India's Ground Water Irrigation Economy: The Challenge of Balancing Livelihoods and Environment

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Abstract

Stagnating agriculture and consequent failure of rapid economic growth to bring about poverty reduction as envisaged have been major constraints for India's economic growth. Contrary to the view that slow-down in public investment for irrigation development is mainly responsible for the deceleration of agricultural growth, the paper argues that in spite of the Government initiatives and substantial investments in irrigation development, the area irrigated by public irrigation systems in India has stagnated or even declined. India's irrigation economy has been undergoing a dramatic transformation with the control of irrigation shifting from the government to the individual farmers through millions of wells owned and operated by them. Though the booming tube well irrigation has generated substantial socio-ecological dividends in terms of flood mitigation and reduction in water logging and soil salinization, it has also been responsible for resource depletion and contamination of ground water in some parts of the country, leading to various adverse environmental and socio-economic consequences. There is need for achieving the right balance between supply and demand side measures for forging a sustainable ground water governance regime. Problems of groundwater overexploitation in India are bound to become more acute and widespread in the years to come unless corrective mechanisms are put in place before the problem becomes insolvable or not worth solving. Lack of information and absence of systematic monitoring of availability and withdrawal of ground water is a major barrier that prevents the transition from groundwater development to management mode. Further, unlike in the case of surface water irrigation systems, public agencies have only an indirect role to play in the national ground water sector due to its development mostly in the private, 'informal' sector and the quality and amount of application of science and management to this sector has been much less when compared to the former.

This paper attempts to trace the history of irrigation development from early 19th century to the present to emphasize the shifting of focus from the government controlled major and medium surface irrigation systems to farmer-controlled ground water irrigation systems. Various ideas adopted for creating demand-management regimes through direct regulations, economic instruments, tradable property rights and community resource management around the world have been reviewed to prove the point that ground water governance, throughout the world, is still 'work in progress'. It also emphasizes the need for recognizing the importance of ground water irrigation systems in South Asia and for information systems and resource planning through establishing appropriate systems for regular ground water monitoring and for undertaking systematic scientific research on the occurrence, use and ways and means for augmenting and managing the resource. Need for initiating suitable demand and supply side management mechanisms and for undertaking ground water management in the river basin context have also been stressed.

1. Introduction

Stagnating agriculture has emerged, during recent years, as a speed breaker in India's otherwise splendid and enviable growth story. The failure of rapid economic growth to bring about poverty reduction in commensurate manner is also another major concern linked with stagnant agriculture. It has been widely thought that the slow down in public investment in agriculture, mainly irrigation development, is the main culprit behind the deceleration in agricultural growth. Government of India's Accelerated Irrigation Benefits Programme (AIBP) was conceived of as a response to the plea for increased public investment in irrigation. In recent budgets, the Union Finance Minister has been laying great stress on completing the "last mile irrigation projects" to step up the pace of irrigation development. Despite these initiatives, the area irrigated by public irrigation systems in India has stagnated, even declined (Shah 2009)[1] . In this paper, I want to argue that irrigation in India is in the throes of a major transition. The irrigation business model that India has followed since early decades of 19th century has rapidly changed in recent years, and public policies based on colonial model of irrigation development are no longer in sync with new developments in Indian agriculture, which has come to depend heavily on groundwater irrigation by boreholes and pumps. Neither the goals of India's irrigation policy nor our irrigation development strategy jives with the reality of our irrigation economy today. This transition has created a wholly new challenge of balancing food security and agrarian livelihoods on one hand and sustaining groundwater aquifers under stress. It brings into play a new socio-ecological dynamic that is best understood in the environmental economics framework.

Irrigation statistics compiled by the Government of India underestimate the scale of India's irrigation economy which is booming like never before. Official estimates of the net irrigated area in India based on land use surveys is 57 M ha and the gross irrigated area is around 90 M ha. Other sources, however, suggest that there is great deal more irrigation going on in India. The most striking have been new estimates of global irrigated area based on remote sensing data published recently by the International Water Management Institute (IWMI). Based on the analysis of high resolution satellite imagery backed by extensive ground-truthing work, IWMI's estimate suggests that in 2004, India had 99 M ha of net irrigated area and 132 M ha of gross irrigated area. Both these estimates are over 50 percent higher than the official estimates. In fact, IWMI's estimates of irrigated area of today are nearest to what the government of India would like to achieve by 2020. Incredible as these new estimates may sound, recent rounds of national sample survey also suggests that India's irrigation economy may be considerably larger than reflected in the official estimates[2].

2. The Groundwater Revolution

At the heart of the transformation that India's irrigation economy has been undergoing is the wresting, by millions of small farmers, of the initiative for irrigation development from the hands of the State. Under the model of irrigation development that India followed since the 1830's, the State has been the architect, entrepreneur, engineer and manager of irrigation systems. 'Command area' and 'duty' were the *mantra* of irrigation planning and management. The

[1] Also, http://www.sandrp.in/irrigation/100000_crores_spent_no_irrigation_benefits_SANDRP_PR_Oct2007.pdf visited on October 12, 2007.

[2] see, e.g., http://www.econlib.org/LIBRARY/Enc/RationalExpectations.html, accessed 25 August 2006.

Government was the provider of irrigation and the farmer a passive recipient. In this model of unbalanced irrigation development, command areas were created near hydraulically opportune sites where reservoirs or weirs could be built and downstream areas could be 'commanded' by gravity flow. Farmers in the rest of the country were left to fend for themselves. Post-Independence, India followed much the same strategy for irrigation development that created pockets of prosperous command areas, leaving other parts to rain fed farming.

By 1970, the population pressure on farm lands in many parts of India had become so inexorable that farmers everywhere felt compelled to work their small farm holdings twice, or even thrice every year. Population pressure on farm lands then flagged off India's tube well revolution. India—especially, in western and north-western parts-- had a centuries old tradition of irrigating with wells. Even in 1900, India had some 4 M ha under groundwater irrigation. At the time of independence, the areas irrigated by groundwater and surface water were evenly balanced. However, it was hardly expected by anybody that India would witness massive spread of tube well irrigation in the surface-water-abundant Ganga-Brahmaputra basin or hard rock peninsular India. Such a pattern of irrigation development appeared wholly inconsistent with the country's hydro-geology. Equally inconsistent seemed to be large-scale groundwater irrigation in peninsular India with hard-rock aquifers that have poor infiltration and low storage; tanks have been considered ideal for capturing and storing rainwater for irrigation in these areas that comprise 65 percent of India's land-mass.

