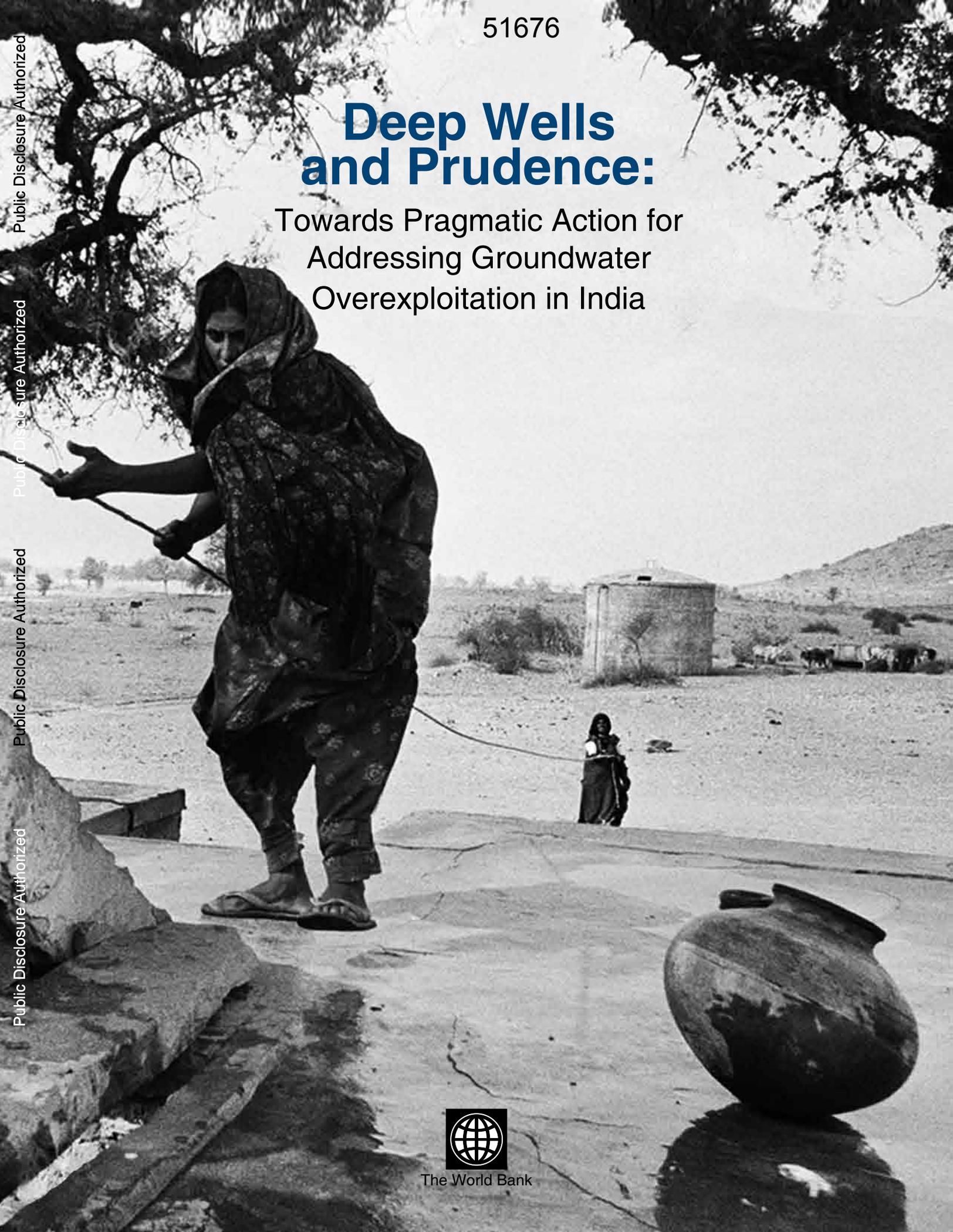


Deep Wells and Prudence:

Towards Pragmatic Action for
Addressing Groundwater
Overexploitation in India



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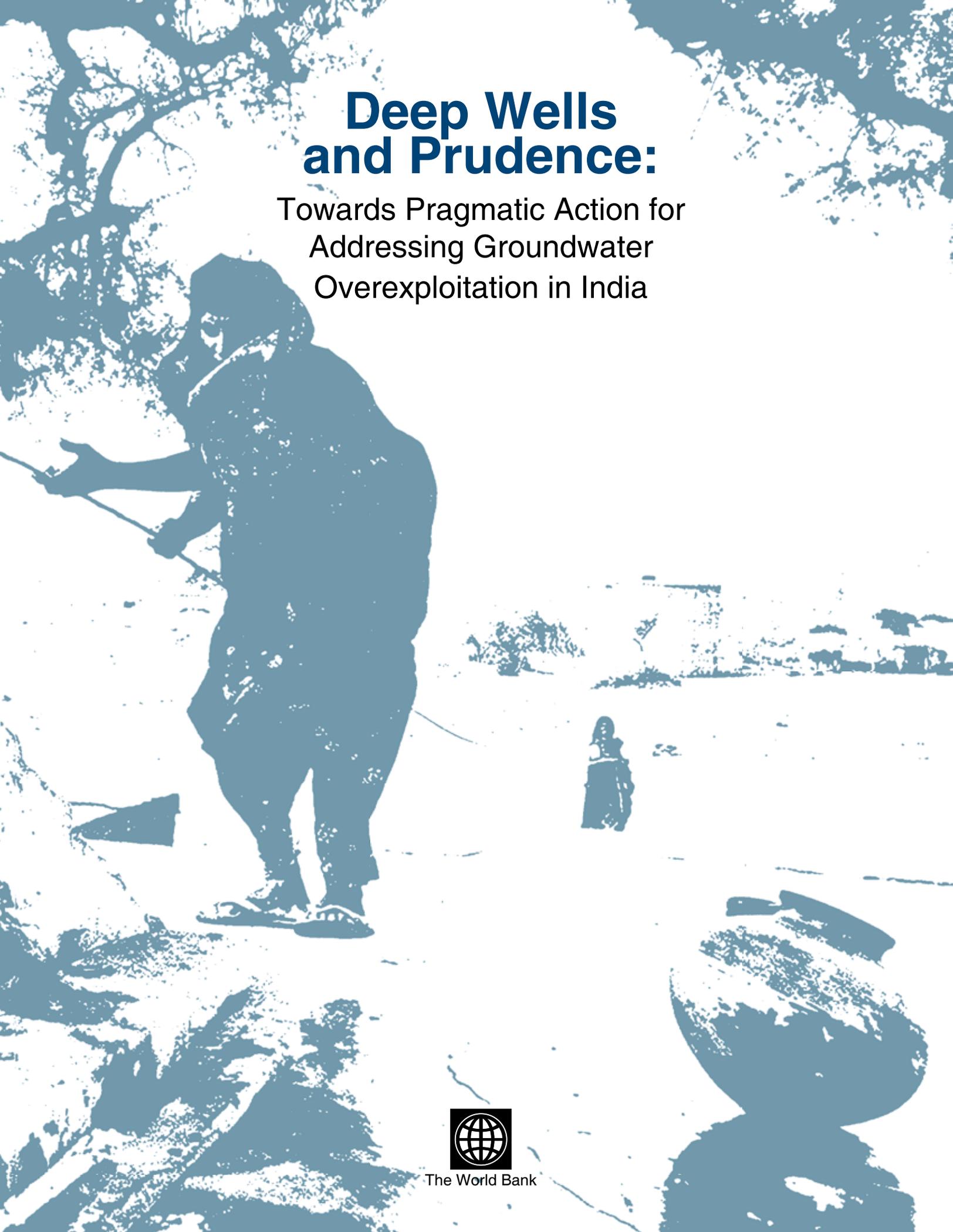
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Executive Summary

Introduction

Background to the current groundwater crisis

India is the largest groundwater user in the world, with an estimated usage of around 230 cubic kilometers per year, more than a quarter of the global total. With more than 60 percent of irrigated agriculture and 85 percent of drinking water supplies dependent on it, groundwater is a vital resource for rural areas in India. Reliance of urban and industrial waste supplies on groundwater is also becoming increasingly significant in India. Through the construction of millions of private wells, there has been a phenomenal growth in the exploitation of groundwater in the last five decades.

A number of factors have encouraged the remarkable expansion of groundwater use:

- ◆ Poor service delivery from public water supply systems has prompted many farmers, and rural and urban households, to turn to their own private supply for irrigation and for drinking water.
- ◆ New pump technologies meant that even farmers and households with very modest incomes could afford to sink and operate their own tubewell.

- ◆ The flexibility and timeliness of groundwater supply presented an attractive alternative to the technically and institutionally less responsive provision of surface water through public systems.
- ◆ Government electricity subsidies have shielded farmers from the full cost of pumping, creating a modality of groundwater use that has proved very difficult to change.

This era of seemingly endless reliance on groundwater for both drinking water and irrigation purposes is now approaching its limit as an increasing number of aquifers reach unsustainable levels of exploitation, and a 2004 nationwide assessment found 29 percent of groundwater blocks to be in the semi-critical, critical, or overexploited categories, with the situation deteriorating rapidly.

The potential social and economic consequences of continued weak or nonexistent groundwater management are serious, as aquifer depletion is concentrated in many of the most populated and economically productive areas. The implications are disturbing for attainment of the Millennium Development Goals, for sustaining economic growth and local livelihoods, and for environmental and fiscal sustainability. The consequences will be

most severe for the poor. Furthermore, climate change will put additional stress on groundwater resources, while at the same time will have an unpredictable impact on groundwater recharge and availability.

World Bank Study and Technical Assistance Initiative on Groundwater Management in India

Concern at this growing crisis prompted the Planning Commission of India to constitute an expert group to review the issue of groundwater management and suggest appropriate policy directions. The issue also featured prominently in the World Bank Water Resources Assistance Strategy for India. Accordingly, the World Bank Study and Technical Assistance Initiative on Groundwater Management in India was conceived with two main objectives:

- ◆ To identify management strategies for promoting sustainable groundwater use in India, within a systematic, economically sound, and politically feasible framework
- ◆ To provide focused technical support for enhancing the outcomes of groundwater management interventions under the World Bank-financed projects in participating states

At an early stage it was recognized that the sheer scale of the problem, and the political sensitivities attached to it, meant that conventional command-and-control approaches as well as the classically prescribed economic approaches were impracticable. Attention was therefore focused on developing a “Plan B”, involving pursuit of pragmatic approaches that could make incremental improvements largely within the existing institutional framework, building political support for gradual and realistic institutional improvements at higher levels by first demonstrating successful interventions at local level.

Under the initiative a number of analytical studies, field surveys, and assessments were undertaken,

and technical assistance provided for groundwater components in World Bank-supported projects in the heavily groundwater dependent states of Andhra Pradesh, Maharashtra, and Uttar Pradesh, with an assessment also carried out in Punjab. Lessons were also compiled from experience in groundwater management gained in other Indian states and elsewhere in the world.

Understanding realities under and above the ground

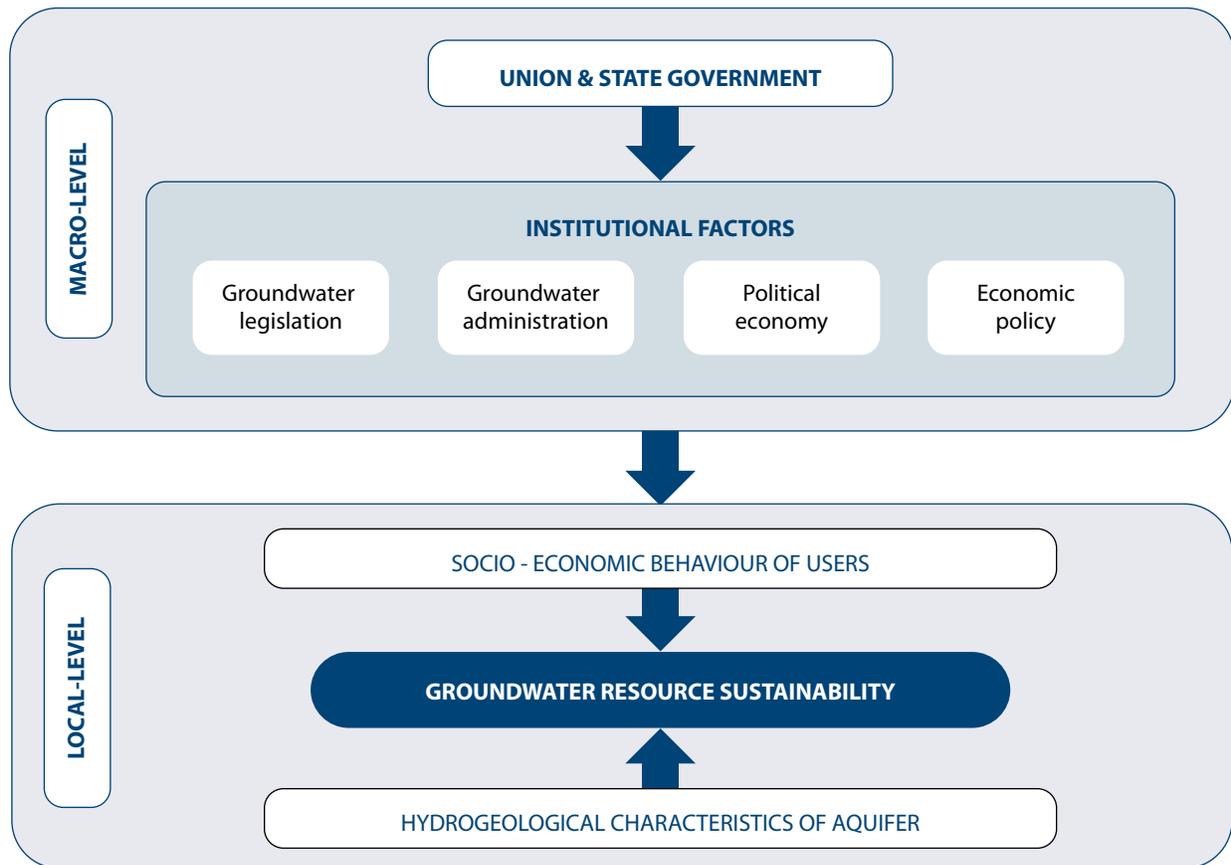
Determinants of groundwater use

While groundwater resource availability is determined by the physical environment, the dynamics of groundwater use are determined by the socio economic environment (nature of economic activity, patterns of population density, societal norms) and the institutional environment (legal, administrative, macroeconomic, political). It is this range of factors that will ultimately determine the sustainability of the resource (Figure 1).

The physical characteristics of the groundwater resources can vary considerably. Within India there are two broad types of hydrogeological settings: the shallow, low-storage hard-rock aquifers occurring in the basaltic and granitic systems of peninsular India; and the large, high-storage aquifers underlying the Indo-Gangetic floodplains of northern India.

Superimposed on those below-ground features is a complex web of above-ground socioeconomic and institutional factors that determine the dynamics of groundwater extraction, including the distinction between rural and urban use; the relative inadequacy and unreliability of public water supply systems; the size of landholdings and the related density of water wells; the political ramifications of subsidized power for irrigation pumping; and the institutional capacity to monitor and regulate the millions of wells found across the face of India.

FIGURE 1 Major determinants of groundwater management sustainability



Typology of aquifers and users

Based on the aquifer characteristics (below ground) and resource use patterns (above ground), a typology of intensively exploited groundwater settings is proposed (Table 1). This typology forms the basis of the analysis undertaken in the present study.

Overexploitation of groundwater and management approaches

“Overexploitation” of an aquifer is a term applied to a physically unsustainable situation in which the extraction of groundwater exceeds replenishment (recharge) within a given area over a given period of time. Such a situation is now occurring in many aquifers throughout India.

While the definition of overexploitation may appear simple, the sheer complexity of physical, environmental, socioeconomic, and other factors related to groundwater abstraction makes it notoriously difficult to understand the nature of the problem and devise effective solutions. Given that proviso, some broad categories of interventions can be identified:

- ◆ **Demand-side measures**, which aim to reduce consumptive groundwater use, for example through an increase in water tariffs in urban settings, or reducing crop water requirements and nonbeneficial evapotranspiration from fields in agricultural settings
- ◆ **Conjunctive use**, where savings are made through better alignment of surface

TABLE 1 Typology of intensively exploited aquifers in India

Land use	General and specific hydrogeological environment		Resource use	Focus states in this study
Rural	Hard-rock terrains of peninsular India	Widespread weathered hard-rock (basalt or granite) aquifers with shallow, low-storage patchy groundwater bodies	Subsistence and commercial agricultural exploitation, drinking water supply, some industries	Andhra Pradesh, Maharashtra
		Occasional but important groundwater bodies in coastal or graben fill sedimentary aquifers		Maharashtra
	Major alluvial formations of rural Indo-Gangetic plains	Alluvial aquifers, in plains largely within major irrigation canal commands with naturally shallow water table	Mainly subsistence and commercial agricultural exploitation	Uttar Pradesh
		Alluvial aquifers in the older elevated alluvial plains, with more limited irrigation canals and deeper water table		Punjab
Urban	Urban environment	Weathered hard-rock aquifers with shallow, low-storage patchy groundwater bodies	Individual urban households, water utilities, industries, tourism	Maharashtra
		Major alluvial aquifers in alluvial plains		Uttar Pradesh

water and groundwater resources in a specific area

- ◆ **Groundwater recharge enhancement**, whereby physical structures are built to retain runoff and encourage infiltration to groundwater

The hard-rock and alluvial aquifers differ considerably in their physical and socioeconomic profiles, and require very different sets of management solutions, at both macro and micro levels.

Hard-rock terrains of rural peninsular India: Characteristics and management options

In a sustainable scenario, dry season depletion of these low-storage aquifers, mainly for irrigation, is adequately compensated by recharge during the monsoonal rains. However, a rapid growth in the number of borewells since 1980 has led to a steady decline in water tables, resulting in a large increase in the cost of pumping a given volume of water, from which farmers have largely been shielded by flat rate, subsidized electricity tariffs.

Groundwater recharge enhancement has been promoted as a means of aiding recovery of water tables. The largest potential for recharge exists in alluvial settings, where there is abundant excess runoff as well groundwater storage capacity required for recharge. Most of the country's overexploited groundwater blocks lie in hard-rock settings, where recharge can provide only limited relief, and may be best employed as a valuable adjunct to other measures, such as rainwater harvesting.

Demand-side measures may offer more hope for controlling overexploitation. With over 13 million wells in the hard-rock areas, bottom-up, community-based approaches are more likely to be effective than top-down, broad-based attempts at regulation.

Alluvial aquifers of the rural Indo-Gangetic plains: Characteristics and management options

The huge aquifers underlying the Indo-Gangetic river systems are recharged both by monsoonal rains and by leakage from the major irrigation canal commands. The problems of excessive groundwater extraction in the tail reaches, and

waterlogging and salinization in the head reaches are often found in the same canal command. In such areas, there is considerable potential for better water management through conjunctive use, based on microzone management.

Elevated alluvial areas of Punjab: Characteristics and management options

In the elevated alluvial areas of Punjab, water tables are deeper and coverage of irrigation canals less extensive than in the lower plains. The state is very agriculturally productive, but again there are growing concerns about falling water tables resulting from the burgeoning use of tubewells for irrigation, with mounting costs to the state government, which subsidizes energy costs, and to farmers, as they chase the water table with more powerful pumps. Demand management interventions offer most potential, and a government prohibition on early transplanting of paddy has resulted in considerable water savings with no negative impacts on productivity.

Urban groundwater use: Characteristics and management options

Rapid urban growth, along with inadequate municipal water supply systems, have led to accelerated expansion in private well development to satisfy escalating water demand in urban areas. Where cities overlie hard-rock aquifers (for example Aurangabad in Maharashtra) this can lead to severe seasonal depletion and pollution of the groundwater body. Even cities above the extensive alluvial aquifers (for example Delhi and Lucknow) are finding the underlying water tables inexorably declining. For such cities a more integrated vision of, and balanced policy between, utility infrastructure provision (water supply and sanitation) and private self-supply, dovetailing both surface water and groundwater supply, will need to be developed on a case-by-case basis, under the aegis of empowered and well-organized regulatory agencies.

