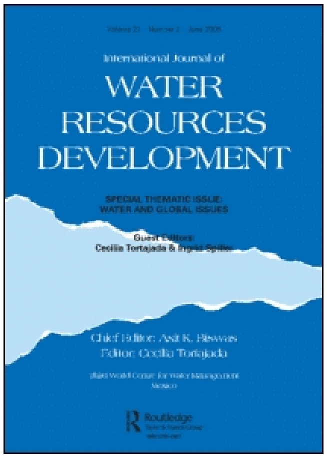

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Groundwater Overdraft Reduction through Agricultural Energy Policy: Insights from India and Mexico

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ABSTRACT *Rapid expansion of groundwater irrigation has transformed the rural economy in regions around the world, leading to significant increases in agricultural productivity and rising incomes. Farmer investment in wells and pumps has driven this expansion on the demand side; however, the supply of cheap agricultural energy—usually electrical power—is a critical though often overlooked driver of the groundwater boom. One serious outcome in numerous regions around the world has been groundwater overdraft; where pumping exceeds aquifer recharge, water tables have declined and water quality has deteriorated. India and Mexico are two of the largest users of groundwater in the world and both face critical overdraft challenges. The two countries are compared, given that electrical energy supply and pricing are primary driving forces behind groundwater pumping for irrigation in India and Mexico alike. Both countries have attempted regulatory measures to reduce groundwater overdraft. However, with low energy costs and readily available connections, there are few financial disincentives for farmers to limit pumping. The linkages between energy and irrigation are reviewed, comparing and contrasting India and Mexico. Examples of legal, regulatory and participatory approaches to groundwater management are assessed. Finally, the implications of linking electrical power pricing and supply with ongoing groundwater regulation efforts in both countries are explored.*

Introduction

Over the past two decades, groundwater has emerged as one of the principal sources of water for irrigation (Shah & Mukherjee, 2001). Because it is distributed across large areas where surface (canal) irrigation is either impossible or prohibitively expensive, groundwater is potentially accessible to far larger numbers of farmers than are conventional sources of irrigation. At the same time, groundwater markets have brought irrigation to the hands of farmers who previously grew rain-fed crops or were dependent on livestock or non-farm sources of income (Buechler, 2004). Reliability of timing and supply,

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Table 1. Extent and magnitude of the global groundwater revolution

Country/ region	Annual groundwater use (km^3)	Number of groundwater structures (million)	Extraction/ structure (m^3/year)	Percentage of population dependent on groundwater
India	150	19	7 900	55–60
Pakistan–Punjab	45	0.5	90 000	60–65
China	75	3.5	21 500	22–25
Iran	45	0.5	58 000	12–18
Mexico	29	0.1	300 000	5–6
USA	100	0.2	500 000	$<$1–2

Source: Shah *et al*. (2003).

control over volumes of water applied to crops, and amenability to improved irrigation technologies (precision irrigation, sprinkler, drip, etc.) are just a few of the many reasons farmers have adopted groundwater irrigation on a massive scale. This is largely based on private investment in drilling wells, installing pumps and irrigation pipe, etc.

The groundwater revolution has caught hold in South Asia, the Middle East/West Asia, and North America, and to a lesser extent in Africa and South America. Table 1 lists the principal groundwater-exploiting countries and some relevant similarities and contrasts in their groundwater sectors. In all these countries, groundwater has transformed rural economies through improved crop productivity and diversification, rising incomes of groundwater farmers as well as agricultural labourers, and value-added post-harvest processing. Such rapid growth, however, is not without serious equity implications. Some of the processes of social transformation resulting from the groundwater revolution include competition for dwindling water resources, adaptation to new production and marketing conditions, the need for increased capitalization of agriculture, intensification of forward and backward linkages, and heightened government regulation of agriculture, water resources and energy supply.

The supply of power to agriculture has been a primary driving force enabling farmers to switch to groundwater irrigation. In the initial phases of pump adoption, diesel technology provided the most flexibility, and farmers throughout South Asia, for example, readily purchased small centrifugal pumps to extract groundwater. This was facilitated, of course, by the significant government subsidies on pump irrigation equipment and on diesel as an energy source. The diesel subsidy was probably based more on the rationale of expansion of road transport generally; however, this itself was critical for agricultural diversification, production for markets, and a series of issues related to the groundwater boom.

In the subsequent phase, rural electrification brought to farmers the means to exploit groundwater more effectively. From this perspective, the comparison between Mexico and India sheds light on the link between electricity supply and pricing on the one hand, and groundwater irrigation on the other. As the power grid spread, farmers had on-demand access to water without the complications of the diesel supply chain. A host of power sector distortions were unwittingly introduced as a result of massive adoption of electrical pumps. These distortions have as much to do with subsidies to agriculture and the resultant tariffs across all consumer groups as they do with power supply infrastructure, its (in)ability to meet demand, and ensuing choices related to rationing. The Indian case presented here is particularly illustrative as power utilities in various states are either totally bankrupt or clinging to financial solvency through massive bailouts from the state exchequers. The only silver lining in the otherwise grey clouds of the power sector crisis is that the inefficiencies in power supply—particularly power rationing—have a braking effect on groundwater exploitation. And herein lies the principal thesis of this paper, that electrical energy supply to agriculture has to be viewed not only as a means to foster agricultural and rural development; it also has the makings of an effective tool to address groundwater overdraft. This is particularly the case with Mexico's Rural Energy Law, which caps an annual energy limit in kilowatt hours (kWh) which, based on the depth of the water table and a fixed electro-mechanical efficiency, yields an equivalent annual volume of groundwater concessioned for a particular well. India could well learn from this fledgling example if in fact it were to meter and charge all end users of groundwater (see further discussion below).