At the onset of the 20th century, RC Dutt articulated the prevailing thinking about how irrigation should develop in different parts of India:

> "Every province in India has its distinct irrigation requirements. In the alluvial basins of the Ganges and the Indus the most suitable irrigation works are canals from these rivers; while away from the rivers, wells are the most suitable. In Bengal with its copious rainfall, shallow ponds are the most suitable works and these were the numerous in the olden times, sometimes of very large dimensions. In Madras and Southern India, where the soil is undulating and the underlying rock retains the water, the most suitable irrigation works are reservoirs made by putting up large embankments and thus impounding the water descending from hill slopes. Such were the old reservoirs of Madras." (Dutt 1989, vol. II, p 119, footnote 1).

This thinking was endorsed 70 years later by the second Irrigation Commission. For millennia, irrigation in India had remained largely faithful to this dictum. Adaptive, minimalist, unobtrusive irrigation in India of 1800 was a reflection of this hydro-geologic make up of the sub-continental terrain. Constructive imperialism pioneered by Arthur Cotton in the south and Proby Cautley in the north took liberties with this ideal scheme. However, come 1970's, and this age-old wisdom lay in tatters as a new era of *atomistic irrigation* unfolded and engulfed India—nay, all of South Asia-- with small-pump irrigation spreading everywhere like wildfire --in canal commands and outside, in arid, semi-arid and humid areas, upstream *and* downstream of river basins, in excellent alluvial aquifers as well as in poor, hard rock peninsular aquifers with limited storage potential. If the era of 'constructive imperialism' began tinkering with the hydrology of river basins, the recent era of atomistic irrigation with small wells and tube wells went about reconfiguring it totally.

The rise of groundwater irrigation also transformed the organization of irrigation at the local level. In pre-Colonial India, co-operation at the community level was the dominant irrigation institution. Under the colonial rule, collaboration between the State and the engineering profession was at the centre-stage of centralized, bureaucratic irrigation development and management. In this new era of atomistic irrigation, the State as well as science became onlookers in a ballgame whose rules and logic they did not understand, much less dictate. In an incipient atomistic irrigation economy of the 1980's and later, neither the State nor the community was the entrepreneur, builder, or the manager of irrigation; it was the multitude of small-holders--Marx's 'millions of disconnected production units'--each with his tiny, captive irrigation system, ostensibly unconnected with the rest. Until now, crops had to wait for water to be released and flow through a network of canals before getting irrigated; now, water was scavenged on-demand and applied just-in-time when crops needed it most.

Between 1960 and 1985, India invested in irrigation projects many times more capital in real terms than the British had invested during the entire 110 year period between 1830 and 1940. Yet, even according to the government of India's figures, over 60 percent of irrigated areas are today served by groundwater. Other indicators suggest even this may be a serious underestimate. Remote sensing data as well as national sample survey suggest that as much as 75-80 percent of India's irrigated area today is served by groundwater wells. Until 1960, Indian farmers owned just a few tens of thousands of mechanical pumps using diesel or electricity to pump water; today India has over 20 million modern water extraction structures. Every fourth cultivator household has a tube well; and two of the remaining three use purchased irrigation service supplied by tube well owners (Shah 2008, forthcoming).

3. Socio-economic significance and impacts of the groundwater boom

The groundwater boom is a sub-continental phenomenon that has encompassed, besides India, arid regions of Pakistan Punjab and Sind—which boast of the world's largest continuous surface irrigation system—and the humid Bangladesh and terai areas of Nepal. 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. An unpublished report for USAID in the early 1990's placed the contribution of groundwater irrigation to India's GDP at around 10 percent (Daines and Pawar, 1987); if that proportion held now, the size of the groundwater irrigation economy of India would be some US $ 75-80 billion. In table 1 below, we attempt a rough estimation of the market value of groundwater use in the Indian sub-continent. India, Pakistan, Bangladesh have active markets in pump irrigation service in which tube well 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. We use available estimates of the number of irrigation wells and estimates from sample surveys on average yield of wells and annual hours of operation of irrigation tube wells in the countries covered. In India, for instance, a large number of farmers paid their neighbouring bore well owners US $ 0.04/m^3 for purchased groundwater irrigation around 2000[3]; applying this price to the annual groundwater use of say 200 billion m^3 gives us US $ 8 billion as the economic value of groundwater used in Indian agriculture/year. For the Indian sub-continent, the corresponding estimate is around 10 billion US dollars. In many parts of water-scarce India, water buyers commonly enter into pump irrigation contracts offering as much as 1/3rd crop share to irrigation service provider; in water abundant areas, in contrast, purchased pump irrigation cost amounts generally to 15-18 percent of the gross value of output it supports. This can be used to draw the general inference that the agricultural output that groundwater irrigation supports is 4-5 times its market value.

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[3] This was when oil prices were less than half of their level in October 2005.

Table 1 Proximate size of the Agricultural Groundwater Economy of South Asia (c. 2001-02)

		India	Pakistan Punjab	Bangla-desh	Nepal Terai
A	**# of wells (million)**	**21**	**0.5**	**0.8**	**0.06**
B	**Average output/well (m3/hr)**	**25-27**	**100**	**30**	**30**
C	**Average hours of operation / well / year**	**360**	**1090**	**1300**	**205**
D	**Price of pump irrigation (US $/hr)**	**1-1.1**	**2**	**1.5**	**1.5**
E	**Groundwater used (km3)**	**189-204**	**54.5**	**31.2**	**0.37**
F	**Value of groundwater used/year in billion US $**	**7.6-8.3**	**1.1**	**1.6**	**0.02**

Explosive growth in shallow tube wells and small pumps has democratized Indian irrigation much like personal computers have democratized computing globally. By the same token, large canal irrigation systems are heading towards the future that mainframe computers are facing. Boreholes and small pumps took irrigation away from command areas to the nook and corner of the country. Among several things, the booming pump irrigation economy has: [a] offered *some* irrigation access to an overwhelming majority, rather than concentrating *all* irrigation benefits on small privileged groups in command areas; [b] thereby, helped soften growing farmer unrest in the region's vast dry-land areas, which would have otherwise destabilized social and political structures; [c] has come to account for over 60 percent of irrigated areas, and 80 percent of irrigated farm output and resultant incomes; [c] drought-proofed the region's agriculture against at least one monsoon failure and made large-scale famines history; [e] improved farm wages and increased demand for farm labor year-round; [f] demonstrated a strong pro-poor, inclusive bias in irrigated agriculture; [g] supported a new drive towards intensive diversification to high value products such as milk, fruit and vegetables, especially in dry land areas in a scale-neutral format. These impacts have benefited—directly and indirectly, to lesser or greater extent--around half a billion rural people in South Asia. One can not say that the South Asian peasant is much better off in 2000 compared to 1975; but one can confidently say that, other things being the same, he would have been immensely worse off but for the pump irrigation boom.

