account (Sandoval, 2004). Indeed in the early 2000s a move to withdraw unused portions of groundwater quotas encouraged farmers to pump more groundwater than they would otherwise have, lest they lose their quota (Luis Marin, personal communication, 2005).

The success of COTAS in governing groundwater is mixed. Expectations were high and they were intended to be consensus-building institutions providing space where integrated water management models could be implemented (Sandoval, 2004, p. 10). Some created local awareness about water issues and, most importantly, were creating alternative sources of income by developing services that water users would value. However, they failed to provide their members with what they valued most – unrestrained access to groundwater. Predictably, few farmers were willing to take up membership in an institution set up to limit their access to water and this is the mandate that many COTAS officials feel they ought to pursue while enforcing the Water Law. In fact, the most serious stumbling block to the success of COTAS is the lack of a proper monitoring structure (Sandoval, 2004). Self-monitoring abstraction to agreed levels to reduce groundwater overexploitation might seem a 'pipe dream', but the high quality public education and awareness programmes that COTAS can provide seem to be a sure way of achieving it in the long-run. Thus, Mexico, even with an ambitious water law, is still grappling with basic issues such as registering wells and issuing water permits.

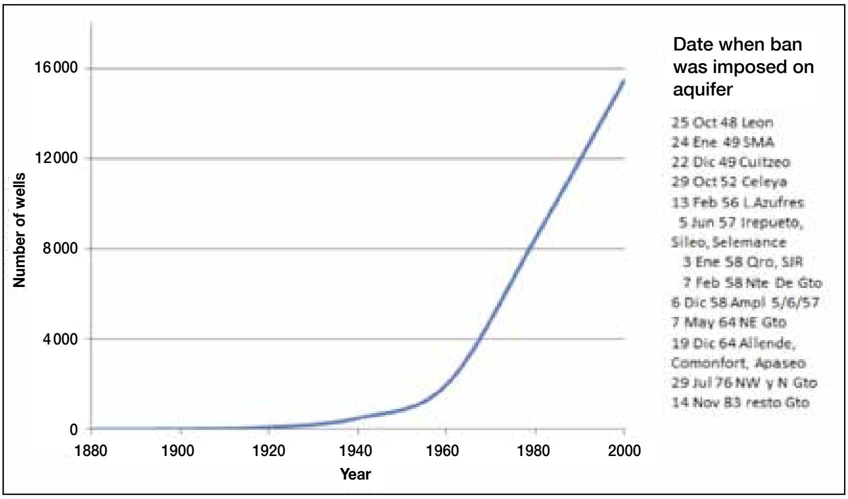


Figure 4. How bans on new wells accelerated growth in well numbers in Mexico

In Spain

Spain has also experimented with a communitarian model of groundwater management. Until 1985 Spain bestowed private property rights over groundwater resources. But the 1985 Water Act in response to intensive groundwater use changed the rules of the game. Like Mexico, groundwater was taken into state ownership and River Basin Management Agencies (RBAs) (Confederacions Hidrograficas) were given the role of managing groundwater and vested with powers to grant permits for groundwater use. The Act also gave authority to the RBAs to declare an aquifer 'overexploited' and to formulate an aquifer recovery management plan to reduce the volume of withdrawals or reject new applications for wells. All users of an aquifer were also required to organise themselves into groundwater users' associations in order to encourage user participation. By 2000, some 16 aquifers were declared totally or partly overexploited (Hernandez-Mora et al., 2003, p. 398), but user associations were formed in only five aquifer areas and only two were functioning. Further amendments to the Act were made in 1999 and 2001, which emphasised the role of groundwater users in aquifer management.

An evaluation of the current status of this law highlights implementation challenges. Even after more than 30 years, the recording of groundwater rights still remains incomplete and less than a quarter of all groundwater structures are registered. The main reason is a lack of human capacity within the implementing agency which affects not just well registration, but also monitoring of registered wells. Thus, Spain, with some 0.5 million wells (according to Ramon Llamas, personal communication, this figure could be 2 million), is still grappling with the most basic issue of identifying and recording groundwater users.