It is not the intent here to detail groundwater overdraft or to describe the excesses of the groundwater boom, its impacts on water table decline, on inter-sectoral competition for water as agricultural pumps lowered water tables below the effective reach of hand pumps for rural drinking water supply, or on water quality. These are well known and have been extensively documented, and are in one sense the starting point for this paper. Suffice it to say that groundwater overdraft clearly has been—and remains today—the principal symptom of a whole range of problems related to the groundwater boom. This is particularly true where groundwater is the primary source of water for agriculture, i.e. in arid and semi-arid regions of the world, characteristic of broad swaths of both India and Mexico. And these are precisely the regions where augmentation of groundwater supplies through enhanced aquifer recharge is limited by sheer physical scarcity of water. The point is that there is an urgent need to devise creative solutions to manage demand for groundwater.

In order to explore the implications of agricultural energy policy as a tool for reducing groundwater overdraft, the cases of India and Mexico will be compared and contrasted. Both have important agricultural sectors that rely heavily on groundwater irrigation; both have had electrified agriculture for long enough to witness adaptation to energy supply. Importantly, both have also experimented with legal, regulatory and participatory approaches to address groundwater overdraft. How far the energy policy card will be played in either country remains to be seen. Mexico has very recently passed an important Rural Energy Law; however, it is embedded in the North American Free Trade Agreement, which constrains its decision making. The important groundwater regions in India have just emerged from the grips of a major drought, which imposes its own constraints in the highly politicized decision-making calculus of Indian democracy. At the end of the day, it is a question of how individual farmers who pump adapt to the supply (and pricing) policies of the electrical power utilities that will make a dent on groundwater overdraft.

The Groundwater Boom in India

India is the world's largest groundwater user, in terms of both absolute volumes pumped and total number of users. There are some 20 million wells, a number that is increasing at approximately one million per year; the majority of these are equipped with electrical pumps. At the same time, the groundwater boom has brought unparalleled economic growth and diversification in rural areas (Shah & Mukherjee, 2001), just as in Mexico it has ushered in export-oriented agriculture through high-value cropping. Policy makers face a unique dilemma: how to ensure and preserve the benefits to farmers and the wider economy of rapid groundwater expansion, while attempting to control its excesses.

Groundwater development has been highly skewed in India, responding in part to energy policy and supply. Figure 1 shows the skewed geographical distribution of the twin water and energy resources in India. Groundwater has not expanded rapidly in the region where it has the greatest potential—in the water-rich Eastern Ganges and Brahmaputra basins—home to half a billion people, including a major concentration of the world's poor.

Increased groundwater extraction in this region would not only boost the economy, it would also draw down groundwater from near the land surface and allow additional infiltration of some of the surface runoff that is responsible for the devastating floods that sweep through Eastern India and Bangladesh annually. By contrast, groundwater use has expanded, in many cases beyond sustainable limits, in Western and peninsular India. In Karnataka, for instance, some 20% of the state's total 1.2 million wells go dry every year. In addition to the fixed value of the groundwater structures and equipment that are affected every year (estimated at Rs. 24 billion, or US$520 million), the cost of drilling new wells is approximately Rs. 8.6 billion (US$190 million) per year because depths now have to exceed 600 feet in order to strike water. Similarly, in parts of central and northern Mexico, declining water levels have forced farmers to invest in expensive well deepening or repositioning. Figure 2 provides a graphic example of the sheer density of wells (up to 20 per km^2) bored in a typical hard-rock, semi-arid watershed near Hyderabad in Andhra Pradesh state. The priority under such conditions must be to find ways of restricting groundwater use.

Shah *et al*. (2003; relevant arguments and findings summarized here) have examined the options available to policy makers to either stimulate or regulate groundwater use. Of the two, regulating groundwater overdraft through demand management is the more complex and difficult task. Although there are now a very large number of groundwater users in India (Table 1), the government agency charged with groundwater management—the Central Groundwater Board, reconstituted as the Central Groundwater Authority in 1996—was initially created to foster and promote groundwater development. In the current context, it has a conflict of interest over development vs management. It does not have an effective field presence for anything other than monitoring, and it continues to guard its trove of groundwater data. It is clear that direct management of groundwater has severe limitations in India.

This does not dampen the enthusiasm of individual states for groundwater regulation based on legal and administrative tools. Andhra Pradesh, for instance, adopted the Water, Land and Trees Act, 2002, which constitutes a state-level authority charged with promoting water conservation, regulating the exploitation of ground and surface water, advising the state government on