Thanks to its myriad and widespread benefits, pump irrigation revolution, aided by irrigation service markets, has been amongst the most powerful rural poverty alleviation phenomena without which the region would arguably have been in the throes of massive social and political instability. Pump irrigation boom in India since 1975 has created more irrigation in 30 years than public investments in canal irrigation did in 170. Pump irrigation has also brought about greater spatial equality in irrigation; it is spread all over the country unlike canal projects which have created concentrated pockets of agrarian prosperity in canal commands. Vibrant local, informal markets for pump irrigation service have helped India's 20 odd million WEM owners to reach irrigation benefits to another 40-60 million small holder families, covering a vast majority of the farming community with access to supplemental irrigation. Especially in north-western India, the rise of groundwater irrigation on private initiative has reduced water logging, which otherwise would have required massive public investment in drainage and salinity management. The pump irrigation economy has been the driving force behind national growth in food and agricultural economies, for example, transforming West Bengal (and Bangladesh) as the region's rice bowls. Pump irrigation farmers apply less water per hectare, achieve higher ratio of evapotranspiration to consumptive fraction, and obtain higher yields/ha compared to flow irrigators. Across rural economic classes, the distribution of pump ownership is more equal than land holdings. In dry-land areas, supplemental pump irrigation has had a dramatic impact of stabilizing rain-fed yields and promoted agrarian diversification. The impact of a widespread drought on agricultural and food production today is much more muted compared to 1960's and before. Pump irrigation boom has been instrumental in all but banishing starvation deaths in the sub-continent. In effect, it has activated a sub-surface reservoir on a sub-continental scale—that always existed but remained largely unused—but which now captures and stores over 250-270 km^3 of water in a normal year, creating on a massive scale space, time and form utility in agricultural water use, the object of any reservoir.

4. Sustaining the Groundwater Boom

Nothing is an unmixed blessing; and this is true about South Asia's pump irrigation revolution since 1970's which has been a prominent target of doomsday prophecies about an impending socio-ecological disaster (see, e.g., Seckler et al.1999; Postel 1999; Vaidyanathan 1996). There is much truth in this concern; however, tube well irrigation has generated substantial socio-ecological dividends as well. In flood prone eastern India, it has helped mitigate the rapacity of floods and water logging by reducing 'rejected recharge' by creating more storage in the aquifers. In the Indus basin too, tube well irrigation has reduced water logging and salinization, a task which would have taken hundreds of million dollars of investments in drainage.

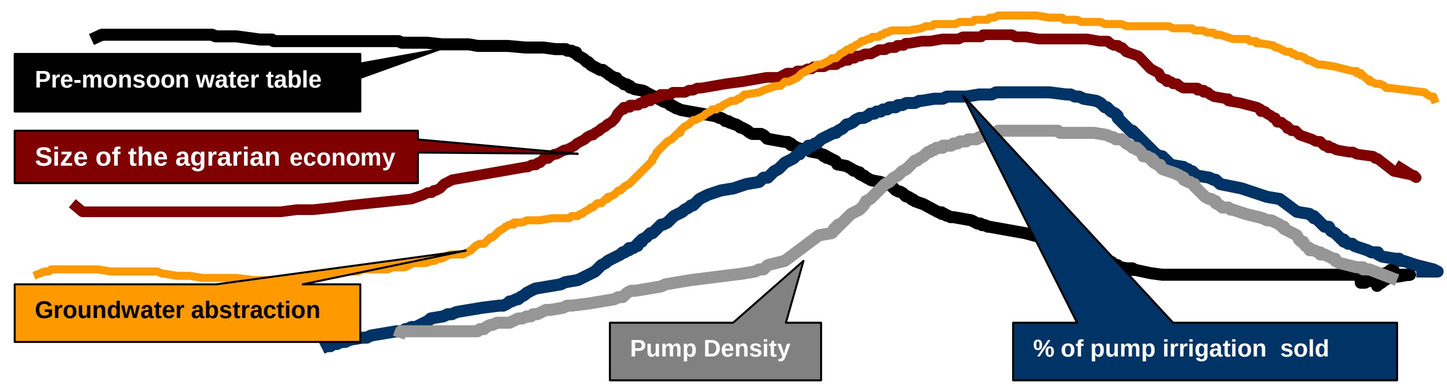
Groundwater horror stories of India are however becoming increasingly frightening in arid alluvial and hard-rock aquifers. In some coastal plains along with arid alluvial plains facing overdraft, the central resource governance challenge is coping with salinization and depletion which, in a chronic form already visible in some parts, may seal the fate of agriculture, and of human settlement itself. Then, in hard rock areas of peninsular India, where tube well irrigation expansion is way out of proportion to the limited storage offered by aquifers, resource depletion is a serious issue in itself but has also aided growing concentration of fluoride and other salts in groundwater which is the main source of drinking water supply for rural as well as urban populations. Problems of geogenic contamination of groundwater—such as with arsenic in eastern Ganga basin and fluoride in much western and peninsular India are large and serious. The causal role of pump irrigation in mobilizing fluoride and other salts in groundwater is clearer than in arsenic contamination whose chemistry is still tenuous and disputed.

A few years ago, David Seckler wrote alarmingly that a quarter of India's food harvest is at risk if she fails to manage her groundwater properly. Many people today think that Seckler's may well have been an underestimate; and that if India does not take charge of her groundwater, its agricultural economy may crash. Sandra Postel (1999) has suggested that some 10 percent of the world's food production depends on overdraft of groundwater to the extent of 200 km^3; most likely, 100 km^3 out of this occurs in Western India. Conditions in North China plains they are no better. In the lower Indus basin in Pakistan and the Bhakra system in Northern India, groundwater depletion is not a problem but soil and groundwater salinization is. IWMI's past research to understand the dynamics of groundwater socio-ecologies indicates some recurring patterns. In much of South Asia, for example, the rise and fall of local groundwater economies follow a 4-

stage progression outlined in Figure 1 below, which is self-explanatory. It underpins the typical progression of a socio-ecology from a stage where unutilized groundwater resource potential becomes the instrument of unleashing an agrarian boom to one in which, unable to apply brakes in time, it goes overboard in exploiting its groundwater.

The 4-stage framework outlined in Figure 1 shows the transition that South Asian policymakers and managers need to make from a resource *development* mindset to a resource *management* mode. 40 years of Green Revolution and mechanized tube well technology have nudged many regions of South Asia into stage 2-4. However, even today, there are pockets that exhibit characteristics of stage 1. But the areas of South Asia that are at stage 1 or 2 are shrinking by the day. Many parts of Western India were in this stage in 1950's or earlier, but have advanced into stage 3 or 4. An oft cited case is North Gujarat where groundwater depletion has set off a long term decline in the booming agrarian economy; here, the foresightful well-off farmers—who foresaw the impending doom--forged a generational response and made a planned transition to a non-farm, urban livelihood. The resource poor have been left behind to pick up the pieces of what was a booming economy barely a decade ago. This drama is being re-enacted in ecology after groundwater socio-ecology with frightful regularity (Moench 1994; Shah 1993; Barry and Issoufaly 2002).