In the light of this experience, the difficulties that countries like Bangladesh, India, and Pakistan face, with several million well owners scattered over the length and breadth of each country, can be appreciated. Given Spain's long tradition of successful surface-water users' associations (some in Valencia are centuries old), the new water law has emphasised the formation of groundwater users' associations particularly for managing overexploited aquifers. While thousands of small groundwater users' associations have been formed, the majority focus on 'collective management of the irrigation network'. Only a handful have a larger mandate of 'collective management of aquifers' and of these, not all are success cases. In the Upper Guadiana Basin (about 16,700 km^2 and severely overexploited), groundwater abstraction was temporarily halted not by positive collective action on the part of the irrigators, but by the European Union's Income Compensation Programme. This was designed to reduce water abstractions by paying subsidies of up to US$580/ha (Hernandez-Mora et al., 2003; Lopez-Gunn, 2003, p. 370). In July 2001, Spain's parliament asked the then government to present, within a year, a water plan to manage groundwater in the Upper Guadiana Basin. This plan ran into serious difficulties and has yet to be approved (Llamas, personal communication). Thus, even in Spain, which has relatively fewer wells, smaller aquifers, is less dependent on groundwater irrigation, and has stronger farmers' organisations than South Asia, implementing various clauses of groundwater legislation has proved to be very difficult. Studies show that most groundwater users' associations are defunct and the water law is widely by-passed (Box 7).

Box 7. Groundwater laws in Spain largely ignored?

The 1985 Water Law, declared that groundwater would be in 'public ownership'. This represented a fundamental change to water rights. Yet this major change, compounded by lack of knowledge about the legal changes and groundwater use, and a poor information campaign, has led to many situations of 'hydrologic disobedience' in relation to water rights and abstraction in almost every stressed aquifer. Indeed, the question remains as to what came first, hydrologic disobedience or stressed aquifers. A typical example of this situation is the Upper Guadiana Basin (Lopez-Gunn and Llamas, 1999).

In arid countries

Many Middle East and North Africa (MENA) countries, which developed substantial irrigated -agriculture economies based on non-renewable groundwater, have increasingly come to the view that their aquifers are better deployed for the more pressing drinking water needs of present and future generations than irrigation. Some are now urgently regulating, and even reducing, their groundwater irrigation economies. In the 1970s, Saudi Arabia expanded wheat irrigation, and even exported some wheat. In 1992, they spent US$2 billion subsidising local production of 4 million MT of wheat which could have been bought at one-fifth of the cost on the global wheat market (Postel, 1992). Saudi Arabia has now moved away from the goal of national wheat self-sufficiency at any cost and substitutes home production with imported wheat. It has successfully reduced wheat irrigation and also overall groundwater use in agriculture (Abderrahman, 2001). In Iran, Soltani and Saboohi (2008) recommend a similar strategy of importing wheat rather than producing it with groundwater irrigation. In Iran, groundwater regulation is divided into *Free areas:* plains where drilling new wells is permitted after obtaining a licence from the Water Authority; *Restricted areas:* plains where drilling new wells is permitted only as an exception on certain occasions; and *Critical areas:* plains where drilling new wells is never permitted. Iran now bans new irrigation tubewells in one-third of its plains (Hekmat, 2002).

Oman, similarly, has used stringent administrative regulation to control groundwater withdrawals for irrigation. According to van der Gun (2007), "Oman's successful strategy for sustainable groundwater management has deftly combined demand-side measures to control, protect, and conserve water resources with supply-side measures to augment the resource. The demand side includes obligatory registration of wells, introduction of well permits; prohibition of wells less than 3.5 km from the mother-well of a falaj; closing down illegally constructed wells and confiscating contractors' drilling equipment involved in illegal drilling; a national well inventory; well metering; well-field protection zoning; water treatment; leakage control; improving irrigation techniques; and public awareness campaigns for water conservation. Supply-side strategies include large recharge dams, intended both for flood control and for groundwater recharge. Treated wastewater is re-used in lieu of groundwater pumping in the Muscat area for watering municipal parks, gardens, and roadsides. Public water supply in this capital area depends mainly on desalinated seawater."