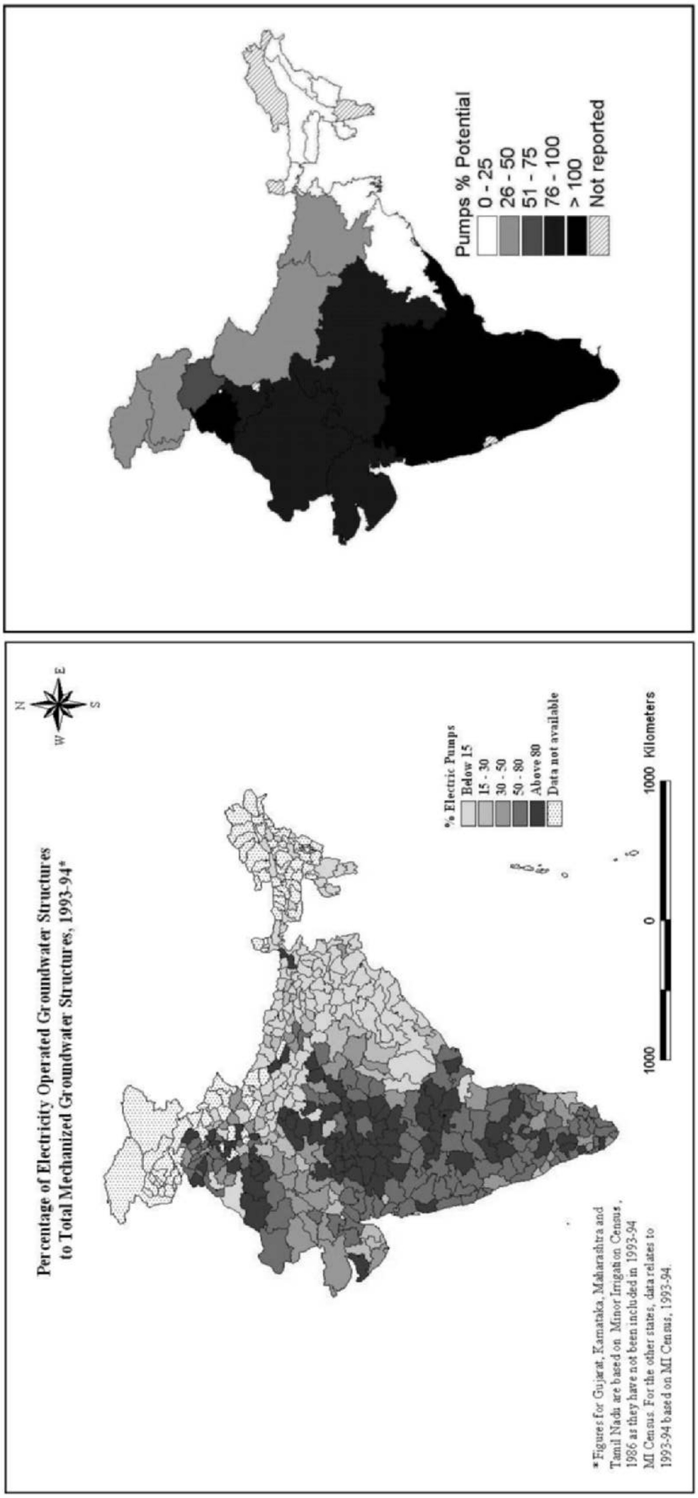

Figure 1. Skewed energy and water resource distribution in India.

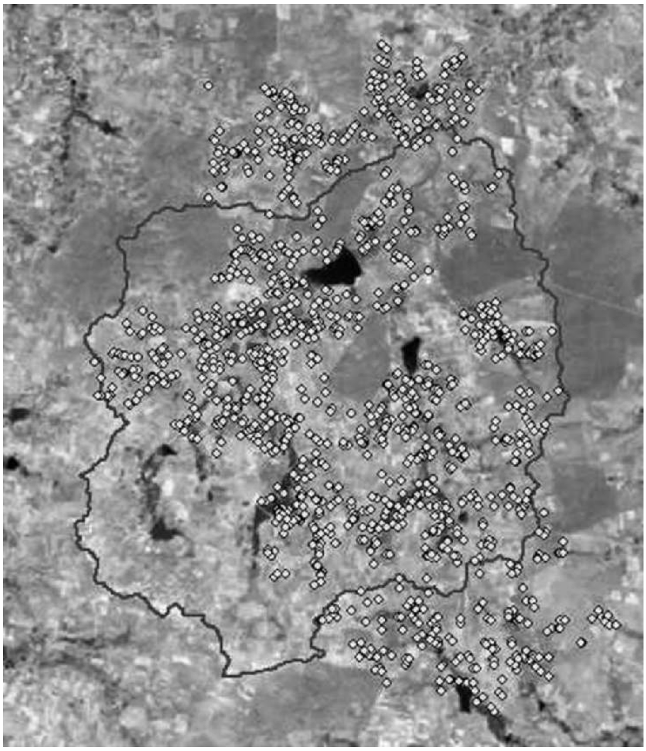

Figure 2. Well density in Maheshwaram watershed, Andhra Pradesh.

legislative, administrative and economic measures to conserve natural resources, and advising the government on enhancing public participation in these matters. The authority is charged with regulating all groundwater, whether through the mandatory registration of all wells, granting permission for new wells to be sunk within a distance of 250 metres of public drinking water sources, or prohibiting new wells in over-exploited areas. The Act also regulates village watershed committees and their rainwater harvesting activities. While the actual implementation is currently underway, it is clear that groundwater regulation is to be achieved through administrative fiat. With two million wells in Andhra Pradesh, the chances of successfully regulating groundwater appear distant. Mexico's experience with over five decades of official bans in numerous groundwater-dependent regions, for example Guanajuato State, would be enlightening to decision makers in India.

In India in general, little attention has been paid to the options for indirect management. Appropriate electricity supply and pricing policies hold huge potential to influence farmers' demand for groundwater and affect their pumping behaviour. The power sector in India—even in reforming states—finds itself unable to contend with the political (electoral) dictates of the agricultural 'vote bank'. In different states, agriculture consumes 27–45% of total energy and represents 0–12% of revenue (Figure 3). Agricultural power is free in Tamil Nadu, and was until just recently in Punjab. In other states it is charged at a flat rate[1] based on the horsepower rating of the pump.