Figure 1 Rise and fall of groundwater socio-ecologies

<table>
<tr><td></td><td>Stage 1</td><td>Stage 2</td><td>Stage 3</td><td>Stage 4</td></tr>
<tr><td>Stages</td><td>The rise of Green Revolution and Tube well Technologies</td><td>Groundwater-based Agrarian Boom</td><td>Early Symptoms Groundwater Over-draft/Degradation</td><td>Decline of the Groundwater Socio-ecology with immiserizing impacts.</td></tr>
<tr><td colspan="5">
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<tr><td>Examples</td><td>North Bengal and North Bihar, Nepal Terai, Orissa</td><td>Eastern Uttar Pradesh
Western Godavari
Central and South Gujarat</td><td>Haryana, Punjab, Western Uttar Pradesh, Central Tamil Nadu</td><td>North Gujarat, Coastal Tamil Nadu, Coastal Saurashtra, Southern Rajasthan</td></tr>
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Characteristics	Subsistence agriculture; Protective Irrigation Traditional crops; Concentrated rural poverty; Traditional water lifting devices using human and animal power	Skewed ownership of tube wells; access to pump irrigation prized; rise of primitive pump irrigation `exchange' institutions. Decline of traditional water lifting technologies; Rapid growth in agrarian income and employment	Crop diversification; permanent decline in water tables. The groundwater-based `bubble economy' continues booming; But tensions between economy and ecology surface as pumping costs soar and water market become oppressive; Private and social costs of ground-water use part ways.	The `bubble' bursts; agri. growth declines; pauperization of the poor is accompanied by depopulation of entire clusters of villages. Water quality problems assume serious proportions; the `smart' begin moving out long before the crisis deepens; the poor get hit the hardest.
Interventions	Targeted subsidy on pump capital; Public tube well programmes; Electricity subsidies and flat tariff	Subsidies continue. Institutional credit for wells and pumps. Donors augment resources for pump capital; NGOs promote small farmer irrigation as a livelihood programme	Subsidies, credit, donor and NGO support continue apace; licensing, siting norms and zoning system are created but are weakly enforced. Groundwater irrigators emerge as a huge, powerful vote-bank that political leaders can not ignore.	Subsidies, credit and donor support reluctantly go; NGOs, donors assume conservationist posture zoning restrictions begin to get enforced with frequent pre-election relaxations; water imports begin for domestic needs; variety of public and NGO sponsored ameliorative action starts.

In stage 1 and early times of stage 2, the prime concern is to promote profitable use of a valuable, renewable resource for generating wealth and economic surplus; however, in stage 2 itself, the thinking needs to change towards careful management of the resource. Yet, the policy regime ideal for stage 1 and 2 have tended to become 'sticky' and to persist long after a region moves into stage 3 or even 4. IWMI's recent work in North China plains suggests that the story is much the same there as well. The critical issue to address is: does stage 4 always have to play out the way it has in the past? Or, are there adaptive policy and management responses in stage 2 that can generate a steady-state equilibrium, which sustains the groundwater-induced agrarian boom without degrading the resource itself? In the remainder of this paper, we review the prospects and opportunities for forging such a steady-state equilibrium.

5. Environmental Economics of Aquifers and Institutional Response

Groundwater modeling is the playing field for hydro-geologists. These have developed a rather formidable repertoire of models that analyze the complex behavior of aquifers in response to development. However, in a region like South Asia where millions of smallholders directly interfere with the aquifer processes without let or hindrance, we have little understanding of how users respond to its development, and in due course, its depletion or deterioration. Developing such understanding is an important area of work for environmental economists.

How do India's groundwater users relate to aquifer development? How do they respond, as individuals and as a collectivity sharing a portion of an aquifer, to groundwater depletion or quality deterioration? When do they choose to co-operate and when to compete? Do they actually choose? Or are they impelled to behave in a certain way by natural processes they are confronted with? Are there situations in which they find it easier than in others to co-operate for the greater common good? These, and many other such questions, are crucial for us to explore but require a marriage of hydro-geology and social sciences such as economics, political science, and sociology.

Much hydro-geology is about the impact of human intervention on aquifer behavior. But environmental economics also needs to explore the impact of aquifer conditions on human behavior, especially, the behavioral response of people living off it. By institutional response, I mean the central behavioral tendencies of groundwater irrigators and the social dynamic that results from different aquifer conditions. In keeping with Veblen (1934), the original institutionalist, I treat institutions as 'settled habits of thought common to the generality of men'.[4]

An average groundwater user in India has little or no *formal* knowledge of hydro-geology. But s/he certainly has ideas and even theories about how it all works underneath the earth's crust (Rosin 1993; Shah 2000). A lot of these popular theories will not withstand scientific scrutiny; yet, farmers' decisions and actions are guided by *their* theories more than by formal science. One way to think about how farmers form their theories is by referring to what economist John Muth (1961) called rational expectations which help people formulate their view of the future state of things. Rational expectations are to be distinguished from *adaptive* expectations, which see the future as little more than a mechanical reproduction of the past. The *rational expectations model* suggests that people take into account all the information available to them—including the expectations of others they regard highly--to arrive at an expectation which differs from the actual only by a random error (Muth 1961; Sargent 2002[5]). When the behavior of most or all agents is shaped by such rational expectations, self-fulfilling prophecies abound. If majority customers expect a bank to fail, and begin a run on it, a small bank may actually fail. If most traders expect stock prices to rise, and start buying in that expectation, the market will actually skyrocket even when fundamentals suggest no reason for it to. Likewise, the expectations people living on or off an aquifer have about where it is headed in response to development or conservation shape their individual or collective behavior towards it and towards the 'aquifer community'.

An 'aquifer community' can be viewed as a collectivity of aquifer users in a locality who are aware of their interdependence in their use of a common aquifer or a portion thereof. Researchers from the British Geological Survey (2004) put it elegantly when they define it as a group of groundwater users who are 'mutually vulnerable and mutually dependent because of the centrality of resource use in supporting livelihoods'. The level of awareness of this inter-dependence is a measure of the strength or weakness of the aquifer community. In understanding the institutional dynamic in an aquifer, important are the rational expectations that a representative farmer has about the impact of another farmer's withdrawal on own water availability (**s**), and of the whole community's withdrawals on her groundwater availability (**S**); individual farmer's water conservation effort on her water availability (**h**) and the community's conservation effort on her water availability (**H**). Five situations outlined in table 2 represent the types of institutional dynamic that aquifer conditions generate in response to development in South Asia.

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[4] Cited in Paarlberg (1993:823-827).