In Jordan, Syria, and Yemen, there are efforts to regulate groundwater irrigation, but they have not proved to be successful even though the urgency to do so is widely accepted. In Algeria, Morocco, and Tunisia the number of tubewells is increasing at a similar rate to those in South Asia (Bahri, no date). The lesson from MENA is that small autocratic or theocratic states, where groundwater regulation is a life-and-death issue, have effectively restricted or reduced groundwater irrigation. Some, like Oman and Saudi Arabia, have already begun using desalinated sea water to meet urban drinking water demands.

In monsoon Asia

In Asia, many millions of smallholder subsistence farmers are using groundwater and most countries have not yet begun to address the problem of groundwater governance in any serious manner. China has done more than most to limit groundwater depletion in the north China plains, but it will take time before these initiatives work on a national scale (Shah et al., 2004a). The Mexican model of community aquifer management is being held out as a panacea for Asia even though there is little evidence that this has helped Mexico move towards sustainability. As Hoogesteger (Shah et al., 2007) noted: "Controlling groundwater use in countries of the South is for governments often a two-edged knife: on one side it costs them a lot of resources (which they often do not have or need for poverty alleviation programs) and on the other side doing so is often politically contested."

In India, an ambitious experiment in participatory groundwater management was undertaken with FAO support in Andhra Pradesh, a mostly semi-arid state notorious for relentless groundwater overexploitation. From 2003 to 2009, the Andhra Pradesh Farmer Managed Groundwater Systems (APFMGS) project, involving over 700 communities, organised and motivated by a group of grassroots NGOs to regularly monitor groundwater levels, undertook annual community crop planning exercises, and adopted water-saving technologies. A succession of reviews by the FAO, the World Bank, and several independent researchers has hailed APFMGS as a model of groundwater governance with global ramifications. But the project closed in 2009 and in 2012 a study suggested that all but a few communities had abandoned the 'best practices' which the project highlighted for sustained intervention, such as an improved 'business model', creating sanctions, legitimacy, and incentives (Verma et al., 2012) (Box 8).

Box 8. Andhra Pradesh Farmer Managed Groundwater Systems: sustaining change requires sustained engagement

Under its 12th Five-Year Plan, India committed itself to Participatory Aquifer Mapping as the basis for initiating the community management of groundwater. The idea originated from the highly influential FAO-supported APFMGS project which sought to demystify hydrology by promoting farmers' collective understanding of groundwater resources. The project argued that this was the best way of catalysing community-based participatory aquifer management. The Indian Planning Commission (2007) had earlier said: "Sustainable use of groundwater is possible only when users restrict average abstraction to long-term recharge. In a common property resource, individuals will restrict their use only if there is a credible agreement among all users to limit their use. Peer group pressures can generate socially responsible behaviour as was observed in self-help groups".

Andhra Pradesh has some 1,195 small aquifer systems, each 100 to 300k m^2 in area, and each with great uniformity in local drainage circumstances, geomorphology, and hydrogeology. It therefore made sense to manage groundwater in a similar manner in each sub-basin. The project was active in 62 hydrological units in seven districts covering some 25,000 groundwater-user households. In each hydrological unit, APFMGS

- promoted participatory hydrological monitoring;
- facilitated crop water budgeting for the entire hydrological unit;
- organised farmer water schools;
- and appointed men and women volunteers trained in taking piezometer readings to work as the nucleus of village level groundwater monitoring committees (GMCs) which constituted the hydrological unit network (HUN) registered as societies.

The aim was to improve farmers' understanding of groundwater processes, introduce water-saving techniques, and change cropping patterns to those consistent with the water endowments of each HUN. In community gatherings, village-specific water budgets were discussed to highlight the need for cropping pattern changes, improving water productivity, increasing the use of farmyard manure, and vermi-compost. The expectation was that, equipped with such improved understanding, farmers would reduce water use of their own volition without any coercion or moral suasion.