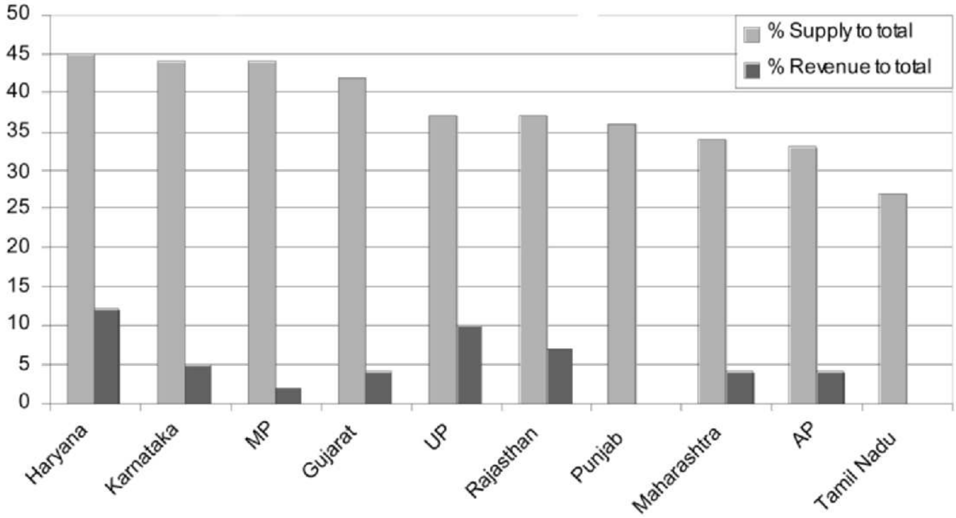

Figure 3. Agricultural power supply and revenue, 1999–2000.

The annual operating losses of the electricity boards have been estimated at Rs. 260 billion (US$5.4 billion) and are growing rapidly (Gulati, 2002; Lim, 2001). Demand significantly exceeds supply, with the result that prolonged power cuts have been institutionalized in rationing schedules. Andhra Pradesh supplies power for nine hours per day, Tamil Nadu for 14, etc. Even these restricted supply schedules are proving difficult to meet as the infrastructure deteriorates, leading to voltage drops, loss of frequency, etc.

Despite the fact that there is significant debate on the veracity of these figures, based on the claim that high losses incurred in supplying paying customers (industry and urban users) are embedded in the agricultural supply figures, the State Electricity Boards are bankrupt largely due to the abysmal revenue collection from agriculture. Bolstered by support mainly from the multi-lateral donors, the power sector in various reforming states in India is set to revert to metered supply. It is held that a zero or flat-rate tariff provides no incentive to limit pumping; however, the increases in metered tariff required for elastic demand behaviour are likely to be significantly higher than are acceptable to either farmers or politicians.

What is notable for the purposes of this discussion is that 'inefficiencies' in power supply to agriculture in India (rationing, erratic voltage and frequency, etc.) are having the unintended consequence of limiting the rate of groundwater exploitation. This point appears to be lost on the power sector reformers intent on advocating efficient supply without rationing. It is clear that the metered tariff increases required to take a bite out of pumping demand are politically infeasible. At the same time, if full supply at constant voltage were made available, the likely (short-term) outcome would be to quicken the pace of groundwater overdraft. The solution—perhaps interim in nature—appears to be to continue with strict rationing.

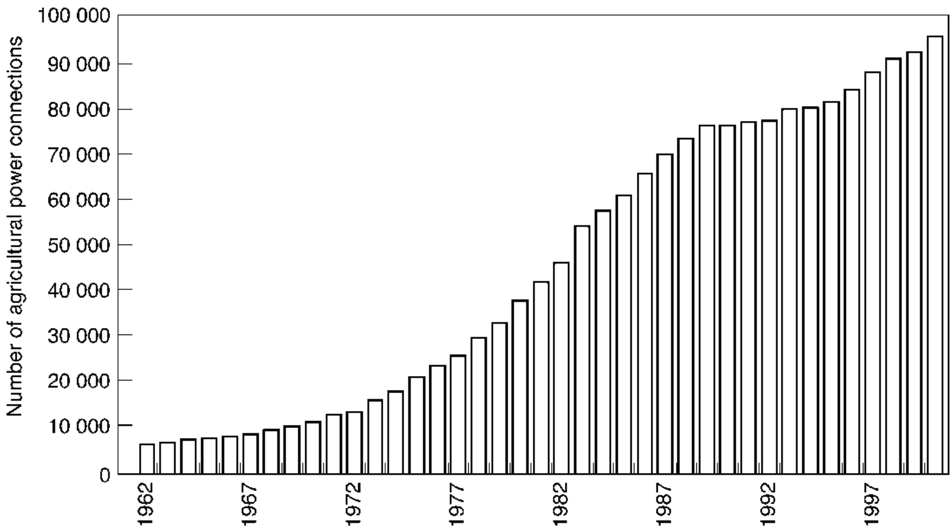

Figure 4. Increase in agricultural power connections in Mexico, 1962–2001. *Source*: CFE (2002).

Groundwater Overdraft: Regulatory and Participatory Approaches in Mexico

Annual groundwater draft in Mexico is estimated to be 29 km^3, modest compared to India's 150 km^3; however, on a per-irrigated-hectare basis it is nearly twice as high, which explains the higher per-hectare crop yields and rapid groundwater depletion. Mexico's municipal and industrial water demand is increasingly met from groundwater (Scott *et al.*, 2001), and the most critical groundwater depletion areas are often under cities. As a result, aquifer overdraft is central to Mexico's water management challenges.