[5] http://www.econlib.org/library/Enc/RationalExpectations.html

[**Situation 1**] ***atomistic individualism (s=0; S=0; h=0; H=0):*** occurs when each farmer is an insignificant user in an abundantly recharged water table aquifer; his abstraction has little impact on himself or other users; likewise, aquifer development has little discernible impact on the individual user; here, interdependence amongst users goes unnoticed; 'aquifer community' is non-existent, and rational expectations fail to generate institutional dynamic of the kind we observe in the remaining four situations;

[**Situation 2**] ***collusive opportunism (s=0; S<0; h=0; H=0):*** occurs when aquifer development sharply raises the cost of groundwater abstraction without greatly reducing water supply or quality; here, wealthy farmers establish de facto control over the resource, and collude against the resource poor but spearhead political mobilization to defend their access to and control over the resource; irrigators display limited inter-dependence and are a weak aquifer community;

[**Situation 3**] ***rivalrous gaming (s<0; S<<0; h=0; H>0):*** occurs when aquifer development sharply raises the cost of water production and also limits available groundwater supply that users actively compete for; this condition promotes intense and destructive rivalry among competing users; irrigators display a strong sense of interdependence but are a dysfunctional aquifer community; sporadic evidence of beneficial effects of community conservation fail to metamorphose into organized collective action;

Table 2 Patterns of institutional responses to aquifer development in India

Institutional response situation	Aquifer characteristic	Impact of aquifer development on typical user	Pump irrigation markets	Example	Ease of political mobilization of farmers	Scope for Local aquifer governance
[1]Atomistic individualism	High storage; high recharge resources	Insignificant	Efficient, deep and broad; WEM ownership a major source of neither power nor profit.	Most of Indo-Gangetic basin; alluvial canal commands	Low	Nil
[2]Collusive Opportunism	High storage; no or limited recharge resources	Sharply rising marginal cost of groundwater	Highly monopolistic, fairly deep and broad; resource poor elbowed out of pump irrigation economy	North Gujarat; Western Rajasthan	High for energy subsidies and surface water imports	Low or nil
[3] Rivalrous gaming	Hard-rock aquifer with low aquifer storage; some recharge resources	Rising marginal cost and declining share in limited water	Highly monopolistic; thin and shallow; poor have limited access at adverse terms	Inland peninsular India; Baluchistan	High for energy subsidies and recharge resources;	Scope for functional aquifer community

[4] Cooperative gaming	Alluvial with a confining layer or humid hard-rock environment with low storage;	Sharply rising marginal cost and declining share in limited water	Monopolistic; moderate in depth and breadth; access to groundwater more equitable	Eastern Rajasthan; coastal Saurashtra;	High for energy subsidies and recharge resources;	High; functional aquifer community
[5] Exit	Fragile aquifers prone to rapid quality deterioration	Sharp deterioration of water quality	Absent or insignificant	Coastal aquifers in Saurashtra; fresh water lenses in Sind	Low	Nil

[**Situation 4**] ***co-operative gaming(s<0; S<<0; h>0; H>>0):*** under certain catalytic conditions**,** rivalrous game metamorphoses into a co-operative game that reduces the cost and risk of water production and augments water availability to the entire community; positive expectations that so result foster a strong sense of benign interdependence and a highly functional aquifer community; such aquifer communities are ripe for proactive local groundwater self-governance;

[**Situation 5**] ***exit (s<<0; S<<0; h=0; H=0):*** This state occurs when groundwater development results in rapid quality deterioration without affecting supply. Costs and risks of groundwater use become prohibitive; and users begin giving up irrigated farming or farming itself. Pervasive negative expectations inspire fatalism, hopelessness and despair that overwhelm the strong sense of interdependence; aquifer community takes a downward spin and eventually withers away.

The framework set out above is helpful in making sense out of how millions of farmers have responded to the ecological consequences of rapid groundwater development in different parts of India. In alluvial aquifers of arid western Rajasthan and North Gujarat, groundwater irrigators are running a race to the ‘pump house’; competitive deepening of tube wells is the name of the game here. In these regions, we never hear about spontaneous efforts by farming communities to harvest rainwater and recharge aquifers on a large scale; the predominant institutional response takes the form of mobilizing to maximize and preserve energy subsidies. In humid alluvial plains of the Ganga-Brahmaputra-Meghana basin, groundwater irrigation here is a major poverty-alleviator and poses no environmental threat. Yet it is rapidly shrinking in the face of a stringent energy squeeze; and small farmers here are unable to organize and mobilize political power to save their livelihoods. Most large-scale mass-based groundwater recharge initiatives are concentrated in hard-rock areas; here, well owners compete fiercely to maximize their share in available groundwater resource but can be organized in a co-operative game to augment the resource and regulate the abstraction. In fragile coastal aquifers, the ecological fall-out of rapid and unregulated expansion in groundwater abstraction are swift and disastrous, leaving ‘exit’ from irrigated farming as the dominant option.

6. In search of sustainability

In thinking about forging a sustainable groundwater governance regime, the emerging global consensus is for achieving the right balance between supply and demand side measures. Governments can meet groundwater depletion in a locale by investing in recharge and/or water imports. However, without effective demand-side measures, increased supply will quickly invite increased abstraction, leaving the resource depleted. In creating demand management regimes, four sets of ideas have been tried worldwide: direct regulation, economic instruments, tradable property rights, community resource management. These are reviewed briefly; but the interesting upshot of this discussion is that throughout the world, groundwater governance is still work in progress.

Direct regulation through administrative action:

State claiming eminent domain and using the administrative apparatus of the government to regulate groundwater abstraction dominates the GwG regime in many countries, notably the Sultanate of Oman, Iran, Saudi Arabia, Israel and of course the western United States. In South Asia too, groundwater departments in most Indian states as well as Bangladesh have norms for siting irrigation wells and the minimum spacing to be maintained to minimize well-interference externalities. India has a draft groundwater law tossing around now for over 30 years; several state governments have passed groundwater laws providing regulatory powers (Planning Commission 2007). The regulatory effectiveness of these however has remained limited for a variety of reasons, the chief being the lack of popular support, political will and enforcement capacity commensurate with the enforcement challenge.

Countries like Oman, Saudi Arabia, Jordan and Iran however have used this instrument with greater vigor and seriousness. The hallmark of Oman's GwG regime is the strong and very visible hand of the state. The experience everywhere has been mixed, in fact quite poor, as was concluded by a conference of MENA[6] countries in 2000 (World Bank and Swiss Agency for International Development 2000:18). Elsewhere, even talk about regulation has generated a groundswell of opportunistic response from farmers. In Mexico, the political leaders have been issuing, from time to time since 1949, 'regularization' deadlines after which new tube wells would be banned in stressed aquifers. Every time, however, the threat has invariably invoked a tube well-boring spree (Scott et al. 2003). The last time the 'deadline' was issued in 1997, the tube well numbers doubled in the central Mexican province of Guanahuato (ibid). A leading Mexican practitioner of GwG concluded regulation would not work 'unless social and economic realities are taken into account' (Sandoval 2004).