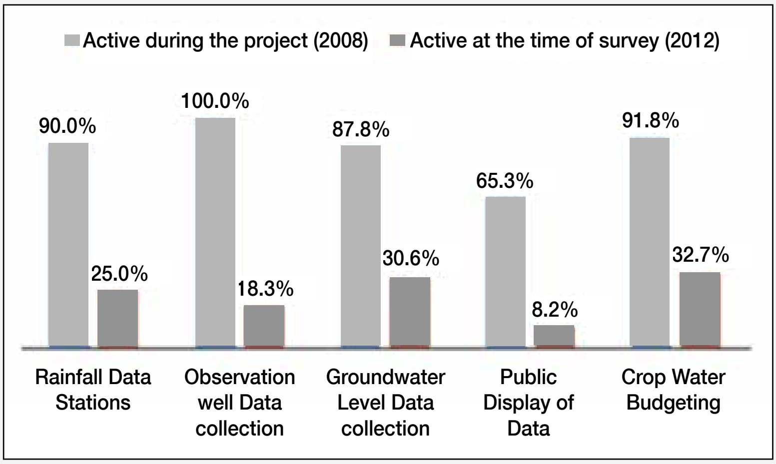
Studies based on APFMGS data showed that during the period 2003–2009, reductions did indeed take place in many HUNs. There was a significant shift from water-intensive crops to water-saving crops and the value of crop production increased, thus belying concerns about loss of income. There was substantial expansion of micro-irrigation and soil-water conservation measures. The massive volume of hydro-geological information, including GIS maps, that many HUNs generated, impressed many a visitor; and some HUNs began generating revenue by selling this information. Local politicians lent support to make the APFMGS approach the centre-pin of state policy. A 2010 World Bank study declared APFMGS a 'proven model' for community-based groundwater governance (Steenbergen, 2010). Another World Bank assessment (Pahuja et al., 2010) argued that, "Community management offers an alternative mechanism to state enforcement for groundwater management…there is now a critical mass of experience [in APFMGS] for

Box 8. Cont.

designing models that could be viable at least for the hard-rock settings in India."

van Steenbergen (2006) asserted optimistically that "social norms and rules will reinforce the innovations that are under introduction, particularly those that are easier to monitor, such as 'no dry season paddy' and 'no new bore wells'."

The APFMGS project funding stopped in 2009. In 2012, IWMI sent two students to 49 of the better developed HUNs to check on how many of the APFAMGS practices were still being used. Their overall impression was that "most had been abandoned by the farmers except in two HUNs in Chittoor and one in Kurnool" (see chart). Verma et al., (2012, p. 9) concluded that eulogies of the APFMGS project "seem to be premature and overly optimistic… and that in the absence of an external authority, GMCs and HUNs lose their legitimacy, leading to a breakdown of trust and legitimacy."



Survival of APFAGMS Groundwater Governance Regime beyond Project Life

There are striking similarities between the experience of the HUNs and GMCs in Andhra Pradesh and the COTAs in Mexico. Both generated a great deal of useful information and contributed to farmers' understanding of groundwater processes. There was also some evidence of behavioural change. However, the absence of external support and sustained engagement with aquifer communities led to a weakening and the eventual erosion of participatory norms and processes. The Chinese experience was markedly different; external support and graduated sanctions brought quick results in terms of reduced withdrawals, even if the consequences included swelling the ranks of ecological refugees.

Governing a groundwater economy in a sustainable manner is not just about the hydrogeology of aquifers, but is more about the larger political and social institutions of nations. How countries respond to the challenge of sustainable management of their groundwater economies depends on many factors that are often unique to a particular country. Table 3 illustrates variables that define the organisation of groundwater economies in six countries. The USA uses about 200 km^3 of groundwater for irrigation, but to manage its economy it has to monitor and regulate only 400,000 pumping plants, each pumping 500,000 m^3 of groundwater annually. Mexico is in a similar position with just 95,000 agricultural tubewells. However, India, which uses 230 km^3, has to manage over 20 million small wells, each pumping an average of 11,500 m^3 annually. Clearly, the task of the USA and Mexican groundwater managers is, in many ways, simpler compared to that of their Indian counterparts.

The nature of the political system also matters. Iran is able to impose and enforce a complete ban on the drilling of new tubewells throughout most of the country (Hekmat, 2002). Likewise, the popular, but astute, Sultan of Oman has brought groundwater abstraction under some control by strict enforcement of regulations (van der Gun, 2007).