The principal energy source for pumping groundwater in Mexico is electricity, just as in India; diesel engines are limited to low lifts from open water sources. Since the early 1960s, the number of electrical power connections for agriculture (98.8% of which are irrigation pumps—other rural connections are reported as domestic, industrial, etc.) has grown by an average of 7.65% annually (Comisión Federal de Electricidad (CFE), 2002). The 95 111 agricultural power connections in 2001, although significantly less numerous than India's 13 million electrically driven irrigation pumps, are the result of dramatic growth over the past four decades (Figure 4).

At the same time, energy consumption in agriculture nationally appears to be stagnating at about 7000 GWh/yr, which in 2001 represented less than 6% of total energy demand (Figure 5). Intensive energy demand for groundwater pumping is concentrated in the centre and northwest of the country, in states such as Guanajuato, Zacatecas, Chihuahua and Sonora.

There has been a groundwater boom in Guanajuato, the state that uses the largest amount of both agricultural energy and groundwater in the country. Groundwater overdraft is estimated at 1.3 km^3 annually in this state. Figure 6 shows the explosion in the number of wells over the past 50 years, a process driven by a combination of direct (federal and state) government support programmes for well drilling and equipment installation as well as favourable

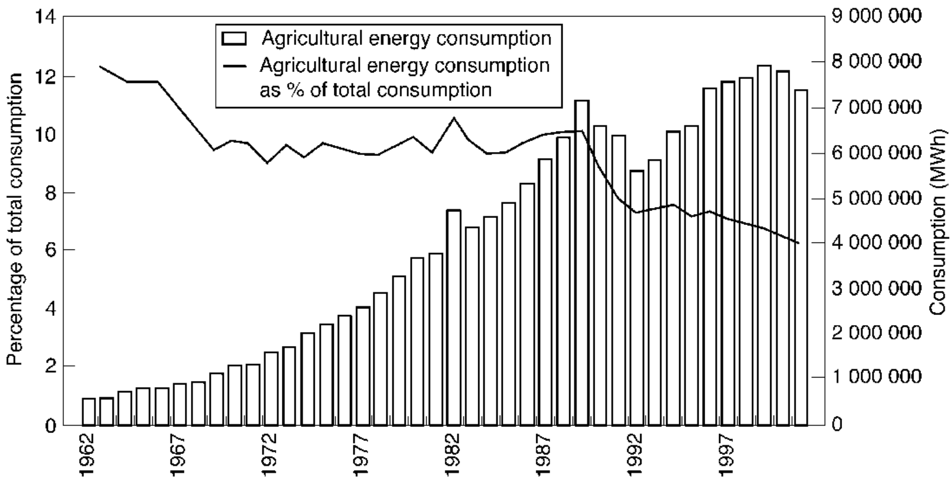

Figure 5. Agricultural energy consumption in Mexico, 1962–2001. *Source*: CFE (2002).

agricultural production and marketing conditions, particularly in the Bajío region of southern Guanajuato (Wester *et al.*, 2001). Regulatory and participatory strategies to control the expansion of groundwater extraction have been adopted with little success, a process that mirrors efforts in India to restrict groundwater exploitation. Official bans on new wells have been imposed in different parts of the state since 1948 (Figure 7) and remain in effect today.

In spite of the bans, the number of wells continued to increase until 2000, when the official data indicate that no new wells were drilled. Unofficially,

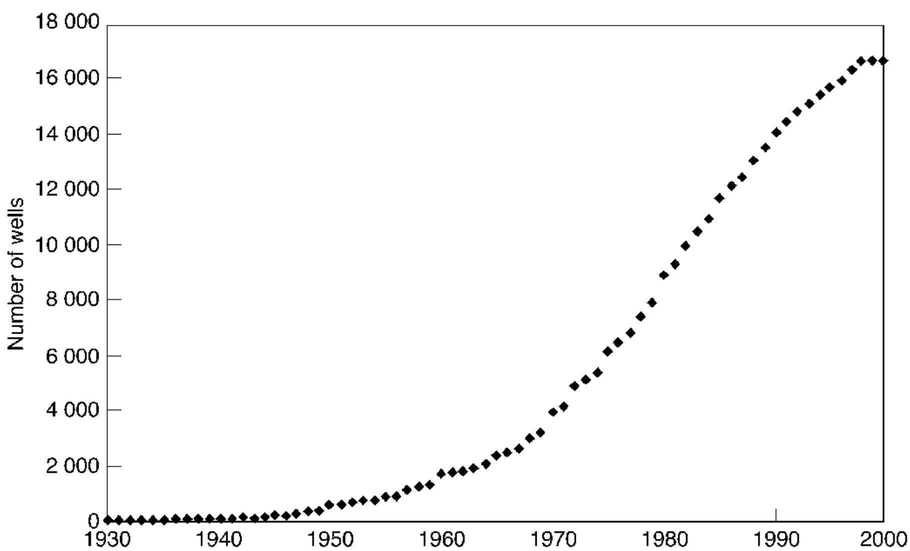

Figure 6. Increase in number of groundwater wells, Guanajuato State, 1930–2000. *Source*: Comisión Estatal de Agua de Guanajuato (2002).