Direct regulation of groundwater users through law is by far the most talked-about intervention in India. A model groundwater bill was formulated during the early 1970's and revised versions have been tossed around since then. Since water is a state subject in India, the action lies with state governments; and few showed interest in formulating a groundwater law; and even fewer in enforcing it. The key problem is the transaction costs of enforcing such a law on millions of scattered borehole owners in the countryside. As the following table 3 shows, the organization of groundwater economy is a major determinant of what kind of regulatory action is appropriate. India withdraws twice as much groundwater as does the US but would have to enforce a groundwater law on 100 times more irrigators.

[6] Middle-east and North Africa

Table 3: Structure of national groundwater economies of selected countries

Country	Annual groundwater use (km3)	No of Agricultural Groundwater Structures (million)	Average extraction/ structure (m3/year)	% of population dependent directly or indirectly on groundwater irrigation	Average farming income per farm worker
India	210	19	7900	55-60	~350
Pakistan	55	0.5	90000	60-65	~400
China	105	3.5	21500	22-25	~458
Iran	29	0.5	58000	12-18	~2200
Mexico	29	0.07	414285	5-6	3758
USA	100	0.2	500,000	<1-2	67800

Economic Instruments:

Economic instruments are attractive because they can influence the behavior of numerous economic agents without having to coerce or invoke eminent domain. Using a price or a Pigovian tax or cess is basic economic instrument to signal scarcity value. The problem in pricing groundwater is often the high transaction costs of metering, monitoring and charge collection; as a result, pricing is effectively used when it can be levied on bulk users or service providers who can transmit the 'price signals' onward to users. In Western United States, 'pump tax', generally higher for industries than for agricultural users, was widely used to control groundwater overdraft (Turral 1998). In China, water pricing—for cost recovery as well as demand management in cities—has worked because municipalities collect them from a handful of water service providing companies; however, collecting water withdrawal fees, provided by the 1995 Water Law, from millions of scattered agricultural tube well owners has proved far more challenging (Shah et al. 2004a). In her new Law of the Nation's Waters, Mexico, like China, has provided water resource fees—besides service charges-- to be levied on all users including irrigators.. However, like with China, Mexico too has found its implementation difficult (Shah et al. 2004b).The best known case of water pricing for agricultural use is Israel where all irrigation diversion and delivery points are metered and closely monitored (Feitelson 2006). Jordan has introduced a groundwater abstraction charge for industrial users; but its extension to agriculture invited much resistance.[7] Jordan had to use force in installing meters on deep tube wells and create 'quasi water police' to enforce pumping quotas (World Bank and the Swiss Agency for Development Co-operation 2000).

There has been greater success when pricing is used to create incentives for moving water to higher value uses. Saudi Arabia and Yemen have tried paying farmers to sell groundwater to

[7] World Bank and Swiss Agency for International Co-operation 2000: 22.

towns than using it for irrigation (Abderrahman 2003; Briscoe 1999). In India, Metro-water, the water service provider of the city of Chennai, too has been able to do this successfully. In the industrialized world, compensating farmers to reduce negative third-party externality is common. Some German cities have been paying peri-urban farmers to reduce chemical use in their farming to reduce non-point pollution of groundwater (Shah, Molden, Sakthivadivel and Seckler 2001); and in the western US, it is common for cities to buy up groundwater rights from farmers or for the federal government to pay groundwater irrigators in over-drafted areas to switch to dry-land farming. Direct scarcity pricing of groundwater use in irrigation in developing countries is, however, rare, not because the principle is in doubt but its actual practice has proved difficult.

Tradable Property Rights:

The conceptual foundation of the tradable property right discussion rests on the premise that under open access, groundwater resource would always be open to depletion and degradation. One road to sustainable resource management is of creating enforceable private property rights, preferably tradable. Tradable water rights modify the outlook of the users as well as third-parties about externalities, leading to more efficient allocation—though not necessarily conservation—of the resource. The historical foundation of tradable rights, however, rests in the history of European settlements in the New World, where secure property rights were essential to attract settlers to make private investments in land and water development. The idea of the groundwater governance regimes in the US and Australia then rests on the worldview that users *can* evolve mechanisms for self-governance of the resource with the state providing an overarching regulatory and facilitative framework. The actual experience with such collective self-governance is a matter of much debate even within these countries; however, their experience has given birth to a growth industry for promoting tradable water rights as a one-stop solution to groundwater mal-governance. Virtues of tradable property rights are widely advertised and commended (Rosegrant and Gazmuri 1994). The outcome of an innovative project of introducing tradable water rights in Chile has been vigorously lauded (ibid) as well as roundly criticized (Bauer 2004; Boelens and Bustamante 2005; GWP, 2006).

At the conceptual plane, there is little to gainsay the hypothesis that tradable property rights result in superior allocation of scarce water. The real problem in using this approach effectively in countries like India, however, is the transaction costs, which rise in geometric progression with the increase in the number of users. While the property rights protagonists have not paid much heed to transaction costs, these were central in the scheme of Ronald Coase, the original master, who warned that the assignment of property rights would be of little avail: [a] if the information available to contracting parties were less than perfect, [b] if transactions costs were high, and [c] if the number of contracting parties was too large to permit easy negotiations amongst them. As Armen Alchian[8], another prominent property rights theorist, similarly argued,

> "The cost of establishing private property rights—so that I could pay you a mutually agreeable price to pollute your air—may be too expensive. Air, underground water, and electromagnetic radiations, for example, are expensive to monitor and control… When private property rights are unavailable or too costly to establish and enforce, substitute means of control are sought. Government authority, expressed by government agents, is one very common such means."

8 http://www.econlib.org/library/Enc/PropertyRights.html

Even where transactions costs are manageable, results are not uniformly satisfactory. Fertile ground for studying the impacts of a variety of tradable water rights regimes is the Western United States. In some states like Kansas and Colorado, groundwater management is centrally about proactive demand management and of third-party externalities generating massive amount of litigation and supporting an army of water lawyers. A contrasting view, however, is that in a state like Texas, which has embraced the 'rule of capture', the situation can be nearly as anarchic as in South Asia. Even where the resource is threatened, demand management by reducing irrigated areas or groundwater withdrawals through rights administration is more an exception than a rule. When groundwater pumping is restricted to meet a threat to the aquifers, it is often because new water supply is offered in lieu of pumping of groundwater or because soaring pumping cost makes groundwater irrigation economically unviable.