Table 3. Structure of national groundwater economies

Country	Annual groundwater use (km^3)	No of groundwater wells (million)	Abstraction/well (m^3/year)	Proportion of population using groundwater (%)
China	105	4.5	23,000	22–25
India	230	20	11,500	55–60
Iran	29	0.5	58,000	12–18
Mexico	29	0.09	414,285	5–6
Pakistan Punjab	45	0.5	90,000	60–65
USA	198	0.4	500,000	< 1–2

But attempts to ban tubewells in other countries have largely failed. Mexico has been trying to ban new tubewells in its bajio (i.e. the uplands north and east of Mexico City) for 50 years and has not yet succeeded. China has a large number of tubewells scattered over a vast area of countryside and is trying hard to bring these within its permit system, but to date this is not working well. Undertaking a similar task in India or Pakistan would be unrealistic in the foreseeable future because of their political structures and systems. In India, several states already have elaborate legislation to control groundwater overdraft, but their enforcement has completely failed (Indian Planning Commission 2007; Narayana and Scott, 2004; Phansalkar and Kher, 2003; Shah, 2009).

The Murray-Darling basin in Australia is widely acclaimed as a water governance exemplar. Yet, governing groundwater has challenged Australian water managers. The Australian Groundwater School at Adelaide says, "Groundwater will be the enduring gauge of this generation's intelligence in water and land management." Many South Asian policy-makers are attracted to the Murray-Darling model, but overlook the differences between the Australian and South Asian groundwater economies. Just 5.5 percent of Australia's irrigated area depends on groundwater, compared with more than 60 percent in India and 90 percent in Bangladesh. The 285 to 300 km^3 of groundwater that South Asia withdraws every year is 50 times greater than the amount used in Australia. But most importantly, South Asia has 20 million groundwater abstractors, 5,000 times more people than Australia, to whom groundwater governance must speak.

China has tried hard to rein in groundwater depletion in the north China plains, but is discovering the implementation challenge of demand management in a vast and atomistic groundwater economy. Just issuing water withdrawal permits to some 7.5 million tubewell owners is a logistical nightmare, let alone monitoring their withdrawals. Not surprisingly, Wang et al. (2007, p. 53), who in 2005 surveyed 448 villages and 126 townships from 60 counties in Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi, and Shanxi, found that "inside China's villages few regulations have had any effect … despite the nearly universal regulation that requires the use of a permit for drilling a well, less than 10 percent of the well owners surveyed obtained one before drilling. Only 5 percent of villages surveyed believed their drilling decisions needed to consider spacing decisions. Even more telling was that water abstraction was not charged in any village; there were no physical limits put on well owners. In fact, it is safe to say that in most villages in China, groundwater resources are almost completely unregulated."

More recently, local governments in the north China plains have begun experimenting with farmer-managed sustainable groundwater-governance pilot projects with support from the central government. It is hard to say whether and how quickly these will scale out in the Chinese countryside (Box 4). It is equally hard to say if other countries in Asia and elsewhere, that do not have strong local authority structures can learn useful lessons from the Chinese pilot projects. Bangladesh has a large programme for groundwater irrigation with government-managed tubewells which tackles the classic problem of perverse incentives that make groundwater governance so tricky in South Asia (Box 9).

Box 9. The Barind experiment in equitable groundwater development, Bangladesh

The Barind tract includes 1.44 million ha of farmland with hard red soil and receives heavy monsoonal rainfall of 1,500–2,000 mm. It includes the Bangpur, Bogra, Dinapur, and Rajshahi districts of Bangladesh and the Maldah district of West Bengal in India.
In 1985, the Bangladesh government established the Barind Multipurpose Development Authority (BMDA) and charged it with implementing the Barind Integrated Area Development Project. In addition to road development, agricultural extension, electrification, drinking water, and pond construction, the project established 14,000 government-managed deep tubewells with buried PVC pipe distribution systems for irrigated farming.
Farmers can access irrigation in two ways. They can buy coupons from the BMDA office or its dealers, who get a 5 percent commission on the value of coupons sold. They hand these to the pump operator who then delivers irrigation water for the number of hours paid for. The alternative is for farmers to get a user smart card embedded with their photo, name, and telephone number. The card can be recharged as needed from a dealer. To irrigate, the farmer inserts the card in the meter slot, selects the number of hours of irrigation needed, and the tubewell delivers the volume of water requisitioned.