Institutional framework of groundwater management in India

At the macro level, legal, administrative, political, and economic factors are all powerful determinants positively or negatively influencing the decisions of farmers and households, at the individual and collective levels, regarding the use of groundwater in India.

Legislative environment

The legislative environment in India is characterized by the strong states within the wider federal framework. The Constitution lists “water supplies” under the State List, thereby giving states jurisdiction over the groundwater within their boundaries, while one of the functions of the Union Ministry of Water Resources is “overall planning for the development of groundwater resources”. In an attempt to regularize the matter the government of India established the Central Ground Water Authority in 1996 to regulate and control groundwater development with a view to preserving and protecting the resource. It has also issued several revisions of the Model Groundwater Bill of 1970, which provides states with a template for regulation of groundwater. The Planning Commission’s Expert Group on Groundwater Management and Ownership has argued that the legislative framework is in fact reasonably robust, and the priority lies in enforcement of existing measures, supported by innovative approaches such as an expansion of community-based management.

Administrative and organizational environment

Management of groundwater suffers from fragmentation of responsibility at both central and state levels. Many agencies in various sectors have mandates relevant to groundwater, but there is little coordination among them and a lack of regulatory oversight. Not all states have dedicated groundwater authorities, and in almost

all cases groundwater-related agencies suffer from understaffing, lack of capacity, marginalization, and outdated mandates that prioritize survey and development ahead of resource management.

Groundwater use in India: Sector policy development

In most environments, the modalities of groundwater use are strongly contextual and intersectorally linked. In agriculture, for example, groundwater use depends significantly on energy options and costs of pumping, availability of surface irrigation, and cropping choices. Similarly, the unreliability of urban domestic and industrial water supplies is the primary driver of self-provision through private wells in urban areas. Of all these sectoral linkages, that pertaining to the provision of power to farmers – termed the “energy–groundwater nexus” – is the most prominent. There is an ideological stalemate on addressing the issue of cheap electricity for farmers, but innovative solutions to this impasse have included a successful initiative in Gujarat to separate agricultural and nonagricultural electricity feeders in rural areas.

High-level policy reform: Available instruments

International experience, and experience within India, give insight into the instruments available for groundwater management and their applicability in the Indian setting. The four main categories are:

- ◆ **Regulatory measures.** Effective regulation requires not only sound legislation but also the administrative capacity to monitor and enforce rules. This becomes extremely difficult when there are very large numbers of small users, as has been shown by the problems encountered in attempting to enforce Central Ground Water Authority directives in overexploited groundwater blocks. Effective use of such measures is only possible for a small numbers of severely threatened resources, as allowed for in the existing legal framework.
- ◆ **Economic instruments.** Pricing measures, including volumetric charges, taxes, and user fees, can act as incentives to conservation and more efficient allocation of water resources, provided they address concerns of equity and affordability to the poor. Again, however, implementability is a major constraint, and the registration of over 20 million well users in India would be a daunting task to say the least.
- ◆ **Tradable groundwater rights.** While a well-defined rights regime helps resource users to reach optimal outcomes, the measure encounters the same fundamental difficulty as for regulation and pricing – the very high transaction costs of implementation.
- ◆ **Community management of groundwater.** Strictly speaking, community groundwater management refers not to a specific instrument but to a means of implementing management interventions. The key is that the resource user community (instead of the state) is the primary custodian of groundwater and is charged with implementing management measures. Hence, community groundwater management can involve any mix of instruments, including regulation, property rights, and pricing. Some well-publicized examples of successful community self-regulation have occurred in India but have often been dependent on the influence of a charismatic leader, raising doubts about replicability, implementability at scale, and the presence of long-term incentives. While community-based management of groundwater is clearly a promising approach in India, global experience offers few models of community management that might be applicable in the Indian setting, and a home-grown solution will undoubtedly be needed. The following section addresses this issue through consideration of a project that has demonstrated considerable potential.

Potential of community groundwater management in India

Andhra Pradesh Farmer-Managed Groundwater Systems Project

Andhra Pradesh is one of several states underlain by hard-rock aquifers that have suffered considerable depletion of groundwater, largely for irrigation use, in recent decades. The Andhra Pradesh Farmer-Managed Groundwater Systems Project (APFAMGS) has adopted a novel approach to the problem. The core concept of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle, and limited availability. To achieve this end, the project has engaged farmers in data collection and analysis, building their understanding of the dynamics and status of groundwater in the local aquifers. Even farmers with limited literacy skills have demonstrated their ability to collect and analyze rainfall and groundwater data, estimate and regulate their annual water use based on planned cropping patterns, and increase their knowledge of improved agricultural practices through attendance at farmer water schools (at which a third of the facilitators are women). The project does not offer any incentives in the form of cash or subsidies to the farmers: the assumption is that access to scientific data and knowledge will enable farmers to make appropriate choices and decisions regarding the use of groundwater resources.

The core organizational component of the project is the groundwater management committee, a village-level community-based institution comprising all groundwater users in a community. The committees are in turn grouped into hydrological units. Data gathered through hydrological monitoring of rainfall and groundwater levels are used to estimate the crop water budget, which is an aquifer-level assessment of the quantity of water required for the proposed rabi (winter) planting. Awareness of this statistic has become one of the essential variables that farmers take into account when

making their cropping decisions for the coming season. Preliminary findings in the project area have shown that the project has achieved a closer alignment of water availability and water use, and reductions in groundwater use have been realized through, for example, crop diversification (with an increase in low-water-use crops) and water-saving irrigation methods. Importantly, farmers have not sacrificed profitability to reduce water use.

Other community-based groundwater management approaches pioneered in Andhra Pradesh have also had some degree of success, including the APWELL project, and a number of similar efforts are being piloted through the Andhra Pradesh Community-based Tanks Management Project and the Andhra Pradesh Drought Adaptation Initiative.

Emerging directions for community-based groundwater management

APFAMGS presents an instructive case study in the “how-to-do” of community-based groundwater management, with its emphasis on participatory rather than passive information gathering, use of nonformal means of education, attention to capacity building and social mobilization rather than physical solutions, generation of a culture of empowerment through engagement of all segments of the community, and respect for farmers’ ability to process crucial information of direct relevance to them.

Importantly, the project does not seek collective action on reducing groundwater abstraction, and individual farmers are free to plant what they want and pump as they desire. The reductions in groundwater draft in APFAMGS are not coming from altruistic collective action, but from the individual risk management and profit-seeking decisions of thousands of farmers. This makes the APFAMGS model robust and replicable, as no authoritative leadership is required for enforcement of compacts.

APFAMGS therefore demonstrates an interesting approach to the concept of groundwater as a common property resource, sidestepping the difficult issue of creating and implementing a collective compact on water use reduction by limiting the collective action to building a common understanding of groundwater dynamics, with sustainable groundwater management emerging as an indirect response to farmers' profit-seeking behavior. A major lesson is therefore that community-based groundwater management need not require sacrifice; in these circumstances the fact that agriculture in many parts of India is operating below optimal productivity could well be an opportunity in disguise.

State-level engagement is still required to support and nurture a community-based approach. State agencies should create an enabling environment, ensuring that community-based initiatives receive the support they need to build capacity, take on the lessons of experience, and improve institutional coordination at the local level.

At the same time, the limitations of community-based approaches need to be recognized. The APFAMGS model, for example, seems well adapted to the recharge and emptying dynamics of hard-rock aquifers, but may not be appropriate to the geographically vast alluvial aquifers of northern India. The available models of community groundwater management would need careful and innovative piloting before they can be replicated and scale interventions become possible.

Pragmatic approaches for managing overexploited aquifers in India

There is an urgent need to change the status quo. The rapidly falling groundwater tables in many parts of India present serious and immediate human development and economic challenges. Given the political difficulties associated with high-level policy reform and a top-down approach, the focus has been on a "Plan B", which has

aimed to devise pragmatic measures that can be effectively implemented on the ground at low political cost. India presents a unique case, with a globally unprecedented level of exploitation of groundwater bodies in a wide range of settings, requiring the formulation of adaptable, context-specific solutions.

The issue of power subsidies to farmers, which has undoubtedly been a major driver of groundwater development, has required particularly careful handling, as any increase in tariffs may be viewed as another financial burden on an already impoverished agricultural society that is being left behind by increasing urban affluence. The focus of this study and initiative has therefore been on the practice of groundwater management at ground level, rather than on changes to the relatively intractable political context.

Elements of Plan B: Building a practice of groundwater management

The findings of the World Bank's Study and Technical Assistance Initiative on Groundwater Management in India point towards a menu of pragmatic management interventions, which fall into three broad categories: (a) community-based groundwater resource management; (b) targeted regulation; and (c) sectoral policy interventions and coordination. Strengthening state groundwater agencies is a cross-cutting intervention underlying the whole process. The suggested implementation actions emerging from this process are therefore as follows:

- ◆ **Implementation action 1: Building capacity and adjusting the role of state groundwater institutions.** The capacity of state groundwater institutions will need to be developed to ensure that they can perform the key functions of providing information and technical support, enabling community management, and enforcing regulatory measures. With community groundwater management emerging as the most viable

model (at least for hard-rock areas), ensuring that community-based initiatives get the required support will be the most critical function of the state groundwater agencies. It is important that the groundwater agency is located at an appropriate level within the state hierarchy to enable it to participate in and influence the dialogue on aspects of policy related to irrigation, agriculture, energy, land planning, and rural and urban development.

- ◆ **Implementation action 2: Community-based groundwater management.** While the “what-to-do” elements of successful community action on groundwater management are broadly known – actionable resource information, social mobilization, and incentives to facilitate change – there is a notable lack of proven models for community-based groundwater management. This report begins to address this gap, and the Andhra Pradesh Farmer-Managed Groundwater Systems Project (described above), with its focus on knowledge building and empowerment rather than on target setting and coercion, offers significant potential for replication and scaling up in hard rock aquifer areas.

- ◆ **Implementation action 3: Sector policy interventions and coordination.** Because of groundwater’s ubiquitous use, it is essential to address linkages with other sectoral policies and programs (public as well as private, and at national, state, and municipal levels) that have a large impact on groundwater:

- ▶ **Implementation action 3.1: Promoting conjunctive use in agriculture.** In the irrigation canal commands of the Ganga and Indus river systems, heavy depletion of aquifers often exists in close proximity to problems of waterlogging and salinization arising from canal leakages and excessive use of surface water in high-water-table

areas. More optimized conjunctive use through microzone planning (including, for example, bank sealing and desedimentation of major canals) could increase the cropping intensity without compromising groundwater resource sustainability.

- ▶ **Implementation action 3.2: Integrating groundwater in urban water supply planning.** There is an urgent and general requirement to move from opportunistic exploitation of groundwater resources to more systematic evaluation of the status of urban groundwater use and the contribution it can make to meeting future demand, together with the integration of this important resource into overall urban development plans. Municipal agencies need to develop a more coordinated vision of, and balanced policy between, utility infrastructure provision (both water supply and sanitation) and private self-supply.

- ▶ **Implementation action 3.3: Technical and political solutions to agricultural power pricing.** The current situation of heavily subsidized power in the agricultural sector is placing a heavy financial burden on the state electricity boards, and a politically pragmatic resolution of the energy–groundwater nexus is important for ensuring the viability and sustainability of both groundwater-based agriculture and the electricity sector in India. Gujarat’s scheme to provide 24-hour power supply for domestic, institutional, and industrial use in villages, with the farmers getting eight hours of improved quality and reliable power on an announced schedule, has proved to be a compromise that has allowed regulation of electricity and groundwater use with few political repercussions, and is potentially replicable elsewhere. Meanwhile, efforts need to be instigated to involve all stakeholders in trying to craft a solution to the energy–

groundwater nexus that is sustainable in the long term.

- ◆ **Implementation action 4: Targeted regulation of groundwater use.** As previously noted, total regulation of groundwater abstraction is not feasible in India. However, a selective command and control approach is needed for critically endangered aquifers. Enforcement of groundwater regulations is urgently required in certain urban settings, and a start could be made in granting individual groundwater allocations to some of the largest users (commercial farms, industry, urban water utilities) in overexploited major alluvial aquifers. Any measures would require capacity building of central and state groundwater agencies.

Epilogue: Summing up

Groundwater is now arguably the most critical water resource of India. In a vast majority of rural and urban settings, it underpins agricultural production, livelihoods depending on the rural agrarian economy, and urban and rural water supplies. The explosive growth in groundwater use, and subsequent overexploitation of many aquifers, has been furtive in its nature, as a result of

millions of private well drillings unfettered by any direct law or management framework, presenting a management challenge of daunting proportions. International experience in groundwater management presents few models applicable to the unique Indian setting. In the meantime a combination of economic, social, institutional, and political factors have rendered central and state agencies powerless to halt the relentless decline of water tables across India.

The premise and mandate of the World Bank's Study and Technical Assistance Initiative on Groundwater Management in India was to accept as given the political economy and identify pragmatic options for groundwater management that can be implemented largely within the existing institutional framework. Together, the proposed set of interventions sets the basis for changing the game on groundwater management in India to one where diligent implementation of interventions within the current framework can start producing immediate management results on the ground. For India today, groundwater is too critical a resource to continue to be left unmanaged, and it is hoped that the findings of this report can inspire an action agenda for moving swiftly to protect the vital but ever-declining aquifers of the country.

Introduction

The invisible vital resource

India is the largest groundwater user in the world, with an estimated usage of around 230 cubic kilometers per year, which is more than a quarter of the global total. Groundwater is a vital resource, with a large fraction of the population relying on the resource directly or indirectly for livelihoods. More than 60 percent¹ of irrigated agriculture in the country is dependent on groundwater, with the crop water productivity of groundwater-irrigated farms being almost twice that of surface water-irrigated farms. The most conservative estimate put the economic value of groundwater irrigation in India in 2002 at US\$8 billion per year, which is four times the annual public investment in irrigation projects and more than all government expenditures in India on poverty reduction and rural development programs (Shah 2007). The significance of groundwater for domestic water supplies is similarly marked, with 85 percent of the rural water supply schemes in India relying on groundwater sources. However, the well has almost always been a private enterprise, and therefore the exact extent and significance of groundwater

use have stayed hidden to all except the most diligent administrations throughout the history of the subcontinent (Agarwal and Narain 1997). Modern India is no exception – the widespread development of private wells that accounts for groundwater becoming the primary source of water today has also been furtive in nature, in that it has happened mostly outside the knowledge and control of governments. Groundwater has therefore been invisible not only physically, but also institutionally, as a critical resource literally underpinning millions of lives and livelihoods in the country.

Groundwater preeminence: An era of individual coping strategies

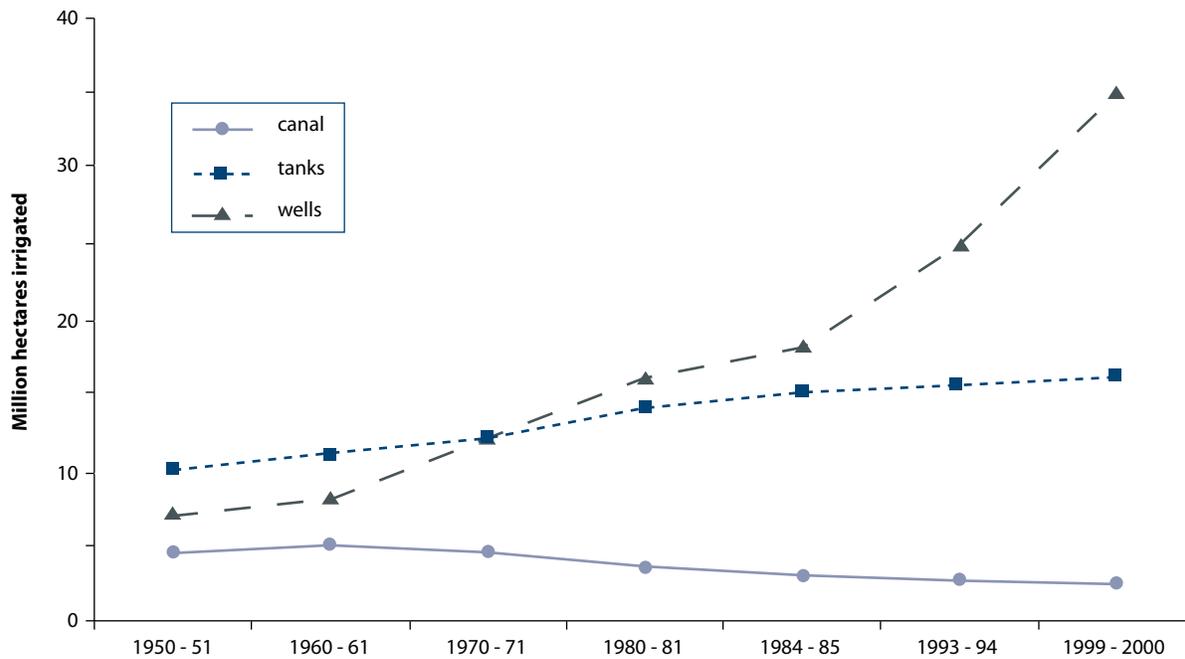
For farmers, as well as rural and urban households, the private water well has become a preferred alternative to the often dysfunctional public water systems. The exploitation of groundwater for self-provision of water supply by private users in India's agricultural and water supply sectors has rapidly expanded over the last five decades.

Groundwater for irrigation

Around 1960, groundwater irrigation started developing at an explosive rate (Figure 1.1).

¹ Based on Government of India 2005. Other estimates are higher. India's National Sample Survey (NSSO 2005) indicated that 69 percent of kharif and 76 percent of rabi irrigated areas depended on groundwater.

FIGURE 1.1 Evolution of canal, tank, and well irrigation in India 1950–2000



Source: Bhatia 2005, cited in World Bank 2005.

The Green Revolution was a turning point in India's agricultural development, providing great benefits to those who could adopt new seeds and fertilizers, for which water control was an essential prerequisite. Although large investments in surface irrigation projects were undertaken to provide an assured water supply to larger numbers of farmers, many remained underserved. A series of additional pull and push factors came into play, prompting an ever-increasing number of farmers to opt for groundwater irrigation: (a) electricity supply expanded in rural areas; (b) in areas where waterlogging and salinity were a growing problem (such as parts of Punjab) it was realized that encouragement of groundwater pumping provided an effective mechanism for lowering the water table and mitigating their impacts; (c) modest new modular well and pump technologies became widely available, as did subsidized credit; (d) farmers became aware that groundwater was abundant, especially in large alluvial basins; (e) farmers realized that water could be applied just in time from groundwater sources, something that

was not possible in the institutionally complex and increasingly corruption-ridden canal irrigation systems; and (f) in later decades, many states started offering "free or nearly free" electricity for irrigators dependent on tubewells.

As a result, groundwater is now the predominant source of water supply for irrigation in India. The pressure on groundwater resources has continued to grow as, over the last four decades, 84 percent of the total addition to net irrigated areas has come from groundwater.

Groundwater for drinking water

For most Indians, groundwater is also a major source of drinking water. Eighty-five percent of rural drinking water supply schemes are based on groundwater sources. Groundwater is also a major source of water supply in urban areas, where the resource is extracted not only by the municipal water utilities but also increasingly through private wells as a coping response to poor municipal

supply. Thus, while in Delhi groundwater accounts for only 11 percent of the total raw water supply to the utility, it accounts for almost 50 percent of the volume received by the end users (Maria 2006). Similarly, in Aurangabad groundwater accounts for close to 40 percent of the water provided to consumers. Although the cost of water obtained from private wells is high – six times higher than the average payment to the utility in Delhi, for example – it is a widespread and economically viable coping strategy amongst the middle class. Purchasing water from vendors or receiving it free from political patrons (who are themselves supplied by groundwater) is another option used in poorer areas and slums, or where groundwater is locally unavailable.

