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Groundwater Policy:
Issues and Alternatives in India

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Cover photograph by J. Colmey: Field irrigation tubewell in a rice field in India.

Contents

Tables

Foreword

GROUNDWATER DEVELOPMENT ISSUES are of increasing relevance for policy development throughout South Asia as a result of population growth and increasing demands for water for irrigation, industry, municipal supplies and environmental needs. In addition, groundwater development for irrigation has been recognized over the last decade as having the potential to play a major role in rural poverty alleviation. Pressures to increase groundwater extraction both to meet growing demands and as a mechanism for poverty alleviation are strong. Already, groundwater irrigation accounts for roughly half of India's irrigated area. Groundwater also forms the primary source of water supply for many urban areas and industrial users. Competition between sectors over limited supplies is a growing theme in many parts of the sub-continent.

With respect to agricultural water use, there are contrasting concerns. On the one hand, there is overdevelopment of groundwater supplies in some areas, while on the other hand, rising water tables and salinization affect large areas in the command of surface irrigation systems. These represent an equal threat to the sustainability of agricultural production in some areas. Other concerns include saline water intrusion in many coastal regions and pollution of groundwater resources because of seepage of fertilizers and residues from ago-chemicals.

The importance of the policy implications arising from these issues prompted the International Irrigation Management Institute (IIMI) to ask Dr. Marcus Moench to prepare a groundwater policy document based mainly on a critical review of the proceedings of two recent workshops. These are the "Workshop on Water Management: India's Groundwater Challenge," held in Ahamedabad, Gujarat in December 1993; and the "Workshop on Farmer Management of Groundwater Irrigation in Asia," held in Dhaka in May 1992. While one of the workshops was on South Asia, this paper mainly summarizes groundwater problems and policy options for India. We recognize that the historical developments in policy formulation by planning and implementation agencies in other Asian countries differ from those in India. For example, the extent to which groundwater development is expected to contribute to poverty alleviation is country specific. Nevertheless, we expect that many of the problems experienced in India as well as the institutional responses which have arisen to cope with the problems, are of interest to policymakers and planners in other Asian countries.

I would like to commend Dr. Moench for the comprehensive overview of the problems associated with groundwater use and the options for improved management which he explains and interprets in considerable detail in this manuscript. Now that we have this paper which focuses on India, the need is felt for another document where the experiences of other Asian countries with regard to policy formulation for groundwater development are brought together. More information is also needed on the experiences in the choice of technology for groundwater extraction in different countries.

We hope that the present paper will generate discussion and we cordially invite you to send us your comments and reactions. The financial support from the Ford Foundation in the preparation of the manuscript is gratefully acknowledged.

Jacob W. Kijne
Director for Research
International Irrigation Management Institute

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Overview

THIS PAPER REVIEWS policy-related issues discussed in recent conferences that will affect groundwater development and management efforts in South Asia. Emphasis is given to the set of policy issues surrounding emerging groundwater depletion and quality concerns. Attention is also paid to issues surrounding the equitable development of groundwater resources for poverty alleviation. Less emphasis is, however, given to this second set because the existing volume of policy literature related to them is much larger—not because they have less significance. This review is based primarily on the results of the "Workshop on Water Management: India's Groundwater Challenge" held in Ahmedabad, Gujarat in December 1993; and the "Workshop on Farmer Management of Groundwater Irrigation in Asia" held in Dhaka in May 1992 (hereafter, referred to respectively as the Ahmedabad [Moench, Turnquist and Kumar 19941 and Dhaka [Abhayaratna, Vermillion, Johnson and Perry 19941 workshops). The paper draws extensively on other sources as well.

The paper outlines first the range of services that depend on groundwater resources—particularly irrigation, but also municipal, industrial, environmental services and, to some extent, poverty alleviation. Then, problems that threaten the ability of groundwater resources to provide those services are identified and discussed. This discussion includes analysis of how well problems are known and identifies basic gaps in data availability. It also emphasizes the complications stemming from the fragmented approach taken to water management throughout the region. Artificial distinctions between groundwater and surface water and between the sectoral demands on available water supplies greatly complicate the development of integrated approaches to water management. Proceeding from this analysis, a range of responses dealing with the management of the physical system, potentially capable of addressing problems, is identified. Institutional frameworks through which management responses could be implemented are then discussed in relation to both the range of approaches theoretically applicable and the existing institutional frameworks in place throughout South Asia.

Overall, five points are emphasized in the review: (1) a wide range of essential services depend on groundwater including irrigation, municipal and industrial water supplies and environmental maintenance; (2) pressures on groundwater resources are growing and depletion, quality and pollution problems are emerging as a result; (3) basic data on the nature of groundwater resources and on the extent and characteristics of problems are lacking; (4) physical management options are often available — the most critical issues lie in the development of institutional arrangements through which responses could be implemented; and (5) tensions exist between current efforts to utilize groundwater as a tool for poverty alleviation and sustainable management of the resource.

CHAPTER 1

Aspects of Groundwater Use

GROUNDWATER RESOURCES PROVIDE a series of services on which both society and the wider environment depend. Demands for some of these. services—irrigation and industrial services, and drinking water supplies—are likely to increase dramatically over the coming decades as populations grow. These demands are already in conflict both with each other and with the often unrecognized environmental maintenance services already provided by groundwater. Furthermore, equitable distribution of services is a major factor in poverty alleviation. Actions to distribute groundwater services equitably often increase net demands on the resource and thus, complicate efforts to manage it in a sustainable fashion. The question of addressing both sustainability and equity goals is a major challenge.

IRRIGATION SERVICES

In South Asia the provision of irrigation has been a key factor in expanding agricultural production to meet the food needs of rapidly growing populations. Groundwater has played a particularly important role in this. As Robert Repetto comments: 'The Green Revolution has often been called a wheat revolution; it might also be called a tubewell revolution" (Repetto 1994: 35). In India, groundwater is now the single largest source of irrigation. Roughly, 35 million hectares (Mha) can be irrigated from groundwater—a figure which exceeds the 33 Mha of irrigation potential created through all major and medium irrigation works (Saksena 1989 and Dhawan 1990a). Where production is concerned, food grain yields on groundwater irrigated areas in India are often twice the amount of yields in canal irrigated areas (Shah 1993: 26).

Year	Well and pumpset numbers (in thousands)				
	Elect	Dsl	STW	DTW	Dug
1951	21	*66*	3	2.4	3,860
1990	8,230	4,350	4,750	65	9.490

Annual growth rate (%)	15	11	19	8	2
Average doubling time (years)	4.5	6.5	3.7	8.2	30

In areas affected by high water tables and associated salinity, groundwater development for the purpose of drainage can be as important as groundwater development for irrigation.

India's population has grown by 2.12 percent annually over the past decade, and is anticipated to double again before stabilizing toward the middle of the next century (Repetto 1994: 11). Water management will be a central requirement for producing sufficient food to support this expansion. Agricultural land is under pressure from urban expansion and environmental degradation. As Repetto states: "Virtually all the additional output must come through increasing yields on a constant or shrinking cropland area" (Repetto 1994: 88). If this is to be done, groundwater irrigation will play a key role in this. The ability of farmers to tap groundwater in the amounts and at the times needed is critical to yield increases as is the buffering capacity groundwater reserves can play in rimes of drought. Drainage will also play a critical role if surface irrigation systems are to remain productive. Overall, from a simple food production perspective, the demand for irrigation services from groundwater resources and the demand for drainage in waterlogged areas can be expected to increase at least as rapidly in the coming decades as they have in those recently past.

MUNICIPAL AND INDUSTRIAL SERVICES

Urban populations in India grew at twice the rate of rural populations over the 1971–1993 period (Mathur 1993, in Repetto 1994: 57). In 1961, 18 percent of the population lived in urban areas, by 1991, 26 percent lived there. In the next century, nearly one third of India's population is expected to live in urban areas (Ghosh and Phadtare 1990: 433). For some states such as Gujarat, urbanization has proceeded further and the corresponding figures are 25.8 and 34.5 percent (Moench, Turnquist and Kumar 1994: 93). The rate of urbanization may well increase in the coming decades if economic liberalization produces rapid growth in manufacturing, industrial and service sectors. This has major implications for all water management activities. As B.J. Verghese comments:

> India is fast moving away from being a predominantly agricultural society. The urban-industrial sector and ecological needs are acquiring a salience they lacked before. An irrigation-led tradition of water deve-

lopment must therefore yield to more comprehensive integrated planning for the future (Verghese 1990: 249–250).

Beyond the effects of urban population growth, it should be recognized that municipal demands are not just a function of urban population size but of economic status as well. Residents in Gandhinagar, a fully planned city with piped water supply, which is the capital of Gujarat. utilize roughly 340 liters per capita per day (lcd)—roughly on par with use in the United States. This contrasts with the 170 lcd supplied in the adjacent city of Ahmedabad and the 7.5 lcd which the slum area residents of that city receive.[1] As the urban middle class in India grows, *so* will their per capita water demand.

Industrial demands for water may well grow even more rapidly than domestic demands. Depending on the degree to which it occurs, deregulation of the economy could lead to a dramatic expansion of the industrial and manufacturing sectors. Furthermore, expansion of these sectors will require energy. This is likely to have a dual impact on groundwater management. First, energy production from thermoelectric plants requires large amounts of water for cooling. Second, energy demands for industrial uses may come in increasing conflict with agricultural energy demands. Electricity supply problems have been a major factor limiting groundwater irrigation in many areas. In 1990-91, agriculture accounted for some 25 percent of electricity consumption nationwide (Pachauri 1994 *in* Repetto 1994:68). In some states, the level was much higher. Estimates for 1990–91 suggest that agriculture accounted for roughly 32 percent of all electricity consumption in Gujarat with 30 percent of total power production used for pumping.[2] These percentages are much higher than the official 18.4 percent agricultural consumption figure reported for Gujarat in 1986–87 (Dadlani 1990). The net result is that as energy demands increase in non-agricultural sectors, competing demands for both groundwater itself and the energy currently allocated to pumping it will also increase.

In India and Bangladesh, irrigation accounts for most of the water use. This is typical of low-income group countries in which domestic and industrial withdrawals account for 4 to 5 percent each of total water diverted from

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[1] Figures for Gandhinagar and Ahmedabad arc provided by the Gujarat Water Resources Development Corporation. Those for slum areas were obtained from a survey conducted by SANCHETNA, an NGO working with community health and awareness programs in Ahmedabad.