According to Henry Vaux, a senior economist from the University of California at Berkeley, out of 431 groundwater basins in California, only 19 are 'actively managed', implying some restrictions on pumping. In all the rest, groundwater management is passive, basically involving federal government grants to build infrastructure to import surface water and supply it to groundwater users in lieu of pumping. Here, nobody is expected to reduce groundwater use. Vaux also suggests that active management basins are generally overlain by highly urbanized areas where governments or municipalities can easily buy water rights to serve high paying urban consumers[9]. US Groundwater Management Districts are held out as a model of collective action in which members make and enforce norms on reducing abstractions; however, such is seldom the case. In his celebrated study of local resource management in eight groundwater basins in California, the collective action that Blomquist studied is mostly about implementing supply side interventions, much like the Indian farmer communities have evolved in hard rock areas of Saurashtra and Eastern Rajasthan we discussed in chapter 6.[10]

All in all, it is by no means clear that the rich institutional and regulatory activity the western and central US has experienced has been uniformly helpful in creating a wholesome GwG regime. The Ogallala aquifer continues to be depleted; Kansas experiences "widespread falls in groundwater level of significant magnitude [that are] non-recoverable in large areas' (Kalf and Woolley 2005). In Arizona, over-exploitation and falling water levels are addressed by legislation that mandates balancing abstraction with recharge; but it is 'not clear that targets will be met" (Kalf and Woolley 2005). In California, courts have determined 'equitable distribution' over large areas; but Kalf and Woolley (2005) think 'it may not lead to sustainable use'. In Texas, James Nachbaur, who studied groundwater governance there, found irrigation interests always defeated laws designed to regulate them (Shah 2006). Allen (in Giordano and Villhoth 2007:75) suggests: 'Even in economies that had the political and economic space to pursue knowledge-based groundwater management policies, both renewable and non-renewable aquifers have been seriously depleted. Overuse of the aquifers of the High Plains of Texas is a sorry tale." The US

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[9] From a presentation made by Henry Vaux at the summer school on "Groundwater Intensive Use in South Asia: Food Security, Livelihoods Security and the Challenge of Sustainability", El Escorial, Complutense University of Madrid, 19th June, 2005.

[10] To quote from Blomquist (1992:303), "...water users in most of these basins originally undertook collective action not in order to enhance efficiency of water use or to implement an 'optimal" management regime but to keep the water supplies...Water users in all the seven basins have augmented local water supplies by instituting natural and artificial replenishment programs, and by acquiring access to imported water for direct use."

experience inspires little faith in demand management; its lesson is that the practical way to protect a stressed aquifer is to ease pressure on it by developing alternative supply sources. That done, try what demand management you can do.

As an interesting aside, groundwater institutions in the US and Australia tend to be highly sensitive to transaction costs. This is why they are careful to 'exempt' numerous relatively small –*de minimis*—users from the GwG regime which has to contend only with a small number of large users. Kansas thus exempts *de minimis* users who divert up to 15 acre feet of groundwater. In Nebraska, only wells that pump 50 gallons or more per minute need a permit, a meter and an allocation (Nagaraj et al 2000). In Australia too, those irrigating up to 2 ha are exempted as *de minimis* users (Macdonald and Young 2000:24). An extreme case of transaction-cost minimizing groundwater governance regime is chosen by states like Texas that have deliberately embraced groundwater anarchy by adopting the principle 'let the locals figure it out for themselves'. If India and China were to undertake institutional management of the Colorado and Kansas kind, the resources they would need, in terms of money and manpower, would be humongous, indeed. And if they were to exempt *de minimis* users by Kansas, Nebraska and Australian standards, over 95 percent of users would fall through the regulatory sieve.

Community Aquifer Management:

In evolving their groundwater governance regimes, Mexico and Spain have adapted the US experience of tradable water rights and Groundwater Management Districts. The underlying premise—somewhat along the Coasean logic-- is that if groundwater users are organized around aquifers for self-governance, they will internalize third-party externalities through bargaining and negotiation, collectively monitor the behaviour of groundwater as well as its abstracters, and ensure the long term sustainability of both. A more practical consideration was to use groundwater associations as agents in monitoring and enforcement of government policies and laws. The idea of groundwater organizations has a wide appeal; it was advocated to India by a British Geological Survey study (BGS 2004). And in south India, the FAO supported Andhra Pradesh Farmer Managed Groundwater Systems Project has organized groundwater users in 650 habitations in 66 hydrological units (Knegt and Vincent. 2001). Spain and Mexico have however embraced groundwater organizations as key element of their official national water governance strategy.

Until 1985, Spain, like Texas, followed the rule of capture. However, the intensification of groundwater stress under unregulated agricultural use prompted stern measures. The 1985 Water Act nationalized groundwater, and prescribed River Basin Management Agencies (*Confederacions Hidrograficas*) with an active role in managing groundwater. These were vested with the power to grant permits for groundwater use, declare an aquifer as overexploited, and formulate an aquifer management plan for its recovery. These typically involved reduction in the volume of withdrawals by rights holders and rejection of new applications for wells. To encourage user participation, all users of the aquifer were organized into groundwater user associations.

An assessment of the results of groundwater reforms in Spain by Spanish researchers suggests a rather gloomy picture. For one, even after 20 years, recording of groundwater rights still remains incomplete; worse, less than a quarter of all groundwater structures have been registered. Intensive groundwater governance does not come cheap; recording rights and monitoring them requires far more human and other resources than are available at the disposal of the implementing agency. Thus, Spain, with some 0.5 million irrigation wells[11], is still grappling with the most basic issue of identifying and recording groundwater users. Given Spain's long tradition of successful surface-water users associations (some in Valencia are centuries old), the new water law hoped similar associations would do the trick for groundwater aquifers as well. Thus, while thousands of small groundwater user associations have been 'registered' on paper, only a handful have made some movement towards `collective management of aquifers' and even fewer have met with some success. Even Spanish researchers were disappointed. Villaroya and Aldwell (1998) concluded "In Spain, [groundwater] overexploitation is dealt with in the water act and implemented by the regulations that enforce that act. Experience has shown that without the cooperation of the water users themselves, good results are not obtained."

Concessions have created a new dynamic of opportunism. Recently, the CNA announced its intention to withdraw unused portions of groundwater quotas; this generated a perverse 'use-it-or-lose-it' feeling among farmers. Luis Marin, a Mexican researcher, reported,

> "In Mexico, the government has tried to give the stakeholders the responsibility for managing aquifers by establishing COTAS. However, COTAS depend financially on subsidies from… governments… Under the new law, stakeholders who don't use all of the volume that they have a permit for, stand to lose the unused volume the following year. As a result, stake holders extract their full volumes, even if much of this water is wasted, only not to have their concessions reduced." (Personal communication by e-mail of 7 July, 2005).