Cracks appearing on the ground

This era of seemingly endless reliance on groundwater for both drinking water and irrigation purposes is now approaching its limit as an increasing number of aquifers reach unsustainable levels of exploitation. The National Commission on Water in 1999 first noted that overall groundwater balances were becoming precarious. Overall, India has around 430 cubic kilometers of annual replenishable groundwater resources. With a net annual groundwater availability of 399 cubic kilometers, in 2004 the net withdrawals amounted to 58 percent of the net annually available resource. This seemingly comfortable average groundwater balance masks, however, a large number of severely stressed locations across the country, mostly in western, northwestern, and peninsular India. According to the 2004 nationwide assessment, 29 percent of the groundwater blocks are in the semi-critical, critical, or overexploited categories.² For the six states of Gujarat, Haryana,

Maharashtra, Punjab, Rajasthan, and Tamil Nadu taken together, 54 percent of the groundwater blocks fall in these categories. In already large and rapidly growing segments of the economy and in many of India's most productive regions, the self-provision model of unlimited groundwater use is no longer sustainable. A crisis situation now exists in a number of states. In Punjab, groundwater in 75 percent of blocks is overdrawn; in Rajasthan the corresponding fraction is 60 percent; and for Karnataka and Tamil Nadu the figure is around 40 percent (Central Ground Water Board 2006). The situation is deteriorating at a rapid pace. Between 1995 and 2004, the proportion of overexploited blocks nationwide tripled from 5 to 15 percent.

If current trends continue, within 20 years 60 percent of all aquifers in India will be in a critical condition (World Bank 2005). The potential social and economic consequences of continued weak or nonexistent groundwater management are serious, since aquifer depletion is concentrated in many of the most populated and economically productive areas (World Bank 2005). The implications are disturbing for attainment of the Millennium Development Goals, for sustaining economic growth and local livelihoods, and for environmental and fiscal sustainability.

Economic and social consequences of groundwater overexploitation

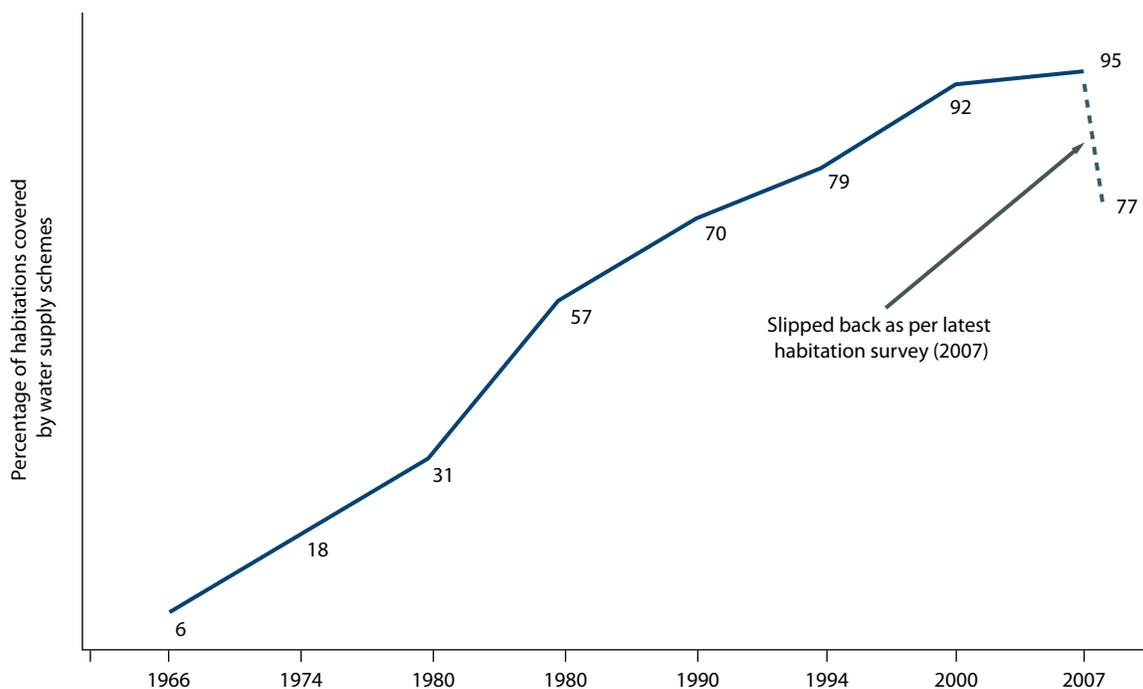
Failing the Millennium Development Goals

Rural areas are almost entirely dependent on groundwater for drinking supplies. Every year, a large number of habitations initially covered by a water supply scheme slip back into the “partially covered” or “not covered” categories, due to failure of schemes. The latest habitation survey in 2007 found the extent of such slippage

² The Central Ground Water Board categorizes the groundwater blocks according to the decline in water level and the stage of groundwater use (the stage of groundwater use is the annual groundwater draft expressed as a percentage of net annual groundwater availability). Safe (stage < 90%; no pre- or postmonsoonal significant long-term decline in water level); semi-critical (stage > 70% and < 100%; significant long-term

decline in pre- or postmonsoonal water level); critical (stage > 90% and < 100%; significant long-term decline in both pre- and postmonsoonal water levels); overexploited (stage > 100%; significant long-term decline in pre- or postmonsoonal water level or both).

FIGURE 1.2 Coverage of rural habitations with water supply schemes (percent of total)



Source: National Advisory Council 2008.

to be more than 150,000 habitations, bringing down the nationwide coverage by 12 percent (Figure 1.2). While causes of slippage are many, ensuring source sustainability of groundwater-

A woman in Barmer district walking to fetch water. The donkeys help in bringing home the filled-up pots and buckets.



based schemes is proving to be critical in view of continuously declining water tables.

Groundwater overexploitation in India may therefore have serious implications for achieving the Millennium Development Goals. Given water's cross-cutting linkages, further slippage due to falling water tables would not only threaten the safe drinking water target but would also be likely to affect improvements in education, health, gender, child mortality, poverty, and hunger.

Deteriorating livelihoods, food security, and agricultural productivity

About 15 percent of India's food production is currently dependent on unsustainable groundwater use (World Bank 2005). In rain-fed or drought-prone areas, where subsistence farming is more prevalent, increased competition between farmers reliant on a given groundwater body results in a spiraling cycle of well deepening or redrilling and the purchase of new pump sets. This has serious social implications for the poorest, who can no longer afford such action and risk exclusion from access to groundwater for their irrigation and drinking needs. Overall, up to a quarter of India's harvest has been estimated to be at risk due to groundwater depletion (Shah et al. 2000). The consequences for rural poverty and economic growth are potentially serious, given that 60 percent of Indians, particularly the poor, depend on agriculture for their livelihoods.

Environmental degradation

While the environmental concerns related to groundwater generally focus on impacts pertaining to pollution and quality degradation, a range of environmental benefits accrue from groundwater in its natural state, and are consequently threatened by overexploitation. In India's highly variable monsoonal pattern of rainfall, with approximately 50 percent of the annual precipitation falling in 15 days in many areas, groundwater makes a crucial

contribution to sustaining springs, inland wetlands, and base flows in rivers during the dry season. Water flows contributed by groundwater are therefore critical for fisheries and aquatic ecosystems. Groundwater levels also directly influence many vegetation species that are important sources of food, fuel, and timber for dependent communities. Groundwater is an integral part of the linked hydrological, ecological, and human use systems, and a range of environmental services is imperiled by groundwater overexploitation and quality degradation.

Fiscal implications

The issue of groundwater resource sustainability is compounded by a growing fiscal problem. Groundwater use in agriculture, especially in areas where overexploitation is a growing concern, rests in a large part on the provision of free or cheap electricity. While electricity subsidies are widely (and correctly) perceived to be one of the main causes of groundwater overexploitation, it can also be argued that the astronomical increase in the power subsidy costs in recent decades is the result of the increasing inability of farmers to bear the full costs of pumping from declining groundwater levels (Shah 2009; Dubash 2007). The total annual economic cost of subsidized power remains contested (mainly due to varying assumptions of transmission and distribution losses, the use of off-peak power, and the unreliability or intermittence of the supply), but has been estimated at Rs 260 billion, growing annually at 26 percent (Shah et al. 2007). Subsidized agricultural power supply is putting an unsustainable burden on state budgets and is the prime cause of bankruptcy of the state electricity boards in India.

Climate change

As most groundwater systems react slowly to changes that occur on the earth's surface, groundwater acts as an important buffer against the hydrological variability of surface water

resources. In water-scarce years, farmers and utilities resort to groundwater to compensate for inadequate rainfall and surface water supplies. Increasing reliance on groundwater has insulated irrigated Indian agriculture to a great degree from the vagaries of the monsoon. A deficit in rainfall in 1963–1966 decreased India’s food production by almost 20 percent and placed the country on the brink of famine, whereas a similar drought in 1987–1988 had a negligible impact on food production, essentially due to the widespread prevalence of groundwater irrigation (Sharma and Mehta 2002, cited in Shah 2007). Precipitation forecasts for India under the likely climate change scenarios suggest higher but more variable rainfall, except in the drier parts, where rainfall could decrease. The scenarios also predict reduced glacier cover in the Himalayas and associated reductions in the base flows of the Himalayan rivers. Conjunctive use of groundwater and surface water can be a key adaptation strategy in such situations, and groundwater’s role in sustaining production and livelihoods would therefore become even more important. At the same time, the changing patterns of rainfall and runoff are expected to significantly impact groundwater recharge and availability (Massachusetts Institute of Technology 2008), adding a further dimension of uncertainty to this critical resource.

World Bank Study and Technical Assistance Initiative on Groundwater Management in India

Background

Over the past 50 years India has become extremely dependent on groundwater, which has provided an informal but remarkably successful private coping strategy in the absence of reliable formal public water supply systems. However, intensive groundwater use has started to result in falling water tables and a growing number of overexploited aquifers, particularly in western and peninsular India. Since aquifer depletion is concentrated in many of the most populated and economically productive areas,

the potential social and economic consequences of inaction are huge. Concern regarding the looming crisis has been mounting in the government, and in 2005 the Planning Commission constituted an expert group to review the issue of groundwater management and suggest appropriate policy directions (Planning Commission 2007). The World Bank’s Water Resources Assistance Strategy for India (World Bank 2005) also emphasized groundwater overexploitation as a critical water sector challenge for India, and advocated developing pragmatic solutions instead of continuing the failed command and control approaches. Accordingly, the World Bank Study and Technical Assistance Initiative on Groundwater Management in India was conceived with the purpose of supporting the development of approaches that are realistic and actionable in the current environment.

Objectives and scope

The aim of the World Bank’s Study and Technical Assistance Initiative on Groundwater Management was to develop a management framework that is not only based on analytical work but is also informed by the operational experience of piloting various groundwater management interventions in different settings in India. The initiative was accordingly designed with the following specific objectives:

- ◆ To identify management strategies (including companion institutional and legal arrangements) for promoting sustainable groundwater use in India, within a systematic, economically sound, and politically feasible framework
- ◆ To provide focused technical support for enhancing the outcomes of groundwater management interventions under the World Bank-financed projects in participating states

The scope of work was structured to combine analytical activity on various aspects of groundwater management in the country with

elements of technical assistance to groundwater interventions in selected states participating in the initiative.

Developing a “Plan B”

The central and state government counterparts consulted during the scoping phase emphasized that despite the extensive scholarship available on the subject of groundwater overexploitation in India directions for action remained unclear. Senior decision makers were almost unanimous in the view that the high-level legal and policy reforms that are often proposed as the solution for groundwater management have no takers in India because they are unviable in the current political economy. However, as taking no action is not an alternative for a resource as critical and as unmanaged as groundwater, assistance was requested for developing a “Plan B”, which would focus on pragmatic and politically feasible approaches that can make incremental improvements largely within the existing institutional framework, and that can build the political support for gradual and realistic institutional improvements at higher levels by first demonstrating successful interventions at local level.

This mandate is reflected in the scope of the initiative:

- ◆ The initiative emphasizes the political feasibility of recommended approaches. Given past failed experiences, policy prescriptions are of limited use unless they have a reasonable chance of implementation under the prevailing political economy.
- ◆ The initiative focuses on the development of management approaches for addressing groundwater overexploitation. In order to avoid a dilution of focus, issues of deteriorating groundwater quality and potential for groundwater development in certain Indian states were not included in the scope of work.
- ◆ Similarly, an assessment of the implications of climate change for groundwater use and management was not included in the scope of this work. Although increased hydrological variability raises the uncertainty surrounding groundwater recharge and availability, and also increases the relative importance of more dependable groundwater reserves as a key adaptation strategy, climate change does not alter the basic assessments and recommendations emerging from this initiative for sound groundwater management practices in India.

Process and audience

The initiative activities were strategically selected for addressing the issue of groundwater overexploitation in a range of groundwater settings across India, taking into account the physical, socioeconomic, and institutional dimensions of groundwater resource use. Accordingly a number of analytical studies, field surveys, reviews, and assessments were undertaken, targeting different dimensions of the subject. In parallel, technical assistance was provided for design and implementation of groundwater-related components in five World Bank-supported projects in Andhra Pradesh, Maharashtra, and Uttar Pradesh. In addition, a preliminary assessment on specific groundwater-related issues was also conducted at the request of the Punjab government.

A large part of the effort is geographically focused in Andhra Pradesh and Maharashtra, which were selected as key participating states primarily due to their heavy dependence on groundwater use, growing concern about overexploitation of aquifers, and expression of strong interest in participating in this Study and Technical Assistance Initiative. A number of ongoing and proposed World Bank-supported projects in these states also meant that advantage could be taken of the learning opportunities afforded by groundwater

management pilots and the strong existing relationships with the state agencies. In addition to engagements in Andhra Pradesh, Maharashtra, Punjab and Uttar Pradesh undertaken through this initiative, lessons were compiled from the World Bank's experience on groundwater management accumulated over the last decade in other Indian states, including Haryana, Rajasthan, and Tamil Nadu, as well as from global experiences in groundwater management.

A number of multistate, national, and international workshops were also organized or supported by this initiative, with the objective

of sharing, discussing, and testing emerging ideas with government counterparts as well as a broad range of stakeholders. Table 1.1 provides a summary listing of the various engagements undertaken by the World Bank's Study and Technical Assistance Initiative on Groundwater Management in India.

Groundwater is primarily a responsibility of state governments in India, and therefore the primary counterparts and audience for this report include senior state-level decision makers who are faced with the responsibility for addressing the challenge of groundwater overexploitation,

TABLE 1.1 Summary list of activities under the World Bank Study and Technical Assistance Initiative on Groundwater Management in India

Engagements	
Preparation of state strategy papers	
1	Maharashtra
2	Andhra Pradesh
Technical assistance to World Bank projects	
3	Maharashtra Water Sector Improvement Project
4	Maharashtra Rural Water Supply and Sanitation Project
5	Andhra Pradesh Community Tanks Project
6	Uttar Pradesh Water Sector Restructuring Project
7	Andhra Pradesh Rural Water Supply and Sanitation Project
Theme papers	
8	Strengthening and transforming the role of state-level groundwater management agencies: A key element for the promotion of sustainable resource use
9	Analysis of organizational options and instruments for sustainable groundwater management in India
10	Literature review of groundwater management experience in India
11	Review of lessons from the World Bank's cumulative groundwater management experience in India
Analytical work	
12	Study on actual role and potential of groundwater for Aurangabad municipal water supply
13	Technical and socioeconomic assessment of community self-regulation of groundwater use in Maharashtra
14	Modeling of groundwater use behavior in rural India using a linked agricultural-hydrological model
15	Data collection and remote sensing analysis for groundwater impact assessment of Andhra Pradesh Farmer-Managed Groundwater Systems Project
Dissemination and training	
16	National conference on groundwater pricing and ownership (support to Central Ground Water Board)
17	Multistate technical workshop on emerging lessons for community-based groundwater management
18	Lessons for community-based groundwater management (joint East Asia and South Asia training on groundwater management)

and state departments and agencies charged with groundwater management. At the central government level, the primary counterpart is the Central Ground Water Board (under the Union Ministry of Water Resources), which is the apex organization for groundwater surveying and exploration, development, monitoring, management, and regulation in the country.

The report also targets the global community of groundwater management practitioners, and it is hoped that the examples of politically feasible and local context-specific approaches recommended for different groundwater settings in India can be useful in informing the design of groundwater management interventions in similar settings elsewhere in the world.

You Cannot Manage What You Don't Know: Understanding Realities Under and Above the Ground

Introduction

Groundwater resource availability is determined by the physical environment, with hydrogeology being the primary determinant. But a much wider range of factors, from the local to the macro level, influence the dynamics of groundwater use. While the physical and socioeconomic environment in which groundwater resources occur varies tremendously across the face of India, the influence of higher-level factors tends to be systemic. A rough categorization of the determinants of groundwater use can be presented as follows:

- ◆ **The physical environment**, including the hydrogeological characteristics of local groundwater bodies and surface water availability
- ◆ **The socioeconomic environment**, including the nature of economic activity, patterns of population density and water and groundwater use, and societal norms
- ◆ **The institutional environment**, which includes the following dimensions:
 - ▶ **The legal environment**, including the roles and responsibilities for groundwater management in the federal setup;

definition of groundwater as a public or private good; presence and type of groundwater rights regime; and relationship of groundwater rights with landholding

- ▶ **The administrative environment**, including groundwater-related regulations and organizations responsible for implementing them; the presence of dedicated state groundwater agencies, and their mandates and capacity to implement; and the position of state groundwater agencies within the governmental hierarchy and their relationships with other departments dealing with water resources
- ▶ **The macroeconomic environment**, including sector policies with indirect but substantial impacts on groundwater (for example, free or nominal-cost power for the agricultural sector, or support prices for water-intensive crops such as sugar cane and paddy)
- ▶ **The political environment**, including democratic tradition and maturity, incentives for management, and the political feasibility of implementing various policy and management measures

The challenge of addressing groundwater management needs to be examined in this nested and multilayered environmental context (Figure 2.1), with due attention to the specific characteristics of the problem at each level.

India is characterized physically by several distinctive hydrogeological settings, which, combined with population and water use patterns, influence the nature of groundwater use and the peculiar challenge of groundwater management in each setting. Therefore, what is collectively referred to as “groundwater overexploitation” is actually a range of problems that can differ widely from one another, depending on the setting. Nevertheless, these important local characteristics have frequently

been overlooked in the discourse around groundwater management.

In order to ensure that groundwater management approaches are informed by and responsive to local realities, this report proposes an analytical framework that draws specifically on a typology of India’s overexploited aquifers, and takes into account their main hydrogeological and resource use characteristics. This chapter sets out the physical context for groundwater resource management and indicates the type of management approach and measures most likely to be appropriate to each typology. Chapter 3 then presents a broader analysis of the institutional environment governing groundwater use and management options.

