The Groundswell of Pumps: Multilevel Impacts of a Silent Revolution

François Molle,[1] Tushaar Shah,[2] and Randy Barker[3]

Paper Prepared for the ICID-Asia Meeting, Taiwan, November 2003

[1]*Principal Researcher at the Institut de Recherche pour le Développement (IRD), France, currently seconded to the International Water Management Institute.* f.molle@cgiar.org. *P.O. Box 2075, Colombo, Sri Lanka.*

[2]*Principal Researcher at the International Water Management Institute.* t.shah@cgiar.org

[3]*Principal Researcher at the International Water Management Institute.* r.barker@cgiar.org

Abstract

In the wake of the "green revolution" another more silent and crucial transformation is occurring. The dissemination of relatively cheap pumping technology has revolutionized access to both underground water (deep wells or shallow wells) and surface water (tapping rivers and drains and flows in irrigation canals). Pumps and tube wells have played a prominent role in irrigation in the semiarid regions for many decades. However, with the steady decline in costs, pumps are now, to a large degree, privately owned and have spread rapidly, especially in the monsoonal regions of Asia. This has superimposed a logic of individual, flexible, and on-demand access to water, which has far-reaching and, as yet overlooked, implications for the regulation and management of our water resources.

The first part of the paper describes the upsurge in the use of pumps and the wide variety of physical conditions and institutional arrangements under which pumps are owned and operated. The second part of the paper, through a series of examples in selected countries, examines the consequences of the spread of cheap pumping technology—water rights and the reordering of access to water, private ownership and collective action, and the implications for integrated management of privately owned pumps with publicly operated surface irrigation systems. These examples serve as a basis for the conclusion, which spells out the hydrological social, management and economic impacts of the pump revolution.

Keywords

Groundwater, pumps, irrigation, water management, aquifer

This research contributes to the Comprehensive Assessment of Water Management in Agriculture (www.iwmi.org\assessment). The research was supported by a grant from the Government of Netherlands to the Comprehensive Assessment

1 Introduction

In the wake of the Green Revolution another more silent, but probably as crucial, transformation has occurred in the management of water resources for irrigation. The dissemination of relatively cheap pumping technology has revolutionized access to both underground water (deep wells or shallow wells) and surface water (tapping rivers, drains and low flows in irrigation canals). Pumps and tube wells have played a prominent role in irrigation in the semiarid regions for many decades. However, with the steady decline in costs, pumps are, to a large degree, privately owned and have spread rapidly from the semiarid into the monsoonal areas of Asia. Depending on the physical and socioeconomic context, different types of pumping devices (fixed/mobile, collective/individual, private/public, shallow/deep) have emerged.

The superimposition of a logic of individual, flexible and on-demand access to water to the distribution patterns of large-scale irrigation schemes has far-reaching, yet overlooked, positive and negative implications. In the first place, water allocation and distribution, as well as their related levels of efficiency and equity, are impacted by the uncoordinated nature of the abstraction of additional sources: rivers, drains, ponds and aquifers. This generally occurs when water rights are ill-defined, a case in which conflicts are likely to develop. Second, collective action in water management (whether surface water or groundwater systems) is potentially undermined by the development of individual strategies fostered by the possibility of individual access to water. However, this may also lead to the reworking of arrangements and collective rules. Third, both the spread and the partial individualization of pumping have an implication on both costs and the amount of energy spent on food production, and more generally on cost-recovery and irrigation financing.

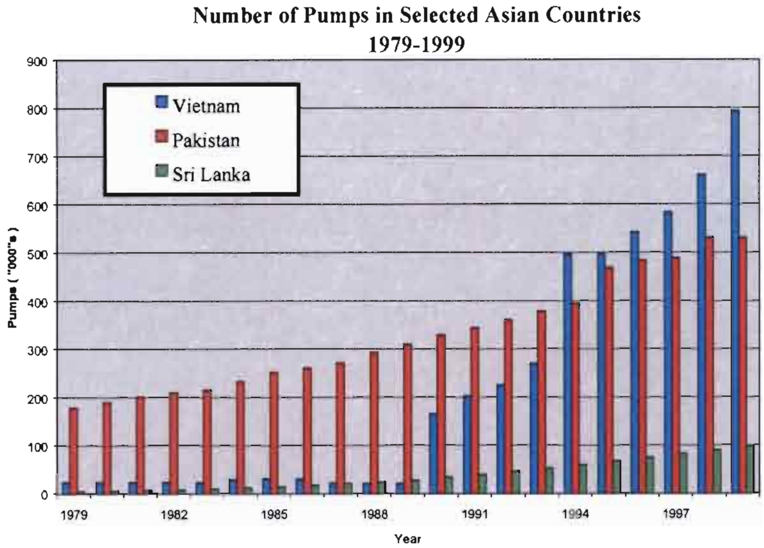
To date, there is no available comprehensive assessment of the magnitude and importance of the spread of pumps, or of their global impact on groundwater resources. The following sections do not intend to make up for this lack but, rather, to illustrate these points through a few examples drawn from Asia and the Middle East.

2 The upsurge and spread of pumps

There is a tendency to associate irrigated agriculture in the developing world with canals, dams, tanks and reservoirs. By contrast, largely hidden from attention, a worldwide explosion has occurred in the use of wells and pumps for irrigation, domestic, and industrial use. A few statistics give a graphic illustration of this upsurge.

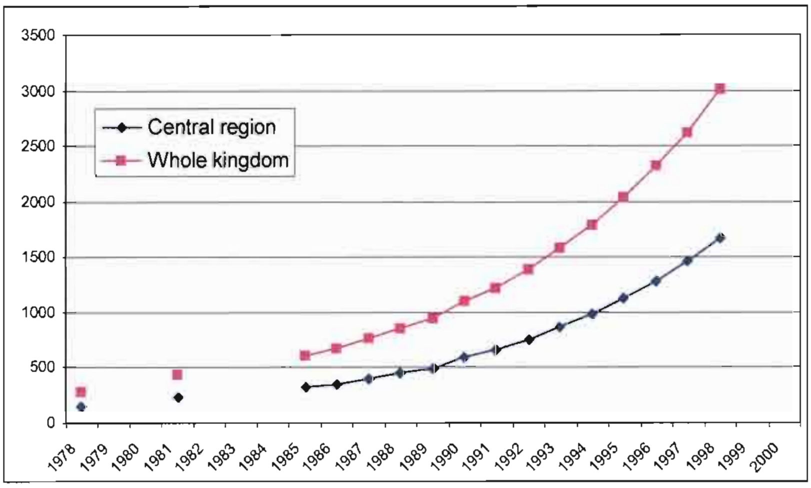
Figure 1 shows the evolution of the number of pumps in Sri Lanka, Vietnam and Pakistan during the eighties and nineties. Both the rate of increase and the actual absolute number of pumps are astonishing. Vietnam, for example, saw the number of pumps multiplied by fivefold in the nineties alone. Data on Thailand (Figure 2) are also impressive: the number of pumps in the kingdom reached 3 million in 1998, 56% of which were found in the Central region. In Iran, 365,000 tube wells are pumped to produce 45 km^3 of groundwater (Hekmat 2002).