Evaluations suggest that the Barind system is regularly monitored and vigorously managed. The BMDA officials daily collect used coupons and monitor meters to record pump usage and tally it with electricity meter readings to minimise malpractice. The revenues earned are used for O&M and for expanding the system. Studies suggest that this system is financially self-sustaining. It serves 600,000 ha of farm land and is a major improvement over the pre-1985 situation when private shallow tubewell owners controlled the landscape. The farmer pays the irrigation cost of BDT600–800/bigha[23], which is a fraction of that previously paid by farmers to private shallow tubewell owners.

The institutional arrangement is incentive-compatible. Farmers doubling up as BMDA dealers supplement their income with commission on coupon sales and recharge of cards. Farmers also double up as tubewell operators and earn supplementary incomes of BDT12/hour as service providers. The Barind's socio-economic impacts are deep and wide. In a region where farmers found it hard to grow one crop, today they grow up to three crops annually. Some 1.5 million small farmers have benefited and many more will benefit when the remaining 450,000 ha are brought into the tubewell programme.

[23] I bigha = 0.16 ha

CONCLUSION: A CONTINGENCY APPROACH TO GROUNDWATER GOVERNANCE

Over the past 20 years, the global debate on groundwater governance has been more prescriptive than analytical. It has advocated 'blueprint' solutions to low-income countries based on intensive institutional management, as in Kansas, USA or in the Murray-Darling in Australia, without much regard for the vast differences in contexts. Some offer tradable property rights, others argue for a 'groundwater cess' as a surrogate for price, or suggest licensing and siting groundwater structures, and organising farmers to self-manage aquifers. In low-income countries, groundwater bureaucracies have favoured all kinds of legislative and administrative instruments, but without paying much attention to enforcement. All have been tried with mixed results. Table 4 summarises these instruments and the countries which have used them to support irrigated agriculture.

Table 4. Instruments of groundwater governance deployed in major groundwater irrigator countries

Instruments of groundwater governance						
	Groundwater pricing: direct or surrogate	Entitle-ments, tradable or otherwise	Admini-strative regulation	Community aquifer manage-ment	Recharge enhance-ment / imported water / conjunctive manage-ment	Indirect approaches
Australia		X	X			
Bangladesh	Barind project of smart-meters[24]					
China (new pilots)	X	X	X	X		
India				(APFMGS)	Saurashtra recharge movement	Gujarat`s Jyotigram
Iran	X		X			
Jordan	X		X			
Mexico	X	X		X		
Oman			X		X	
Pakistan					X	
Spain			X	X		
USA		X		X	X	

[24] http://www.waterintegritynetwork.net/index.php?option=com_mtree&task=att_download&link_id=96&cf_id=61

This review has explored these various 'groundwater governance models'. They are strongly advocated as international 'best practices' based on the experiences of specific countries, even though many have not always been critically examined. An assessment of the evidence available from these countries, however, indicates that while each of these models has merit, none can claim to have achieved the sustainable use of groundwater. Moreover, there is little evidence to suggest that models that work in the USA or Australia will work in low-income countries, such as Bangladesh, Myanmar, and Pakistan.

What is clear, however, is that the socio-ecological and political environment is critical in determining the elements of an appropriate groundwater governance regime. What is also clear is that there is no 'one best way' to organise and govern a country's groundwater irrigation economy simply because of the many different combinations of resources, people, society, economy, and polity that change in significant ways across space and time. Achieving a policy goal depends on a complex mix of socio-economic and political contingencies.

Governance is about 'power and authority and how a country manages its affairs' (Plummer and Slaymaker, 2007) and 'encompasses all the mechanisms, processes, relationships and institutions through which citizens and groups articulate their interests and exercise their rights and obligations' (Plummer and Slaymaker, 2007). Groundwater governance is thus less about groundwater and aquifers and more about social systems, stage of economic evolution, and society's political organisation. The governance of groundwater irrigation in South Asia is particularly complex because it involves many millions of private sector actors. The social networks, formal and informal rules and norms, laws, markets, and administrative apparatus only add to this complexity. But politics are centre-stage as this provides the '*rules under which power is exercised in society*'.

The approach to groundwater governance in any society is contingent upon a variety of internal and external factors that policy-makers and implementers cannot ignore. Strong local authority structures enable China, for example, to experiment with pilot administrative procedures in a way that Pakistan, which has no such village governance structures, would find hard to emulate. Similarly, a country with little capacity to defend constitutionally guaranteed citizen's right to life would find it difficult to defend private groundwater rights.