FIGURE 2.1 Major determinants of groundwater management sustainability

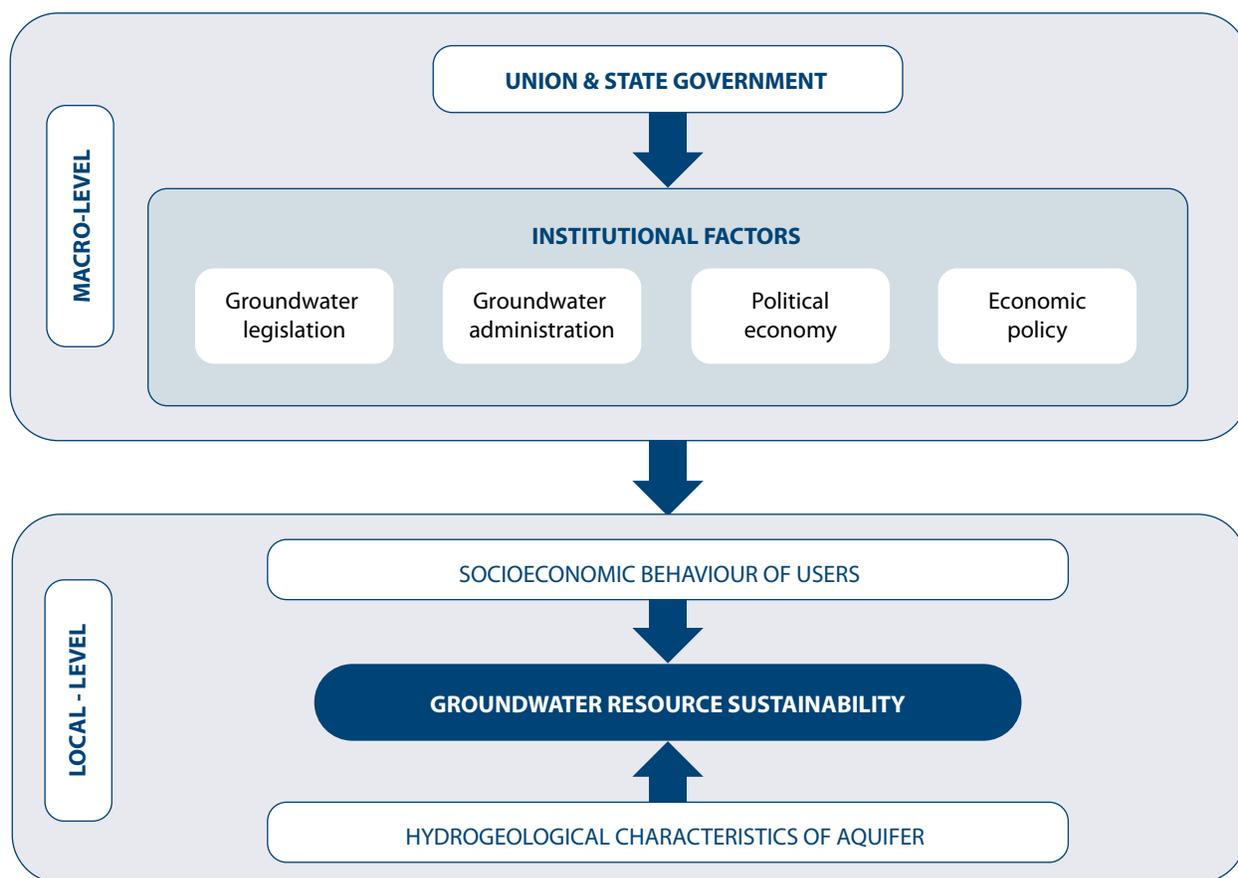
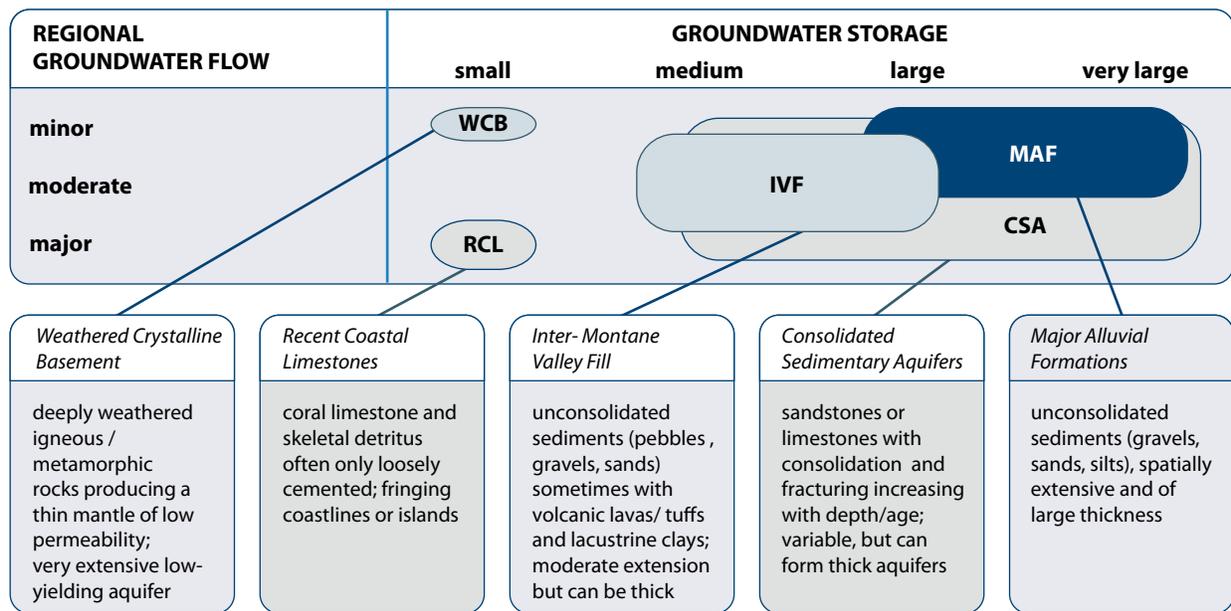


FIGURE 2.2 Key types and properties of the most widely occurring aquifer types



Source: GW-MATE BN-2.

The essential foundation of groundwater characterization: A context for resource management

The underground (hydrogeological) and above-ground (socioeconomic) settings shape the dynamics of groundwater resource use. Therefore, while a broad and nationally uniform approach to groundwater use management may be simple to promulgate, it would not be effective in responding to particular local needs. Globally emerging practice also points towards a more local and decentralized approach to groundwater resource management, with administration at the regional government or river basin level and operations at the district or subbasin level.

Understanding and characterizing the groundwater resource is thus the key prerequisite for devising a sensible management framework, as the hydrogeological setting defines resource potential and susceptibility to irreversible degradation. The most commonly occurring types of aquifers worldwide are shown in Figure 2.2, along with their comparative storage capacities and groundwater flow potentials.

A first-pass characterization can normally be made from information that is already available. For the present purposes, and to simplify the picture significantly, hydrogeological settings in India can be divided into two main and contrasting categories, described below and shown in Figure 2.3. The approximate area under these settings in selected states of India is presented in Table 2.1.

◆ **Hard-rock aquifers of peninsular India.**

These belong to the “weathered crystalline basement” category shown in Figure 2.2. Mostly outside the command of the primary irrigation canals of large rivers, these shallow aquifers represent around 65 percent of India’s overall aquifer surface area. Most of these aquifers are found in central peninsular India, where the land is typically underlain by hard-rock formations. Deccan Trap basalts cover most of Maharashtra, while a granite basement complex predominates elsewhere. These hard-rock formations give rise to a complex and extremely extensive low-storage aquifer system. Although these aquifers are partially recharged following

each monsoon, the total available storage of groundwater in hard-rock aquifers is variable and is strictly limited by the hard rock's weathering characteristics and water-bearing properties. Water yields tend to drop very rapidly once the water table falls by more than 2–6 meters. Overall, these

aquifers display a high degree of spatial variation in local storage characteristics and recharge processes.

- ◆ **Alluvial aquifers of the Indo-Gangetic plains.** These include the Gangetic and Indus alluvial plains, large parts of which are within the command of primary irrigation

FIGURE 2.3 Main hydrogeological provinces of India

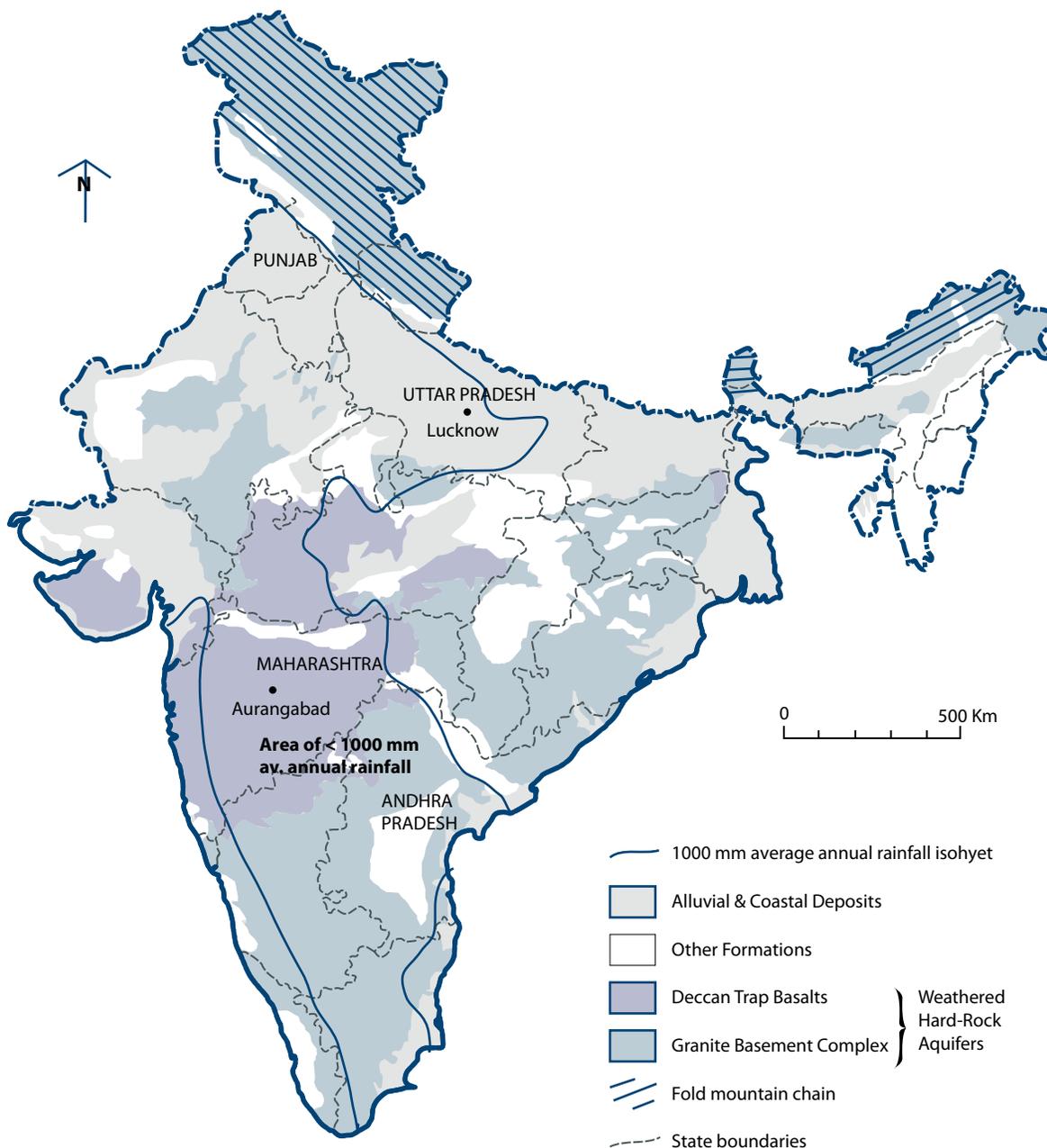


TABLE 2.1 Main groundwater settings in selected states of India

State	Approximate Area (%)				
	Weathered hard-rock aquifers			Alluvial & coastal/ floodplain deposits	Other formations
	Deccan Trap basalts	Granite basement complex	Sum		
Andhra Pradesh	3	65	68	14	18
Gujarat	30	7	37	52	10
Haryana	0	2	0	98	0
Karnataka	7	90	97	2	1
Kerala	0	75	75	25	0
Madhya Pradesh	49	12	61	15	24
Maharashtra	77	15	92	5	3
Punjab	0	0	0	97	3
Rajasthan	5	25	30	55	15
Tamil Nadu	0	73	73	22	5
Uttar Pradesh	0	20	20	70	10

Source: Estimates based on Central Ground Water Board 2006.

canals. These also include the older elevated alluvial plains where the water table is deeper and coverage of irrigation canals is not so extensive. These areas are underlain by major aquifers with moderate-to-high yields and very large storage, constituting an extremely valuable source of freshwater supply. Recharge rates that are low relative to storage, combined with the common occurrence of saline groundwater at greater depths, can put these large alluvial aquifers at risk of aquifer mining and irreversible overexploitation. Only a few large aquifers are found south of the Indo-Gangetic plains.

Understanding the drivers of groundwater demand

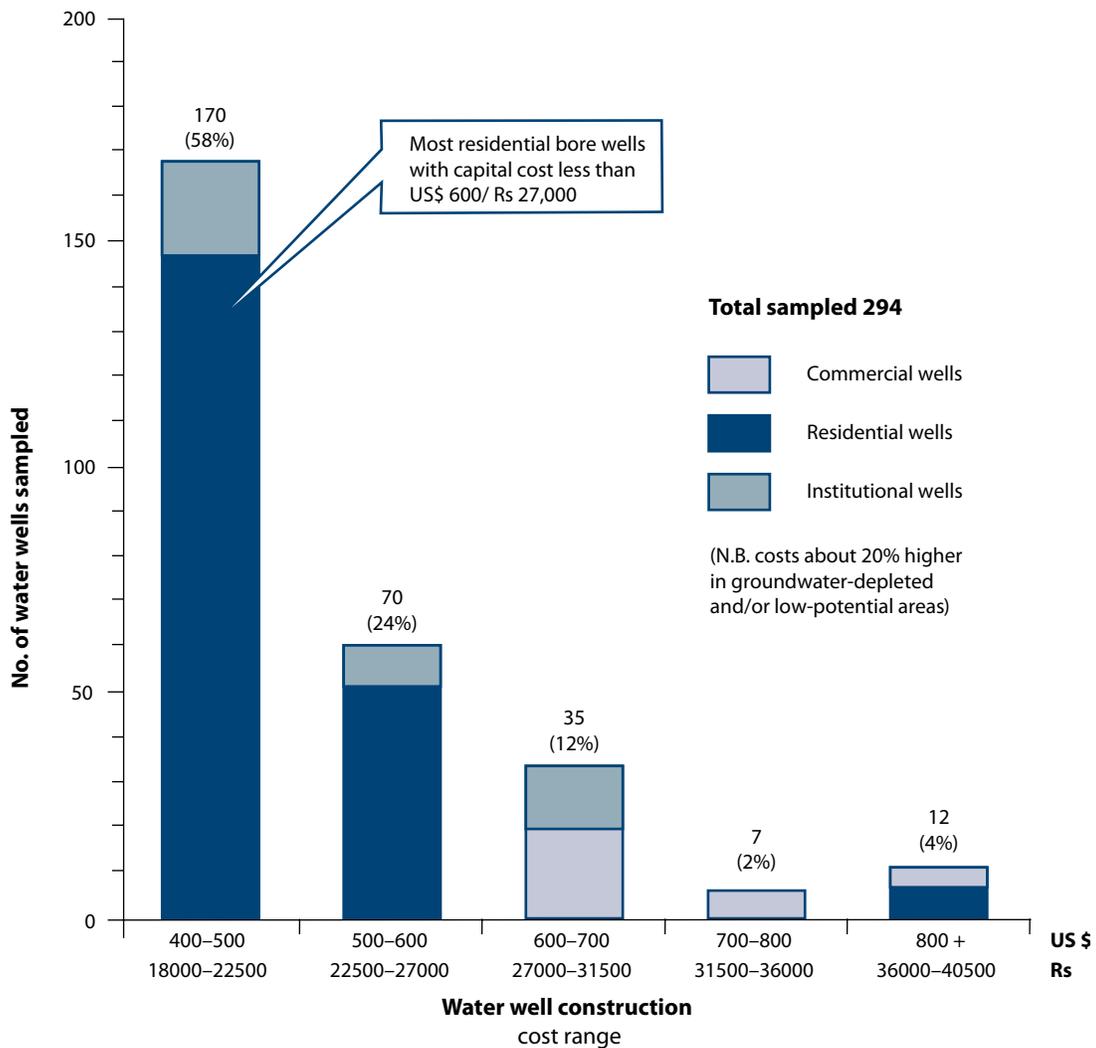
As described above, different types of hydrogeological settings are associated with specific aquifer types that vary widely in their capacity to transmit and to store groundwater, surface area, thickness, and replenishment levels (normally termed recharge). In Uttar Pradesh, storage in thick aquifers is probably 200–500 times

larger than the annual groundwater replenishment, whereas in most of inland Maharashtra, stored groundwater represents only 1–5 times the annual rate of resource renewal.

Superimposed on and interacting with the underground physical realities of aquifers are the differing water use and demand dynamics. The first major above-ground distinction in this regard is that between rural and urban areas. In rural areas, groundwater provides both drinking water and irrigation supplies, with the latter being far more significant in terms of volume. In contrast, groundwater is predominantly a source of drinking and industrial water supply in urban areas.

It is important to emphasize that in India the primary driver of private groundwater use is neither resource availability nor well yield potential (Shah 2007), but the inadequacy and unreliability of water provided through the public water supply systems, in the face of escalating water demands. It is therefore also useful to consider whether areas are wholly dependent on groundwater or also benefit from access to surface water, most notably

FIGURE 2.4 Shallow borewell construction costs in 2007 for Aurangabad City



Source: Study on actual role and potential of groundwater for Aurangabad municipal water supply, 2008 (background analytical work for this initiative).

canal irrigation. Although not yet formally and systematically practiced, there is great potential for conjunctive use of surface water and groundwater to meet rising demand in both rural and urban settings.

Finally, the nature of the user also matters. The size of average landholdings can vary markedly from state to state. Large commercial exploitations mean fewer users, and hence greater ease in monitoring and regulating. However, most of the states in India are dominated by smallholder agriculture, implying small plot sizes and large numbers of tubewells,

which translates into very high transaction costs of monitoring and regulating.

Table 2.2 shows the more general socioeconomic drivers for groundwater use and resource status for selected states in India.

The effect of these factors is further magnified by a series of secondary drivers, including

- ◆ flat rate or highly subsidized rural electricity for irrigation well pumping;
- ◆ the low cost of well (especially borewell) construction and equipment (Figure 2.4)

TABLE 2.2 Groundwater resource and socioeconomic aspects in selected states

State	Groundwater resource status					Socioeconomic status		Socioeconomic drivers for groundwater demand and pollution							
	In-storage groundwater resource (cubic kilometers) (alluvium, hard rocks)	Net annual groundwater availability (cubic kilometers)	Annual use (cubic kilometers)	Groundwater development (%)	Critical and overexploited units (%)	Per capita income as percent of all India average	Poverty index (% of population)	Drinking water	Irrigated agriculture						Industries
									Gross irrigated area (million hectares)	Marginal to medium landholdings (% of landholdings > 10 hectares)	Large landholdings (% of landholdings > 10 hectares)	High-water-demanding (rice, wheat, sugar cane) (% of gross area)	Irrigated with groundwater (% of gross area)	Power consumption (gigawatt hours/cubic kilometer)	
Andhra Pradesh	10	33	15	45	24	92	16	84	5	92	8	66	39	1,131	1.92
Gujarat	10	15	12	76	19	114	17	83	4	89	11	29	63	1,160	0.78
Haryana	42	9	10	109	66	129	14	146	5	77	23	65	29	696	0.47
Karnataka	2	15	11	70	68	84	25	84	3	89	11	37	34	1,024	1.36
Kerala	1	6	3	47	13	114	15	82	0.4	93	7	40	28	128	0.44
Madhya Pradesh	4	35	17	48	9	54	38	60	6	84	16	86	64	388	2.77
Maharashtra	4	31	15	48	2	125	31	96	4	93	7	36	50	804	2.45
Punjab	91	21	31	145	79	124	8	147	8	73	27	79	40	276	0.75
Rajasthan	13	10	13	125	80	66	22	50	7	60	40	33	60	520	0.63
Tamil Nadu	10	21	18	85	46	105	23	146	2	93	7	56	52	610	1.66
Uttar Pradesh	350	70	49	70	7	46	33	102	18	97	3	82	52	513	2.61
All India	1,081	399	230	58	19	100	28	100	55	87	13	28	48	524	19.59

as a result of Indian manufacturing ingenuity;

- ◆ support prices for some crops with very high consumptive use of water, such as paddy rice and sugar cane.

Typology of aquifers and users

Based on the aquifer characteristics (below ground) and resource use patterns (above ground), a typology of intensively exploited groundwater settings is proposed (Table 2.3). It is important to emphasize that this typology of intensively exploited aquifers is only intended to provide a general framework for analysis. There may be significant variations in hydrogeological conditions and resource use at the micro level within a typology, and more specific analyses of the hydrogeological and socioeconomic characteristics remain critical for tailoring management needs.

Assessing when groundwater exploitation becomes excessive

Since the focus of this report is excessive exploitation (often termed “overexploitation”) of groundwater resources, it is necessary to

consider the dynamics of depletion of aquifer reserves. The term “aquifer overexploitation” applies to a physically unsustainable situation in which the extraction of groundwater exceeds the replenishment (commonly termed “recharge”) within a given area over a given period of time. However, the definition can be difficult to apply in certain situations, for example:

- ◆ Major groundwater recharge episodes occur only once in decades, as in many arid to semiarid climates (such as parts of north-western India).
- ◆ Aquifer storage is very small (such as in some weathered hard-rock aquifers) and is fully replenished and virtually emptied every year.
- ◆ Natural aquifer discharge, and associated stream base flow, is important for the environment or for downstream users.