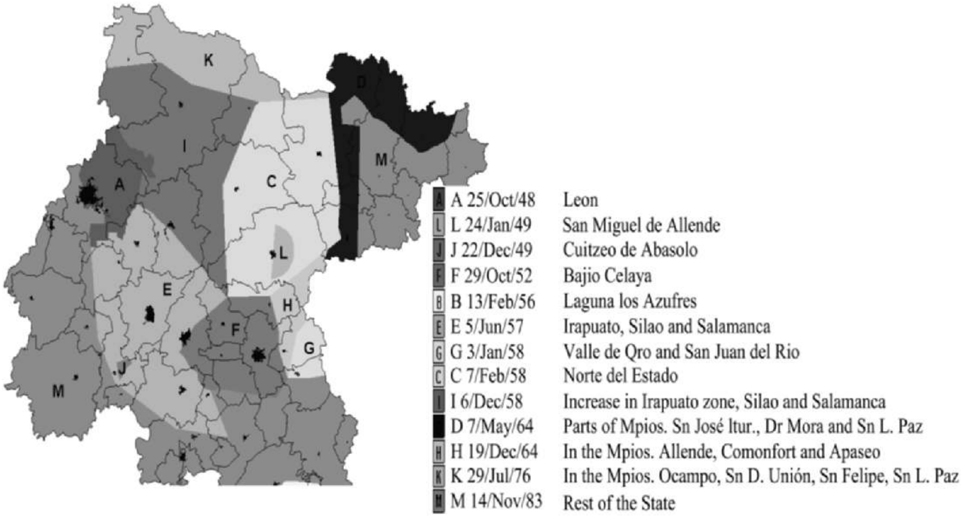

Figure 7. Imposition of official bans on new wells, Guanajuato State, 1948–present. *Source*: Comisión Estatal de Agua de Guanajuato (2002).

however, it is apparent that unregistered wells continue to be sunk. An informal association of Guanajuato well drillers indicates that over 1000 wells were drilled in 2001, while only about one-quarter of these had official permission to reposition existing wells.

Mexico's attempts at groundwater overdraft management through purely regulatory means have not been successful. In the past six years, efforts have emerged to organize water users around the central problem of groundwater overdraft at the aquifer level—the COTAS (*consejos técnicos de aguas*, or water technical councils). A third element of groundwater demand behaviour—energy supply and pricing—must be incorporated in order that users, who hold the ultimate decision of how much to pump, (a) accept regulatory controls (whether externally mandated on the part of the government, or indeed, internally devised and imposed on the part of water users' associations, aquifer councils, etc.) and (b) affiliate with participatory approaches.

Demand for energy for pumping is strongly influenced by farmers' financial calculus of costs and returns. Irrigation generally represents a relatively small fraction of the total input costs, although it conveys a significant degree of risk mitigation for other factors of production (seed varieties, fertilizers, etc.). As a result, farmers tend to irrigate in excess of the crop's water requirement. A positive outcome may be that irrigation return flows replenish rivers, wetlands, other surface water sources and notably groundwater. Particularly damaging outcomes, on the other hand, are waterlogging and secondary salinity. Farmers' preference for over-irrigation as a risk mitigation strategy must be addressed when attempting to reduce groundwater draft. This applies equally in Mexico and India, and other groundwater-intensive regions.

Economic theory tells us that farmers will adopt conservationist behaviour when the cost of water increases to a level close to its marginal value. When costs are significantly lower than returns, the elasticity of demand remains low and incremental price increases have little or no impact on demand. This is the case with groundwater in many regions, including Guanajuato where studies have shown that irrigation depths for the same crop irrigated from surface or groundwater sources were essentially the same (Kloezen & Garcés-Restrepo, 1998), despite the fact that the cost of groundwater exceeded that of surface water by approximately three times. In Guanajuato's canal irrigation systems, water supplies are limited due to water scarcity resulting in drawn down or depleted surface reservoirs; as a result there is little scope for the expansion of surface-water-irrigated area. Groundwater availability, on the other hand, is not physically constrained, and unbounded demand results in overdraft through an increase in the area under groundwater irrigation (Scott & Garcés-Restrepo, 2001).

The large difference between the high fixed cost for a well and the relatively low operating costs militates against conservationist behaviour by those who pump groundwater. In order to recover the high capital investment, the tendency is to maximize the volume pumped. One very real though often overlooked outcome of technical efficiency improvements for groundwater irrigation is that the total area irrigated per well increases as a result of farmers' efforts to recover their investments. The only real ways to reduce groundwater draft through the efficiency approach are to downsize pump capacity while increasing irrigation efficiency (in other words to irrigate the same area at lower recurring pumping costs) and to shift to lower-water-demand crops.

In addition to efficiency improvements through a range of technical programmes to promote piped distribution, drip irrigation, etc., Mexico has taken bold steps to transfer concessionary rights for groundwater to users. The National Water Commission (CNA, Comisión Nacional de Agua) administers the titling and concessioning of all water rights,[2] to both surface and groundwater sources, which are recorded in the Public Register of Water Rights (REPDA, Registro Público de Derechos de Agua). Concessions are granted for a specified annual volume over the period of the concession (typically 10 years for groundwater) and must be renewed. The application process requires that no damage to third parties be substantiated; however, in practice this is just a formality. Three principal uses of groundwater are recognized: public/urban, industrial and agricultural. Agriculture, which represents the largest share of groundwater extraction, does not have to pay the CNA for rights. However, a process of 'regularizing' agricultural rights for groundwater—even those that defied all the official bans described above—has been set in motion over the past several years, in which individual well owners (or groups of users) must formalize their concessions with a title. In addition to specifying the annual volume concessioned based on the discharge of the well and the area of irrigable land reported, the title spells out the norms regarding repositioning of the well, cessation of rights for unutilized volumes (over three consecutive years), the transfer (sale) of rights, etc.