Figure 1



Source: Barker and Molle 2003.

Figure 2. Evolution of the number of pumps in Thailand (1,000 units)



In India, the number of pumps, used mostly for groundwater irrigation, grew from less than 100,000 in 1960 to over 19 million by the turn of the century and at the current rate of growth, the number of irrigation pumps in India will be close to 25 million by 2007 as suggested in (Moench 2002). India has varied hydrological regimes. The Indo-Gangetic basin, which has some of the best aquifers, can sustain intensive groundwater irrigation with pumps. However, the rapid spread in pumps in India is not confined to such well-endowed regions. As the following map from Debroy and Shah 2002—which overlays density of irrigation pumps on density of human population—shows (Figure 4), even in the semiarid regions of India and Pakistan Punjab, groundwater irrigation has grown steadily since the 1960s to the point where groundwater exceeds surface water systems as a source of irrigation. Each black dot in the map represents 5,000 pumps, and the concentration of pumps tends to be higher in regions with high density of human population.

Figure 3. Growth of energized pumpsets

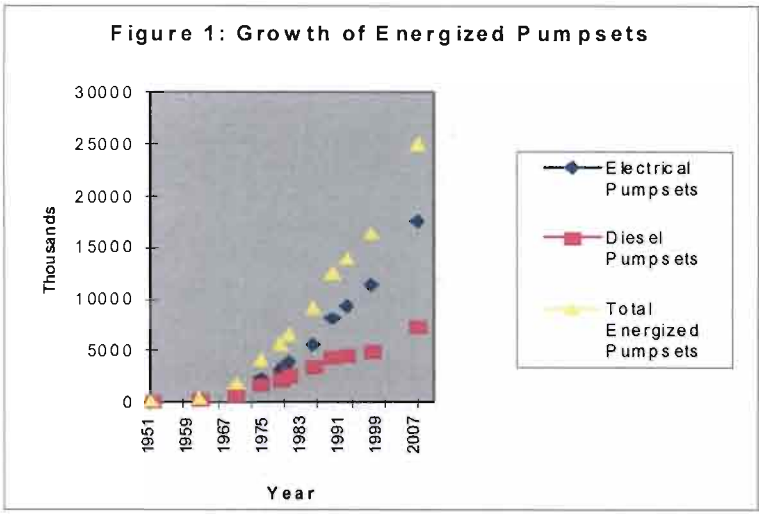
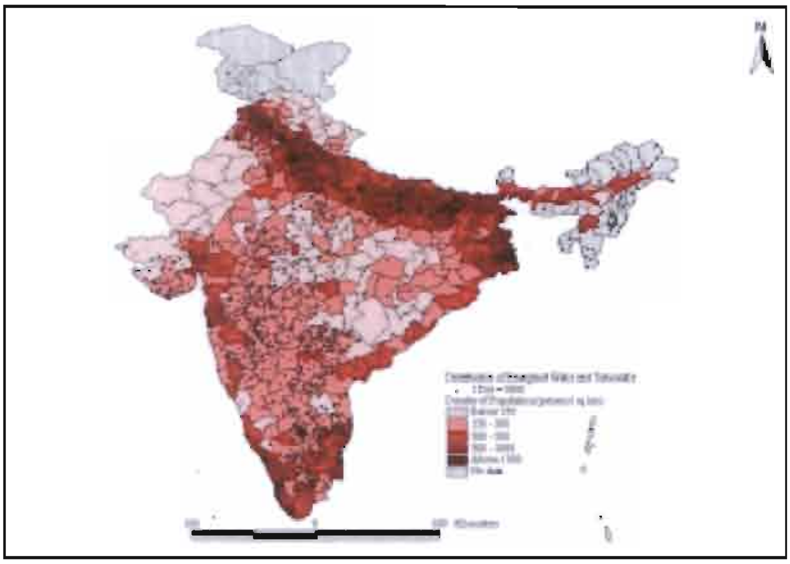


Figure 4. Distribution of pumps in India



While all these figures exemplify the rather recent groundswell in pumps, it should be noted that the expansion in the use of pumps has occurred over a much longer time period in semiarid regions such as Pakistan (see later) than in monsoonal areas such as Vietnam and Sri Lanka. Large pumps have been widely used in the Red river since the 1950s.

These statistics are not devoid of ambiguity. It is not always clear how yearly data are extrapolated, or whether pump sets which are out-of-order are also included in these data. The type of pumps is also not specified and the data may include devices like low-lift axial pumps powered by 2-wheel tractors together with larger diesel-powered suction pumps, or even large-scale pumping stations. For all these shortcomings, the data presented above are sufficient to convey the sense of an upsurge that may not be unworthy of the term "revolution."

3 Pumps in various environments

In discussing pumps and wells it is useful to distinguish between several environments with very different management problems. First, a distinction can be made between situations where abstracted water is surface water or underground water. A second distinction can be made between high-discharge and low-lift pumping operations,[1] and a third one between individual uses and collective uses. When the use of water is collective, management can be collective and, in that case, either state-driven or not, and individual. These categories appear in Table 1, and are illustrated by several examples.

Surface water low-lift pump operations are best illustrated by Asian deltas. In the Chao Phraya delta, Thailand, 80% of farmers have at least one pumping device; in their great majority axial-pumps are powered by the ubiquitous 2-wheel tractors. These pumps are used for all sorts of operations: pumping water into paddy plots from adjacent canals, ditches or drains, but also pumping water out after land preparation or to speed drainage in case of heavy rainfall. Small pump sets are also used to pump water from farm ponds. In the Mekong delta, the most common low-lift device is the shrimp-tail pump, which consists in using the propeller of a boat to put water under pressure in a box and deliver it through a hose. This service is often collective, delivered by entrepreneurs who move their boats around in the network of channels and supply several groups of farmers on a seasonal contract basis. Alternative management patterns have been tested with limited success. A cooperative established at the instigation of the state using a fixed pumping station has tried to offer pumping service but could not operate with the required flexibility.

On the contrary, collective pumping stations implemented by localities in the Red River delta, are all the more successful. Because of the failure of the large-scale state-run irrigation units in delivering flexible and satisfactory irrigation and drainage services, these "local stations" have mushroomed in the delta, superimposing themselves upon the existing hydraulic network. In Bac Hung Hai, for example, the largest polder in the delta, there were 814 local stations in 1996 supplying 54,487 ha, against 324 centralized stations supplying 41,490 ha (Fontenelle and Molle 2002).