Therefore, while the usual classification of groundwater blocks (based on an assessment of levels of extraction relative to recharge) provides a workable physical indicator of overexploitation, the bottom-line concern for management is that the direct and indirect environmental and

TABLE 2.3 Typologies of intensively exploited aquifers in India

Land use	General & specific hydrogeological environment		Resource use	Focus states in this study
Rural	Hard-rock terrains of peninsular India	<i>Widespread weathered hard-rock (basalt or granite) aquifers with shallow, low-storage patchy groundwater bodies</i>	Subsistence and commercial agricultural exploitations, drinking water supply, some industries	Andhra Pradesh, Maharashtra
		<i>Occasional but important groundwater bodies in coastal or graben fill sedimentary aquifers</i>		Maharashtra
	Major alluvial formations of rural Indo-Gangetic plains	<i>Alluvial aquifers, in plains largely within major irrigation canal commands with naturally shallow water table</i>	Mainly subsistence and commercial agricultural exploitations	Uttar Pradesh
		<i>Alluvial aquifers in the older elevated alluvial plains, with more limited irrigation canals and deeper water table</i>		Punjab
Urban	Urban environment	<i>Weathered hard-rock aquifers with shallow, low-storage patchy groundwater bodies</i>	Individual urban households, water utilities, industries, tourism	Maharashtra
		<i>Major alluvial aquifers in alluvial plains</i>		Uttar Pradesh

socioeconomic costs of groundwater exploitation must not outweigh the benefits accrued. The multiple and multiplier effects of declining water tables – for example deeper drilling depths, decreasing well yields and frequent well failures resulting in increasing farmer expenditures and debt, and failures of local drinking water supply sources – also provide a set of indirect indicators of overexploitation, and emphasize the need for considering its distributive aspects as well, which affect the poor disproportionately in both rural and urban settings. Furthermore, the long-term environmental concerns pertaining to the health of the groundwater resource, for example the susceptibility of the aquifer systems to rapid and irreversible degradation (through salinization or compaction with associated land subsidence), also need to be considered. Therefore, while a simple index of groundwater exploitation levels (as currently used) is useful as a basic tool for identifying problem areas, it may not be a sufficient indicator in many settings, where a broader context of environmental and socioeconomic dimensions of overexploitation will be needed both for understanding the nature of the problem and for devising management solutions.

Exploitation concerns and management approaches

An overall approach for the definition and implementation of groundwater resource management measures would comprise an initial phase of appraisal of the resource setting (both hydrogeological and socioeconomic), followed by identification of the types of management measures at micro (and possibly macro) level that are required to achieve a given level of groundwater resource stability. It will then be necessary, in each individual case, to decide how such measures might be implemented and by whom, giving consideration to the balance between state regulation and community self-regulation, and how government and the community might

be organized and mobilized to confront the groundwater management challenge.

The following sections look at these issues for the two main groundwater settings that are threatened by overexploitation in India: the hard-rock aquifers and the deep alluvial aquifers. Given the very different dynamics of rural and urban groundwater use, each is considered separately in the context of the two aforementioned settings.

It is clear that to correct a condition of serious imbalance (“overexploitation”) of groundwater resources, technical interventions that reduce groundwater demand or increase groundwater availability will be required, by one implementation route or another. In a broad scope these technical interventions include:

- ◆ **Demand-side measures.** These refer to the interventions that, when applied at field, village, district, state, or federal level, have the effect of significantly reducing consumptive groundwater use. Demand management can result in producing true water savings only if it targets those volumes of water that are normally not returned to groundwater via seepage or other return flows. Hence, in urban settings demand-side management could include increased water tariffs as a means of reducing the total demand for groundwater. However, if most of the leakage from mains and distribution networks is going back as recharge to the local aquifers, reducing this leakage will not produce any real groundwater savings even though it will improve the water delivery efficiency of the water utility system. Similarly, in rural agricultural settings, demand management includes all measures that are capable of (a) reducing the net consumptive water use requirement in agriculture; (b) reducing nonbeneficial evapotranspiration from fields; and (c) reducing the size of any nonrecoverable fraction of nonconsumptive use of water in agriculture (such as seepage

to saline water bodies as opposed to irrigation returns to fresh groundwater). Hence, technical interventions such as shifts in the cropping pattern (resulting in reduced consumptive water use requirement) and improved irrigation technology (reducing nonbeneficial evapotranspiration and possibly reducing nonrecoverable losses) can be effective demand management measures in agriculture, but interventions need careful evaluation in the specific local circumstances to assess their respective water-saving potential.

- ◆ **Conjunctive use.** In settings where both surface water and groundwater are important, conjunctive management of the two resources to better align use with availability can reduce local areas of excessive and unsustainable groundwater use, improve surface water delivery in scarcity-prone areas, and simultaneously increase the overall land and water productivity in the case of irrigated agriculture.
- ◆ **Groundwater recharge enhancement.** Physical engineering measures can be implemented to retard and retain the runoff from seasonal precipitation and to provide conditions more conducive to infiltration to groundwater, with the objective of increasing the amount of precipitation stored in aquifers.

Successful technical interventions tend to be context specific, and a careful scrutiny of the hydrological balance at different local scales is required for their specification. This can sometimes reveal that some options may not be as positive for groundwater resource sustainability as initially hoped for, particularly when external factors are taken fully into account. For example, real groundwater resource savings achieved through the introduction of innovative cropping measures are frequently offset by increases in

areas under cultivation, thereby resulting in no lasting improvement in aquifer sustainability. In the case of aquifer recharge enhancement, the associated reductions in streamflow are not usually factored in, and yet can have negative impacts for downstream users. In sum, technical interventions on the demand and supply sides do not provide a magic solution, but will almost always need to be implemented alongside other complementary groundwater management measures.

Hard-rock terrains of rural peninsular India

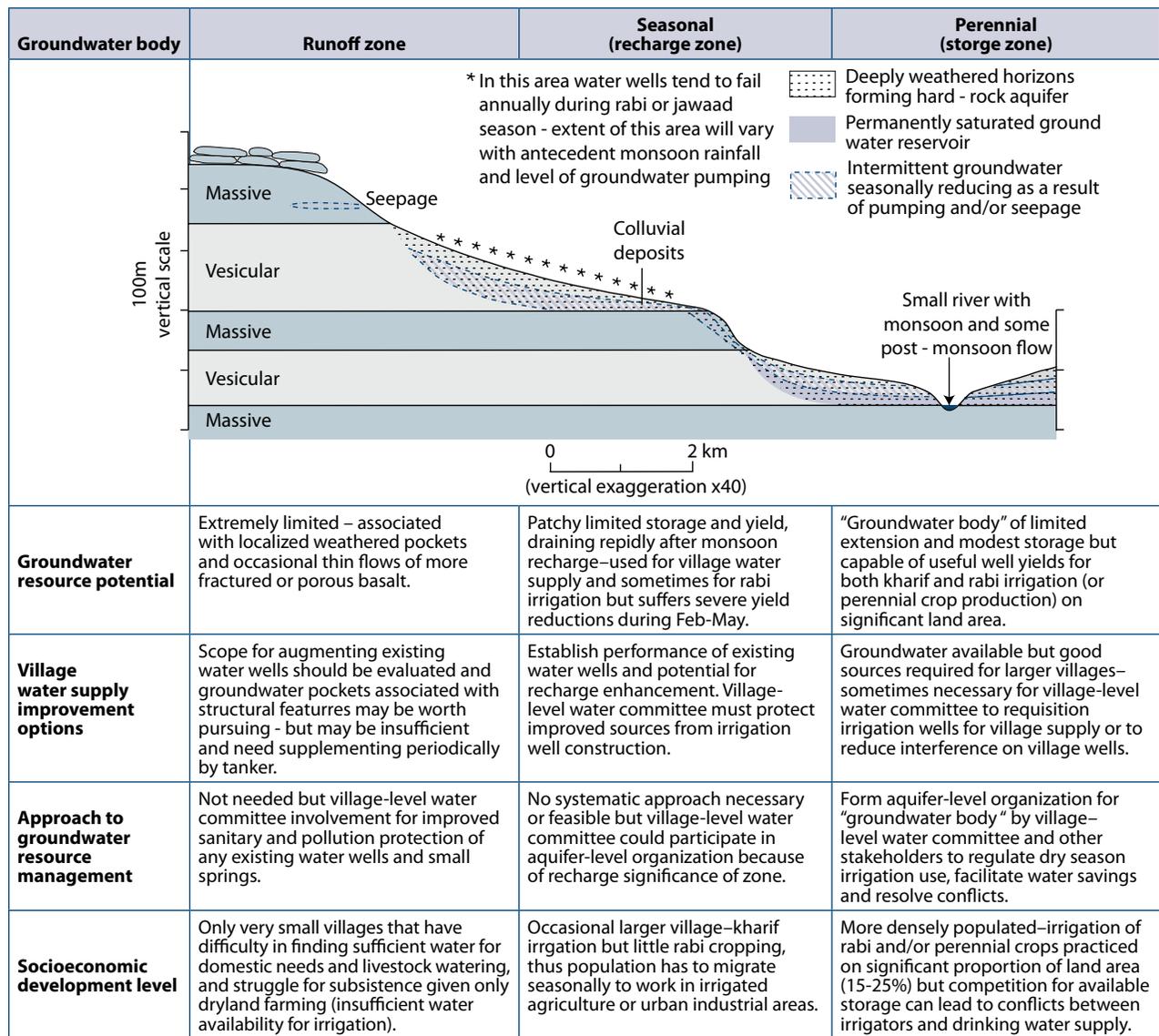
Manageable groundwater bodies

Deep tropical weathering of hard-rock formations in peninsular India has created an extensive, low-storage, aquifer system that is annually recharged to varying degrees by the monsoonal rains. The very large area underlain by weathered hard-rock formations can be subdivided into two main groups with somewhat different characteristics:

- ◆ **Weathered Deccan Trap basalts**, which exhibit considerable variation in the depth of weathering and landscape evolution.
- ◆ **Weathered granitic basement**, in which away from topographic highs the weathering is generally more uniform, but typologies of significantly differing groundwater potential (well yield and exploitable storage) are present.

In both cases, however, the aquifers are shallow, with relatively low storage, and rather patchy. These aquifers are capable of providing small yields to dug wells and borewells and are critical for drinking water supply in the drought-prone lands. In hard-rock aquifer settings across the world, this scarce natural resource is used only for drinking water supply, meeting pastoral demands, or high-value industrial use. In India however, a rather unique confluence of different factors has resulted in these aquifers becoming widely exploited for agricultural irrigation.

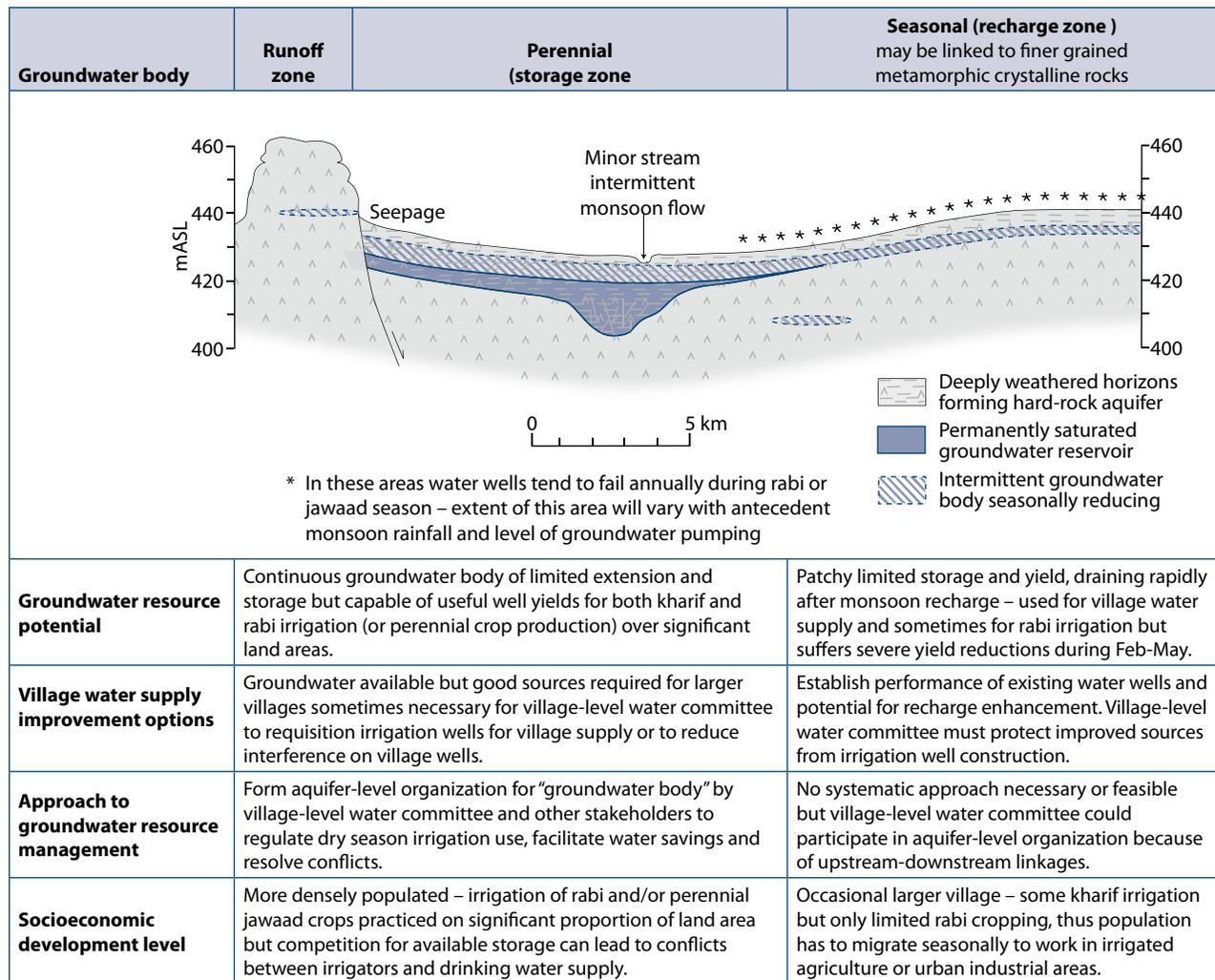
FIGURE 2.5 Cross-section of groundwater occurrence in weathered Deccan Trap basalt terrain indicating varying resource potential and management implications



Within these hard-rock formations, the groundwater bodies (permanently saturated water bodies with sufficient interannual storage to support significant summer season irrigation and to warrant some type of systematic management approach to resource allocation) are of restricted spatial distribution. Outside these groundwater bodies, obtaining rural drinking water supplies and some limited rabi season irrigation may be possible from localized or ephemeral groundwater-bearing fractures, but the possibilities for groundwater management

do not exist per se. Figures 2.5 and 2.6 provide instances of significantly varying resource potential at the local level in hard-rock formations, and its implications for groundwater management. It is clear that there is little incentive for groundwater management in those parts of microwatersheds that are dominated by surface water runoff and do not possess significant perennially saturated aquifers (groundwater bodies). Trying to mobilize participation in groundwater management initiatives in these areas has questionable merit,

FIGURE 2.6 Cross-section of groundwater occurrence in weathered granitic basement terrain indicating varying resource potential and management implications



unless the people in these areas are an integral part of the benefiting village panchayat, or payments are made for their land and water management efforts. The key message, which is also one of the salient conclusions of this report, is that groundwater management needs to be intensively context specific, as the physical realities can vary significantly even at the microwatershed scale.

Dynamics of overextraction in hard-rock aquifers

In peninsular India, while there has not been a significant increase in the number of dug wells over

the past 40 years, there has been extremely rapid growth in the number of borewells since 1980, with millions more having been added and typical depths steadily increasing from about 30 meters to over 60 meters.

Over most of the drought-prone areas of hard-rock India rainfall averages 500–800 millimeters per year, but is highly concentrated in a single monsoonal season during which natural recharge rates are believed to average 60–90 millimeters per year. In contrast, groundwater extraction rates have grown to reach an equivalent of 100–180 millimeters per

year in the late 1990s, with heavy population and cultivation densities, and energy subsidies often insulating the groundwater users from the costs of escalating energy consumption.

As a consequence the water tables of most groundwater bodies have declined steadily from the late 1980s (showing only partial recovery in years of exceptional rainfall), with a widespread net fall in premonsoonal water levels of 15–20 meters over 25 years. In many areas the groundwater table now stands almost permanently below the weathered zone, as shown by the drying up of traditional dug wells early during the rabi season.

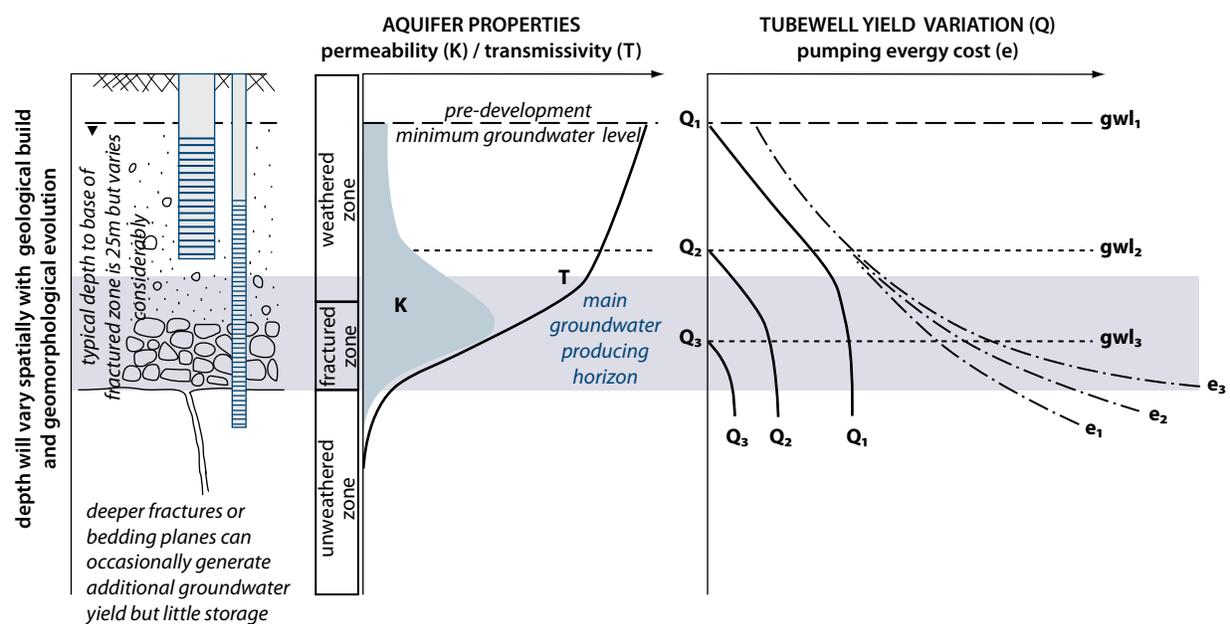
The total available storage of these groundwater bodies is strictly limited by their weathering characteristics and water-bearing properties, and declines markedly as the water table falls through the most productive zone, which is situated typically 10–20 meters below the land surface (shaded in Figure 2.7). If groundwater resource abstraction significantly exceeds average recharge rates and this horizon is rapidly dewatered (to gw13 and below in Figure 2.7), it leads to dramatic increases in

pumping head losses and energy costs (profile e3) with little increase in volume of water supply (profile Q3). Therefore, while investment in well drilling in all hard-rock terrains is always a gamble (in terms of obtaining a sustained yield sufficient for mechanized irrigation pumping), the risks increase greatly when through excessive exploitation the water table falls below the weathered zone horizon.

However, the widespread existence of flat rate electricity tariffs has allowed extremely inefficient pumping practices to arise and to persist, with farmers continuing to operate tubewell pumps at groundwater levels that are far too low and at which pumping losses are very high, and leaving pumps switched on to obtain a supply whenever the power supply activates (since it is not operating according to a regular schedule).

