

THE GROUNDWELL OF PUMPS: MULTI-LEVEL IMPACTS OF A SILENT REVOLUTION

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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 tubewells have played a prominent role in irrigation in the semi-arid 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 monsoon 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

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 tubewells have played a prominent role in irrigation in the semi-arid 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 semi-arid into the monsoon areas of Asia. Depending on the physical and socio-economic 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, both 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, 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 or groundwater systems) is potentially undermined by the development of individual strategies fostered by the possibility to access water individually. However, this may also lead to the re-working of arrangements and collective rules. Third, both the spread and the partial individualisation of pumping have an implication on costs and on 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, nor 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.

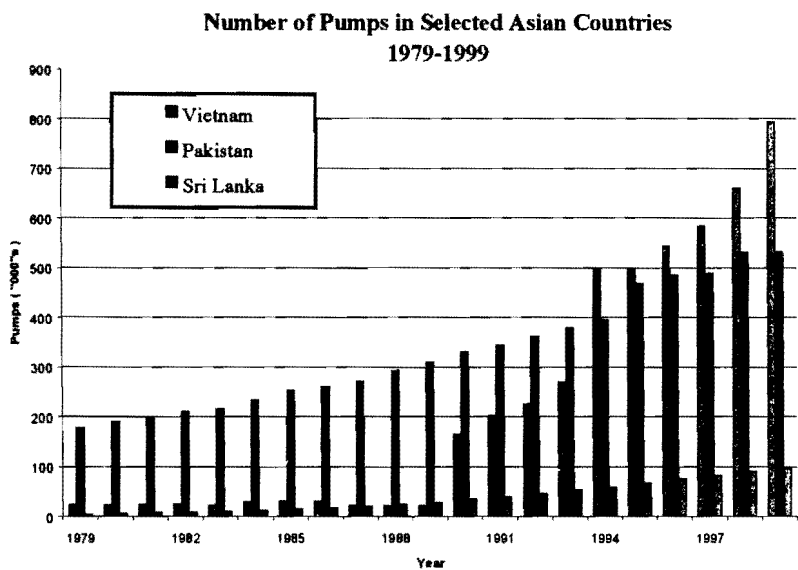
Figure 4 shows the evolution during the 80s and 90s decade of the number of pumps in Sri Lanka, Vietnam and Pakistan. Both the rate of increase and the actual absolute number of pumps are astonishing. Vietnam, for example, saw the number of pumps multiplied by 5 in the 90s decade only. Data on Thailand (

Figure 5) are also impressive: the total of pumps in the kingdom in 1998 reached 3 million in 1998, 56% of which were found in the Central region. In Iran, a total of 365,000 tubewells are pumped to produce 45 km³ of groundwater (Hekmat 2002).

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 current rate, India's population of irrigation pumps will be close to 25 million by 2007 as suggested in

Figure 7 (Moench 2001). India has varied hydrological regimes. The Indo-Gangetic basin which has some of the best aquifers can sustain intensive groundwater irrigation with pumps. However, wildfire growth 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 9), even in the semi-arid regions of India and Pakistan Punjab, groundwater irrigation has grown steadily since the 1960s to the point where groundwater exceeds surface systems as a source of irrigation. Each black dot in the map represents 5000 pumps; the concentration of pumps tends to be higher in regions with high density of human population.

Figure 4



Source: Barker and Molle (2003)

Figure 5. Evolution of the number of pumps in Thailand (1000 units)