[2] Note prepared by Chatper, C.S., GSEB headquarters, I January 1992

natural sources. It contrasts significantly with the 14 percent domestic and 47 percent industrial water withdrawals for high-income group countries (World Resources Institute 1990 *in* World Bank 1992 100).

ENVIRONMENTAL SERVICES

Although poorly documented; groundwater provides numerous environmental services. Dry season flows in rivers are often directly dependent on groundwater levels. These flows provide basic environmental services to communities — from drinking and irrigation water supply to the dilution and flushing of pollution and the maintenance of river fisheries. Furthermore, without dry season flows, rivers would become (as they already have in some cases) open sewers for a major portion of the year.

In addition to the environmental services on which communities directly depend, groundwater levels influence the extent and quality of wetlands and the degree of saline intrusion along coastal areas. They can also influence surface vegetation by allowing deep rooted plants access to water throughout the dry season. There is little data on the role of groundwater in providing basic environmental services. As groundwater development levels grow however, impacts on these services can be expected to increase and, with them, debates over groundwater management goals. Even in some of the largest river basins, such as the Ganges, concern has been expressed over "the potential impact of increased groundwater extractions on the base flow," but the data are insufficient to determine the likely impact of anticipated extraction patterns (Kahnert and Levine 1993: 14). Although data are lacking in most situations, the case of the Ahmedabad City provides a good example of the issues that can emerge.

Water levels in tubewells in Ahmedabad have been falling at 1.5 to 2 meters per year (m/year) over the past few decades (Gupta 1985 and Gupta 1989). As groundwater extraction by the AMC (Ahmedabad Municipal Corporation) increased in the late 1960s and the early 1970s, flow in the Sabarmati River — which had been highly correlated with basin rainfall—declined to nearly zero by 1970. Surface flows and groundwater are closely connected in this zone. Model results suggest that roughly 19 percent (in 1984) of the groundwater extraction in the Ahmedabad City is derived by induced seepage from the Sabarmati River (Gupta 1985 and 1989). Declines in river flows have been stabilized by increased releases from the Dharoi

Reservoir since 1976, but municipal demands are nevertheless increasing (Patel, Sharma and Ramnathan 1979). Partially as a result of the low flow levels, pollution in the Sabarmati has increased. A comprehensive study by the Central Pollution Control Board (CPCB) in New Delhi tested the Sabarmati's surface water quality at various points along the river and stated that in the Gandhinagar-Ahmedabad reach: "The Sabarmati becomes essentially a trunk sewer" (Central Pollution Control Board 1989: 43). In response they recommended that: "The real key to the success of any effort to restore Sabarmati to any reasonable quality levels [*sic*] will be to ensure minimum flows at all points and at all times in the river [sic]" (Central Pollution Control Board 1989: 4).

The need to maintain instream flows is a critical, often unrecognized, component in groundwater management. Groundwater and surface water are part of the same hydrologic system. Unless base and flushing flows are maintained, downstream users will lose access to water supplies for their needs at critical points in time. and the pollution of both surface water and groundwater is likely to increase. At the same time, in arid areas maintaining base flows represents another demand on already stretched water supplies. For the Sabarmati, roughly 50 percent of the live storage in Dharoi Dam would be required to keep base flows at the minimum level needed for pollution control (Central Pollution Control Board 1989: 4). The Dharoi Dam—the main potential storage reservoir in the Sabarmati—was initially developed for irrigation purposes. Now most of the supply goes to Ahmedabad. Even in the Gangetic Basin—hardly a water-short region—dry flows have become a major point of contention between India and Bangladesh. Hence, the potential impact of groundwater development on dry season flows should not be ignored.

POVERTY ALLEVIATION

The potential of groundwater irrigation to act as a tool for poverty alleviation has been the focus of discussion for over a decade. This discussion has focused primarily on the range of factors influencing access to groundwater for irrigation by the rural poor and has been carried on in equity terms. Although there is substantial evidence that the wealthy have been the primary beneficiaries of past groundwater development policies, further development is widely seen as offering "an opportunity to rectify the biases against access of the poor to irrigation benefits—biases that have been prevalent in groundwater exploitation in the past" (Kahnert and Levine 1993: 14). Policies such as the provision of credit for well development, extension of the rural electricity supply network, and electricity subsidies to the agricultural sector have been central in governmental efforts to encourage groundwater development. In addition, flat rate electricity pricing policies have been shown, at least in some cases, to allow greater access for the rural poor to groundwater through the emergence of water markets (Shah 1993). As a result, they have been widely advocated as a tool for poverty alleviation.

Poverty alleviation through groundwater development is, however, not just a rural irrigation question. There is growing consensus that the amount of water available for personal and domestic hygiene is as important a determinant of a community's health as the quality of that water (Esrey and Habicht 1986). In areas where water availability is low, "the provision and use of sufficient water, albeit of poor quality, could prevent the contamination of food, utensils and hands and thereby reduce the transmission of major infectious agents of diarrhea" (Esrey and Habicht 1986: 118). Health is a critical factor in the poverty of many urban slum areas throughout South Asia. Although the minimum volume of water absolutely required for health purposes is low (roughly 20 lcd) this exceeds the amount currently available in many urban slums.[3] As the World Development Report (World Bank 1992) states: "As long as families have to go out of the yard to collect water, the quantities used will remain low" (typically between 15 and 30 lcd). The use of water for personal hygiene usually increases only when availability rises to about 50 lcd and generally depends on getting water delivered to the yard or house (World Bank 1992: 99).

Both rural and urban poverty are likely to be major issues over the coming decades. Irrigation development and domestic water supply and sanitation will be major features in efforts to address poverty. This will add to existing demands on available water resources. Where scarcity exists, efforts to increase access equity are likely to conflict directly with the need to use available supplies efficiently and, in some cases. reduce existing levels of use. It is difficult to increase the equity with which a resource is distributed without increasing the overall amounts supplied.

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[3] Studies done in Milamagar, a slum in Ahmedabad, found that only 7.5 liters of water were available per capita (Data from SANCHETNA, Ahmedabad).

CHAPTER 2

Emerging Problems

PARTICIPANTS IN THE Ahmedabad Workshop (Moench, Turnquist and Kumar 1994) emphasized the emergence of numerous problems related to groundwater management including aquifer overdevelopment, saline intrusion, waterlogging and salinization. pollution, competition within and between sectors, inequity in access, inefficient use, and the fragmented approach taken to water issues. In contrast, issues of access, equity and the support services required for groundwater development by rural fanners dominated the papers presented at the Dhaka Workshop. The above contrast reveals a basic change in debates over groundwater development. Groundwater resources in South Asia are huge and, until recently, were relatively untapped. Ease of access (through wells), widespread distribution of the resource, and the central role of irrigation in improving agricultural yields have made groundwater development an obvious choice for addressing rural poverty. Problems in developing access for the poor to this resource have, as a result, been a primary topic of debate over the past decade. Now, with the rapid expansion of groundwater irrigation, it is being recognized that a huge resource is not the equivalent of an unlimited one. Depletion, pollution and environmental problems are emerging in many locations. Concerns over these problems often conflict with earlier sets of concerns over how to develop the resource and ensure access equity for the rural poor.

Lack of basic information is a significant constraint in debates over the extent and nature of groundwater depletion, pollution and environmental concerns. Critical issues surround both the groundwater database and the methods used for analyzing it. Groundwater conditions in South Asia are heterogeneous both nationally and at a very local scale. Given the lack of basic data and the lack of a framework suitable for collecting them, discussions of concerns tend to remain anecdotal or site specific. At the same time, the number of instances where well documented problems appear coupled with the rapid increase in extraction capacity that is ongoing throughout the region. strongly suggest that responses should not wait until full information is available. More about the need for reliable information will be said in a later section of the paper.

AQUIFER OVERDEVELOPMENT AND GROUNDWATER MINING

The extent to which aquifers are being overdeveloped (as indicated by falling water tables) and the extent to which it matters even if water tables are falling are both subjects of substantial debate. Given the lack of quantitative information, this section focuses on the types of overdevelopment problems emerging in specific locations, the probability of their occurrence on a more widespread basis and the implications that they would have in relation to the services identified above.

Groundwater mining, defined as long-term continuous drops in the water table, is adequately documented in only a few locations in India. One of these, Mehsana District of Gujarat, has been the focus of official concern for at least four decades. Other areas—Coimbatore District in Tamil Nadu, Kolar District in Karnataka, Bikaner and Jodhpur districts in Rajasthan, Chandigarh and other parts of Haryana—have been the subject of recent research, but scientific documentation is not readily available. Beyond this exists a wealth of site-specific information, but little accessible scientific data.

CASE STUDY OF MEHSANA DISTRICT, GUJARAT

The case of Mehsana District in Gujarat is instructive. The district overlies a deep alluvial basin between the Aravali hills that border Rajasthan and the Saurashtra Region. Rainfall in the district averages roughly 650 millimeters (mm) (Bagchi 1991: 12). Groundwater development, initiated in the 1950s, tapped shallow unconfined and deeper artesian aquifers. By 1972, the Irrigation Commission noted that: "groundwater withdrawals had already led to a serious and potentially dangerous drop in the water levels in Mehsana District where about 500 tubewells are operating. The drop in some wells has been as much as 18 m" (GOI 1972 112). As early as 1976. the United Nations

Development Programme (UNDP) reports recommended reducing extraction by 25 percent in parts of North Gujarat (United Nations Development Programme 1976). In 1981, the Central Ground Water Board reported declines of 2 to 3.5 m/year in the confined aquifers of South Mehsana and 0.5 m/year in East Mehsana (Phadtare 1981: 45). Tubewell numbers continued to expand rapidly. Current estimates place the number of private tubewells at 8,000 to 10,000, and government wells at 500.[4] This may be low, and driller estimates suggest that roughly 2,000 new wells may be drilled annually in the district.[5]

As a result of the growth in tubewell numbers, the area under artesian conditions rapidly shrank. Drops in the water table increased from roughly 1 m/year in 1970 to, in some locations, as much as 5 to 8 m/year in 1991 (GOG 1992). Shallow open wells, common in the 1950s, have now gone out of use. Tubewells, which were initially drilled to depths of 60 to 100 m now average 250 to 300 m according to official sources (GOG 1991).