Such practices would be completely uneconomic if farmers felt the full cost of the electrical energy consumed. The consequences are clearly reflected in the data on rural electrical energy consumption for pumping in Andhra Pradesh (Table 2.4) showing that more than 10 times as much energy is required

FIGURE 2.7 Hydrogeological profile of an Indian weathered hard-rock aquifer system with indicative pumping yields and energy costs



now to irrigate only 2 times the area in 1980, which suggests that the disproportionate increase in electrical energy consumption is due in significant part to a marked deterioration in pumping

efficiency and overheating rather than generating additional irrigation water supply.

On the other hand, it is arguable that in political terms some form of rural energy subsidy (or other allowance) is justified to compensate for the great price differential for irrigation water supply between farmers outside irrigation canal commands (who are wholly dependent on groundwater) and those in the command areas where traditionally the hydraulic infrastructure has been provided free by the government and where irrigation water pricing recovers only a small fraction of operation and maintenance costs.

But viewed from the groundwater perspective, the overriding need is to find a way of facilitating recovery of water table levels, such that the most productive horizon of weathered hard-rock aquifers remains partially saturated in the dry season. The benefits of such an outcome, however achieved, would be a major reduction in electricity consumption for only modest reductions in irrigation water supply availability.

Realistic groundwater management measures

Groundwater recharge enhancement

Over the past decade or so, the predominant response to indications of excessive groundwater abstraction for agricultural irrigation has been to try to promote aquifer recharge enhancement in association with the implementation of rainwater harvesting techniques. Championed initially by advocates of watershed development and community stewardship of natural resources, artificial groundwater recharge has gathered momentum both within and outside the government,



Husain Shikalgar, chairman of the Water Committee of Vardhangarh village (Satara, Maharashtra). He decided to grow soybeans and sunflower knowing that these crops posed lesser risk of failure due to water scarcity.

TABLE 2.4 Historical evolution of groundwater use for irrigated agriculture and corresponding electrical energy consumption in Andhra Pradesh

	YEAR		
	1980–81	1998–99	2004–05
Number of irrigation water wells (million)	1.06	1.40	1.74
Area under irrigation with groundwater (million hectares)	1.12	1.76	2.48
Power consumption for pumping (gigawatt-hours)	920	10,220	12,240

Box 2.1 India's Groundwater Recharge Master Plan

The National Groundwater Recharge Master Plan (Central Ground Water Board 2005) provides a nationwide assessment of the groundwater recharge potential and outlines the guiding principles for an artificial groundwater recharge program.

The plan estimates that through dedicated recharge structures in rural areas and rooftop water harvesting structures in urban areas a total of 36 billion cubic meters can be added to groundwater recharge, at a cost of approximately US\$6 billion (Rs 25,000 crores). The additional quantity of groundwater amounts to approximately 15 percent of India's total current groundwater use.

The Groundwater Recharge Master Plan follows two criteria for identifying recharge: availability of surplus water and availability of storage space in aquifers. The investments in the program would therefore be driven by the potential available for groundwater recharge, and not by the need for recharge. This is clear when the funds allocated for recharge under the plan are examined on a state-by-state basis. The three states of Andhra Pradesh, Rajasthan, and Tamil Nadu, which together account for over half of India's threatened groundwater blocks, receive only 21 percent of funds, whereas the states of the Ganga-Brahmaputra basin, which face no groundwater overdevelopment problems, receive 43 percent of the funds. The disparities are similarly marked in a district-level analysis of recharge potential and needs (Shah 2008).

If implemented successfully, this recharge program will be able to add a significant quantity of water to India's groundwater storage, but it will not provide much help in the areas that are most in need of help. The Groundwater Recharge Master Plan illustrates the difficulties arising from disparate spatial variations in recharge potential and aquifer overexploitation, and also the limitations of recharge in addressing groundwater overexploitation in India.

and there now exists a veritable groundwater recharge movement in India (Sakthivadivel 2007). Both central and state governments have espoused the concept in a major way, and investments are supported through dedicated recharge programs in urban and rural areas as well as being part of watershed development programs.

Following the analytical framework of major aquifer typologies present in India, the relevance and value of artificial groundwater recharge needs to be assessed in the specific hydrogeological and water use context of each aquifer setting.

From the technical perspective, alluvial aquifers present the best opportunities for groundwater recharge because of the large volumes that can be

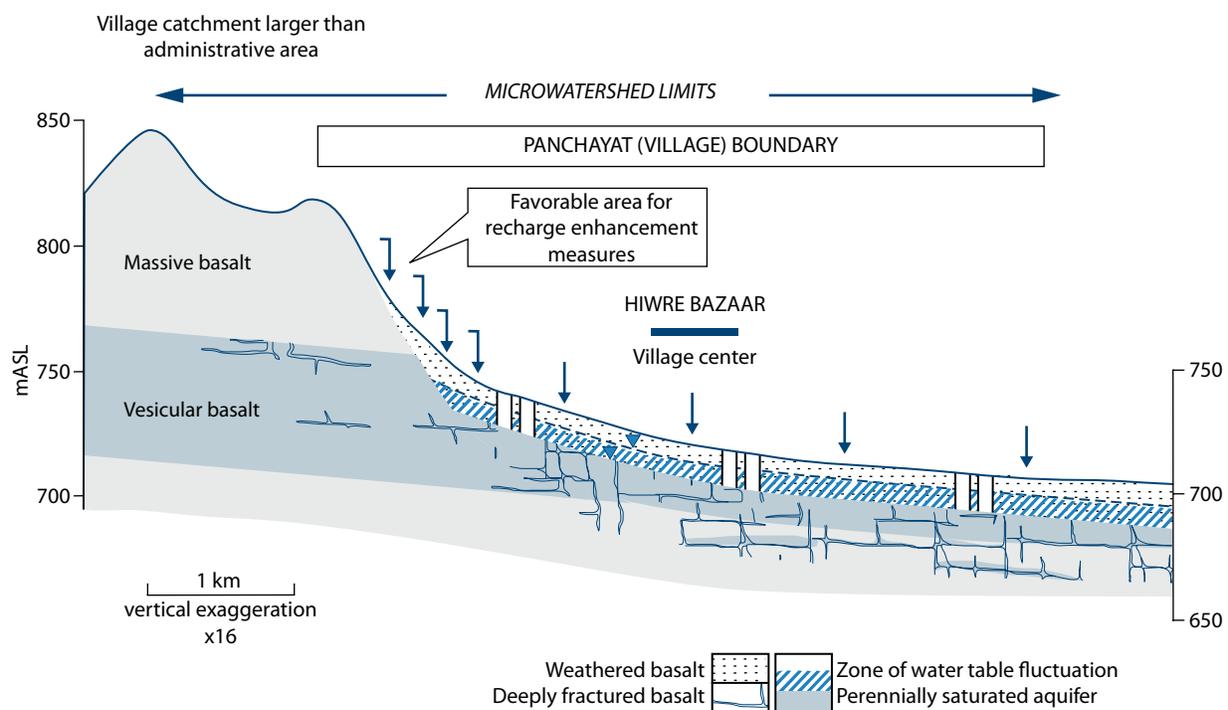
recharged into and abstracted from groundwater. It is also in these settings that most of the global experience in large-scale artificial recharge has been gained, with southwestern United States and California being the leading examples (Shah 2009). However, while recharge efforts in regions with alluvial aquifer settings can have the most successful outcomes, most of the groundwater overexploitation problem in India lies elsewhere. The seven states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Tamil Nadu account for more than 80 percent of critical and overexploited groundwater blocks in India, mostly in hard-rock aquifer settings. Therefore focusing recharge efforts in predominantly alluvial settings, as would happen if India's proposed Groundwater Recharge Master Plan (Box 2.1) were

implemented, would miss the real problem areas of groundwater overexploitation.

The first concern regarding reliance on recharge as a possible solution pertains to potential water yields from recharge interventions. Compared to alluvial aquifer settings, recharge potential in hard-rock areas is comparatively lower because of the limited surplus runoff and relatively limited storage space in aquifers. Technical estimates of the possible increase in available groundwater if all the hard-rock areas of Andhra Pradesh and Maharashtra were saturated using groundwater recharge structures range from 15 to 20 percent of the current sustainable yield levels.³ When compared with the scale of overdevelopment of many threatened groundwater blocks, it becomes clear that the gains of groundwater recharge do not come close to bridging the gap between supply and demand.

Recharge in these areas therefore does not offer an alternative solution, but a valuable complement that should ideally be reserved for priority local uses. Second, recharge programs on a large scale inevitably affect the hydrological upstream downstream linkages, often adversely impacting downstream populations and ecosystems through reduced surface and groundwater availability (Ray and Bijarnia 2006; Kumar et al. 2008). Third, analysis of available data from pilot projects shows that artificial recharging using dedicated recharge structures is quite expensive, with the cost of a cubic meter of recharge water turning out higher than the expected gross returns from its use in irrigation (Kumar et al. 2008). While there exist some localized favorable hydrogeological conditions, such as escarpment and foothill locations, where recharge-based approaches can contribute significantly to improving the groundwater resource balance (the

FIGURE 2.8 Hydrogeological profile of Deccan Trap basalt around Hiwre Bazaar (Maharashtra) illustrating favorable foothill conditions for recharge enhancement



³ Personal communication with Ground Water Department, Government of Andhra Pradesh, and Groundwater Survey and Development Agency, Government of Maharashtra, 2008.

TABLE 2.5 Qualitative assessment of groundwater recharge enhancement measures

How beneficial is artificial recharge? A summary of the arguments for and against	
For	Against
Increase in the volume of water available, which may be reserved for priority uses, for example drinking water supply or increased security for higher-value dry season crops	Distracts attention from the more pressing need for irrigation demand management and increasing productivity of scarce groundwater. Can give impression that a simple single solution to groundwater resource problems exists
Village groundwater sources can be improved in quality and dry season yield	Upstream downstream impacts (on streamflow and irrigation tank filling) often ignored and never costed into scheme appraisal
Stimulus for formation of village-level water resource associations or committees	Successful local recharge enhancement often just leads to more active irrigation wells, with groundwater resource imbalance, competition, and sustainability problems continuing
Promotion of dialogue between local government, social nongovernmental organizations, village authorities, and community on water resource issues	Not necessarily (or usually) focused on rural poverty reduction (apart from creation of short-term employment in construction)
Provision of work and mobilization of rural landless laborers in construction	Results in terms of enhanced recharge have been mixed in most state-implemented programs

well-known village of Hiwre Bazaar in Maharashtra is a good example, see Figure 2.8), recharge enhancement measures over large areas in hard-rock areas are subject to considerable physical constraints and will not be cost-effective (Kumar et al. 2008).

An innovative concept to substantially lower the costs of recharge involves use of millions of existing dug wells as recharge structures in peninsular India (Shah 2008). The government of India has launched a US\$450 million pilot recharge scheme based on this concept in the 100 districts that account for 60 percent of India's critical and overexploited groundwater blocks. Even though the increase in groundwater availability would be relatively small, the cost-effectiveness of the interventions is increased by the low cost of modifying a well for recharge (as opposed to building new recharge structures) and the potential value of the incremental water in high-value uses such as the protective irrigation of kharif crops. Even with such innovative approaches, sustainability is not assured unless institutional arrangements for managing groundwater can be put in place.

Factors that argue for and against artificial groundwater recharge are summarized in Table 2.5. A careful assessment of groundwater

overexploitation and recharge potential in the major groundwater settings prevalent in India leads to the conclusion that at best artificial groundwater recharge can be a part of the solution in certain settings, but it is not a panacea nor a substitute for the more difficult measures that are needed for addressing the problem of overexploited aquifers. In sum, notwithstanding the growing strength of the groundwater recharge movement and increasing public expenditure on it, India cannot recharge its way out of the deepening hole of groundwater overexploitation.

Demand management in agriculture

It follows that efforts to address excessive groundwater exploitation, however implemented, must concentrate largely on the promotion of appropriate measures to manage demand. Possible demand-side measures include:

- ◆ Dry-season crop planning for a part or whole of the area depending on the aquifers, and adjusting overall groundwater extraction and evaporative use in accordance with antecedent monsoonal rainfall or water table level. This would include, local conditions permitting, some degree of shift towards higher-value and lower-water-consumption crops.

- ◆ Adoption of modern precision irrigation technologies, which can reduce evaporation or other nonbeneficial, nonrecoverable fractions of water use in agriculture. Here it has to be recognized that with current irrigation practices, which predominantly involve traditional small-scale flood irrigation, a substantial proportion of total soil water losses is actually infiltration as the applied irrigation water returns to groundwater, and that reducing total soil water losses therefore does not necessarily represent a real water saving.
- ◆ Restrictions to control groundwater abstraction or use (enforced voluntarily or through regulatory measures). These may include restricting the depth of irrigation water wells (for example by only using dug wells for irrigation), establishing and enforcing minimum distances between irrigation water wells, and setting up drilling prohibition zones around public groundwater sources.

While some elements of demand-side management (for example adoption of precision irrigation technologies such as drip and sprinkler systems) are easier to implement than others (for example effecting cropping pattern shifts to reduce water demand), achieving overall reductions in groundwater abstraction remains the most difficult challenge of groundwater management. The main hard-rock states of India account for close to 13 million irrigation wells, more than twice the corresponding number for the states situated in the alluvial plains (Shah 2009). This very large number of groundwater users distributed over an extensive area makes it clear that broad-based regulation is unlikely to be the solution to problems of excessive exploitation in these settings. While the issue of regulatory effectiveness is discussed in detail in the following chapter, it is clear that for most hard-rock aquifer settings, groundwater resource management must primarily be founded upon community-based groundwater management.

The characteristics of the hard-rock aquifers, whereby groundwater depletion is not accompanied by irreversible side-effects and where the drawdown effects of intensive abstraction are rather localized and essentially confined to the immediate area, also make these systems robust enough for communities to attempt self-regulation. Chapter 4 is dedicated to the presentation of successful community groundwater management experiences in Andhra Pradesh, which has produced what is arguably a global first in large-scale reductions in groundwater abstraction through community self-regulation of groundwater use. The report posits that this approach can be scaled up in the state and even replicated, with due adjustments to local hydrogeological settings, socioeconomic conditions, and institutional setups, in other hard-rock states in India.

The fact that community-based approaches are likely to offer the most effective and pragmatic means for groundwater management does not (and must not) diminish the responsibility of state government agencies to take action, which needs to include:

- ◆ provision of transparent information on resource status;
- ◆ extension support for the elaboration of cropping plans developed to reduce groundwater and energy use and concomitantly increase crop productivity per unit of energy and water consumption;
- ◆ ensuring the sustainability, potential for scaling up, and replicability of community-based initiatives through appropriate support incentives and oversight;
- ◆ reform or realignment of policies in other sectors acting as drivers of groundwater use, including looking at more creative ways for targeting the electrical energy subsidy and providing incentives for reductions in electricity and groundwater use.

Some exceptions in hard-rock areas needing a different approach

Over most of the vast subregion of hard-rock India the use of groundwater for irrigation is largely by subsistence farmers, who cultivate primarily to provide for their own family needs and sell any excess production only in local markets.

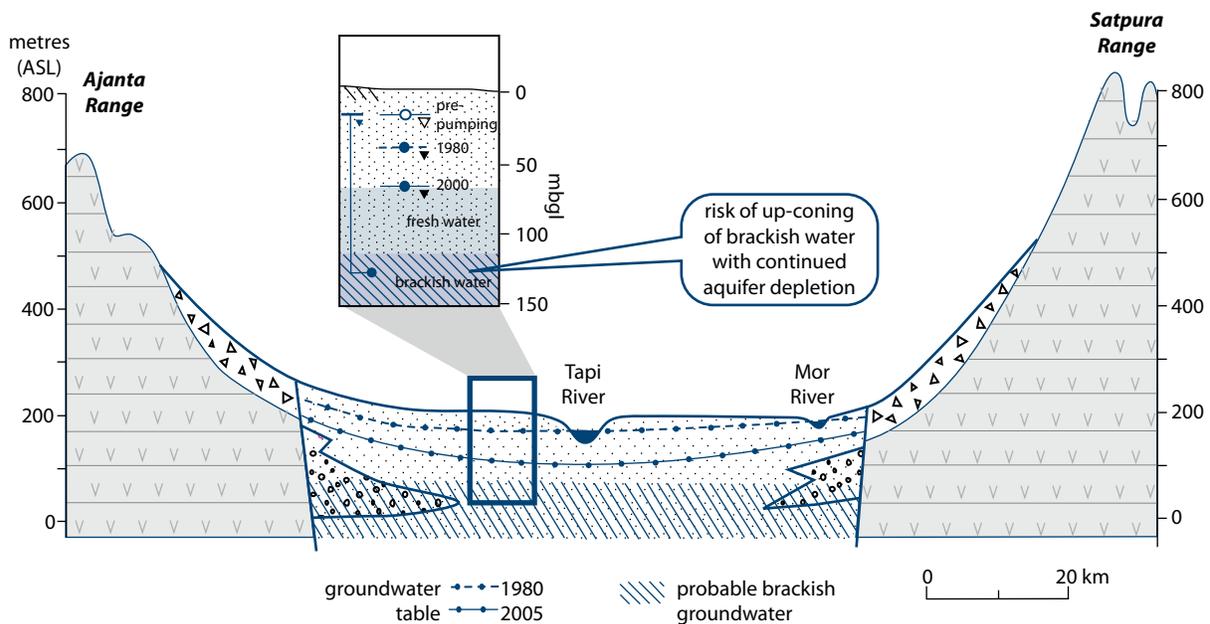
However, it should be noted that within this subregion there are some small but important groundwater bodies, in coastal or graben fill sedimentary aquifers such as those of the Tapi graben in Maharashtra and the Kortalaiyar basin in Tamil Nadu, which offer much greater potential in terms of water well yields and storage reserves. Their groundwater is often under exploitation for commercial agriculture with production of cash crops (such as banana plantations and grape cultivation) for major national markets and for export, and also sometimes for large-scale abstraction for the urban water supply of municipal utilities. Due to a combination of very intense resource exploitation and the intrinsic susceptibility of the aquifer system,

these groundwater bodies may be under threat of irreversible degradation, for example from saline intrusion (upwelling of brackish water if the aquifer keeps getting depleted, leading to its permanent salinization, as shown in Figure 2.9).

In cases where groundwater bodies under exploitation for large-scale agroindustrial production or municipal water supply are at risk of irreversible degradation due to excessive exploitation, there is a strong case for a greater element of state regulation and investment in engineered recharge to provide a solid framework in which demand management measures can be required of commercial groundwater users.

Since the total consumptive water requirement of highly profitable fruit cultivation even when using efficient systems of drip irrigation can be quite substantial (around 1,500 millimeters per year), achieving groundwater use sustainability in these localized high-potential but susceptible aquifer systems will require a major long-term effort, including:

FIGURE 2.9 Hydrogeological structure of the Tapi valley (Maharashtra) showing the major graben fill aquifer system prone to saline intrusion



- ◆ enforcing an overall ceiling on irrigation use through a system of individual and community-aggregated groundwater rights, thereby reducing the proportion of cultivated land area under irrigation;
- ◆ innovative supply augmentation measures, such as use of excess wet season canal flows for aquifer recharge via existing dug wells.

An example of such ongoing efforts to put groundwater abstractions on a sustainable basis comes from the Mendoza province in Argentina, where a high-value agricultural economy based on world-class wine and fruit production in the Carrizal valley is threatened by groundwater overexploitation and salinization (GW-MATE CP-6). The provincial irrigation and water resources authority has banned well drilling in critical areas, and is working to integrate the groundwater use dimension in the framework of existing canal water users associations. It is emerging that the existing water rights system would need to be made more flexible in order to allow better conjunctive use management of surface and groundwater resources, for example by convincing irrigators to relinquish their existing groundwater abstraction rights in favor of more reliable and enhanced surface water supplies.

Major alluvial aquifers of the rural Indo-Gangetic plains

The vast alluvial tracts of the Ganga and Indus river systems, with their many important tributaries, are underlain by extensive and frequently thick aquifer systems, with hundreds of meters of layered sandy deposits and large storage reserves. In southwestern Uttar Pradesh and large parts of south-central Punjab (and also elsewhere, such as in parts of Haryana) the alluvial sedimentary aquifer often contains saline water horizons. Where they occur within 100 meters or so of the surface these saline layers considerably complicate sustainable groundwater resource

exploitation, and care is needed when exploiting the deeper groundwater resources in these settings. For the most part the alluvial aquifers have good well yield potential (even where exploited by tubewells of only moderate depth), and are recharged directly from infiltrating monsoonal rainfall and in many areas indirectly from surface water via irrigation canal leakage and excess field application.