Table 5 offers a list of enabling and disabling contingencies that influence the way different countries respond to groundwater overexploitation. Countries, where public systems aggressively manage the groundwater economy by pro-actively intervening through demand as well as supply-side initiatives tend to have most or all of the enabling contingencies present. Where many or all of the disabling contingencies dominate, groundwater governance tends to be absent, primitive, perverse, or dependent on indirect instruments, which achieve a socially desired outcome without coercing individuals to change their behaviour.

These contingencies help to explain why different countries choose different policy instruments to govern their groundwater economies. In Mexico and the USA, only a small proportion of the total population depends on groundwater for their livelihoods and so governments have more easily adopted a tough regulatory posture. In South Asia though, where over half the population directly or indirectly depend on groundwater for their livelihoods, it is not surprising that political and administrative leadership is reluctant to legislate tough measures for regulating groundwater use. Even in China, where political resistance from farmers is not an overriding issue, and Mexico, where irrigators are a small enough group to be 'ignored', governments have steered clear of enforcing tough regulatory measures.

But many countries still pursue perverse and contradictory policies, often for political reasons, such as one arm of government offering subsidies to farmers to make groundwater abstraction lucrative while another arm is saying that groundwater use for irrigation must be curtailed.

Table 5. Contingencies influencing groundwater governance regimes

	Disabling contingencies	Enabling contingencies
National and local authority structures	Weak	Strong (China, Viet Nam)
Organisation of the groundwater economy	Numerous small users	Few large users
Proportion of the population dependent on farming	High	Very small
Groundwater's significance to national food and livelihoods security	High	Low (USA, Mexico, Spain)
Capacity, reach, and effectiveness of water bureaucracy	Low (South Asia)	High (China, Mexico)
Perverse incentives in groundwater irrigation (energy and tubewell subsidies)	Present: India, Iran, Syria, Mexico	Absent (China, Pakistan, USA, Australia)
Productivity of groundwater irrigation	Low (South Asia)	High (China; Mexico, California, Spain)

Policy-makers will need to negotiate their way around a plethora of disabling contingencies and build a groundwater governance regime on the basis of their country's enabling contingencies. The experience in farm-power rationing in Gujarat, India is a good example of the way in which enabling contingencies can be exploited to advantage (Box 10).

A three-stage evolutionary protocol for groundwater governance

This review highlights the futility of recommending any one way as the best way to achieve groundwater sustainability. The challenge for each country/state/region is to evolve its own path to sustainable groundwater governance that resonates with its unique set of contingencies.

This review offers a three-stage approach to evolving an integrated groundwater governance regime that fits well with hydro-geological and socio-ecological reality (Figure 5):

STAGE I – FOCUS ON REFORM

Reform does not necessarily mean abolishing perverse subsidies and incentives that sanction and even provide incentives for groundwater depletion. Abolishing subsidies altogether may involve unacceptable political costs. But there are opportunities to rationalise subsidies that minimise their distorting effects. The Barind experiment in Bangladesh is one example of organising smallholder groundwater irrigation with minimal scope for perverse incentives (Box 9). The Gujarat experiment with farm-power rationing suggests a second-best option (Box 10).

STAGE II – BUILDING CAPACITY

The chances of reforms succeeding can be increased substantially by creating an information-rich decision-making space for sustainable groundwater management. Building the capacities of governance and rule enforcement are critical in both agencies and in communities for groundwater governance to work. Many countries have made stringent groundwater laws and regulations that have not worked because there is a lack of enforcement capacity and there is little preparatory work with aquifer communities.

STAGE III – INTRODUCE ADVANCED INSTITUTIONAL MANAGEMENT

Only after stages I and II are completed does it make sense to introduce advanced institutional groundwater management using any, or a blend of, the approaches tried and described in this paper. During this stage, the enabling and disabling contingencies are critical. What may suit China may not be appropriate for Nepal or Pakistan, and the elaborate institutional groundwater management regime in Kansas may be too costly for India.