Quality problems related to overdevelopment of aquifers in Mehsana are also common. Wells recently drilled for the Indo-Dutch Tubewell Project in Sami and Haraj taluks contain fluoride levels generally ranging from 1 to 2 milligrams per liter (mg/l) but going as high as 11 mg/l. Studies completed for the project correlate the increases with irrigation-related water table declines (Kingdom of the Netherlands and Government of India 1992). Overall, fluoride concentrations range from 2 to 6 parts per million (ppm) in major parts of Mehsana District (Phadtare 1988). Fluoride is far from being the only quality problem. Many of the aquifers in Mehsana are linked to saline water bodies. As extraction has increased, so has leakage between saline and fresh sources. Salinity has increased greatly in many wells and large areas have gone out of production (GOG 1991: 17). Furthermore, according to the above report: "The recycling of irrigation water in conjunction with use of chemical fertilizers has further resulted in increased groundwater salinity, making groundwater unsuitable for sustained irrigation in many parts" (GOG 1991: 16). No data to support this effect is, however, provided.

Although steady drops in the water table and associated quality problems were adequately documented, official estimates compiled as late as 1986 showed only 66 percent of the available groundwater recharge in Mehsana

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[4] Discussion with the Ex-Director of the *Jal Sansthan* in Gujarat on 3 March 1991.

[5] According to interviews with well drillers in Meshana on 4 March 1991, there are 25 drilling companies working out of Meshana Town alone. Most companies own two rigs and each rig drills roughly 40 wells per year.

District as being tapped (GOG 1986). This pattern continued. Estimates for the taluks of Sami and Harij completed in 1991 indicated, respectively, that only 41.45 and 49.39 percent of available recharge were extracted (GOG 1991: 108). Later in 1991, with no change in the available data, extraction in these taluks was estimated as 85 and 117 percent of recharge (GOG 1992: 84). In these same taluks, independent monitoring of groundwater levels through the Indo-Dutch Water Supply Project, indicated average water table drops of 2 to 3 m/year (Wijdemans 1993 and 1994).

Estimates of groundwater availability are the primary guide used to allocate funding to districts for credit provision in support of well development. The provision of credit to farmers is very popular. As a result, political pressures on the resource estimation process are great (Moench 1992 and 1993c). Groundwater-level measurements as recorded in the original log books maintained by the State Groundwater Department have been corrected as many as four times. Methodologies commonly used for estimating recharge and extraction are even more uncertain and susceptible to manipulation than the data on which they are based (Moench 1992 and 1993c). As a result, although direct evidence of groundwater mining has been available for several decades in Mehsana District, this did not translate into restrictions on the provision of credit for well development in many affected areas. In 1986, only three of the 11 taluks in Mehsana were officially recorded as "dark" areas, resulting in total closure of well development credit (GOG 1986).

This case study illustrates some of the basic problems in evaluating the extent of groundwater mining in India. There is increasing evidence that groundwater mining does occur in many areas. Of the 70 papers presented at the Ahmedabad Workshop, roughly half commented on long-term drops in water tables in different parts of India. Drawdown concerns also received prominent attention in the Dhaka Workshop and in the Symposium on Groundwater Irrigation and the Rural Poor (Kahnert and Levine 1993).

Despite the attention, how extensive real groundwater mining is remains a matter of conjecture. The Central Groundwater Board estimates that “more than 120 blocks have reached a state of overexploitation” (Sharma 1994). Administrative blocks categorized as either overexploited or in danger of becoming so account for roughly 14 percent of all blocks nationwide in India and much more in some states such as Punjab, Haryana, Rajasthan, Gujarat and Tamil Nadu (Ray 1994). As the Mehsana case indicates, however, official statistics on the number of blocks where extraction approaches or exceeds recharge may be misleading. Great uncertainty exists over the reliability of published extraction and recharge estimates (Moench 1992 and Dhawan

1990b). Furthermore, even the basic water table measurements on which these estimates rest may, in some case, be open to question (Moench 1993c).

SALINE INTRUSION IN COASTAL REGIONS

Saline intrusion due to overextraction from aquifers hydrologically connected to the Ocean is emerging as a major point of concern in many coastal regions. Along the eastern coast of India, saline intrusion now extends as much as 60 kilometers (km) inland to the Baitarani, Brahmani and Mahanadi river basins (Ray 1994). It is also a major problem facing the city of Madras (Srimannarayan. Imbarage and Vellaichamy 1993). In coastal sections of Junagadh District in Gujarat, saline intrusion was recognized as a problem in the early 1970s. In 1971, salinity affected an area of 35,000 hectares (ha). By 1977, the affected area had grown to 100,000 ha (Barber 1989: 2). Overall, saline intrusion affected a total of roughly 34,625 square kilometers (sq.km) in Gujarat as of 1988 (Phadtare 1988: 58).

As with groundwater mining, data on the extent of the area affected by saline intrusion and the impact it has on agricultural production are not widely known. Recent groundwater statistics published by the Central Ground Water Board include no data on water quality (GOI 1993). Specific problem areas, such as those listed above, are relatively well known. Generalized maps have also been produced for some states such as Gujarat (Phadtare 1988: 59), and probably exist for most others as well. Basic data on the hydrological dynamics of coastal aquifers and the degree to which groundwater extraction is related to saline intrusion are, however, not generally available.

SEASONAL DEPLETION AND DRAWDOWN

In addition to long-term groundwater mining, seasonal drops in the water table have emerged as a significant point of concern in both hard-rock and alluvial aquifers. In alluvial aquifers, drops in the water table can cause shallow wells to go out of production during critical periods of irrigation. This can have substantial impacts on access to groundwater for those—typically the less wealthy—who are unable to deepen their wells sufficiently to maintain access. In hard-rock regions, where groundwater storage tends to be confined to the upper weathered zone, seasonal drops in the water table can signify temporary depletion of the available resource—a factor which affects both the wealthy and the poor alike.

The effects of well interference and seasonal drops in the water table have been raised as a point of concern in Bangladesh (Sattar and Haq 1994; Kahnert and Levine 1993: 14; and Pittman 1993). Recharge in the Lower Gangetic Basin is high and deep alluvial aquifers containing good quality water extend to depths of 1,000 to 3,000 m in many areas (Prasad 1993). Although the volume of water potentially available for use is very great, increasing development of groundwater will inevitably increase fluctuations in the groundwater table. Where there is no long-term decline in water tables, these fluctuations increase the volume of groundwater storage available and result in the capture of additional recharge. As long as excess water is available for recharge at a basin scale, this recharge represents an increase in the total water available for use.[6] At the same time, since water table drops are greatest during low flow seasons and drought years, they could have a large impact on base flows and thereby on the communities and environmental resources that depend on these flows. In addition, fluctuations can have significant implications for access to groundwater by different classes of well owners.

Hand pumped tubewells are only effective to depths of 3.5 to 5.5 m; shallow tubewells utilizing energized suction pumps are effective to depths of roughly 6 to 8.5 m if they are deepset (Pittman 1993). Deep tubewells can tap water to virtually any depth—they are only limited by the economics of well drilling and pump energy supply. If water table levels drop below the depth to which shallow tubewells are effective, farmers depending on these wells will lose access to groundwater. Furthermore, efficiencies of the centrifugal pumps utilized by shallow tubewells typically vary greatly depending on the pumping head. Where fluctuations in water level are significant, shallow tubewells can become uneconomic to operate (Levine, Abeyratne and Pradhan 1993).

As groundwater extraction increases so will the seasonal rate of drop in the water table, even where extraction does not exceed potential recharge. Particularly in areas where deep and shallow tubewells coexist, shallow wells may go out of production for a portion of the year. This could be caused either by regional declines in the water table or by localized interference between

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[6] Additional recharge in upstream areas could. in some cases. be at the expense of existing users lower in the basin.

different capacity wells. During drought years, particularly successive ones in which the water table never fully recovers between irrigation seasons, shallow tubewells can be non-functional for extended periods. Since shallow tubewells are much less expensive to install and run than deep tubewells. the impact of water table fluctuations is likely to affect the poor disproportionately.

Data on the extent of seasonal water table fluctuations and the actual impact they have on different types of wells are unavailable. Furthermore. the implications of increasing groundwater extraction for base flows and the communities and environmental resources that depend on them have never been fully examined. Tension is likely to emerge between the objectives of maximizing groundwater storage (and, therefore, total water availability) and the impact this may have on base flows particularly lower in the basin.

In India, 50 to 60 percent of usable groundwater resources are in alluvial and other unconsolidated sediments which underlie roughly one third of the country, notably the Gangetic Basin. Most of the remainder of the country is underlain by hard rocks (Saksena 1989: 6).

In hard-rock regions, most groundwater storage is confined to the upper weathered zone. Well discharges typically increase linearly with increases in the width and number of fractures and, due to a decline in fracture width and spacing, decrease linearly with increases in depth to the static water level (Basak, Lekha and Prasad 1993). Since specific yield declines with depth, water table fluctuations do not create as much additional storage as they would in an alluvial aquifer. In this situation, drops in the water table affect well yields and reflect declines in the actual volume of water available for extraction. Past a certain point, increases in the number of wells or their depth will not increase the amount of groundwater that can be extracted. As the number and depth of wells grow the rate of seasonal decline in the water table may simply increase resulting in less favorably situated or shallow wells rapidly going dry. Regional drops in the water table—either long term or over a season—can represent dewatering of the available aquifer space. If this occurs, additional wells simply capture a portion of the resource that would otherwise have been captured elsewhere.

Evidence from the Coimbatore area in Tamil Nadu is suggestive of the issues likely to emerge in many hard-rock areas. Groundwater depletion is a well known problem in the Coimbatore District. During the last 30 years, the number of wells has doubled but the net area irrigated by them has increased only marginally from about 1,41,655 ha to 1,42,096 ha (Palinasami and Balasubramanian 1993: 3). As a result, the average net irrigated area per well has shown a SO percent decline from 1.56 ha in 1960-61 to about 0.747 ha in 1989-90 (Palinasami and Balasubramanian 1993: 3). Along with this, the number of abandoned wells in the district increased from 4,033 in 1960 to 16,700 in 1990 (Palinasami and Balasubramanian 1993: 4). Risks associated with well construction have also grown since depths have increased and since many fail to strike significant amounts of water.

The net result is that many farmers have failed to maintain access to groundwater for irrigation and other uses. In addition, tremendous resources have been expended in the construction of new wells and the deepening of existing ones with no net increase in the area irrigated.