All agricultural concession titles now specify that the user must install a volumetric flow meter and report pumped volumes to the CNA. This clause is not enforced. Users and the CNA alike admit that pumped volumes exceed concessioned volumes. In the Silao-Romita aquifer in Guanajuto, for instance, only one-third of the 1900 wells are concessioned to pump in excess of 200 000 m^3/yr; however, it is estimated from the aquifer draft figures for this aquifer that the average pumped volume per agricultural well is 250 000 m^3/yr. The CNA is understaffed and admits its own inability to make supervision visits to even a

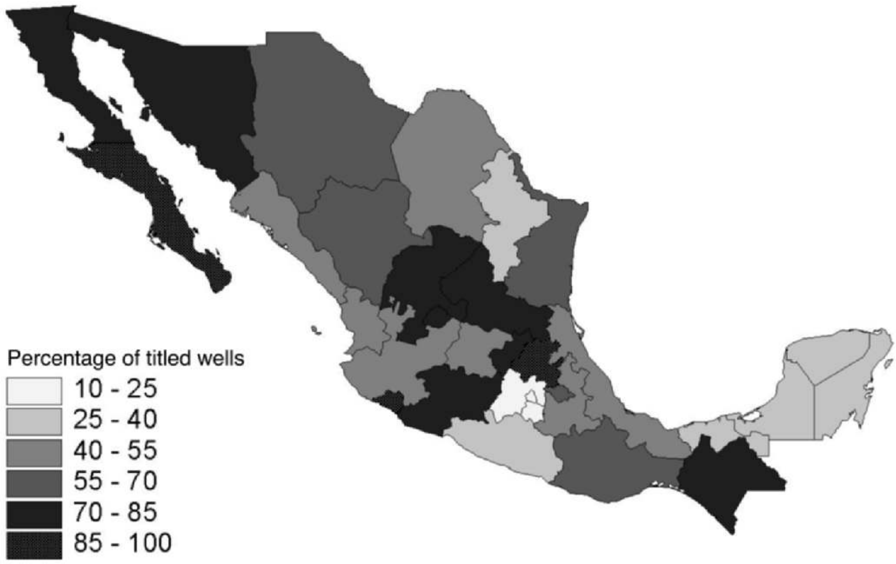

Figure 8. Percentage of wells titled.

meaningful sample of the nearly 17 000 agricultural wells in the state. Figure 8 shows the progress with concessioning of agricultural wells in Mexico in 2001 (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA), 2002). Efforts afoot in Indian states such as Karnataka and Andhra Pradesh to locate and register millions of wells, let alone effectively regulate their pumping, would benefit from a strong dose of the Mexican experience, where it has taken years to concession just 100 000 wells.

The regularization process for water rights in general, including wells, has set and then passed several deadlines over the past seven years (October 1995, October 1996 and February 2002). The latest extension of the deadline from 4 February to 30 September 2002 applied to agricultural wells only, with the caveat that all unregistered agricultural wells would not be entitled to subsidized electrical power tariff for agriculture but would instead have to pay the regular (commercial) tariff with effect from 1 October 2002. This introduced a significant element of the energy link with groundwater demand that will be assessed below.

The energy–groundwater nexus is not lost on federal and state authorities in Mexico. The estimated power subsidy to agriculture at the national level in 2000 was Mex$5.62 billion (US$592 million). In relation to the volumes of water pumped, this is higher than India's power sector subsidy of US$5.4 billion. The CFE (Federal Electricity Commission—Comisión Federal de Electricidad) and SAGARPA (the federal agricultural department, whose mandate also covers livestock, rural development, fisheries and food security) have examined various means to defray the rising costs of power supply to agriculture. The average tariff cost per unit of energy for agricultural use in Mexico in April 2002 was Mex$0.3133 (US$0.033) per kWh. In a joint policy initiative, the CFE and SAGARPA proposed a tariff rationalization that would establish a uniform Mex$0.30 (US$0.0316) per kWh and eliminate increasing slab tariffs. SAGARPA

Table 2. Agricultural energy tariffs,[a] January 2003

	Consumption			
	1–5000 kWh	5001–15 000 kWh	15 001–35 000 kWh	>35 001 kWh
Low tension (9)	0.300 (0.0316)	0.332 (0.0349)	0.364 (0.0383)	0.398 (0.0419)
Medium tension (9M)	0.300 (0.0316)	0.336 (0.0354)	0.367 (0.0386)	0.401 (0.0422)

[a]Mex$ per kWh (US$ in brackets) by consumption block per billing cycle.

would provide the subsidies to agricultural users who consume less than 15 000 kWh annually, while CFE would step in to subsidize those consuming more than this level. Incentives were proposed to further stimulate 'irrigation technification', i.e. the adoption of drip and sprinkler technology.

In December 2002 the Chamber of Deputies unanimously passed the Rural Energy Law (Ley de Energía para el Campo) to regulate market mechanisms and incentives for petroleum-based energy sources and electricity use in agriculture, effectively adopting the tariff rationalization discussed above. The law mandates a Rural Energy Programme with an annual budget and implementation plan that must be included in the federal budget. The intent of the law appears to be to level the playing field with Mexico's principal competitors—US and Canadian agricultural producers—who enjoy significant energy subsidies.