Enacting and enforcing a groundwater law, establishing clear tradable property rights on water, pricing groundwater as an economic good, installing and enforcing a licensing and permit system—all these have been discussed *ad nauseum* as desirable policy interventions to regulate groundwater overdraft (see, e.g., Arriens et al 1996: 176-178; 239-245). Nobody seems to disagree with the need for these; yet, no Asian country has been able to deploy any of these interventions effectively even as the groundwater situation has been turning rapidly from bad to worse. The scale of the groundwater threat is long recognized; but viable strategies for dealing with it are not forthcoming; indeed, governments are still busy promoting more groundwater development, as if they were in Stage 1.

Indirect levers

Because of our large number of small, scattered groundwater abstractors, India would need to devise its own groundwater governance strategy that fits with her context. There are potentially powerful *indirect* demand-management strategies that are not even part of the academic discussion on groundwater management in the developing world. These offer important trade-offs that need closer scrutiny. For example, it has been suggested that the Indian Punjab's groundwater depletion problems could be easier to resolve if its export of 'virtual' groundwater in the form of rice could be reduced or stopped; on the other hand, IWMI researchers have suggested that, in North Indian plains, using earthen canals for recharging with flood waters of monsoon rains can help counter groundwater depletion (IWMI-Tata Water Policy Briefing 1).

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[11] According to Ramon Llamas, this figure could be well up to 2 million suggesting that, leave alone issuing formal water rights, even building an inventory of groundwater irrigators is not easy.

Water- saving irrigation research—such as Alternate Wet and Dry Irrigation (AWADI) for rice in China or the System of Rice Intensification which has found enthusiastic following in scores of countries including India and Sri Lanka (Satyanarayana, 2005 and Sinha and Talati 2007)—can help reduce groundwater use; but it needs to be examined if these technologies would work as well in dry areas. In many developing countries, pricing and supply of electricity to tube well owners can offer powerful levers for agricultural demand management for groundwater. Since levying a price on groundwater itself may entail high transaction costs of collection, energy price can serve as a useful 'surrogate' (Shah et al 2004c; Scott and Shah 2004).

Another key are to work upon in South Asia, especially India, are the perverse energy subsidies for tube well irrigation. In the populous South Asian region, there seem no practical means for direct management of groundwater; laws are unlikely to check the chaotic race to extract groundwater because of the logistical problems of regulating a large number of small, dispersed users; water pricing and/or property right reforms too will not work for the same reasons. However, electricity supply and pricing policy offers a powerful toolkit for *indirect* management of both groundwater and energy use. Since electricity subsidies have long been used by governments in this region to stimulate groundwater irrigation, the fortunes of groundwater and energy economies are closely tied. India is a classic example. Today, India's farmers use subsidized energy worth some US $ 4.5-5 billion/year to pump some 150 km^3 of water mostly for irrigation; the country's groundwater economy has boomed by bleeding the energy economy. With electricity industry getting close to bankruptcy, there are growing demands for eliminating power subsidies; but governments find it unable to do so because of stiff opposition from farmer lobby. Recent IWMI research (Shah et al 2004) has argued that sustaining a prosperous groundwater economy with viable power sector is feasible but it requires that the decision makers in the two sectors jointly explore superior options for energy-groundwater co-management. IWMI studies recognize that switching to volumetric electricity pricing may not be politically feasible at present. However, they advocate flat tariff accompanied by sophisticated management of high quality but carefully rationed power supply to maintain at once the financial sustainability of energy use in agriculture and the environmental sustainability of groundwater irrigation; and has argued that such a strategy can curtail wasteful use of groundwater in irrigation to the extent of 15-18 km^3/year.

7. Transition Needed: From Resource Development to Management Mode

In the business-as-usual scenario, problems of groundwater over-exploitation in India will only become more acute, widespread, serious and visible in the years to come. The frontline challenge is not just supply-side innovations but to put in to operation a range of corrective mechanisms before the problem becomes either insolvable or not worth solving. This involves a transition from resource 'development' to resource 'management' mode (Moench 1994). Throughout Asia—where symptoms of over-exploitation are all too clear—groundwater administration still operates in the 'development' mode, treating water availability to be unlimited, and directing their energies on enhancing groundwater production. A major barrier that prevents transition from the groundwater *development* to *management* mode is lack of information. Many countries with severe groundwater depletion problems do not have any idea of how much groundwater occurs, and who withdraws how much groundwater and where. Indeed, even in European countries where groundwater is important in all uses, there is no systematic monitoring of groundwater occurrence and draft (Hernandez-Mora et al. 1999). Moreover, compared to reservoirs and canal systems, the amount and quality of application of science and management to national groundwater sectors has been far less primarily because unlike the former, groundwater is in the private, 'informal' sector, with public agencies playing only an indirect role.

Gearing up for resource management entails at least five important steps:

[1] Recognizing that even as the bulk of the public policy and investments are directed at large government managed irrigation programs, in reality, South Asia's agriculture has come increasingly to depend upon small-holder irrigation based largely on groundwater; policy effort as well as resource investments need to adjust to this reality if these are to achieve *integrated* water and land resources management in the true sense;

[2] Information Systems and Resource Planning through establishing appropriate systems for groundwater monitoring on a regular basis and undertaking systematic and scientific research on the occurrence, use and ways of augmenting and managing the resource;

[3] Initiating some form of demand-side Management through [a] registration of users through a permit or license system; [b] creating appropriate laws and regulatory mechanisms; [c] a system of pricing that aligns the incentives for groundwater use with the goal of sustainability; [d] promoting conjunctive use of surface and groundwater by reinventing main system management processes to fit a situation of intensive tube well irrigation in command areas; [e] promotion of 'precision' irrigation and water-saving crop production technologies and approaches;

[4] Initiating Supply-side Management through: [a] promoting mass-based rain-water harvesting and groundwater recharge programs and activities; [b] maximizing surface water use for recharge; [c] improving incentives for water conservation and artificial recharge; and finally,

[5] undertaking Groundwater Management in the river basin context. Groundwater interventions often tend to be too 'local' in their approach. Past and up-coming work in IWMI and elsewhere suggests that like surface water, groundwater resource too needs to be planned and managed for maximum basin level efficiency. A rare example one can find where a systematic effort seems to be made to understand the hydrology and economics of an entire aquifer are the mountain aquifers underlying the West Bank and Israel. The actual equity effects of shared management by Israeli's and Palestinians here are open to controversy, however, this offers an early example of issues that crop up in managing trans-boundary aquifers (Feitelson and Haddad 1998). Equally instructive for the developing world will be the impact of the entry of big-time corporate players in the business of using aquifers as inter-year water storage systems for trading of water. As groundwater becomes scarce and costlier to use in relative terms, many ideas—such as trans-basin movement or surface water systems exclusively for recharge--, which in the yesteryears were discarded as infeasible or unattractive, will now offer new promise, provided, of course, that Asia learns intelligently from these ideas and adapts them appropriately to its unique situation.

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