In these formations groundwater resource availability and therefore the management needs vary significantly between:

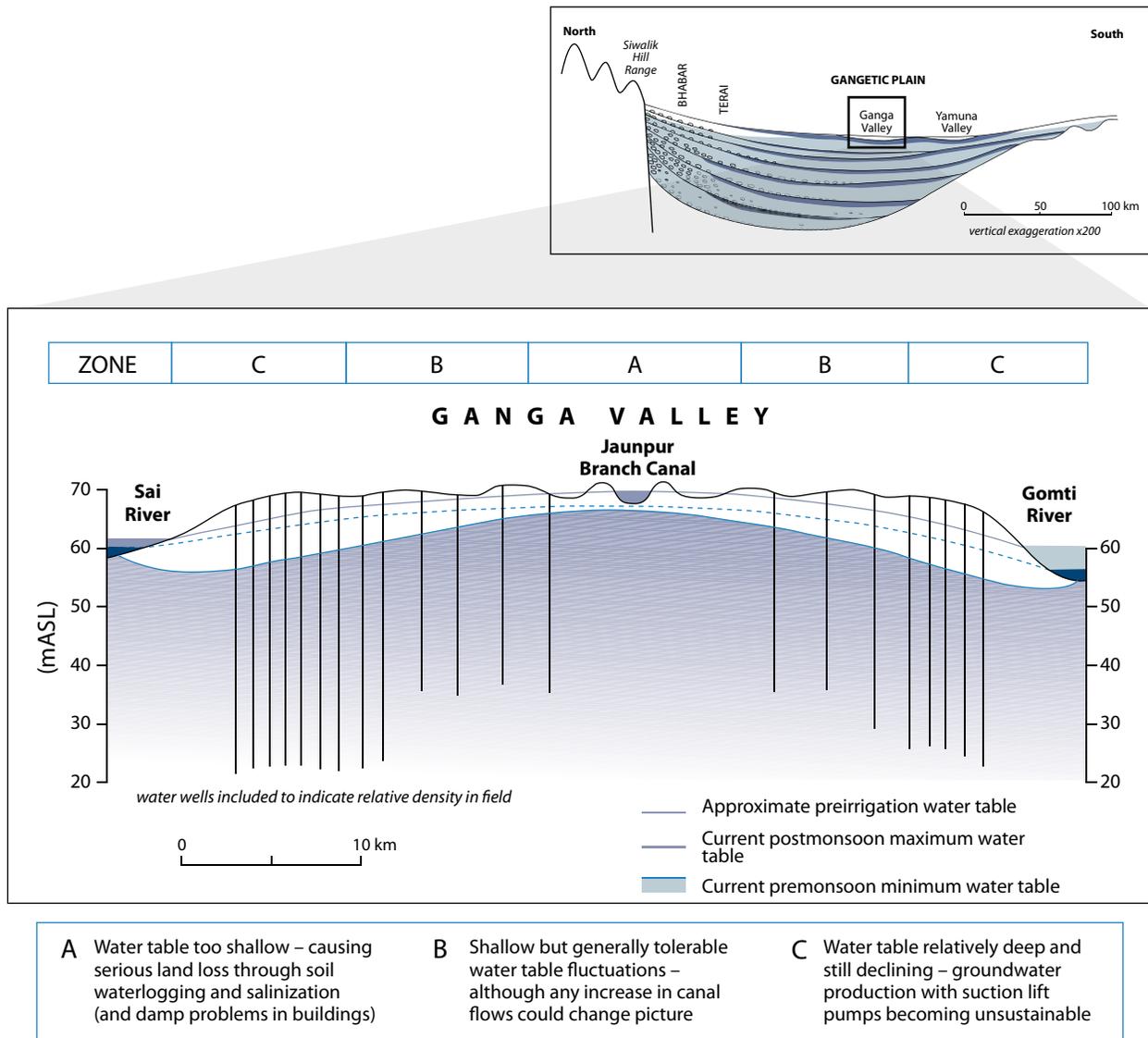
- ◆ **alluvial plains largely within major irrigation canal commands**, which have naturally shallow water tables and receive major recharge from irrigation canal leakage and excess field application;
- ◆ **older elevated alluvial areas with more limited irrigation canal commands**, where the groundwater table is considerably deeper.

Both these hydrogeological settings require further consideration in the present report, since both are associated in one way or another with continuously declining groundwater tables related to excessive and unplanned resource exploitation for irrigated agriculture, especially in areas of less than 1,000 millimeters per year rainfall (Figure 2.3). Moreover, in climate change scenarios predicting progressive reduction of Himalayan glaciers, and of the associated base flow in the Ganga river system, the vast groundwater reserves of the alluvial deposits of the Indo-Gangetic plains would become the key resource in adaptation to new water resource realities.

Conjunctive use: Addressing the problem of too much and too little groundwater use in command areas

The alluvial tracts of the central part of the Ganga valley are underlain by sediment deposits up to 600 meters thick, forming the Gangetic plain Quaternary

FIGURE 2.10 Sections illustrating overall scale of the Ganga alluvial aquifer system with inset illustrating surface water groundwater relations between major tributaries



aquifer, which is one of the largest aquifer systems in the world. Figure 2.10 shows a typical setting in this aquifer system, representing the Jaunpur canal command in Uttar Pradesh. Groundwater use in this aquifer was first developed for agricultural irrigation as a coping strategy by farmers experiencing inadequate or unreliable service from the canal irrigation system or falling just outside the limits of canal command. The main kharif and rabi crops are rice and wheat respectively, accounting for almost 70 percent of all crops grown, although sugar cane

can locally reach 40 percent of the total in major irrigation canal headwater zones.

Groundwater use has increased to widely represent as much as 70 percent of the overall irrigation supply despite very limited coverage of rural electrification and dependence on diesel engine pumps, and despite the fact that during the dramatic 2007–08 increases in the price of hydrocarbon fuels, groundwater users were paying Rs 2,000–3,000 per acre for pumping

groundwater, compared to only Rs 100 per acre for canal water use.

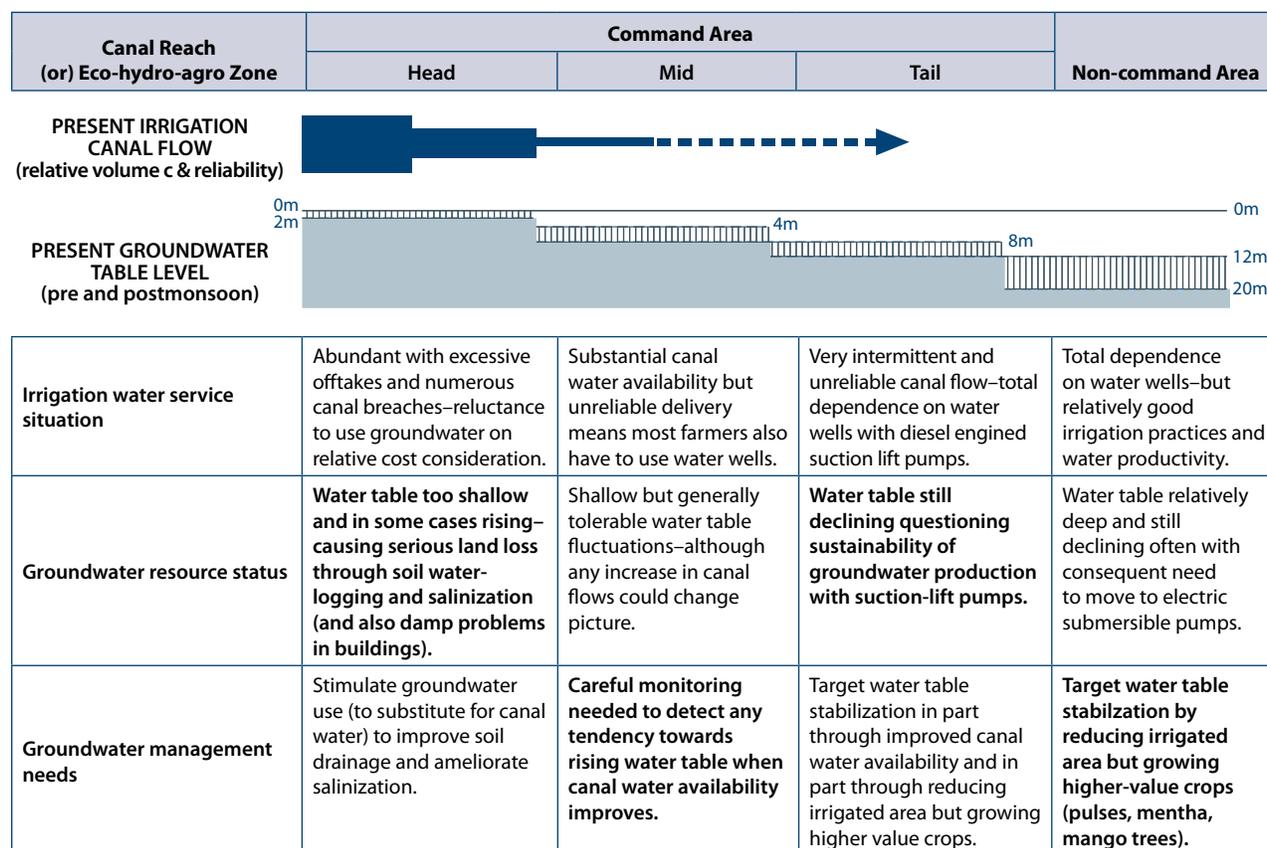
As a result of the high dependence on groundwater for irrigation, over 50 percent of the land area of Uttar Pradesh (comprising all areas towards and beyond irrigation canal tail end zones) now has a falling water table. The impacts of this decline are increasingly visible in terms of irrigation tubewell dewatering and yield reductions, and the failure of handpumps and rural water supply wells.

Concomitant with and sometimes in relatively close proximity (10–20 kilometers distant) to these groundwater overexploitation scenarios, canal water leakage and flood irrigation in the canal headwater zones is resulting in around 20 percent of the land area being threatened by shallow and rising water tables, with waterlogging and

salinization leading to crop losses and even land abandonment.

The two problems are linked because the excessive use and seepage losses in the upper reaches of the canals, in addition to being responsible for waterlogging and salinization in these areas, are also the main reasons for poor surface water availability in the lower reaches. There is sound scientific argument and field experience to show that more optimized conjunctive use (with improved surface water distribution and use, complemented by more rational groundwater use) could increase the cropping intensity from generally below 150 percent to well over 200 percent without compromising groundwater resource sustainability. This can be pursued by delineating and managing microzones based on hydrogeological and agro-economic criteria. Figure 2.11 provides a

FIGURE 2.11 Groundwater irrigation on the Gangetic plain of Uttar Pradesh: Moving from coping strategy to conjunctive use





Land unfit for agriculture due to severe salinization, Hallor village (Rae Bareli, Uttar Pradesh).

schematic representation of the existing canal water and groundwater availability in the different zones, along with the needed management measures. It is important to note that in such settings the highest current cropping intensity is found in those parts of the irrigation canal headwater zones where all illegal canal breaches and offtakes have been sealed, and which are irrigated in a large measure by tubewells. This switch to promoting groundwater use in canal headwater zones is critical for success in optimizing conjunctive use, and would conceptually require both physical interventions (such as completing bank sealing and desedimentation of irrigation canals) and management measures (such as enforcing existing operational codes for the distribution of canal water). However, in practice the real challenge lies in developing appropriate incentives to achieve the desired water-use behavior at the individual farmer level. Such incentives may include measures like extending rural electrification and targeted subsidies for promoting the construction and

energization of tubewells in the upper reaches of canal commands. There will also be a need for a long-term campaign to educate farmers on the benefits of managing conjunctive use of groundwater and canal water through microzone planning.

The specific patterns of groundwater availability and use and surface water supply options within each command area will determine the nature of appropriate management interventions. An innovative example of combining conjunctive use management with artificial aquifer recharge is provided by the Quibor valley in Venezuela (GW-MATE CP-7), which possesses very favorable conditions for vegetable, fruit, and livestock production, but where only 15 percent of the potentially irrigable land is under production because of the severe overexploitation of the underlying aquifer during the last 40 years for irrigation and urban water supply. The Yacambu-Quibor water transfer scheme has been designed

to meet the urban and irrigation water demands that will mature slowly over a period predicted to be between 5 and 30 years, and the excess transferred water during this time will be used for reducing groundwater pumping and recharging the aquifer, with full recuperation of the aquifer reserves expected in 15 years. While the physical setting of the Yacambu-Quibor project is quite different from the canal-irrigated schemes in Uttar Pradesh, it presents a good example of how integrated use of surface and groundwater resources can be effective in meeting increasing urban and agricultural demands while at the same time relieving the stress on depleted aquifers.

Sustaining groundwater irrigation on the elevated alluvial areas

Central Punjab provides the most significant and illustrative example for considering the issues and approaches for addressing excessive groundwater exploitation in the older elevated alluvial areas

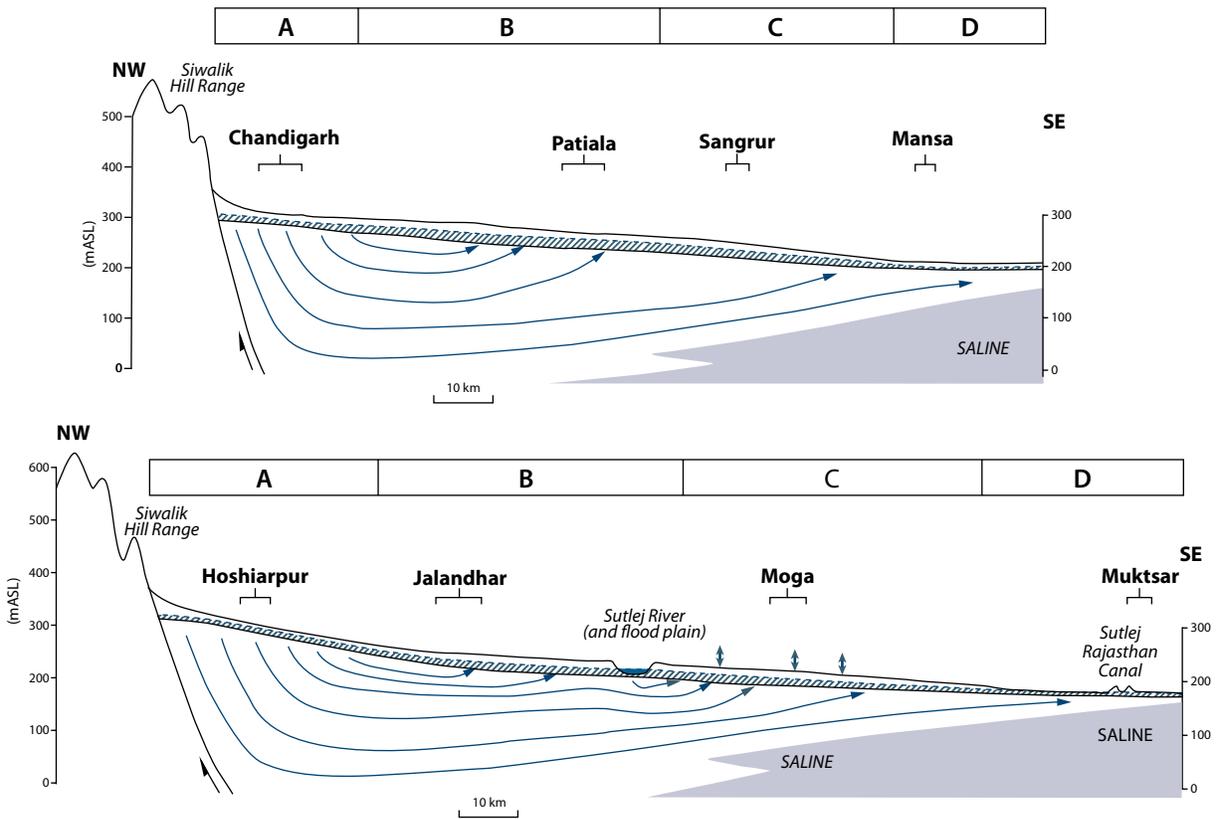
where water tables are deeper and coverage of irrigation canals is not very extensive. Punjab was a showcase for the so-called Green Revolution, with modern agricultural techniques allied to fertile soils and industrious farmers transforming the state into India's "grain basket". Punjab today accounts for about 20 percent of the national wheat production and 11 percent of the national rice production on only 1.5 percent of the country's land area. Punjab has experienced major increases in the area under double-cropping of paddy rice and wheat, and also in the yields of these crops per unit area, with around 80–85 percent of the land being under irrigated cultivation and a cropping intensity of just under 1.9.

A major part of Punjab's agricultural success has been based upon the exploitation of groundwater resources, with the number of operating tubewells increasing from 0.5 million in 1960 to around 2.3 million currently, and it is estimated that about 70 percent of the irrigated cultivation is dependent on

Siltation in Haidergarh Branch Head Canal, Uttar Pradesh. The silted canal now draws local fishermen.



FIGURE 2.12 Cross-sections of the Indus alluvial plain in Punjab, illustrating the regional groundwater flow regime and water table decline



A - Highest rainfall area with major groundwater recharge from direct infiltration and riverbed
B - Decreasing rainfall and canal seepage direct infiltration but important recharge from irrigation and seepage
C - Much reduced recharge from all sources
D - Very limited recharge except from any major regional transfer canals, but shallow (and in some cases, rising) water table with soil waterlogging and salinization widespread

groundwater, as the system of surface water canals can only meet a minor proportion of the current total agricultural demand. One result of this massive and uncontrolled exploitation of groundwater is that the water tables have been in continuous decline on a widespread basis (Figure 2.12), with aquifer depletion rates currently in the range 0.7–1.2 meters per year (approximately equivalent to a net 100–200 millimeters per year of excessive extraction).

Over most (but not all) of Punjab the aquifer system is thick (over 150 meters) and not susceptible to salinization, and thus this storage depletion (part of which is a normal consequence of any groundwater development) cannot yet be regarded as absolutely critical, though it is resulting in mounting cumulative costs:

- ◆ To the state government, which underwrites most of the cost of rural electrical energy

provision (apart from a small annual fixed charge paid by farmers). Consumption is estimated to be currently increasing at around 5 percent yearly, at a time when unit energy prices are generally rising and additional generating capacity is difficult to earmark.

- ◆ To farmers, who are being confronted with the need to move from low-cost water wells equipped with surface-mounted centrifugal pumps (generally costing less than US\$500) to deeper tubewells with electric submersible pumps (whose total unit cost is likely to be more than US\$2,500), with inevitable adverse impacts on the smaller farmers.

For these reasons there is an urgent concern to find ways of stabilizing the groundwater table (and even of inducing a partial recovery), provided that this does not severely constrain farming activity. While broader interventions in groundwater and other sectoral policies will certainly be needed to bring down groundwater use in the state within the sustainable limits, there seem to be possibilities for technical demand management interventions that can be immediately promoted to good effect. A number of potential water-saving measures are possible for paddy rice, cultivation of which is the single biggest user of water in Punjab. A promising recent approach was the postponement of paddy transplanting from May to mid-June, which seems capable of reducing consumptive water demand by at least 200 millimeters per crop without compromising rice yields (Box 2.2).

Punjab presents a special case where reducing consumptive water use in the main water-intensive crop can actually translate into lower groundwater abstractions, because there are no significant unrealized water demands in the agricultural sector. Coupled with the fact that a number of water-saving interventions also directly increase crop yields, investing in large-scale adoption of these interventions could be the preferred entry-point for efforts to address the problem of excessive

groundwater exploitation in Punjab. At the same time it will also be important to monitor closely the aquifer response to this demand management measure and to check that other components of the groundwater balance do not experience significant change. In this context it is important to appreciate that while over 70 percent of the irrigation water supply is derived from tubewells, as much as 35 percent of total groundwater recharge in the state can be linked to leakage of the irrigation canal system. This leakage could be reduced if greater lengths of irrigation canal were lined, and may decrease naturally if climatic change reduces surface water availability.