High-lift operations of surface water are typical along (steep-sided) river valleys. They are implemented by farmers who find a crop with returns high enough to offset the costs of pumping (unless electricity is highly subsidized). A good example is that of almonds growers along the upper reach of the Zayandeh Rud river, in Iran, who pump water up to the bordering plateaus, 300 m above the river level. State run pumping schemes with significant head can also be found (e.g., certain districts in China), but are not widespread because of the O&M costs.

Low-lift groundwater is abstracted generally by tapping the shallow alluvial, which is usually replenished every year. Such aquifers are common in the low-lying areas and valleys of Asia where rice is grown. Depending on the physical characteristics of the soil and the discharge desired, tube wells or large dug wells are dug. Typical dug wells are the "agro-wells" of Sri Lanka. Since the depth of abstraction is limited by the 8-10 meter constraint of suction pumps, there is often the need to lower the body of the pump when the water level drops further. In dug wells, this is rather easy but for tube wells, this requires sinking round-shaped concrete rings to allow for accommodating the pump in a lower position, a technique Thai farmers are good masters of.

High-lift water abstraction from deep aquifers can be found in virtually all countries in the world, particularly in arid countries. Their use in agriculture is usually individual but, notably in India and

Pakistan, such well may be owned and operated by entrepreneurs who sell water to users around. In other cases, such as the Sukhothai Project in upper central Thailand, wells are operated by the government and serve several hundreds or thousands hectares of land divided among small (or large) holders. In western Indian state of Gujarat, where farmers have depleted excellent aquifers over decades of sustained overdraft, tube wells go to the depth of 400 m or more. Here farmers use 90-150 hp pumps to produce a discharge of 60-90 liters/second, and use complex network of buried pipes to distribute this water. The cost of making such tube wells often amounts to US$15-20,000. Since no farmer is large enough to mobilize such capital, tube wells here are typically built and owned by informal 'tube well companies' in which farmers share capital, costs, profit and losses in proportion to their land in the command (Shah 1996).

Table 1. Typology of uses of pumps in irrigation, with some examples.

	Low-lift		High-lift		
	Individual use	Collective use	Individual use	Collective use	
				State management	Private management
Surface water	Deltas (Mekong, Chao Phraya, etc)	Mekong delta, Red river delta	River sides	China	
Groundwater	Valley aquifers, paddy areas Agro-wells	Agro-wells	Morocco, Iran, India, Pakistan, Bangladesh, Nepal	China, Thailand (Sukhothai)	China, India, Pakistan, Iran

4 Consequences of the pump revolution

All these different situations show the diversity of environments where pumps play a role in irrigated agriculture, often a major one. The picture gets even more complex when one considers their incidence both on the hydrological cycle and on collective action or management.

Hydrology-wise, particularly in the semiarid regions, the picture is little encouraging. The groundswell of pumps and wells has had a critical impact on poverty alleviation, but has led to massive groundwater withdrawals which have altered the hydrology of the river basins (e.g. drying up of springs), jeopardized intergenerational equity (mining of main aquifers) and provoked environmental damages (coastal saline water intrusion, contamination, land subsidence). While groundwater has contributed much to the growth in agricultural productivity, the overexploitation of groundwater is affecting both the quantity and quality of water available for agriculture, domestic use, and other purposes (Shah et al. 2000).

Management-wise, the consequences are equally critical. Pumps are being used not only for groundwater extraction but also for providing greater flexibility in the reliability and delivery of surface water. Kikuchi et al. (2003) comment as follows:

> In the history of irrigation and irrigated agriculture in monsoon Asia in the tropics, the last few decades of the 20^{th} century will be remembered as the decades of well and pump diffusion that enabled individual peasant farmers to irrigate their crops at their discretion, as opposed to those

in gravity irrigation systems in which decision making as to water allocation and distribution rests at best on groups of farmers or at worst on bureaucratic government agency totally unaccountable to farmer beneficiaries.

In the areas where surface and groundwater systems are hydrologically strongly linked, conjunctive use has not led to conjunctive management. The growing ascendancy of private investment in groundwater has undermined collective management by fostering individualistic strategies. Farmers who have acquired pumps may be less willing to participate in irrigation associations or the widely promoted participatory irrigation schemes. But failure to maintain the surface irrigation systems can, in turn, affect the groundwater recharge and increase the cost of pumping as groundwater tables fall.

This section provides a few illustrations of all these interrelated aspects of the pump revolution.

4.1 Iran

"The leitmotiv of the country's irrigation ecology" (McLachlan 1988), qanats are widely believed to have originated in Iran, where they were common as far back as the 600 BC. Qanats are galleries with a gentle slope which drain aquifers and provide regular flow at their outlet, and can be seen as man-made springs. Estimates of the number of qanats in Iran vary between 30,000 and 40,000 (McLachlan 1988; Beaumont 1989) but a large part of them is now out of order. After the nationalization of water resources in 1968, the growing intervention of the state came together with a modernist ethos, whereby traditional village irrigation was considered as primitive, backward and inefficient (McLachlan 1988; Ehlers and Saidi 1989). The demise of qanats became apparent in the 60s (Ehlers and Saidi 1989) when landlords withdrew money from annual repair of qanats to invest in wells, despite a 1943 law obliging them to take steps whenever necessary (Lambton 1953). Qanats enjoyed a renewed interest and consideration during the post-revolution time but the emphasis on self-sufficiency and production eventually favored the wells. Wells provide a more flexible and more abundant source. Their great advantage is to allow over-exploitation of aquifers in periods of drought, thus ensuring a regulation of supply. On the other hand, uncontrolled expansion of wells leads to the overdraft of aquifers, and jeopardizes this regulation advantage due to reduced yield, declining water quality, or growing costs.

Year after year, wells took a heavy toll on qanats. While in 1950 the contribution of tube wells was negligible and existent qanats were providing 60% of all supplies and serving 1.2 million hectares of irrigated land, by the mid-1970s wells were already providing 8 billion m^3, against 9 billion m^3 for qanats (McLahan 1988). The history of the destruction of qanats by wells is documented by several studies (e.g., Ehlers and Saidi[2] 1989; Lambton 1969). What have been the implications of such a change? In many instances, qanat right-owners have often also been the beneficiaries of well development, either because they were encouraged by the government to expand production, or because they felt forced to do so to weather pressure over resources. In all cases, this resulted in growing local abstraction and reduced sub-superficial flows to downstream. Consequently, users who were tapping these flows (either through other qanats, or after the reemergence of these groundwater flows in downstream river streams) were impacted. In closed basins, where all the water is used up, this is tantamount to a spatial redistribution of water use or, more to the point, to a re-appropriation of water by upstream users. In other cases, where qanat right-owners could not make up for the loss of their qanat with adequate alternative sources, they were stripped of their water by those having the financial capacity to invest in wells and pumps.