As in the case of alluvial aquifers, data are not available that permit the evaluation of the above concerns in a quantitative manner. Many authors at the Ahmedabad Workshop presented evidence that problems similar to those outlined for the Coimbatore District also exist in other areas. It is as yet unclear how widespread this problem is. The impact of overextraction in hard-rock areas is likely to be evident first as seasonal water shortages rather than as a reduced growth rate of the irrigated area, as has occurred in the extreme case of Coimbatore. Except in Tamil Nadu — where data are gathered on a monthly basis — groundwater data in India are only collected 2 to 3 times per year by the State Groundwater Organizations. This typically occurs prior to and following the monsoons. As a result, existing data do not capture the extent and timing of seasonal fluctuations.

WATER QUALITY AND POLLUTION

Two aspects of the relation between groundwater quality and extraction rate are of particular importance: (1) problems associated with water bodies of naturally low quality, and (2) pollution from anthropogenic sources.

Often, groundwater quality is low due to natural causes. Roughly 65 percent of Haryana State is, for example, underlain by saline groundwater (Gangwar and Panghal 1989). Explorations in Rajasthan have located large, highly productive, alluvial aquifers. Unfortunately the water quality, particularly in Western Rajasthan, is often poor with electrical conductivities locally exceeding 10 decisiemens per meter (dS/m) at 25°C (Krupanidhi 1987: 5). In Gujarat, more than one'third of the groundwater at depths of less than 40 m contains more than 1,000 mg/l of total dissolved solids, and large areas contain more than 3,000 mg/l (Phadtare 1988: 59). Deeper aquifers are also often highly saline. Saline aquifers are also common in Punjab and Western Uttar Pradesh.

Where low-quality water is in hydrologic connection with aquifers containing high-quality water, development of the aquifers can cause intrusion of the low-quality water. This is, for example, the cause of saline intrusion in coastal areas. Saline intrusion is, however, not just a coastal phenomenon, but often occurs between adjacent high- and low-quality aquifers. In addition to salinity, other natural constituents such as fluoride, arsenic and, in some cases, nitrates can pose major water quality concerns. Much of the groundwater in Northern Gujarat, for example, has a high fluoride level which causes major health problems when used as a primary source of drinking water.

The link between surface water and groundwater is important when considering groundwater quality. Recharge of surface water or pumped groundwater to low-quality aquifers may be lost for future use and could contribute to a waterlogging or salinity problem. Conjunctive management of surface supplies and groundwater for irrigation, and the design of irrigation systems in ways that avoid recharge to low-quality aquifers will increase in importance in the future.

In addition to water quality problems related to natural sources, groundwater pollution has been identified as a growing area of concern by participants at the Ahmedabad Workshop. As Turnquist (1993: 1) points out, groundwater quality is: "limiting the usability of water, and therefore exacerbating water scarcity. In industrialized nations there is growing doubt that groundwater, once degraded, can feasibly be restored to acceptable quality levels." Little data on the extent or significance of groundwater pollution problems in India are available, and it should be acknowledged that the collection of reliable data is not easy and comes at considerable expense. Most studies have hitherto been site specific and focus on industrial pollution. The Central Pollution Control Board has, for example, just initiated a program to monitor groundwater quality in 22 critically polluted areas across India (Biswas, Venugopal and Sharma 1993). The Tamil Nadu Pollution Control Board monitors pollution from a large number of industrial sources, such as tanneries, across the state.[7] In Gujarat, large areas of groundwater are reported to be affected by pollution from a combination of agricultural and industrial sources (Phadtare 1988: 6547). Maps prepared by the Central Ground Water

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[7] **Baliappa, P.M. Retired Chairman, Tamil Nadu Pollution Control Board. Personal communication.**

Board (CGWB) show nitrate concentrations exceeding 45 mg/l in over 370 sample sites scattered throughout the state (Phadtare 1988: 63). The extent of pollution from anthropogenic sources and the criteria by which polluted areas have been identified are, however, unclear.

Pollution problems arising from agriculture are likely to emerge as a major point of concern for groundwater management in the coming decades. As Repetto (1994: 38) points out: "By 1991, fertilizer use per acre in India was no longer low by international standards. In fact, per hectare of agricultural land was 60 percent higher than in the United States [*sic*], although yields of most major crops are much lower." He further comments: "Pesticide use has increased 3.4 times, growing by more than 6 percent per year between 1970-71 and 1990-91" (Repetto 1994 38-39). With data collection focused on pollution "hot spots" related to urban use or industrial point sources, there is little basis for evaluating the extent of groundwater pollution due to agricultural return flows. As fertilizer and pesticide use continues to expand in response to growing demands for agricultural products, groundwater pollution can be expected to intensify as well.

COMPETITION BETWEEN SECTORS

Competition over scarce water resources — including groundwater — is likely to grow over the coming decades. Urban populations are growing rapidly, and with increases in income and access to services, demand for water supplies increases far more rapidly than the population itself. Industrial growth and the energy requirements associated with water are also likely to be major sources of competition for groundwater use.

In many parts of India, systems initially designed for irrigation now play a role in municipal and industrial water supplies (Moench 1991). Numerous examples of this exist. Delhi's population exceeds 8 million and is expected to cross 12 million by the turn of the century. Water requirements are anticipated to increase from the 1,860 million liters per day (Ml/d) supplied in 1988 to 4,660 Ml/d in 2001 (Verghese, B.G. 1990 248). The city's water demand far exceeds locally available supplies and it gets much of its water from surface sources initially developed for irrigation. Chandigarh, on the Punjab-Haryana border, has had declining water tables since 1966. As early as 1983, there were proposals to "solve" depletion problems by diverting water, initially intended for irrigation, from the Bhakra Canal (Jindal and

Bhatnagar 1983: 140). Madras in Tamil Nadu has had water shortages for a long time. Water levels under the city have declined and saline intrusion is a major problem. The city intends to draw water from the Cauvery River (210 km away) and will need to get supplies from the Krishna and Pennar rivers as well (Rao 1979: 187). Hyderabad is currently reviewing options for withdrawing water from the Krishna and Godavari rivers which are—at least where short-run options are concerned—expected to have high opportunity costs and impose significant impact on third party users. In Gujarat, Dr. V.B. Patel, the former chairman of the Gujarat Water Supply and Sewerage Board (GWSSB) and a Secretary to the State Government, recently called for irrigation uses in the state to be reduced by 20 percent so that municipal needs could be met.[8]

Competition is not just an urban-rural issue. A report for the Indo-Dutch Drinking Water Supply Project in Northern Gujarat recommends reduction of imgation pumping as a primary need if drinking water supplies for rural villages served by the project are to be safeguarded (Kingdom of the Netherlands and Government of India 1992). Falling water tables in the section of Northern Gujarat where the Indo-Dutch Project operates, appears to be associated with increasing fluoride levels. Water table drops and fluoride increases related to groundwater extraction for irrigation purposes threaten the well field which now serves a 80 to 100 km long piped drinking water supply system (Wijdemans 1993).

Overall, competition between sectors over access to water, including groundwater, can be expected to form a major theme in water management debates over the coming decades. Groundwater currently accounts for some 87 percent of all drinking water supplies in India (Kittu 1993). Increases in domestic use will, therefore, tend to focus particularly on groundwater resources. How water allocations to municipal and industrial users can be increased while, at the same time, increasing food production on imgated areas presents one of the major challenges facing planners.

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[8] Keynote address at a Seminar on People's Participation in Water Management. at the GWSSB in Gandhinager on 18 June 1992.

ACCESS AND WATER MARKETS

Access to groundwater resources for the rural poor has been a major point of concern in all recent debates over groundwater resources. Evidence from many regions suggests that the large credit subsidies allocated to support agriculture over the past decades have gone primarily to the rural elite (Mundle and Rao 1991: 1,162). Marginal fanners and the landless often have difficulty in obtaining access to credit due to a variety of "transaction costs" and lack of collateral (Kahnert and Levine 1993). The explosive growth in well numbers coupled with energy subsidies (for electricity in India), and the emergence of groundwater markets has, however, increased access for the rural poor to groundwater resources (Shah 1993 and 1994). The degree to which groundwater markets are competitive and equitable and the degree to which their characteristics depend on energy pricing policies are, however, a matter of some debate (Janakarajan 1994 and Palmer-Jones 1994).

In India, electricity charges for groundwater pumping are collected (if at all) on the basis of pump horsepower only. It has been argued that this flat rate pricing system is central to the goal of poverty alleviation through groundwater development. Essentially, flat rate systems encourage well owners to pump more water both for their own use and for sale. Once the electricity charge is paid, average costs decline with the amount of extraction, and the more water the farmers sell the greater are their returns. Where buyers (often small fanners) have access to more than one seller, competition may develop resulting in relatively low prices (Shah 1993 and 1994). In both the competitive market and monopoly cases. poor farmers and fanners with fragmented holdings obtain access to groundwater which may otherwise have been inaccessible.

The extent to which the above scenario could serve as an engine for poverty alleviation is open to question. Some argue that water markets are highly inequitable and, as part of interlinked labor and produce markets, serve primarily as "a source of power and accumulation" for the rural elite (Janakarajan 1994). More commonly, researchers call for increased theoretical and empirical work on water markets as a basis for strengthening policy formation (Strosser and Meinzen-Dick 1994 and Palmer-Jones 1994). Several things are however clear: (1) the characteristics of water markets vary greatly, often within limited areas, and the factors influencing that variation have not been clearly identified; (2) the presence of water markets increases incentives for extraction which could exacerbate overdevelopment problems in regions where groundwater resources are limited; and (3) current electricity pricing policies, whatever benefit they provide to the rural poor, entail substantial costs. It is worth examining the third point in detail.

EFFICIENCIES

Agricultural pumpset efficiencies in India are very low. Surveys by the Institute of Cooperative Management indicate.typical energy efficiencies of 13 to 27 percent in farmers' pumping systems, while readily available and inexpensive pump improvements can reduce connected load by about 50 percent (Patel 1989 and 1991). In Gujarat, electricity charges to pumpers were equivalent to 0.15 rupees per kilowatt-hour (Rs/kwh) (US$0.0054/kwh) in 1991, while generation costs were 1.18 Rs/kwh (US$0.0421/kwh).[9] In Tamil Nadu, electricity is provided free for most agricultural pumps. In most states, electricity prices were shifted from a consumption based pro rata tariff to flat rates in the 1970s and 1980s. In Uttar Pradesh, this shift resulted in power consumption per pump increasing "from 2,065 kwh in 1973–74, when the switch was made to 6,724 kwh in 1979–80." In Maharashtra, the increase was from "2,191 kwh in 1975–76 to 3,142 kwh in 1979-80" (Shah 1994: 95–96). Shah attributes this increase in energy consumption to increased pumping (Shah 1994:96). Increased energy usage for pumping may also be attributable to a loss in pump efficiency as farmers have little incentive to invest in pump energy use efficiency.