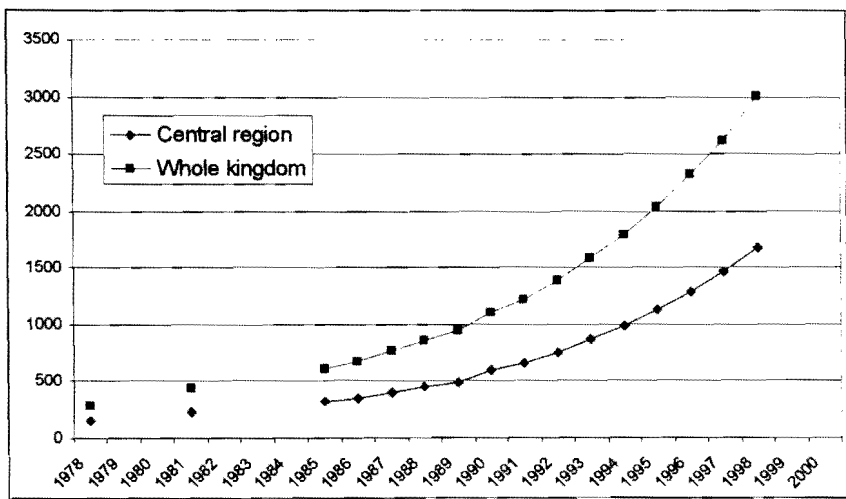


Figure 7. Growth of energized pumpsets

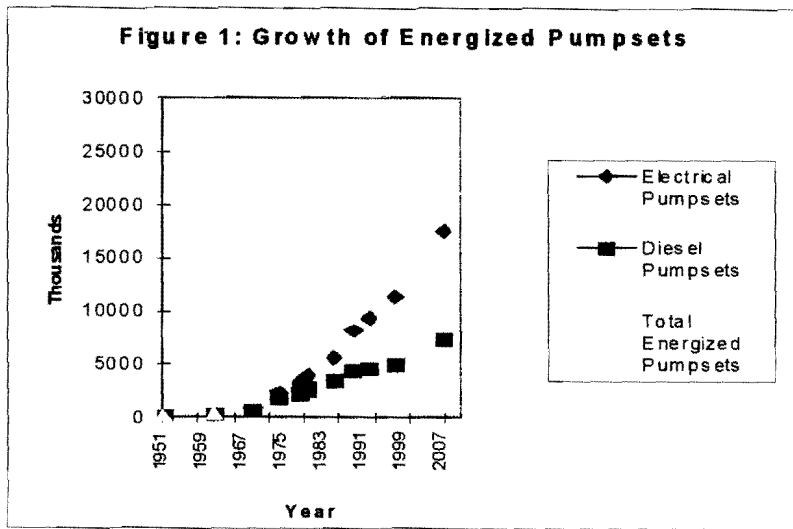
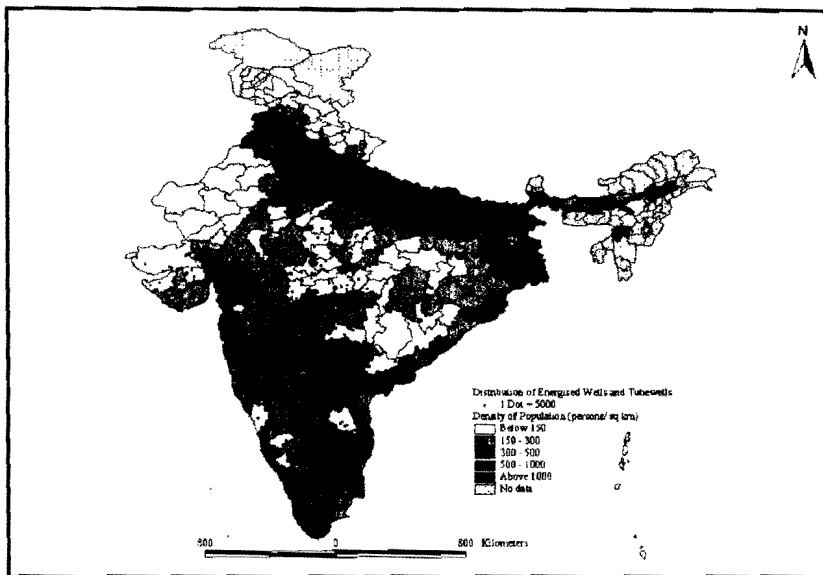


Figure 9. Distribution of pumps in India



While all these figures exemplify the rather recent groundswell in pumps, it should be noted that the expansion in use of pumps has occurred over a much longer time period in semi-arid 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 deprived of ambiguity. It is not always clear how yearly figures are extrapolated, nor whether pumpsets which are out-of-order are computed. The type of pump is also not specified and the figures may pool devices like low-lift axial pumps powered by two 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 which 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 or underground water. A second distinction can be made between high-discharge and low-lift pumping operations¹, and a third one between whether the use is individual or collective. When the use of water is collective, management can be either collective, and in that case either state-driven or not, or individual. These categories appear in Table 10, 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 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 grower along the upper reach of the Zayandeh Rud river, in Iran, who pump water up to the bordering plateaus, 300 m higher. 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 abstraction is generally the tapping of shallow alluvial which are 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, tubewells or large dug wells are dug. Typical dug wells are the "agrowells" 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 tubewells, 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