The social cohesion of villages depending on a sole and vital source like a qanat had several managerial, legal, and economic dimensions (Spooner 1974). Obviously, the breakdown of the qanat also had social implications. In some cases, qanat shareholders themselves invested together in wells and pumps, building or existing social arrangements and cohesion (Molle and Miranzadeh 2003). In other cases, landlords were able to get most of the benefits from the change and social links tended to disaggregate, including traditional dependencies between peasants and landlords. While this is not necessarily deplorable, the new order has failed to bring more equity. According to Ehlers and Saidi's (1989) case studies, "modernization worsened in the long run existing social and economic discrepancies".

4.2 Western and Peninsular India

This same story got repeated in vast regions of India where tanks, like Iran's qanats, were the mainstay of rural communities and their livelihoods over the millennia. At the time of India's independence in 1847, the three south Indian states of Tamil Nadu, Andhra Pradesh and Karnataka had between them over 300,000 such tanks, many in cascades. Northern states too had tanks and tank like structures in large numbers. Like Iran's qanats and Afghanistan's karezes, India's tanks too have fallen into disrepair. Many factors played a role but the most important culprit has been the rise of the pump irrigation economy. As large affluent farmers in command areas of tanks were able to secure captive water source in the form of a tube well and a pump, they increasingly lost incentive and interest in adhering to traditional customs and rules for sustained management of tanks. Privately owned tube wells thus became the enemy of common property tanks.

Unlike in many other parts of the world, semiarid areas in India are now coming full circle when it comes to tanks. As groundwater economies have grown, farmers are increasingly finding that the only way their wells remain productive is by keeping their tanks in good shape. While the interest in tanks for flow irrigation ebbed, there is a new found interest in tanks as groundwater recharge structures. During the past decade, in western Indian states like Gujarat and Rajasthan, communities have constructed largely from their own contributions, tens of thousands of new tanks and tank-like water storage structures primarily to enhance local recharge which they can use to save their crops from moisture stress (Shah 2000).

4.3 Thailand

In the central plain of Thailand, three kinds of pumping operations can be found. The first one, generalized in the delta flat, is the use of axial pumps to achieve water transfers between plots and adjacent channels, with very low lift-heads. This is done by farmers individually and generates few problems. A second situation is found on some alluvial terraces, where shallow wells are exploited when supply in the irrigation canals is unsatisfactory. These wells have low costs and are operated individually, although two or more farmers may share the investment. Aquifers may drop but they are usually replenished during the next wet season. They are, to some extent self-regulating. A more interesting situation is that created by the need to compensate for the insufficient water level in traditional gravity schemes, as found in the upper part of the delta (see Molle et al. 2001). Low water levels in main canals mean poor or no inflow into lateral canals. Farmers thus ensure inflow by closing the regulator and pumping at the head of lateral canals with the use of their low-lift axial pumps (*tho phayanak*), generally powered by a 2-wheel tractor. Sometimes, up to 15 pumps can be set at the same time, although 5 or 6 are generally the maximum number of pumps activated at the same time.[3]

This operation is more complex than it may appear at first sight: in what order do farmers pump? The accepted right is that whoever comes first (i.e., whoever has an urgent need of water for his/her plot) pumps first. Latecomers must wait for those who have set their pumps first to finish filling up their rice fields. Farmers with no pumps (a minority) do not engage in risky cropping or pay neighbors to pump for them. Things get complex because pumping water from the main canal into the lateral is not enough to raise the water level as to ensure gravity inflow into tertiaries or into plots adjacent to the canal. It follows that whoever pumps at the canal head must also pump a second time in the lateral, at his/her plot or where the tertiary leading to his/her plot branches off.

Whoever has only one pump set will try to team with a neighbor and will pump at the head while the neighbor pumps at the plot level. Costs are balanced and shared on an area basis. Obviously, cases arise in which one farmer uses a more powerful pump near his plot than the one he uses at the head of the canal (typically an axial pump of 8" in diameter against one of 6"). Normally, this is observed by fellow farmers and the trespasser is told to change his system at the next rotation or can be barred from pumping by the other farmers at the next opportunity. However, complacency with particular cases seems to be rather common ("he has high land," "his land is dry," "he lost his rice last year"). The system functions rather smoothly and is internally controlled. Some inequity is accepted as far as it is not perceived as outright cheating. This example shows that, in a context reputed for its lack of effective Water User Groups, the possibility offered by pumps to partly redress the deficiencies of gravity water supply are successfully taken advantage of through ad hoc social arrangements.

While such individual and collective pumping strategies have allowed farmers (but more particularly head enders) better access to water, it is all the more true that—in return—this has discouraged whatever regulation improvements the Royal Irrigation Department (RID) would have otherwise been pushed to achieve. Rotational arrangements are part of the paraphernalia but as their implementation entails significant transaction costs, RID officials understandably prefer the actual *status quo* where their role is to ensure water in the canal, even with a low level. The embracing (or the strengthening) of a pervasive individualistic concept of gaining access to water implicitly reinforced the acceptance of the *first-pumping-first-served* principle, and the idea that locational advantages necessarily translate into privileged access to water, thus privileging head enders and choking claims of greater equity. This also ended up altering the role and power of the RID as water manager.

Apart from these agricultural uses of pumps and/or groundwater, it is worth mentioning the overdraft of Bangkok aquifers by tube wells, which provide 95% of the water used by industries in the Bangkok Metropolitan Area (BMA) (Christensen and Boon-Long 1994). The actual pumping rate is approximately 3 million m^3/day, against a sustainable level of 1 million m^3/day (Molle et al. 2001). Despite critical externalities in terms of land subsidence and flood damage, the overdraft is continuing, although recent drastic measures taken by the government seem to bear some fruit.[4]

4.4 Egypt

Irrigation of the Nile delta is based on the supply of water through different arms of the river which feed branch (and subbranch) canals, generally with an on-and-off pattern. From these channels, water is elevated by traditional lifting devices (*saquia*) or by using diesel pumps and flows to tertiaries (*mesqa*) and quaternaries (*marva*). The extension and intensity of cropping has therefore always been contingent upon the overall abstraction capacity, including its manpower, animal power and machinery components. Although the first steam-powered pumps appeared in the last quarter of the nineteenth century and diesel pumps in the 1930s, the number of mechanical lifting devices became significant in the 1980s. More recently, the drilling of deep wells has also become very common. These wells provide a supply of water which is independent of the distribution network.