A crude calculation of the energy savings achievable through improvements in pump efficiency is presented in Table 2. In some of the key agricultural states–Haryana, Punjab, Uttar Pradesh, Rajasthan and Tamil Nadu—pump efficiency improvements could save over 15 percent of total energy consumption. In many other agricultural states, power savings of 9 to 10 percent could be achieved. These estimates are conservative. In Gujarat and Karnataka, for example, agricultural consumption was estimated respectively at only 18.36 and 19.72 percent of the total in 1986–87 (Table 2), while more recent estimates place it at 415 3 and 35.95 percent (Planning commission 1994 *in* Tata Energy Research Institute 1994 3). Furthermore, the 13 to 27 percent range in pump efficiencies reported by S.M. Patel (1989) suggests that average pump efficiencies may well be lower than the 25 percent assumed for purposes of calculation. Diesel pump improvements and maintenance

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[9] Gujarat State Electricity Board officials. Personal communication.

*Table 2. Electricity consumption in the agricultural sector in India (1986–87).**

State	Total electricity produced GWH	Total electricity consumed GWH	Electricity consumed in agriculture GWH	Percent agriculture consumption	Consumption redudions by increasing average pump efficiency from 5 to 50 percent*'	Percent drop in otal consumptio achievable by efficiency improvement**
Andhra Pradesh	13,826.61	11,778.58	2,953.49	25 08	1,476.75	12.54
Arunachal Pradesh	32.69	25.12				
Assam	997.71	970.45	22.1	2 28	11.05	1.14
Bihar	3,695.7	5,799.78	971.61	16 75	485.81	8.38
Goa		372.8	6.47	174	3.24	0.87
Gujarat	14,683.32	11,378.71	2,088.73	18 36	1,044.37	9.18
Haryana	5,480.18	3,848.66	1.624.05	42 20	812.03	21.10
Himachal Pradesh	614.29	686.69	22.69	3 30	11.35	1.65
Jammu and Kashmi	1,059.8	950.92	59.58	6 27	29.79	3.13
Karnataka	7,830.91	7,756.23	1,529.53	19 72	764.77	9.84
Kerala	4.641.66	3,688.22	131.16	3 56	65.58	1.78
Madhya Pradesh	12,460.31	9,946.26	1,042.47	10 48	521.24	5.24
Maharashtra	29,127.69	22.330.65	4,056.85	18 17	2,028.43	9.08

(Continued on p. *25)*

Table 2. *(Continued).*

Manipur	15.1	77.84	1.83	2.35	0.92	1.18
Meghalaya	301.47	129.22	1.13	0.87	0.57	0.44
Mizoram	20.89	15.77				
Nagaland	1.1	50.58				
Orissa	4,232.89	3,842.07	88.12	2.29	44.06	1.15
Punjab	12,181.72	8,930.81	3,570.77	39.98	1,785.39	19.99
Rajasthan	5,331.79	5,445.79	1,676.07	30.78	838.04	15.39
Sikkim	33.8	22.32				
Tamil Nadu	75.24	69.1	10.56	15.28	5.28	7.64
Uttar Pradesh	14.740	13,472.15	4,999.75	37.11	2,499.88	18.56
West Bengal	8,737.78	7661.79	139.87	1.83	69.94	0.91
Total	149,572.35	131,321.53	28,167.09	21.45	14,083.55	10.72

*Data in columns 1-4 from Dadlani 1990, Annexure 6: 21.

**Assuming most agricultural electricity use is for pumping projects undertaken by 11 states produced an average 23.6 percent reduction in fuel use combined with a 26.9 percent increase in water discharge (Mishra 1990: 27). This is equivalent to a 40 percent increase in the efficiency of energy use per unit of water pumped.

Electricity deficits in India are estimated to be 8.5 percent of total generation and 17.5 percent of peak needs (Pachauri *in* Repetto 1994: 73). Availability of power is a major constraint for industry as well as agriculture. Thus, the opportunity costs associated with inefficient pumping are huge from the electricity perspective alone. Improvements in pump efficiencies could go a long way toward meeting current deficits.

Links between power pricing policies and overdevelopment of groundwater are widely debated as is the potential effect of energy price changes on groundwater extraction (Arora and Kumar 1993: Ebrahim and Mohanty 1993; Malik 1993 and Nagaraj and Chandrakanth 1993). Often, the combination of subsidy and a flat power tariff is seen as providing strong incentives for inefficient water use and contributing to overdevelopment (Moench 1991). As a result, shifting electricity prices to a consumption-based structure and removing (or at least reducing) the current level of subsidy have been advocated by many groups, including the World Bank, as an essential first step toward addressing groundwater overdevelopment problems (World Bank 1991).

Increasing the cost of extraction by changing the electricity tariff structure would cause farmers to focus more attention on the return they receive per unit water extracted—or more accurately—per unit of electricity used. Their response to this could be: (1) to shift to crops with higher returns per unit water applied; (2) to decrease the amount of water applied per unit area for the same crops and yields; or (3) to increase the efficiency of pump electricity use. However, none of these logical responses may have any inherent implications for the overall level of extraction. Increased application efficiencies could increase consumptive use percentages. The evapotranspiration requirements of most crop plants are relatively fixed. “Savings” achieved through increasing application efficiencies might not be real due to reductions in seepage and return flow to aquifers. Finally, farmers could respond to increased electricity prices by increasing pump electrical efficiencies.

The evidence presented so Saris mixed but tends to indicate that pro rata prices at the levels currently under consideration would have little impact on overall rates of extraction. Studies undertaken in Mehsana District in Gujarat have estimated the elasticity of water demand with respect to energy prices to be substantially less than one for power price increases up to 0.7 Rs/kwh. Below this level, power price changes do not influence water use at all due to the presence of unmet demand caused by powerrationing.[10] Price increases up to 0.5 Rs/kwh have been advocated by the Central Government and are under consideration in a number of states. The Gujarat Study was undertaken in an area of deep water tables where high capacity pumps (30 to 80 hp) are utilized. It assumed constant technologies and did not examine the potential for farmers to invest in pump efficiency improvements, thus changing the energy use-water delivery equation. Similar results indicating limited effects on groundwater extraction from energy price differentials have also been obtained in preliminary work done by other researchers involving comparisons between farmers using diesel and electric pumpsets (Moench 1993a and 1994b; and Kumar and Patel 1993).

In sum, although electricity price changes are caught in a wide debate, there is little evidence to suggest they would have significant impact on extraction problems. Electricity price changes could, however, have major implications for both electricity and water use efficiency. Direct and opportunity costs associated with current agricultural energy use patterns are huge. There is also substantial potential for large savings in electricity use with no reduction in irrigation service through inexpensive improvements in the efficiency of existing pumps.

IMPACT ON ABILITY TO MEET PREDICTABLE NEEDS

Poverty alleviation in agricultural areas may depend on maintaining access to groundwater resources for the rural poor. In urban areas it will require provision of adequate water to meet health and sanitation needs. Both these services could be affected by overdevelopment or pollution of groundwater. Long-term declines in the water table, depending on how extensive they are, could reduce access for the rural poor to groundwater by reducing the effectiveness of shallow tubewells. This same mix of problems threatens the ability of urban areas to increase water supplies to meet the needs of their growing populations. Increasing food production beyond the rate of popula-

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[10] Mohanty, Sanjay. Economist, TERI, New Delhi. Personal communication.

tion growth is another key component of the poverty alleviation and larger development agenda. The combination of long-term declines in alluvial aquifers, seasonal depletion in hard-rack regions, saline intrusion along coasts and quality and pollution problems emerging in other regions could reduce irrigated areas and threaten production particularly in drought years. Given India's need to expand production rapidly to meet the needs of its growing population, all threats to agricultural production are important.

Competition between sectors over water supplies could have major impacts on the ability of groundwater resources to provide many of the services identified as necessary at the beginning of this report. This is most evident in cases of direct competition between agriculture and the drinking water supply such as those in Northern Gujarat (Wijdemans 1993).Municipal and industrial demands, although a relatively small fraction of total water consumption, may represent a much larger fraction in dry periods. Farmers require assured, timely water delivery, particularly in critical periods, to maximize yields. If the unreliability of surface supplies to agriculture increases, either agricultural production will decline or farmers will be forced to depend more heavily on groundwater. In regions where groundwater supplies are limited, this could exacerbate existing overdevelopment problems.

CHAPTER 3

Information Needs

A WIDE RANGE of groundwater problems are now evident which have *potentially* great significance for food production, poverty alleviation, environmental services and energy/water use efficiency. Lack of relevant data is, however, a common theme with regard to many of the debates over the extent and significance of overdevelopment and pollution problems.

GROUNDWATER MONITORING AND POTENTIAL ESTIMATION

State and Central Groundwater Organizations were set up in India primarily for the purpose of guiding the development of the resource. Their main purpose was to identify areas of high potential for development and provide basic data usable for appropriation of funding (primarily in the form of credit) to support the construction of wells by individual farmers. The monitoring systems and analytical procedures used reflect both these original goals and the lack of resources for more technically sophisticated approaches. At the national level, in 1992 the Central Ground Water Board maintained a network of nearly 15,000 monitoring wells (GOI 1993) in which water levels were measured four times each year. State organizations maintain a separate network of, on average, 1,000 to 2,000 wells in which water levels are usually monitored twice a year before and after the monsoon.[11] Data from these wells are analyzed to produce estimates of extraction and recharge utilizing methods recommended by the Groundwater Estimation Committee in 1984 (GOI

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[11] Some states such as Tamil Nadu monitor wells on a monthly basis

1984). As has been documented elsewhere, the resulting estimates are highly unreliable (Moench 1992 and 1993c; and Dhawan 1990b). Linden Vincent has summarized the situation well for the Dhaka Workshop:

> The wealth of organizations involved in groundwater development in India suggests that there should also be a wealth of information. There is indeed a wealth of figures, but the majority is derived from highly empirical calculations, and is still based on relatively crude groundwater analyses, with limited studies on key aquifer parameters for modeling recharge and flow. These comments are in no way meant to criticize Indian field workers, who perform the tasks set to a very high standard. The problems are in the techniques they are required to use and the data they are able to collect....
>
> As a result, many of the techniques used to estimate aquifer behavior and water yield are now widely criticized. They make heavy use of data which are easily accessible–such as climate and water levels—but very little use of conventional aquifer parameters. The figures used for aquifer parameters like transmissivity and storativity have often been derived through quite inventive (but unconventional) procedures." (Vincent 1994: 51)

Beyond the issue of monitoring and analytical techniques lies the one of fragmentation. State Groundwater Organizations (SGOs) and the Central Ground Water Board (CGWB) have relatively rudimentary programs for monitoring groundwater quality. Pollution is generally monitored by the pollution control boards. Similarly, groundwater extraction data are fragmented. The CGWB and SGOs focus on irrigation. A mix of municipal corporations, water development corporations and other organizations focus on drinking and industrial water demands. The net result is a highly fragmented database which often does not bear on emerging points of concern.