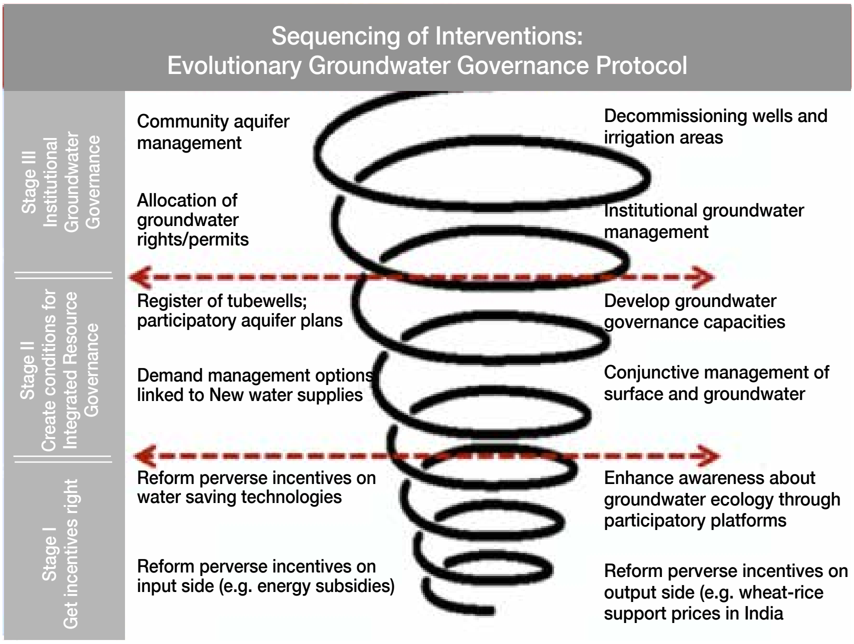


Figure 5. Evolutionary protocol for sustainable groundwater governance

Box 10. Indirect approaches to groundwater governance in Gujarat: combining supply augmentation with demand-side management

Attempts to regulate groundwater abstraction through legal and administrative means has been a logistical and administrative nightmare. M.S. Ahluwalia, the powerful Deputy Chairman of India's Planning Commission, suggested levying "a volumetric groundwater cess" to reflect the scarcity value of the groundwater resource. But the transaction costs of monitoring groundwater withdrawals and collecting the cess from over 24 million small groundwater well owners would be prohibitive. The groundwater governance debate in India has, therefore, focused on indirect means of demand and supply management that improve the groundwater regime without inflicting pain on the small farmer.

Indirect approaches to groundwater governance have been show-cased best in India's western state of Gujarat. This semi-arid state has developed a booming agrarian economy founded on sustained groundwater overdraft. Around 1990, some local NGOs and religious institutions encouraged farmers to experiment with groundwater recharge using the flood waters of the monsoon. By mid-1990s, some 400,000 open irrigation wells were retrofitted for recharge. The early experiments met with such success that decentralised groundwater recharge emerged as a popular mass movement. Diamond merchants from Surat and Brussels, who originally hailed from Saurashtra region, began offering financial support to recharging communities. An NGO invested in earth movers and offered them free, with diesel and driver, to any village wanting to deepen or dig a new percolation pond. Local cement companies provided free cement for check dams. Urban groups contributed free community labour. Eventually the state government set up a scheme

Box 10. Cont.

to provide liberal support to communities to construct check dams, percolation tanks, sub-surface dykes, and other water harvesting and recharge structures.

On the demand side, a US$250 million government programme put 1.1 million irrigation tubewells on separate electricity feeders so that that power could be rationed to eight hours per day on a roster. This capped the overall groundwater withdrawal for agriculture. It also created a 'switch on-switch off' groundwater economy. The government could provide additional power to help farmers to survive a dry spell; conversely, it could reduce the power when the rains were good. The government could thus influence the aggregate groundwater demand without having to monitor and regulate individual farmers.

This regime of indirect levers is showing good results. Gujarat's agricultural economy is growing at an annual compound rate of around 10 percent. Much of this growth is supported by groundwater. Yet, Gujarat is perhaps the only state in India where the overall groundwater regime is slowly improving. For a long time, water levels in large pockets used to fall even during the monsoon; now monsoonal recovery of groundwater levels is a rule rather than the exception in large parts of Gujarat (Shah and Verma, 2008).

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