Two conflicting forms of logic are making progress in the delta. On the one hand, there is a trend towards dispersion, individualization, and conjunctive use of water. The quest for higher reliability and flexibility is based on a growth of the pumping capacity (going well beyond that corresponding to flat water requirements), and on the tapping of multiple sources (canals, drains, groundwater). This, however, comes with higher energy costs and lower average water quality, and greatly complexifies the understanding of water flows in the delta (Pintus 1997). On the other hand, there is a rationalizing process going on, whereby a hierarchical management structure is intended to parallel a modernized network of distribution of the Nile waters. It includes the modernization of the *mesqa* level (limitation of losses as a way to reduce pumping operation and maintenance (O&M) costs and the time required for irrigation (Depeweg and Bekheit 1997; Hvidt 1995), and attempts to increase the predictability of water supply at the branch level, in view of transferring the management of the latter to Water Boards. This policy towards management transfer appears to be neatly driven by financial considerations, with Water Boards expected to gradually share O&M costs of irrigation and drainage (Abdel-Aziz 2003).

Because of its vital role in agriculture and the collective nature of its ownership and management, the *saquia* is part and parcel of the Egyptian landscape and social fabric (Mehanna et al. 1983). The introduction of mobile pumps was deemed to impact negatively on the preexisting traditional structure of water management, based on the *saquia* unit. However, Pintus's (1997) fieldwork in the Menoufeyya Province shows that *saquia* and pumps did not really conflict with each other and that the gains in flexibility have contributed to reducing the occurrence of conflicts. Traditional structures were still needed for the management of the pumps themselves and for their inclusion in the *mesqa* system. The spread of pumps also appears to be boosted by external factors, including the policy to lower water levels in the delta initiated in the 1970s, the growing difficulties to raise the cattle needed for power, the opportunity cost of labor outside agriculture, and the social prestige of modern mechanical devices.

4.5 Vietnam

Both the Red river and Mekong delta offer a few lessons on the spread of pumps. As mentioned earlier, with the failure of large-scale state-run irrigation units to deliver flexible and satisfactory irrigation and drainage services in the Red river delta, "local" pumping stations have been implemented by cooperatives and communes, often with public financial support (Phong 2002). Here, again, pumps have been instrumental in raising control over water by users, including better satisfaction of water requirements, quicker land preparation, making the cropping calendars flexible and better conveyance efficiency (Fontenelle and Tessier 1997; Mai Van Hai 1999). If this change is, on the whole, technically and socially positive, it also has implications on the financial sustainability, since the implementation of local pumping stations has amounted to a duplication of investments resulting in high—and costly—pumping capacity per hectare. The distribution of O&M costs over farmers, cooperatives, district hydraulic companies, provincial hydraulic companies and, finally, the state appears to be a complex issue (Fontenelle and Molle 2002). It is also a highly political issue, where the strategies, the political weight and the room for maneuver of the different actors of these embedded levels eventually define who pays what and how much.

The historical and physical context of the Mekong delta has generated different responses to the challenge of controlling water. As mentioned earlier, pumping from the millions of channels that crisscross the delta has developed thanks to entrepreneurs providing pumping services using mobile pump sets on boats (northern part of the delta), as well as to individuals often using "shrimp-tail pumps". This dramatic supply of pumping capacity, added to the growing availability of freshwater in the lower delta, has contributed to boost dry-season cropping all over the delta.[5] The resulting effect of this change is to radically—albeit gradually—alter the outflow to the sea. In dry years, this effect is bound to result in severe saline intrusions into the arms of the river and to damage plantations, notably orchards. This example shows how the combined effect of scattered and uncontrolled pumping operations may significantly alter the hydrologic regime and increase vulnerability.

4.6 Yemen

Home to an ancient and remarkably efficient system of terracing and irrigation (Milton 2001), Yemen has seen its agriculture completely changed by the irruption of pumping technologies, leading to a severe overdraft of aquifers. Water use is estimated at 3.4 Bm^3, [billion m^3] in excess of 35% of renewable resources (2.5 Bm^2) (Kohler 2000), but the situation is much worse in some localities. The extraction rate in Sana'a area, for example, is believed to be four times higher than the sustainable yield (Ward 1998). It is estimated that there are about 45,000 private wells in the country (although some estimates are considerably higher) and about 200 drilling rigs (Ward 1998) with largely uncontrolled activities. In other words, despite providing significant short-term benefit to rural populations, the pump revolution has gone awry.

The current water crisis is the result of several internal factors (population growth at 3.5%, government and international development agencies' support to the "modernization" of agriculture through tube well technology in the 1970s [Milton 2001; Ward 2001], subsidies for oil and pumps and protective measures for *qat* production) as well as external factors (absorption of a population of 1.2 million expelled from Gulf countries after the first Gulf War, mostly in the agriculture sector and the supply of cheap groundwater-extraction technologies).

The main consequences of the overdraft are of course the unsustainable nature of current agriculture, which has already driven some farmers out of business, as well as the growing costs of supply to cities, which must look for deeper or more distant resources. In some of the most stressed areas of the country, agriculture is running out of water. In *wadi* Bani Khawlan, near Ta'iz, uncontrolled groundwater extraction and upstream riparian use development have drained aquifers, drying up springs and leading to the abandonment of agriculture further down the *wadi* (Ward 2001). In the Hadramaut coastal region as well as in the western highlands, pumps have also dried up most of the ancient qanats (Lightfoot 2003).

While spate irrigation from *wadis* had traditionally been regulated by strict tribal codes and enduring social arrangements, the groundswell of individual boreholes has escaped local control (Al-Sakkaf et al. 1999). This can be partly attributed to the lack of awareness of the finite nature of groundwater resources and to the inadequacy of customary laws: the necessity of collective management was not perceived, local costumes were not adapted to the technological revolution brought about by pumps, and the individual nature of the investment made local control more difficult. As in the Iranian case, the pump revolution has worsened inequities by favoring those with higher financial capacity, including larger landowners who sell water to surrounding poorer farmers (Ward 1998; Milton 2001).

Due to the prevalence of local tribal power over state power and to the specificity of each locality, there is a large consensus that solutions must be devised locally, with the involvement of stakeholders and traditional structures[6] (Milich and Al-Sabbry 1995; Ward 1998; Kohler 2000), rather than believing that formal state-driven legal approaches will suffice. In addition, instead of ignoring the importance of *qat* in the water problem, Milich and Al-Sabbry (1995) emphasize that the state should invest in research and development as a way to improve water productivity. Other solutions advocated by analysts to resolve the gridlock include new legal provisions, the end of subsidies (already partly implemented), price incentives or water markets, or conservation measures.