MONITORING NEEDS

Groundwater monitoring systems that generate basic data suitable for evaluating the overall functioning of the hydrologic system need to be developed. Unless basic data are available, it is impossible to evaluate or monitor different points of concern. In some cases, such as the hard-rock zones of India, basic research may be required to improve understanding of hard-rock hydrology so that the types of data that need to be collected can be identified. If, for example, storage in the unsaturated zone is the primary source of water, monitoring conditions there may provide a much better guide to water availability than do current data collection efforts focused on well water levels. Similarly, if seasonal depletion of hard-rock aquifers appears to be a reasonable concern, then it will be essential to collect data on rates of seasonal decline and the impact they have on water availability toward the end of irrigation seasons.

The existing monitoring system is narrowly focused on the estimation of extraction relative to recharge and it provides little insight into matters such as the seasonal rate of drop in water levels or changes in water quality. Moreover, as hydrologic conditions commonly vary greatly at a local scale, regional hydrologic data can provide little information on water availability or problems at the village or local scale at which most groundwater development activities occur. It is therefore recommended that integrated monitoring systems be constructed of groundwater and surface water data that allow detailed modeling of hydrologic behavior at both basin and local levels.

Developing an integrated set of basic water resources data will take time and is likely to be expensive. As a result, datagenerated by existing monitoring systems need to be used more effectively. Participants in the Ahmedabad Workshop emphasized three considerations with regard to this:

(1) Current methods for assessing extraction and recharge of groundwater lack scientific validity, and, hence, give an incomplete or even incorrect picture of the groundwater conditions. Publication and analysis of basic water-level data (on which current recharge estimates are based) and those water quality data which exist would provide a more accurate guide to resource trends.

(2) The wide variety of data on groundwater and surface water systems currently held by a variety of organizations should be collected and made more generally available, which would improve its accessibility for many interested parties, including academics, nongovernmental (NGOs) and government agencies.

(3) Many types of hydrologic data, such as well water levels, are straightforward to collect and, to some degree, interpret as well. Since micro-level data are important but expensive and complicated for centralized organizations to collect, participation of the local population in data collection and analysis was regularly recommended (Moench. Tumquist and Kumar 1994).

ESTIMATION OF GROUNDWATER POTENTIAL

Discussions held at both the Ahmedabad and Dhaka workshops seem to imply a dual track approach to groundwater potential estimation and development planning.

Direct measures of water levels, water quality changes, and well failure rates could serve as guides to regions where groundwater problems are emerging. Indicators such as these could be used as guidelines for attempts to regulate or limit groundwater development activities and the targeting of detailed hydrologic investigations. Data for these purposes could be gathered from the existing monitoring networks run by the CGWB and SGOs, and from credit institutions such as the National Bank for Agriculture and Rural Development (NBARD). Overall, the short-run approach would not he to define a region as having the potential for "n" number of wells but more to leave development open until indicators of emerging problems suggest otherwise.

On a long-term basis, the above approach will encourage development to proceed to the point where problems exist before any management responses are initiated. As a result, some type of integrated resource planning process is required which will allow all water resources to be developed to their full potential without impinging seriously on the range of services generated. Groundwater potential, it must be recognized, depends not just on the hydrologic system but also on the services required. Thus, the estimation of the groundwater potential can only proceed through an integrated analysis of the range of factors affecting demand and supply for all water resources within a given hydrologic unit.

Although the need for integrated approaches was widely discussed at the workshops, specific avenues for doing this were not. In general, it was recognized that resource potential estimation needs to be done on the basis of hydrologic units, preferably basins. The system of river basin management common in France is currently receiving widespread attention (World Bank 1993: 46). This provides an institutional structure through which water management decisions can be made in relation to the range of demands on the available supply. Integrated Resource Planning (IRP) approaches currently being developed in the U.S. may also be useful in this regard. IRP processes are standard practice in U.S. energy planning. They are now being applied to the water field as well (Moench 1994a).

Two features are important with regard to groundwater planning in South Asia. First, IRP methodologies could provide a framework and an associated set of analytical techniques which would allow a relatively comprehensive analysis of the factors affecting water supply availability and the services provided by the resource. Second, and probably more important, IRP is process oriented. The goal is to institutionalize a system through which water management initiatives can evolve in response to emerging concerns. Participation by stakeholders (e.g., local population) is a core component of the process. IRP processes are iterative. There is explicit recognition that data are imperfect and need change, and the underlying causes of specific problems may only become evident over time. As a result, while the process is designed to produce plans that can guide policy and (through stakeholder involvement) have widespread legitimacy, it is also intended to be flexible and allow decisions to be revisited as the need arises.

CHAPTER 4

Physical Management Options

IN AREAS WHERE long-term declines in the water table occur, there are essentially four physical management options: (1) allow continued declines until the water table stabilizes either because lateral inflows increase or extraction in excess of recharge becomes uneconomic; (2) import supplies; (3) increase recharge; or (4) reduce extraction. This discussion will focus on the last two of the above options since the first option is generally perceived as undesirable and the second is often unfeasible due to lack of sources, excessive cost or environmental considerations. It should be recognized, however, that the first option is the most likely to occur unless viable management responses to overextraction can be implemented. Ultimately, if the first option is to be avoided, an integrated approach to water management combining elements of the remaining three will need to be developed for many regions. This, along with implications for tubewell technologies and access to groundwater by the rural poor, are discussed at the end of this section.

INCREASING RECHARGE

Attempts to increase recharge are generally the most popular management option within local commuhities in response to water-level declines. While this is only applicable where surplus runoff exists, it is often attempted with little analysis regarding the surplus or non-surplus nature of the water captured. A number of papers presented at the Ahmedabad Workshop documented efforts by NGOs and local communities to increase recharge. Artificial recharge possibilities have also been investigated in detail by governments in areas where water tables are declining (see, for example, GOG 1992).

The most extensive and technically well documented set of recharge activities at the village level are those undertaken by the Shri Vivekanand Research and Training Institute (SVRTI) in Kutch, Gujarat (Raju, K.C.B. 1993). In this case, watershed treatment involving a mix of percolation ponds, check dams, innovatively designed infiltration wells, and underground dikes have been effective in checking saline intrusion and improving groundwater levels. Since these activities are relatively new, however, how well recharge rates will be maintained over time remains an open question. Furthermore, SVRTI-supported recharge activities are being undertaken in a coastal region where excess flows go to the ocean. Surplus flows may be less available for capture in larger basins with numerous downstream users.

In other areas, recharge attempts have been plagued by high rates of evaporation *(80%* in some cases) and the clogging of recharge wells (Bohra and Sharma 1993 and Karanth 1995). For recharge to, be effective aquifer storage area is required—a factor which may limit the viability of this approach in hard-rock regions (Raju, T.S. 1993). Furthermore, artificial recharge requires the availability of water for that purpose. In many of the arid sections of India, surplus water is unavailable. Even where it is (theoretically) available, the variability of precipitation patterns may limit our ability to capture it for recharge purposes. According to Pisharoty (1993), the average intensity of rainfall in arid sections of India is 1 centimeter per hour (cm/h) and has a very high coefficient of variation both within and between years. Under these conditions runoff is rapid, flood flows high and erosion intense.

Beyond simple efforts to recharge available supplies, recharge could be increased through a carefully orchestrated conjunctive use program. Conjunctive use of groundwater and surface water implies the joint operation of available surface and underground water storage facilities (reservoirs, canals, rivers and aquifers) in ways that allow the capture of surplus flows and increase net water availability. Conjunctive use possibilities are greatest in areas where surface systems permit the capture of excess flows and their transport to aquifers suitable 'for storing the water. Conjunctive use could increase available water supplies in many deficit areas. It is important to note, however, that this would not be without cost. Aside from the direct costs of transporting and storing water, opportunity and third party costs could also be great. In order to capture excess surface flows, for example, reservoir levels should be kept low to prevent the possibility of overflow. This could conflict with optimal reservoir operations for power generation. Furthermore, increasing aquifer storage space requires drawing water tables down extensively prior to periods when recharge would be expected. Increased water table fluctuations could affect both base flows in rivers and access to groundwater for the rural poor.

EXTRACTION REDUCTION

Aside from increasing recharge, extraction reduction is the only physical response capable of arresting drops in the water table. This can be achieved either by limiting the physical capability to extract water or by reducing the demand for water..

EXTRACTION CONTROL

Three direct avenues for limiting extraction capacity have been under discussion. These are: (1) well licensing and spacing; (2) regulation of well types and depths; and (3) power rationing (Shah 1993; Sattar and Haq 1994; and Pittman 1993). Full discussion of these options is beyond the scope of this paper. It is important to note, however, that none are straightforward to implement and most could have significant side effects. Licensing and spacing regulations tend to disproportionately limit access for small land owners and those currently lacking wells. Regulating well depths would not reduoe the rate of extraction until water tables have declined close to the effective pumping depth. As a result, water table declines could still be rapid within seasons and could limit access for all users to groundwater during critical irrigation periods. The effect would be similar to that already experienced in hard-rock regions. Furthermore, the implementation of well spacing and other regulations designed to limit groundwater extraction has been difficult. Gujarat enacted groundwater legislation over a decade ago but has yet to implement it. Where spacing regulations are in force, wealthy individuals and those with social connections have been able to bypass them (Moench 1991 and 1992; and Shah 1993). Power rationing (similar to that already practiced in many areas due to electricity shortages) is, perhaps. the most viable method of limiting extraction (Shah 1993). This, however, penalizes other users of electricity and often generates coping behavior. In some areas, for example, farmers have constructed ponds into which they pump as much water as possible when electricity is available. In other areas, where power is available only at night, pumps are left on and the resulting water use may be quite inefficient. Furthermore. limitations on the availability of electricity have resulted in many farmers investing in diesel pumps. In Gujarat. for example, many farmer-owned pumps are diesel-powered except in the very deep aquiferregions. Developing effective limitations on the amount of water extracted would, thus, require regulation of diesel pumps as well as electricity rationing (Shah 1993).