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

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, tubewells go to the depth of 400 m or more. Here farmers use 90-150 hp pumps to produce a discharge of 60-90 litres /second, and use complex network of buried pipes to distribute this water. The cost of making such tubewells often amounts to US \$ 15-20,000. Since no farmer is large enough to mobilize such capital, tubewells here are typically built and owned by informal ‘tubewell companies’ in which farmers share capital, costs, profit and losses in proportion to their land in the command (Shah 1996).

Table 10. 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 Agrowells	Agrowells	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 semi-arid 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 20th 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 1,200,000 ha of irrigated land, by the mid-1970s wells were already providing 8 billion m³, against 9 billion m³ for qanats (McLahan 1988). The history of the destruction of qanats by wells is documented by several studies (e.g. Ehlers and Saidi² 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 re-emergence 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

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

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 karez's, 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 tubewell and a pump, they increasingly lost incentive and interest in adhering to traditional customs and rules for sustained management of tanks. Privately owned tubewells thus became the enemy of common property tanks.

Unlike many other parts of the world, semi-arid areas in India are now coming a 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.* 2000). 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 two-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 time³.

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 plot) pumps first. Latecomers must wait for those who have set their pump first to finish filling up their rice fields. Farmers with no pump (a minority) do not engage in risky cropping or pay neighbours 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

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

canal head must also pump a second time in the lateral, at his plot or where the tertiary leading to his plot branches off.

Whoever has only one pump set will try to team with a neighbour and will pump at the head while the neighbour 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 by the other farmers out 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 controlled⁴. 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) a 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 tubewells, which provide 95% of the water used by industries in Bangkok Metropolitan Area (BMA) (Christensen and Boon-Long, 1994). The actual pumping rate is approximately 3 million m³/day, against a sustainable level of 1 million m³ (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 fruits⁵.

4.4 Egypt

The irrigation of the Nile delta is based on the supply of water through different arms of the river which feed branch (and sub-branch) 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 19th 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 from the distribution network.

⁴ "When we pump together, no problems occur because farmers know each other. If one is sowing, for example, the neighbours will reduce the water depth in their field to limit seepage to the plot next to their", a farmer said (Molle *et al.* 2000).

⁵ 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 has decreed a ban on groundwater use for areas where tap water is available which seem to be enforced with some vigour.

Two conflicting logics 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 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 pieces of the Egyptian landscape and social fabric (Mehanna *et al.* 1983). The introduction of mobile pumps was deemed to impact negatively on the pre-existing 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 labour 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, flexibilization of cropping calendars, 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 financial sustainability, since the implementation of local pumping stations amounted to a duplication of investments and resulted in high –and costly– pumping capacity per ha. The distribution of operation and maintenance 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 pumpsets on boats (northern part of the delta), as well as individuals (often using 'shrimp-tail pumps'). This dramatic supply of pumping capacity, added to the growing availability of fresh water in the lower delta, contributed to boost dry-season

cropping all over the delta⁶. 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 un-controlled pumping operations may significantly alter the hydrologic regime and increase vulnerability.

4.6 Yemen

Home of 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 severe overdraft of aquifers. Water use is estimated at 3.4 Bm³, in excess of 35% of renewable resources (2.5 Bm²) (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 terms 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 tubewell technology in the 1970s (Milton 2001, Ward 2001), subsidies for oil and pumps, and protective measures for *qat* production), as well as external ones (absorption of 1.2 million people expelled from Gulf countries after the first Gulf War, mostly in the agricultural sector; supply of cheap groundwater extraction technologies).

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. Like in the Iranian case, the pump revolution has worsened inequities by favouring 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 involvement of stakeholders and traditional structures⁷ (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

⁶ This was possible because of structures impeding salinity intrusions from the sea, but also the widening of the canal spreading the Mekong fresh waters over the delta.