The initial regulations for the law appeared in the Official Gazette (Diario Oficial) on 7 January 2003. A new single-rate tariff of Mex$0.30 (US$0.0316) per kWh called 9-CU was introduced for agricultural pumping under both low and medium tension. Normatively, 9-CU is linked to groundwater draft; it requires proof of a valid concession title from the CNA. Additionally, an Annual Energy Limit (AEL) in kWh/yr is set for each well as follows:

$$\mathrm{AEL} = 438 + KVC/e$$

where 438 is the lighting requirement for the well shed, $K = 0.0026$ (a units conversion constant), V is the annual concessioned volume (m^3), C is the dynamic lift equal to the depth of the bore in metres as authorized in the concession title, and $e = 0.52$, the electromechanical efficiency of the pump-motor set. Consumption lower than the AEL is billed at the single 9-CU tariff of Mex$0.30 (US$0.0316) per kWh. Electrical energy consumption that exceeds the AEL is to be billed at the regular agricultural 9 and 9M tariffs (see Table 2). Every month the tariff increase will be compounded at 2%, equivalent to 26.8% per year.

Despite the intent of the law, which links groundwater extraction to energy supply, it is likely that enforcement will prove difficult. Indeed, the regulations allow data and technical studies—based on local conditions—to be presented to the authorities which can be used to modify the values of dynamic lift and efficiency (the latter may not be less than 0.52 under any circumstances). This suggests that a certain degree of manipulation is possible.

It is apparent from the review above that while regulatory and participatory approaches to groundwater management in Mexico have been set in motion, there is significant additional consolidation required. The Rural Energy Law and COTAS are far-reaching initiatives that will require public and political commitment if they are to be successful in addressing groundwater overdraft.

Conclusion

Groundwater irrigation has provided significant economic benefits to farmers around the world, yet aquifer overdraft is a major challenge that needs to be addressed through regulatory, participatory and energy supply- and pricing-based approaches. This paper has reviewed the links between groundwater irrigation and energy in India and Mexico, two countries that have significant groundwater overdraft problems with emerging initiatives to address these through agricultural energy policy, primarily through pricing mechanisms. Less attention has been paid to energy supply options, although in India energy rationing has served as an unintended brake on groundwater extraction.

The energy supply options warrant some further discussion here; for electrical power, this entails (in order of least to most difficult or acceptable socially, politically and technically in the Indian and Mexican contexts):

(a) restrictions on new connections
(b) caps on capacity or amperage
(c) reductions in hours of power supply.

In both Mexico and Indian states with groundwater legislation, for example Andhra Pradesh, new electrical connections for agricultural wells are granted even though the well itself may be in defiance of exiting bans on new wells. There is at present no parallel ban on new electrical connections—this appears to be another shortcoming of the regulatory approach to groundwater management.

Amperage caps through limits to transformer capacity have been experimented with in Mexico. However, pumps must be sized to meet peak irrigation demand for the land authorized to be watered under the concession title, with the result that idle capacity may be used during non-peak periods to irrigate additional land, including through water trading or selling. Additionally, transformer installation is the responsibility of the well owner—transformers are sold by pump distributors—so voluntary capacity upgrades are now possible. With state electricity boards in India on the verge of bankruptcy, farmers there too are compelled to purchase transformers to compensate for the lack of SEB investment capacity (Samra, 2002). Similar to the assessment that not limiting electrical connections is a lost opportunity, allowing well owners to size their own transformers appears to be a lacuna in the regulatory framework.

A reduction in the hours of service is an energy supply control being used in countries such as India, although there it has more to do with generation and distribution capacity relative to demand than being a conscious regulatory approach. However, the groundwater overdraft implications of limiting hours of power supply are immense. Exercising this option in a country like Mexico would be very difficult both socially and politically. Urban areas already command a disproportionate share of public services, and further cutbacks, for instance in rural power supply, would cause unrest and spell political doom.

The ungovernability of highly competed water resources may simply be a feature of rapidly expanding demands for limited water resources. The Indian scenario appears to present frenetic user activity (the groundwater boom, a rush to harvest water where it falls, head-end appropriation of canal water, etc.) on the ground in disregard or ignorance of stated policy prescriptions. In the final analysis, the challenge for India or Mexico is to create a policy environment in which multiple and competing interests and demands for water can be accommodated. Finally, integrated regulatory/legal mechanisms, public participation around groundwater and water management in general and, above all, appropriate energy supply and pricing options are the cornerstones of sustainable groundwater management.

Notes

1. Up until the 1970s, the State Electricity Boards (SEBs) charged agricultural users based on metered consumption; however, as the number of tube wells increased, SEBs found it impossible to manage metering and billing, particularly the transaction costs associated with tampering of meters, pilferage, under-billing, corruption at the level of meter readers, and the costs of maintaining a large staff of meter readers. As a result, during the 1970s and 1980s, agricultural power tariffs were converted to a flat rate based on the horsepower rating of the pump. Although falsification of horsepower rating still proved to be a problem, the switch to flat rate eliminated the financial and transaction costs of metering. In the ensuing two decades, however, tariffs stagnated or fell in real terms as agricultural power became the centerpiece of rural political largesse. Nevertheless, this would inevitably have been the case for metered tariffs as well. International financial institutions like the World Bank have played roles in electricity supply and pricing that are often contradictory. For example, the World Bank designed and implemented a project on Groundwater Irrigation in Uttar Pradesh, funded by The International Fund for Agricultural Development (IFAD), that contained a loan stipulation for a dedicated electricity supply line to the pumps so that farmers could pump 24 hours a day uninterrupted. The loan further stipulated that farmers should receive highly subsidized energy for pumping, an unsustainable move for which the country is being criticized by the same donors at present.
2. Water is considered the property of the nation; however, there is some definitional ambiguity regarding 'state' waters (surface sources that originate and are depleted within a state). All groundwater is national property.

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