EFFICIENCY IMPROVEMENTS

Increases in "use efficiency" are the primary physical avenue for reducing water demand without reducing the services provided. Substantial debates have emerged over where the real potential for efficiency improvements lies. Efficiency advocates often suggest the use of improved irrigation techniques (drip, sprinkler, system lining, etc.). These techniques may, however, result in few real savings either in the amount individuals extract *or* with regard to total water availability at the basin level. At the individual level, water "saved" through conservation techniques is often **used** to expand the area cultivated — with no net reduction in the actual amount **of** extraction. More importantly, water "lost" at project level (due, for example, to flood irrigation or leaking canals) often forms part of the "supply" available to other users (Moore and Seckler **1993).** At the basin level, consumptive use fractions and recharge to low-quality groundwater bodies are the only true ''losses'' of usable water to the system. Efficiency improvements only generate real increases in the volume of water physically present to the extent that they reduce consumptive use, by avoiding such losses as deep percolation to saline aquifers and undesirable evapotranspiration through weeds and trees.

While the above arguments regarding the limitations of efficiency improvements are true in a general sense, it is equally correct that many losses due to "inefficient" use patterns at the project level are unrecoverable. "Inefficient" irrigation practices higher in a basin may generate substantial return flows that can be reused multiple times lower in the basin. The same practices at low points in a basin generate the same return flows, but these are far more likely to flow to the ocean or saline sinks without being reused.

Furthermore, it should be recognized that, particularly in arid areas, substantial unrecoverable losses occur via a range of pathways including avoidable evaporation (for example, from percolation ponds and flood irrigation) and through seepage losses to low-quality water bodies. These considerations suggest that water management systems capable of capturing the nuances of local situations are essential if high levels of efficiency are to be achieved.

WATER MANAGEMENT

Effective water availability is a product of two factors: (1) the volume of water physically present, and (2) water quality. Furthermore, at the basin level, water use efficiency is not a function of the amount flowing in at a given quality versus the amount flowing out at a lower quality. Efficient water use patterns would maximize the range of services (crop production, poverty alleviation, drinking, instream flow, etc..) the water available within a basin could provide. While this objective is slightly problematic to quantify or implement, the underlying points in the above discussion do have strong practical implications for groundwater management:

(1) Water use practices that result in large return flows or seepage to groundwater are less inefficient the higher in the river basins they occur.

(2) Water use patterns that result in high levels of consumptive loss (evapotranspiration). return flows to low-quality water bodies, or losses to the ocean are the primary points where efficiency improvements could generate real water savings. Other efficiency improvements may simply be techniques for reallocating available water, and need to be evaluated with much more care to identify any real savings achieved.

(3) Over the long term, attempts to address groundwater overdevelopment and other water-scarcity problems should focus on increasing the number of times water available within a basin can be reused and the total amount of services generated.

It is important to note that where overdevelopment and waterlogging problems coexist within a region, policies designed to address one set of problems are likely to conflict with policies designed to address another set of problems. Shah, for example, recommends liberal licensing policies, no annual fee. subsidized flat-rate power tariffs, and priority power allocation to areas with rising water tables; and the reverse in overexploited areas (Shah **1993:** 150). While this could address both sets of problems theoretically, it may be politically difficult to convince farmers that they should, for example, pay dramatically more for electricity in areas where water is scarce when farmers in adjacent areas, sometimes adjacent villages, are heavily subsidized and suffer no water scarcity.

The potential for groundwater development to play a major role in the alleviation of rural poverty is widely recognized. To tap the potential, it is essential to increase (or at least maintain) access for the rural poor to groundwater resources. In areas where groundwater scarcity is increasing (due to overdevelopment, quality declines or other reasons) this will be difficult to achieve.

Actions that increase the equity of access to groundwater resources tend to decrease use efficiency and the sustainability of development patterns. Scarcity by itself often disproportionately limits access for the rural poor. In water-scarce regions, physical options for increasing access by the rural poor while avoiding the above problems fall into two categories: (1) those allowing maintenance of the physical resource (water table levels), and **(2)** those having to do with technologies for water extraction and distribution.

The groundwater level is a primary factor influencing the ability of those with limited capital to develop **or** maintain access to the resource. **As** a result, the maintenance of groundwater levels within the range accessible by shallow tubewells and other low-cost water extraction mechanisms is likely to be a major factor determining access for the rural poor. The two primary avenues for doing this without disproportionately limiting access to the rural poor are via supply increases (e.g., recharge or import) or. potentially, well depth/capacity limitations. As noted above, neither of these responses is without problems. Furthermore. as with other regulatory approaches, the rural elite may well be able to bypass any regulations. Since the elite would tend to be the ones with sufficient capital to construct deeper or higher capacity wells in the first place and would, thus, be the primary ones limited by depth and well capacity regulations, these regulations would not tend to be **as** selectively enforced against the poor as would other regulations.

Where it is not possible to maintain water table levels at depths accessible by traditional technologies, access by the poor to groundwater will depend on either access to technologies capable of extracting water at the lower fluctuation depths (via shallow or deep tubewells) or on access to water via water markets. Encouraging tubewell installation or water markets as a way of increasing access in areas with falling water tables is likely to increase water table fluctuations. The same will happen as a result of strategies to increase water supply via conjunctive use or the creation of aquifer storage prior to the monsoon.

A variety of tubewell technologies could be appropriate depending on the specific situation for increasing access by the rural poor to groundwater. Policy interventions discussed in the Ahmedabad and Dhaka workshops that could be appropriate include: (1) credit or subsidies for well construction, equipment, spare parts, operation and maintenance; (2) the provision of reliable electricity supplies; and (3) training in pump and irrigation system maintenance (Moench, Turnquist and Kumar 1994 and Abhayaratna, Vermillion, Johnson and Perry 1994). How groundwater can bedistributed is another major factor influencing access by the rural poor. Groundwater markets are least likely to be competitive where purchasers must depend on a single supplier. Physical interventions that increase access by the rural poor to multiple points of supply could, therefore, be a primary means of increasing access equity. Support for the development of underground pipeline networks, common in Gujarat, or the purchase of pipes by the poor could be ways of achieving this objective.

CHAPTER 5

Institutions for Management Implementation

INSTITUTIONAL QUESTIONS DOMINATED both the Ahmedabad and Dhaka workshops. Until recently, most discussions of institutions have focused on equity and, to some extent, efficiency issues. The role of water markets in providing access to groundwater resources for the rural poor has been widely discussed. Similarly, substantial experimentation has been done with the formation of Water User Associations (WUAs) to enable groups to develop and maintain well irrigation systems. Most of the literature dealing with governmental organizations has focused on the effectiveness and efficiency with which they provide services supporting groundwater development such as credit. training, technical advice and information, infrastructure (particularly electricity), and so on.

Debates over what appropriate institutional frameworks might look like have begun but not yet matured and, in some cases, little or no practical experience exists. In the Ahmedabad Workshop:

> There was a polarization in the debate between those who view management as primarily a state (i.e., government) subject and the advocates of local participatory management based around community institutions. Despite this polarization, discussions were characterized by widespread support among,government as well as NGO and academic representatives, for higher degrees of community and user involvement in groundwater management. There was also recognition that management will require new institutions. The extremes of state and village control do not function well in the groundwater context. Problems are too heterogeneous and control too dispersed for state regulation to be effective as the primary solution. On the other hand, the flow nature of groundwater resources coupled with intersectoral competition and the regional scale of most hydrologic systems limits *[sic]* the viability of

> village level management approaches. Discussion of intermediate level "quasi-government" institutions was recognized in several sessions as a major gap in current management debates. In general, it was recognized that addressing emerging water problems may well require the evolution of institutions between the village and the state (Moench, Turnquist and Kumar 1994: 2-3).

The role water markets play in providing access to individuals who lack wells and debate over their functioning in relation to power pricing policies have been mentioned at various points in this monograph. Two points are worth repeating: first, water markets as they exist in South Asia function only at a very local level. Second, while power availability and pricing policies are the main indirect levers governments have to influence groundwater use through water markets, the actual role of these policies in relation to different management objectives remains poorly understood.

Water user associations are widely advocated as an avenue for the management of water resources throughout South Asia. As in the case of water markets, this discussion has focused on the role they can play in the management of well irrigation systems and the allocation of water from them. Although there have been experiments with the formation of WUAs for establishing percolation ponds and other recharge structures, no large-scale attempts to involve them in implementing solutions to depletion or quality problems have been undertaken. (Shah and Bhagwat 1993; Raju, K.C.B. 1993; and Salunke 1993). WUAs have proved to be effective avenues for providing the rural poor with access to groundwater in a variety of locations in India, Nepal, Bangladesh, Indonesia and the Philippines (Abhayaratna, Vermillion, Johnson and Perry 1994).

The Dhaka Workshop participants emphasized the need for a range of support services to enable farmer management of groundwater irrigation systems. These included: (1) easy availability of credit for all activities (construction, maintenance and operation); (2) price and marketing support systems; and (3) subsidies for operation, maintenance and replacement. They also emphasized the need for providing a range of institutional development support (legal frameworks, training, technical services, etc.) (Sakthivadivel, Parker and Manor 1994: 5). In direct contrast, the Ahmedabad Workshop participants highlighted the spontaneous evolution of farmer-owned and managed "water companies" which are the primary form of groundwater irrigation system development and management in much of North Gujarat (Shah 1993). These have emerged in hostile credit environments (in many areas access to credit from banks is closed due to overdevelopment problems) with no external sources of institutional support. They have, however, occurred in a state where electricity supplies (although rationed) are very reliable, and among the relatively wealthy, well-educated sections of the community.

From a policy perspective, there appears to be a basic difference between the issues involved in establishing effective farmer management of groundwater extraction by the rural poor in areas such as the Lower Gangetic Basin, and issues in more organized, wealthy regions such as Gujarat. In the former set of areas, improvement of rural electricity grids and provision of support services such as those discussed in the Dhaka Workshop are important for the equitable development of farmer-managed irrigation systems. In the latter, development support is not really a concern. Instead, questions of energy pricing policy and the functioning of water markets dominate equitable resource development equations.