4.7 *South Asia and North China Plains*

Unlike in Thailand, most pump-irrigation schemes in the South Asian region and in North China Plains (NCP) are dependent on groundwater. In these predominantly agrarian regions, the booming groundwater economies have assumed growing significance from the viewpoints of livelihoods and food security. However, their significance as engines of rural and regional economic growth has remained understudied. There are several ways to consider the scale of the groundwater economy, but one practical measure is the economic value of the groundwater production. India, Pakistan and Bangladesh have active markets in pump- irrigation services in which tube-well owners sell groundwater irrigation to their neighbors at a price that exceeds their marginal cost of pumping. This price offers a market valuation of groundwater use in irrigation. Table 2 constructs a profile of the groundwater economy in three Asian countries (India, Pakistan, China) using such valuation and suggests that groundwater irrigation in Asia may well be a US$10–12 billion/year business. It needs to be noted that this figure is likely to understate the contribution of groundwater to the agricultural economy of the regions covered, which may be several times greater, more likely near US$25–30 billion. Thus the groundwater economy of South Asia is of huge size and the unique feature of this economy is that it is mostly at the hands of the farmers.

Table 2. The size of the Agricultural Groundwater Economy of India, Pakistan and China.

		India	Pakistan	China
A	Total no. of groundwater structures (million)	19	0.5	3.5[1]
B	Estimated groundwater use (km^3)	150	59	106[2]
C	Average output of groundwater structures m^3/ho	25	100	41[3]
D	Average hours of operation/well/year [(B*1,000,000,000)/A]/C	315	1,180	1,134[3]
E	Price at which pump irrigation from standard-siz pump sells (US $/hour)	1	2	0.96[3]
F	Imputed value of groundwater used/year (B/C*E or (E*D*A) (billion US $)	6	1.2	2.5

[1]. Shi 2000.
[2]. Ministry of Water Resources 2000.
[3]. Wang et al. 2000.

India's 100,000 public tube wells and Pakistan's 15,000 tube wells[7] of the Salinity Control and Reclamation Project (SCARP) represent a small "public" component in the total groundwater capital stock of these countries. In China, groundwater capital stock was financed for long mainly by local village and township governments with varying levels of central government subsidies prior to the implementation of household production responsibility system (HRS) in the late 1970s. Till then, farmers contributed mostly in labor, and collective ownership dominated all groundwater irrigation.

With the implementation of HRS, the shares of the collective and government in groundwater irrigation investment declined from 21% and 12% in the 1983 to 5% and 3% in 1998, respectively. During this period, the share of farmers' investment increased from 67% to 92% (Wang et al. 2000).

Throughout South Asia, public initiative played a strong promotional role in the historical evolution of groundwater irrigation in the early 1950s. In India, for example, the government program to establish public tube wells in Uttar Pradesh way back in the 1930s provided the first exposure of farmers to the advantages of the modern tube well technology. Two decades later, the government initiative to set up SCARP tube wells gave the first impetus to groundwater irrigation development in Pakistan. In all these countries, however, private tube wells soon took over and left the government sector marginalized. Today, India's public tube- well program and Pakistan's SCARP tube-well program lie in complete disarray, while the private tube-well economy is booming. In China, groundwater economy took a somewhat more circuitous path but its organization has eventually assumed pretty much the same shape as in South Asia. Much groundwater irrigation capital in China was collectively created and owned before the end of the 1970s. However, collective ownership has gradually given way to a more market-oriented, private or quasi-private irrigation ownership since the 1980s. In a study of 30 villages in the Hebei Province of NCP, Wang and co-researchers found that the share of collective property rights declined from 83% in 1983 to 31% in 1998, while the share of non-collective property rights increased from 17% in 1983 to 69% in 1998 (Wang et al. 2000). Today, we find four types of tube-well ownership arrangements in China: private individual, private shareholding, pure-collective and quasi-collective in the NCP. In the pure collective system, village collectives invest in all pumping-related facilities and also manage the operation of the tube well, while in quasi-collective arrangements, village collectives only invest in tube well (drilling the bore of the tube well); other investments—such as in the pump and pipe line—are made by one or more private farmers. Table 3 provides an overview of changing institutional arrangements for the ownership of groundwater structures in the 30-village study in the Hebei Province by Wang et al. (2000).

Table 3. Changing structure (%) of property rights in groundwater irrigation system, 1983-98.

Year	Collective v non-collective		Within collective		Within non-collective	
	Collective	Non-collective	Pure	Quasi	Shareholding	Private
1983	83	17	52	48	100	0
1990	56	44	24	76	99	1
1997	32	68	16	84	87	13
1998	31	69	18	82	86	14

Source: Wang *et al.* 2000

Institutional development in groundwater economies of these regions in Asia has responded essentially to the economic opportunity it has offered for agrarian wealth creation through accessing modern tube-well and pump technology. Where the resource itself is concerned, unrestricted open access has been the general rule even in regions that have begun to face depletion or deterioration of the resource through overuse. Nowhere in Asia do we find credible informal rules or formal laws that seek to ensure either the protection of the resource itself or a modicum of equity in access to it. Private ownership of groundwater structures throughout these regions has tended to reflect the inequality in landownership and wealth in the rural socioeconomic structures. As tube wells have emerged at the center-stage of the spread of green-revolution technologies, ensuring some equity in access to groundwater has become an important concern. In India and Bangladesh, this concern has prompted the governments to institute a range of policies—subsidies to the poor on the cost of pumps and wells, credit support from public-sector financial institutions, generalized subsidies on power supply to agriculture—that have shaped the evolution of the sector. Other countries, notably Pakistan and China, have recognized, but ignored, the equity-in-access issues; Pakistan did offer some subsidies in the 1960s; but today, government policies in these countries do little to promote the access of the resource-poor to groundwater irrigation.

During the eighties and nineties, there has been growing interest in the functioning of pump- irrigation markets as an institution that enables poor farmers to access groundwater irrigation without having to own wells and pumps. However, while these are pervasive and dominant in South Asia, their role has been limited in the PRC. In seeking efficiency, equity and sustainability in surface water and groundwater management, developing countries have tried public management, administrative regulation, farmer groups and cooperatives, but with only limited success. A growing debate on water markets has opened up new directions in thinking about water-resources management. Interest in South Asian groundwater markets has been fuelled by their spontaneous emergence and rise to a position of centrality in agrarian economies and their wide-ranging efficiency and equity impacts. Water markets have the potential to move water from low- to high-value uses, to promote investment in increasing the efficiency of water use, and to transform water from being a "scarce but free" resource into an economic good with an opportunity cost. The South Asian experience has shown that groundwater markets have opened up new big livelihood opportunities for the poor who would be worse off in their absence. Groundwater markets have also created new powerful instruments for public policies to influence millions of pumpers and their water buyers. On the flip side, groundwater markets exacerbate the problems of overexploitation in areas with fragile groundwater ecology. Either way, understanding their working is central to formulating effective public policies in the water-resources sector (Shah 1993; Shah et al. 2000).