⁷ Although there are indications of instances where some local sheikh might be more interested in serving their own interests than the common good (see Ward 1998).

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 South Asian region and in North China plains are dependent on groundwater. In these predominantly agrarian regions, the booming groundwater economies have assumed growing significance from viewpoints of livelihoods and food security. However, their significance as engines of rural and regional economic growth has remained under-studied. 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, Bangladesh have active markets in pump irrigation services in which tubewell owners sell groundwater irrigation to their neighbours at a price that exceeds their marginal cost of pumping. This price offers a market valuation of groundwater use in irrigation. Table 11 constructs a profile of the groundwater economy in three Asian countries (India, Pakistan and China) using such valuation and suggests that groundwater irrigation in Asia may well be a US \$ 10-12 b/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 b. 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 11. The size of the Agricultural Groundwater Economy of India, Pakistan, China.

		India	Pakistan	China
A	Total # 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 m3/hour	25	100	41 ³
D	Average hours of operation/well/year [(B*1000000000)/A]/C	315	1180	1134 ³
E	Price at which pump irrigation from standard-sized 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 (2000)

India’s 100,000 public tubewells and Pakistan’s 15,000 Salinity Control and Reclamation Project (SCARP) tubewells⁸ represent a small ‘public’ component in the total groundwater capital stock of these countries. In China, groundwater capital stock was for long mainly financed 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 labour 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 2000).

⁸ Established to provide vertical drainage in increasingly waterlogged command areas of the great Indus system.

Throughout South Asia, public initiative played a strong promotional role in the historical evolution of groundwater irrigation in early 1950s. In India, for example, government program to establish public tubewells in Uttar Pradesh way back in the 1930s provided the first exposure to farmers to the advantages of the modern tubewell technology. Two decades later, in Pakistan too, government initiative to set up SCARP tubewells gave the first impetus to groundwater irrigation development. In all these countries, however, private tubewells soon took over and left the government sector marginalized. Today, India's public tubewell program and Pakistan's SCARP tubewell program lie in complete disarray, while the private tubewell 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 PRC 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 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 tubewell ownership arrangements in China: private individual, private share holding, pure-collective and quasi-collective in the NCP. In pure collective system, village collectives invest in all pumping related facilities and also manage the operation of the tubewell, while in quasi collective arrangements, village collectives only invest in tubewell (drilling the bore of the tubewell); other investments—such as in the pump and pipe line—are made by one or more private farmers. Table 12 provides an overview of changing institutional arrangements for the ownership of groundwater structures in the 30-village study in Hebei province by Wang *et al.* (2000).

Table 12. Changing structure (%) of property rights in groundwater irrigation system, 1983-98.

Year	Collective vs 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 and Huang 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 tubewell 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 over use. 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 land ownership and wealth in the rural socio-economic structures. As tubewells have emerged at the centre-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 1960's; but today, government policies in these countries do little to promote the access of the resource poor to groundwater irrigation.

During the 1980s and 90s, 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 and groundwater management, developing countries have tried public management, administrative regulation, farmer groups and co-operatives, 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 over-exploitation in areas with fragile groundwater ecology. Either way, understanding their working is central to formulating effective public policies in water resource sector (Shah 1993; Shah and Hussain 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; 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 generally cannot 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 un-coordinated local pumping operations may also impact the hydrological regime (or disrupt hydraulic regulation).
- 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, Iran). Problems combine those affecting cases a) and c).

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

Hydrological impact. 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 (Vietnam, initially 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. They may be used for their owner's benefit but 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 pre-existing uses. Whenever collective dependency upon vital water resources defines a tight knitting 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 have social implications (Iran, or the breakdown of the *bethma* system in some parts of Sri Lanka)⁹.

Management impact. 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 and underground water, they make integrated management more complex. While, on the one hand, pumps are managed locally and by users, obviating the need of large scale infrastructure and bureaucracies, 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 re-appropriation– 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 re-allocation. Last, because their main attractiveness resides in the flexibility and security of the supply of water they allow, there is a tendency towards over-capacity, 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 showed 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 of 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.

⁹ This of course applies to a much wider range of cases than those where the hydrologic regime is disrupted by pumps.