The potential for WUAs to play a major role in addressing depletion, quality and competition concerns was seen by participants in the Ahmedabad Workshop as facing major obstacles. In most cases, aquifer size and water use patterns require action at scales much larger than typical village communities. Technical requirements for understanding groundwater management needs and identifying the benefits flowing from a given set of actions are also high. Benefits are often dispersed and difficult for communities to capture—reducing the incentive to invest time and energy in management efforts. Despite these obstacles, local communities are often the source of innovative solutions to groundwater problems in their areas. Furthermore, management solutions will ultimately require acceptance by local communities. Institutional avenues for community involvement in the generation and implementation of management solutions are thus, essential (Moench, Turnquist and Kumar 1994: 102–107).

The development of intermediate-level representative organizations for groundwater management was widely discussed in the Ahmedabad Workshop. No such organizations with broad stakeholder representation currently exist in South Asia. However, districts, water basin authorities and similar regional entities are common internationally.

In parts of the U.S., highly decentralized approaches based on individual rights with management occurring through local "quasi-governmental" districts have been followed. After examining this history, Thomas concluded as follows in a paper presented at the Ahmedabad Workshop: "The local management option has the strong advantage of being sensitive, adaptable and responsive to local conditions and perceptions of need. It also has the virtue of depending largely upon local rather than state or national initiative to create, finance and govern the management institution and avoids the type of ponderous bureaucracy which has been the bane of too many natural resource management regimes historically" (Thomas 1994: 49). In many ways, as Chris Perry comments: 'This is the crux of the matter—how to design and delineate water rights into the current chaos."[12]

Debates in India tend to polarize between those advocating fully centralized control and the proponents of "local" (i.e., village or user-group) management. Given the large number of wells and the history of private ownership, implementing a centralized regulatory regime appears extremely difficult. At the same time, fully decentralized approaches (based, for example, around private ownership or village-level groups) are unlikely to incorporate wider social needs in the management approaches that emerge: and often, given the size of the aquifers, will not function at a scale sufficient to address physical management needs. Some form of intermediate-level institutional structure that can function at the scale of an aquifer or a somewhat larger administrative unit, and yet retain local legitimacy appears essential. For any organization at this scale to retain legitimacy, a transparent system of rules which can guide its actions at the local level is essential. This suggests that the definition of "use rights," even if it is largely theoretical initially, would be an important starting point. Ultimately, effective management may require a mix of actions at multiple levels ranging from the individual user up to the central government:

There are at least two roles governmental organizations at the state or central level could play with regard to groundwater management. The most widely discussed role involves attempts at direct management by groundwater departments or authorities through regulation (Sharma 1993; Sharma 1994; and Chandrashekar 1993). The second, would be to provide an "enabling framework" which would support the evolution of local management approaches by local or regional stakeholder institutions (Moench 1993c). In a sense, this second approach would parallel existing government efforts to provide credit, technical support and basic infrastructure for groundwater development. The provision of these facilities is one of the major factors that has "enabled" the extensive development of groundwater that has already occurred.

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[12] Perry, Chris. 12 June 1994. IIMI. Written comments on draft.

The development of effective and equitable approaches based on centralized regulation faces many obstacles. The State of Gujarat passed a groundwater bill to enable this a decade ago but has yet to enforce it. As participants at the Ahmedabad Workshop emphasized, the physical issues inherent in policing a large number of wells located on private lands are huge. Those regulations that exist at present (well spacing regulations, limitations on electricity connections, etc.,) are widely acknowledged to be ignored. Aside from the question of regulation, government organizations have a major role to play in the provision of technical and institutional support services in ways that enable the development of management solutions. Areas where the role of government organizations is important include the collection, analysis and dissemination of basic data (scientific, socioeconomic, etc.,) and the provision of targeted supportservices. Policies which strengthen the ability of governmental organizations to collect, analyze and provide access to basic information could play a large enabling role in the development of management responses to specific problems.

In addition to basic information, the Dhaka Workshop identified a wide range of support services as important for the development of farmer-managed irrigation systems. Requirements identified included: credit, extension, training, marketing and technical support services (Sakthivadivel, Parker and Manor 1994: 5). Given the variability in needs, policies which encourage governmental institutions to develop flexible support systems capable of responding to local conditions could be an important feature in an overall enabling approach to water management.

LEGAL FRAMEWORK[13]

With overdevelopment and pollution problems threatening groundwater availability and quality in many areas, legal frameworks which enable effective management to occur are widely regarded as essential. How those frameworks should be structured is, however, the subject of substantial debate. The primary tension is between those advocating centralized regulatory structures and those who view decentralized approaches as being both more implementable and equitable. In addition, issues related to the inclusion

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[13] This section is drawn primarily from Moench (1994b).

of quality criteria and environmental rights were raised in several papers and in the workshop discussions.

Groundwater rights in India are currently tied to land ownership. Individual landowners have the right to construct wells in whatever manner they desire and extract **as** much groundwater **as** they can. This rights structure, derived from the English Common Law, has been widely criticized. Many call for the separation of land and water rights **as** a prerequisite for the establishment of effective management systems (see: Singh, C. 1993; Singh, **K.** 1993; Sharma 1993 and 1994; Turnquist 1993; and Chandrashekar 1993). How rights should be defined and where they should be vested is the subject of less agreement.

Government officials such **as** H. Chandrashekar and S.C. Sharma explicitly or implicitly call for water rights to be vested in the state, and for the state to have full regulatory authority over use (Chandrashekar 1993; Sharma 1993; and Sharma 1994). This approach lies at the core of a model bill circulated by the Central Government in 1970 and again in 1992. In contrast, many of the nongovernmental organization (NGO) and academic researchers present at the Ahmedahad Workshop advocate the creation of use rights which are vested at multiple levels and enforced through less centralized mechanisms. Debates over the model bill with respect to the relative viability and desirability of centralized control-based approaches were common in many of the papers presented at the Ahmedabad Workshop.

In theory, a wide variety of alternatives to centralized regulation could be possible. Most authors. however, suggest the need for **laws** supporting some form of intermediate-level institutional framework which is capable of reflecting both local conditions and capturing some of the wider social objectives in resource management. Turnquist, for example, proposes a "three- or even four-tiered system of quality management in India. in which the center provides certain resources to the states, who in turn provide certain rights and resources and designate responsibilities to smaller, hydrogeologically based groups" (Turnquist 1993). Moench (1993b: 24) argues that rather than a specific set of rights or regulations, it may be useful to create a legislative superstructure to enable and guide the formation of locally appropriate management institutions and approaches. Elements **of** this superstructure could include: (1) rights definitions through which public interest in groundwater use can be expressed and standing can be created for individuals or organizations to defend that interest; (2) a neutral negotiating and dispute resolution forum; (3) management area identification mechanisms; **(4)** recognized organizational forms for groundwater management with associated financing mechanisms and powers; (5) a system for information generation and dissemination; and (6) coordination mechanisms to integrate local approaches with regional needs and counterbalance the tendency toward fragmentation inherent in decentralization.

With the exception of the paper by Chhatrapati Singh, all authors writing on water law at the Ahmedabad Workshop concentrated on human use rights. Singh argues forcefully that rights definitions should encompass environmental uses and that these rights should be held in public trust by the state (Singh, C. **1993).** Turnquist, however, is the only author to focus on the quality dimensions of groundwater. She argues that: "Groundwater rights should include rights to groundwater of usable quality" (Turnquist **1993).** Overall, both the environmental role played by groundwater and the fact that water quality greatly affects the value of groundwater resources are important dimensions frequently missing from discussions of legal issues-related groundwater management.

C. Singh **(1993)** provides a research agenda for the development of a legal rights structure. According to him:

> At least four different types of legal research need to be carried out to explore alternatives for appropriate groundwater legislation. First, examination is needed of the existing and possible legal regimes where private rights to groundwater can be contrasted with common property or common access rights. Second, research is required to understand situations in which water rights are separated from land rights and the possible legal alternatives and consequences of this separation. Third, understanding of legal regimes in which environmental and other multiple-use values (such as conjunctive use of groundwater with other natural resources) play significant roles is required so that appropriate elements for reflecting these values can be incorporated in any new legal structures created in India. The fourth type of research required relates to legal regimes for different hydrological or ecological situations (Turnquist **1993).**

To this agenda must be added the issues of effective institutional structures for management implementation and ways for incorporating quality and pollution dimensions into the overall rights and regulatory framework (Turnquist **1993).**

Finally, there is the question of process. Since it is not clear what approaches to groundwater management will ultimately prove viable, flexibility is required so that experimentation and research can occur and initiate a process of institutional evolution. Legal frameworks that allow this flexibility appear desirable.

CONCLUDING REMARKS

Groundwater management issues are likely to greatly increase in importance over the coming decades. Management will need to focus not just on the range of development and access issues that have dominated debates over the preceding decades but also on competition, overdevelopment, efficiency and pollution concerns. While basic data are lacking on the extent and magnitude of this latter set of concerns, it is generally recognized that groundwater resources are being overdeveloped and polluted in many regions. Integrated approaches to management that incorporate demands from multiple users and reflect the interconnected nature of surface water and groundwater in both quality and quantity dimensions need to be developed. Access and poverty alleviation issues remain of central importance and there is a general recognition that these will be far more complicated to address under conditions of scarcity where supplies must be allocated between competing users.

Sustainable management of groundwater resources to meet the needs of current and future generations depends on effective action on several fronts. First, basic data on groundwater systems and emerging problems must be strengthened and made more accessible generally. We know that although various problems emerge, data are often lacking that would permit the evaluation of their causes and overall significance. Understanding of the hydrologic system in many areas is also very weak making it difficult to determine which, if any, of the available physical management options might address specific points of concern. Second, analyses of groundwater problems and management alternatives need to move away from narrowly defined supply- or sector-based approaches to integrated evaluation of the array of needs and options for meeting them. The fragmented approach generally adopted in water management is a major obstacle to the development of effective responses to emerging problems. Third, institutions through which management can be effectively implemented must be devised. Institutional issues dominate technical ones in the development and implementation of management responses to points of concern. What institutional form or forms will ultimately prove effective in relation to the range of social goals remains unclear. Institutional innovations are required. Support for experimentation and innovation toward the development of effective groundwater management institutions is, therefore, particularly important. Identifying and defining a rights structure for groundwater use, even if it remains theoretical or impossible to implement over the short term, could he the most important point at which to begin.

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