5 Conclusions

Several observations and lessons can be drawn from the various examples given above. In addition to the typology proposed earlier, it appears that pumps are used in four main situations, each of them presenting different constraints, problems and threats!

a) To tap deep or shallow aquifers to expand agriculture or increase cropping intensity (India, Pakistan, Bangladesh, Nepal, Yemen, Iran, and most MENA countries); these developments are in most cases the result of unchecked individual initiatives and are very hard to control. Aquifer mining, declining water table and water quality, land subsidence and rising pumping costs are the most common threats. Management problems are those related to open-access resources and/or associated with states with low regulation and enforcement capacity. Poor farmers also cannot generally afford costs (Pakistan, India, Yemen).

b) To ease the lifting of water from nearby channels in deltaic environments (Nile, Red river, Mekong, and Chao Phraya deltas); problems are limited to overcapacity, costs and sometimes water quality. The combination of all uncoordinated local pumping operations may also impact the hydrological regime (or disrupt hydraulic regulations).

c) To gain flexibility and reliability in surface irrigation schemes with poor management (Thailand, Northern Vietnam); water is pumped in general from drains or shallow aquifers, more rarely deep aquifers. Hydraulic regulation is disrupted and collective management weakened.

d) To compensate for the decline of existing surface-water sources (Yellow river in China, and Iran). Problems combine those affecting cases a) and c).

The different types of impacts identified in the above examples can also be broken down and summarized as follows:

Hydrological impacts. Pumps in large numbers may significantly, sometimes radically, alter the hydrological regime. They may not only deplete aquifers but by doing so also dry springs and qanats, and reduce the baseflow to rivers. These modifications of flow regimes also impact the quality of water and, through irrigation, the evolution of soil salinity. Overall, the actual degree of overdraft of groundwater in the world is a very critical question with implications on the sustainability of food production.

Social impacts. Where pumps are owned/managed collectively it is, in general, because of economies of scale and/or because of a technical choice oriented by a collectivist ideology (in Vietnam and, initially, in China). User groups are sometimes defined based on existing social structures or groups of water-right holders (Egypt, Iran). In a majority of cases, pumps tend to be owned individually. The may be used for their owner's benefit and also to sell water to other users. Since they require access to capital, they also tend to exclude poorer users. The hydrological disruptions mentioned above also impact on preexisting uses. Whenever collective dependency upon vital water resources defines a tight-knitted relationship between the social structure and arrangements around water management, the disruption of supply, as for example caused by the expansion of area served by private pumps, necessarily has social implications (Iran, or the breakdown of the *bethma* system in some parts of Sri Lanka).[8]

Management impacts. Because pumps easily multiply in large numbers and are often mobile, they are not easily taken into consideration in basin-level water management. By altering the balance and the flows between surface water and underground water, they make integrated management more complex. On the one hand, pumps are managed locally and by users, obviating the need for large-scale infrastructure and bureaucracies, and they pose challenges both at the scheme level (when they complement surface irrigation water supply) and at the basin level. Their control, when becoming necessary, calls for the provision of laws and regulations. These, however, are typically marred with enforcement problems.

Economic aspects. The first economic impact of pumps is that their action on the hydrological cycle is often tantamount to a redistribution—or spatial reappropriation—of water. Third-party impacts are very common, especially in closing basins (Molle and Miranzadeh 2003), although they are often made "invisible" by the complexity of surface water/underground water interactions. A second economic impact is that pumps often tap a resource that would/could otherwise be diverted by gravity somewhere further downstream, thus adding energy costs to the reallocation. Last, because their main attractiveness resides in the flexibility and security of the supply of water they allow, there is a tendency towards overcapacity, the installed capacity of all the pumps being several times the requirements of the crops (Red river delta).

This brief review of the "pump revolution" in diverse contexts has shown the variety and complexity of the implications of the spread of pumping devices. It claims that this revolution has often been "silent" and that its importance and significance are generally overlooked. Pumps are the main instrument of both water reuse/recycling and the tapping of groundwater: as such, they are central to the most crucial aspects of the closing of river basins and to the much-heralded need for integrated water management. Pumps have also largely shifted from communal or state control towards private ownership and management. They are, therefore, a central element of the articulation between public and private spheres, including political, managerial and financial dimensions.

6 References

Al-Sakkaf, R.; Zhou, Y. and Hall, M. J. (1999) A strategy for controlling groundwater depletion in the Sa'dah Plain, Yemen. *International Journal of Water Resources Development*, 15(3): 349–365.

Beaumont, Peter (1989) The qanat: A means of water provision from groundwater sources. *Qanat, Kariz, and Khattara* eds. P. Beaumont, K. Borine and K. McLachlan. pp. 13-31.

Barker, Randy and Molle, François (2003) Evolution of irrigation in Asia. Comprehensive Assessment of Water Management in Agriculture, Research Report. Colombo: IWMI. Draft.

Bonine, M. E. (1996) Qanats and rural societies: Sustainable agriculture and irrigation cultures in contemporary Iran. *Canals and communities: Small-scale irrigation systems* ed Mabry, J. B., pp. 183-209, Tucson, AZ, USA: University of Arizona Press.

Christensen, Scott R. and Boon-Long, Areeya (1994) *Institutional problems in Thai water management*, TDRI, 54 p.

Debroy A. and Shah, T. (2002) Socio-ecology of groundwater irrigation in India. *Intensive se of groundwater: Challenges and opportunities* eds. Llamas R. and E. Custodio, Swets and Zeitlinger, The Netherlands.

Depeweg, H. and Bekheit, J. (1997) Evaluation of proposed mesqa improvements. *Irrigation and Drainage Systems* 11(4): 299-322.

Ehlers, Eckart and Saidi, Abbas (1989) Qanats and pumped wells: the case of Assad'abad, Hamadan. *Qanat, Kariz, and Khattara* eds. P. Beaumont, K. Borine and K. McLachlan. pp. 89–112.

Fontenelle, J.-P. and Tessier, O. (1997) L'appropriation paysanne de l'hydraulique agricole du delta du Fleuve Rouge: processus et limites, *Autrepart 3*, Editions de l'Aube, ORSTOM, Paris, pp. 25-43

Fontenelle, Jean Philippe and Molle, François (2002) *The intricacies of water pricing in the Red River Delta, Vietnam.* Paper presented at the conference on irrigation water policies: micro and macro considerations, 15-17 June 2002, Agadir, Morocco. http://lnweb18.worldbank.org/ESSD/essdext.nsf/18DocByUnid/3E4D7505BE90DC2685256BEB0050D732/$FILE/Fontenelle_Molle.pdf

Hekmat, Akbar (2002) *Overexploitation of groundwater in Iran: need for an integrated water policy.* Paper for the IWMI-ICAR-Colombo Plan sponsored Policy Dialogue on "Forward-Thinking Policies for Groundwater Management: Energy, Water Resources, and Economic Approaches' organized at India International Center, New Delhi during 2–6 September, 2002 .

Horsey, H. R.; Sunada, D. K.; Richardson, E. V. and Skold, M. D. (1984) *A technical and economic analysis of low-lift irrigation pumping in Egypt.* Cairo, Egypt: Egypt Water Use and Management Project. 228p.

Hvidt, Martin (1995) *Current efforts to improve irrigation performance in Egypt.* Papers presented to the Third Nordic Conference on Middle-Eastern Studies, 19–22 June, Joensuu, Finland.

Kohler, Stefan (2000) *The place of ancient agricultural practices and techniques in Yemen today: Problems and perspectives.* http://www.mafhoum.com/press2/83E13.htm

Lambton, A.K.S. (1953) *Landlords and peasants in Persia.* Oxford.

Lightfoot, D. (2003) *Traditional wells as phreatic barometers: A view from qanats and tube wells in developing arid lands.* Proceedings of the UCOWR Conference: Water Security in the 21st Century, Washington, D.C., July.

Mai, Van Hai (1999) Participation des agriculteurs aux travaux d'irrigation depuis le contrat 10. *Agriculture familiale et gestion des ressources du milieu dans le basin du Fleuve Rouge*, INSA, GRET, PFR, Maison d'Edition de l'Agriculture, Hanoi, pp. 25-38.

McLachlan, Keith (1988) *The neglected garden: The politics and ecology of agriculture in Iran*. London: L.B. Tauris & Co. Publishers.

Mehanna, S.; Huntington, R.; Antonius, R.; Fahim, M. and El Kadi, M. (1983) *Water allocation among Egyptian farmers: Irrigation technology and social organization*. Report prepared for the Ford Foundation Middle East and North Africa Regional Office. The American University in Cairo, Social Research Center. 111p.

Milich, Lenard and Al-Sabbry, Mohammed (1995) *The rational peasant" vs. sustainable livelihoods: The case of qat in Yemen*. http://ag.arizona.edu/~lmilich/yemen.html

Milton, R. (2001) Hung out to dry: Disastrous World Bank intervention in Yemen. *The Ecologist*. November 22, 2001.

Ministry of Water Resources (2000) China Water Resources Bulletin.

Moench, Marcus (2002) *Groundwater and food security in India: Evaluating the implications of emerging overdraft concerns*. Denver, USA: Institute of Social and Environmental Transition (unpublished).

Molle, François; Chompadist, Chatchom; Srijantr, T. and Keawkulaya, Jesda (2001) *Dry-season water allocation and management in the Chao Phraya basin*. Research Report submitted to the European Union, Research Report n°8, Bangkok, 278 p.

Molle, François and Miranzadeh, M. (2003) *Robbing Yadullah's water to irrigate Said's garden: Hydrology and water rights in a village of central Iran*. IWMI Research Report. draft.

Pintus, Florence (1997) *La gestion de l'eau à Sushay, Egypte: Un example de recomposition sociale et technique en milieu rural*. Montpellier: CNEARC.

Shah, T.; Debroy, Aditi; Qureshi, Asad and Wang, Jinxia (2003) Sustaining Asia's groundwater boom: Overview of issues and evidence, *Natural Resources Forum*.

Shah, T.; Hussain, I. and Rehman, Saeed ur (2000) *Irrigation management in Pakistan and India: Comparing notes on institutions and policies*. Colombo: IWMI Working Paper 4.

Shah, Tushaar (1993) *Groundwater markets and irrigation development: Political economy and practical policy*, Bombay: Oxford University Press.

Shah, T. (1996) *Catalysing co-operation: Design of self-governing organisations*. New Delhi, India: Sage Publications. 315p.

Shah, T. (2000) Mobilising social energy against environmental challenge: Understanding the groundwater recharge movement in Western India. *Natural Resources Forum*, 24(3):197-209.

Shi,Yubo (2000) *Groundwater development in China*. Paper for the Second World Water Forum.

Spooner, Brian (1974) Irrigation and society: Two cases from the Iranian Plateau. *Irrigation's impact on society*, eds. T.E. Downing and McGuire Gibson. Tucson: University of Arizona Press. pp. 43-57.

Wang, Jinxia; Huang, Jikun and Rozelle, Scott (2000) Property right innovation and groundwater irrigation management. *Journal of Economic Research*, No 4, pp: 66-74.

Ward, Christopher (1998) *Practical responses to extreme groundwater overdraft in Yemen*. Paper presented to the international conference "Yemen: The Challenge of Social, Economic and Democratic Development," 1-4 April, 1998, University of Exeter, Centre for Arab Gulf Studies.

Ward, Christopher (2001) *Yemen's water crisis*. The British-Yemeni Society. http://www.al-bab.com/bys/articles/ward01.htm

Xiang, Qing; Huang, Jikum and Wang, Jinxia (2000) *Property right innovation and cropping pattern adjustment: Case study of groundwater irrigation system in Hebei, China*. Beijing: Centre for Chinese Agricultural Policy (draft).

Zhen, L. and Routray, J. K. (2002) Groundwater resource use practices and implications for sustainable agricultural development in the North China Plain: A case study in Ningjin County of Shandong Province, PR China. *International Journal of Water Resources Development*, 18(4):581–593.

[1]Tentatively, and arbitrarily, we may consider low-lift operations as raising water over a few tens of centimeters up to 2–3 meters. For groundwater, low-lift would correspond to wells with less than 7–8 meters (allowing for the use of suction pumps).

[2]In the Assadabad region studied by Ehlers and Saidi (1989), the numbers of wells were 39 in 1962, 439 in 1969, and 1,386 in 1979. All qanats eventually dried up.

[3]In the case of using many pumps, there is a lack of space to accommodate all the pumps. Some set their pumps on the side and use soft hoses to channel water down to the canal.

[4]The political clout of the Federation of Thai Industries has long impeded both the control of extraction and the rise in volumetric taxation. Recently, the government decreed a ban on groundwater use for areas where tap water is available which seems to be enforced with some vigor.

[5]This was possible because of structures impeding salinity intrusions from the sea, but also the widening of the canal spreading the Mekong freshwaters over the delta.

[6]Although there are indications of instances where some local sheikhs might be more interested in serving their own interests rather than that of the common good (see Ward 1998).

[7]Established to provide vertical drainage in increasingly waterlogged command areas of the great Indus system.

[8]This of course applies to a much wider range of cases than those where the hydrologic regime is disrupted by pumps.

Molle François, Shah T., Barker R

The groundswell of pumps : multilevel impacts of a silent revolution : paper prepared for the ICID-Asia meeting

s.l. : s.n., 2003, 18 p. multigr. ICID.International Commission on Irrigation and Drainage Asia Meeting : Asian Regional Workshop : Management and Operation of Participatory Irrigation Organizations : Topic 1 : Sustainable Water Resources Development, Taipei (CHN), 2003/11/10-12 .