Urban groundwater use and policy concerns

Across India urban water utilities are under enormous pressure to cope with escalating water demand arising from both increasing urban population and from increasing per capita water use, which has led to a major demand on groundwater resources where they are available. But significantly different dynamics of groundwater use, deriving ultimately from widely different groundwater resource availability, mean that recommended management approaches for cities underlain by relatively low-potential hard-rock aquifers are very different from those where the municipal water utilities are readily able to tap major underlying alluvial aquifers. For this reason, cities on hard-rock terrains are treated separately from cities on major alluvial plains in the rest of this section.

Cities on hard-rock aquifers: The forgotten dimension of private groundwater use

India is urbanizing at a fast pace, and a large number of the fastest growing cities (for example Coimbatore, Bangalore, Hyderabad, Nashik, Pune, and Aurangabad) are located in hard-rock areas. The experience pertaining to cities on weathered hard-rock aquifers summarized in this report is based mainly on detailed investigations

Box 2.2 Possibilities for demand management interventions in Punjab

In 2008, the government of Punjab issued orders to prohibit early transplanting of paddy, which had become an increasingly prevalent practice in the state. By pushing back the transplant time from as early as mid-May to mid-June, significant water savings were made across the state, as the peak irrigation need for paddy was realigned with the monsoonal rains. This measure was highly successful for several reasons: (a) there was limited public resistance as yields were not negatively impacted; (b) any lack of compliance would be highly visible; and (c) most importantly, once a critical mass of farmers decide to delay transplanting, those transplanting early face an increased threat of pest infestation. Initially issued as a government order for the 2008 planting, the measure is now under the consideration of the state legislature, with the objective of permanently disallowing early paddy transplanting. This experience indicates that given the technologically progressive nature of farming in the state, measures to increase agricultural productivity while indirectly inducing water savings could be effective in reducing groundwater use. The government of Punjab is considering additional measures, such as the leveling of fields using laser techniques; soil moisture-based irrigation timing; short-duration rice varieties; and the system of rice intensification. All of these water-saving techniques would also increase crop productivity. Although information is not yet available on the cumulative impacts of these interventions on water needs and crop yields, a preliminary tabulation (not accounting for return flows and nonbeneficial evapotranspiration) indicates significant water-saving potential.

Water-saving potential of individual interventions (water savings are not cumulative)

Proposed interventions for rice farming	Reduction in water need (mm)
Laser leveling	410
Delayed transplanting by one month	210
Timed irrigation with tensiometer	370
Short-duration rice varieties	300
System of rice intensification	370
<i>Baseline water requirement for rice = 1,840 millimeters</i>	

The potential for such interventions to actually bridge the demand–supply gap is specific to Punjab, and may not be replicable elsewhere. Punjab benefits from particularly progressive and technically aware farmers, who are quick to adopt promising new approaches. Moreover, the unusual fact that Punjab has reached saturation point in both area under cultivation and net irrigated areas means that there is no significant unrealized demand for water in the agricultural sector, thereby avoiding the risk that these gains would be offset by an increase in area under irrigation.

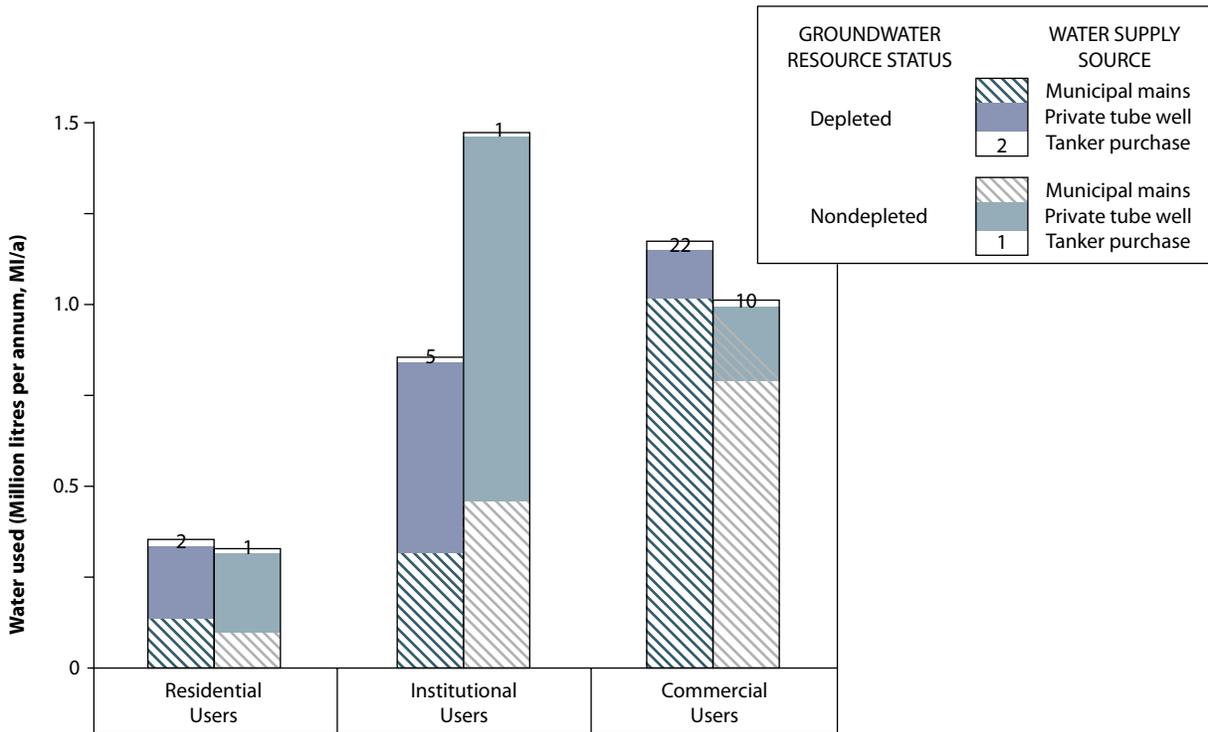
in Aurangabad City commissioned under this initiative, and general indications from various other cities, where in all cases private water well construction and groundwater dependency has mushroomed, essentially as a coping strategy, given the inadequacy of municipal water supply.

In most wards of Aurangabad City, the municipal water supply provides less than 1-in-24-hour service at low mains pressure. In order to reduce dependence on the purchase of much more expensive tanker water supply (costing more than Rs 40 per cubic meter), urban dwellers and commercial water users in particular have widely turned to private in situ borewell construction as an alternative source of water supply. This has

proved to be very effective from the perspective of generating additional water supply for the users (Figure 2.13), despite the low yield potential and very limited reserves of the weathered Deccan Trap basalt aquifer system underlying the city. It also demonstrates that the costs of and implicit capacity to pay for a more reliable urban water supply are considerably above the level of the current highly subsidized domestic urban water tariff.

However, this major urban private investment in self-supply from shallow groundwater is not without its problems. In areas of very deficient municipal water supply and higher population density it usually means heavy seasonal

FIGURE 2.13 Average annual water use by different user categories in Aurangabad City distinguishing adequate and depleted groundwater areas



Source: Study on actual role and potential of groundwater for Aurangabad municipal water supply, 2008 (background analytical work for this initiative).

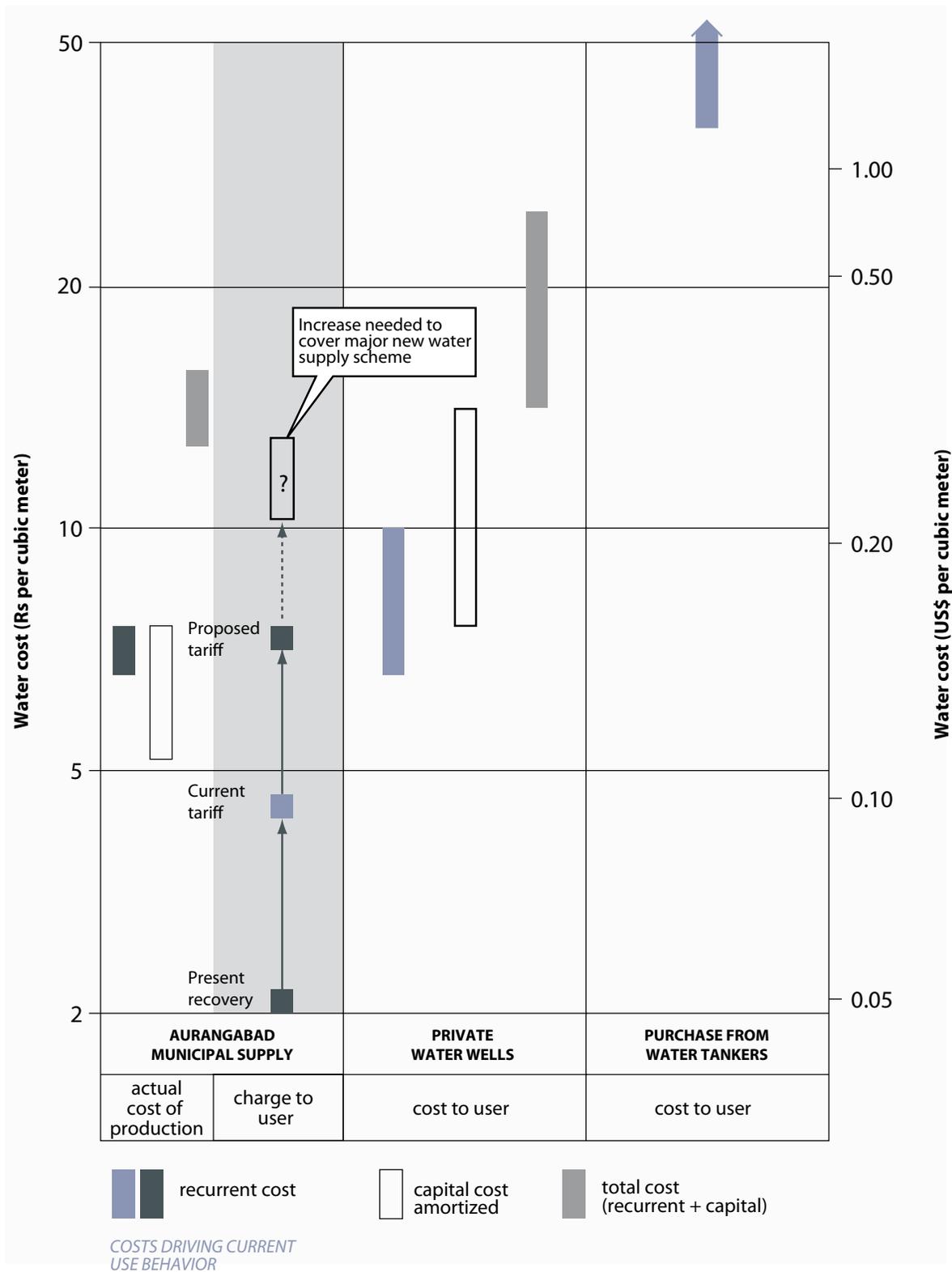
depletion (almost emptying) of the low-storage groundwater body, with widespread water well failure (especially in May–June). In addition, concerns are growing about bacteriological and chemical pollution and nutrient overloading of aquifers. However, the most important concern is that in Aurangabad and in other cities on weathered hard-rock aquifers the existing private access at moderate cost to in situ groundwater will inevitably be a key factor affecting the cost recovery potential for major new urban water supply schemes based on expensive transport and treatment of water from distant surface water sources. Figure 2.14 shows the relative costs of existing supply and recovery requirements for additional supply augmentation in Aurangabad. It is clear that in such cities a much more integrated vision of, and balanced policy between, utility

infrastructure provision (both water supply and sanitation) and private self-supply will need to be developed on a case-by-case basis, including direct measures to increase the availability and reduce the quality risk associated with the use of in situ groundwater.

Cities on major alluvial aquifers: Towards more sustainable use of groundwater for municipal supplies

A large number of urban centers in the Indo-Gangetic plains now obtain a major part or all of their municipal water supply from groundwater. In Delhi, for example, groundwater accounts for 11 percent of the water production by the municipal utility, but almost 50 percent of the total supply to the final users if private abstraction is counted in (Maria 2006). Other examples of such cities are Agra, Amritsar, Lucknow, Ludhiana, and Noida. Even when surface water resources are available,

FIGURE 2.14 Indicative relative costs of main sources of Aurangabad City water supply



Source: Study on actual role and potential of groundwater for Aurangabad municipal water supply, 2008 (background analytical work for this initiative).

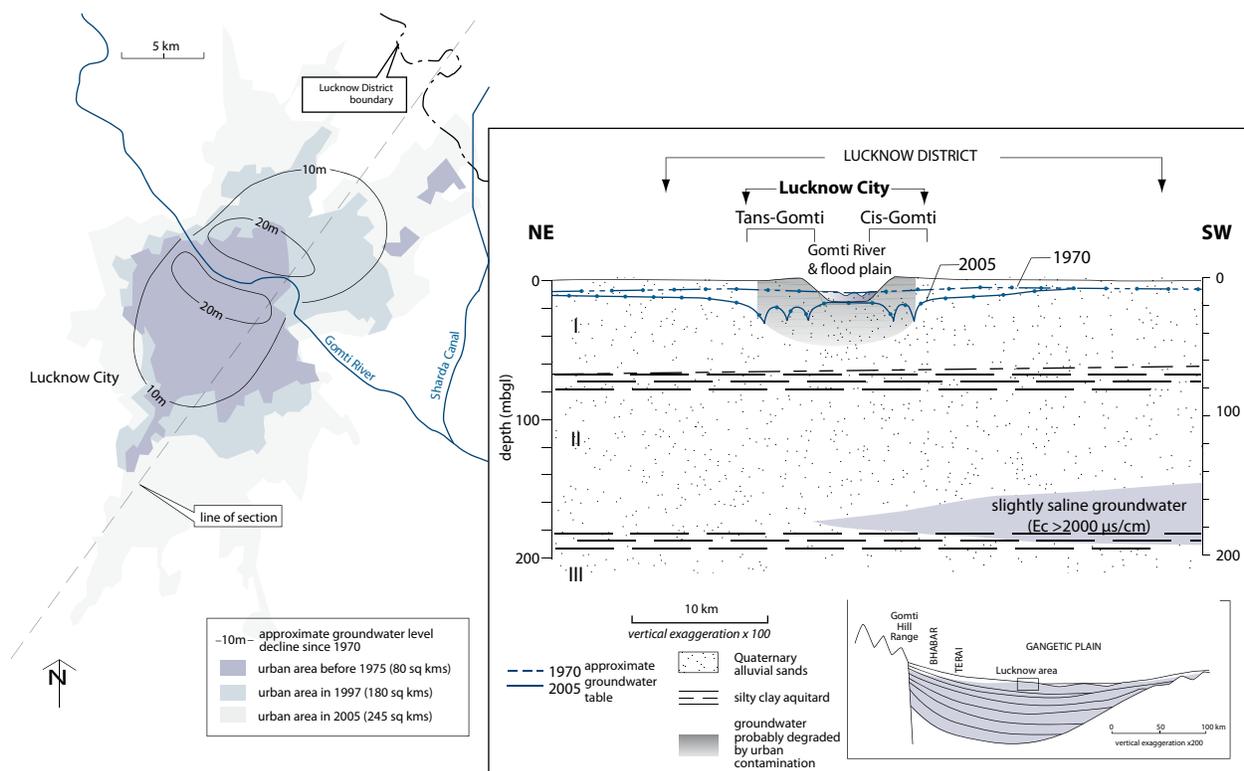
reliance on groundwater is common because it is much more economical to develop than river intakes, owing to lower capital cost for treatment and flexibility of developing the resource in stages with the growth of demand. Owing to this access to a large buffer resource, such cities have not generally suffered periods of widespread and extreme water service inadequacy while waiting for major investments in new surface water sources to be mobilized. Most utilities that have the possibility of constructing high-yielding water wells locally construct a few new water wells every year, connecting them to the overall system where feasible or using them to supply water to specific new periurban developments. There does not normally exist a high and competitive level of private in situ self-supply, because municipal utility shortages have not been so severely experienced and because water well construction and operation costs are higher. However, with the rapid expansion of urban areas and increasing

demand, groundwater is being relied upon more than ever, at a time when the resource condition is deteriorating because of historical lack of management.

These dynamics are illustrated with the example of Lucknow (Figure 2.15 and Box 2.3), the capital city of Uttar Pradesh, which is situated on the central Ganga alluvial plain, where localized water shortages are caused by unplanned growth rather than absolute resource scarcity. It is clear that the way forward to more robust urban water supply solutions, with sustainable groundwater use, on the major alluvial plains must involve

- ◆ planned conjunctive use wherever exploitable surface water resources are available;
- ◆ development of more easily protected and managed peripheral municipal well fields (through appropriate arrangements with rural communities);

FIGURE 2.15 Historical growth of urban sprawl in Lucknow City (Uttar Pradesh) and current rate of water table decline



Box 2.3 Groundwater in municipal water supply of Lucknow

Lucknow stretches across both banks of the Gomti River, a tributary of the Ganga, which is dependent mostly on natural groundwater discharge for its dry season flow. The climate is subtropical with an average rainfall of around 1,140 millimeters per year, and the city is underlain by a rich alluvial aquifer system with multiple productive layers.

The population of Lucknow has grown from 1.0 million in 1981 to 2.3 million in 2001 (Figure 2.15), and is projected to reach 4.0 million by 2020. Before the 1970s the municipal water supply was based on an intake on the Gomti River, but from 1973 Lucknow started construction of tubewells in an effort to meet rapid urban growth and spiraling water demand. By 1985 the Lucknow Municipal Water Board was operating 70 tubewells, and by 2005 this number had risen to around 500 tubewells. The depth of tubewells had also increased from 120 meters to 200 meters (approximately).

The current gross available municipal water supply is about 490 million liters per day, of which around 240 million liters is derived from the 500 tubewells and 250 million liters from surface water (with the Gomti River intake having been replaced by an offtake from the Sardar irrigation canal because of reduced base flows and quality deterioration in the river). However, the Municipal Water Board is faced with substantial physical leakage losses (estimated to be around 30%), which reduce the total deployable supply to about 345 million liters per day. The service provided is typically for 6 hours per day with individual use at about 100 liters per capita daily, but a few wards offer 24 hours per day supply of up to 250 liters per capita.

Over the last two decades, there has been an increasing trend of private water well drilling and operation by those seeking and prepared to pay for a more secure 24 hours per day supply. Although there is no inventory of private groundwater use, it is estimated that around 1,100 tubewells are in operation by commercial, industrial, and institutional water users in addition to the large abstractions at the military cantonments and railway depots. With increasing groundwater draft, the water tables have been steadily declining from 10 meters below ground level in the 1950s to 20–30 meters below ground level at present. The water table decline is due to the highly localized concentration of tubewells, and not due to any overall resource deficiency in the aquifer system. Although there have been no systematic groundwater studies, one of the consequences of the water table decline is the reduction in municipal tubewell yields, from 20–25 liters per second in the 1970s to 10–20 liters per second currently. It is also no longer feasible to use surface-mounted centrifugal pumps for private tubewell pumping. Furthermore, the declining water table has changed the condition of the Gomti River from effluent (gaining flow from natural groundwater discharge) to influent (losing flow to groundwater infiltration), causing concerns about groundwater pollution from the polluted river water and insufficient river flow for dilution of sewage discharges.

Lucknow is planning to further augment Sardar canal flows from the Sardar River 150 kilometers away in an attempt to guarantee the availability of 500 million liters per day in all seasons. However, such a scheme is vulnerable to other demands that are also rising in the basin, and potential conflicts with the farming community across whose land the canal runs. Moreover, the 2025 demand prediction requires a gross available supply of 810 million liters per day (before leakage losses are deducted), which would imply maintaining or even expanding local groundwater production.

It is noteworthy that, because of the availability of local groundwater resources, the municipal water supply situation in Lucknow is considerably better than in most cities of peninsular India, and the current problems have more to do with distribution system constraints caused by unplanned growth than with an absolute resource shortage. Groundwater is a significant element of the overall water supply situation of Lucknow, from the perspectives of resource availability, financial sustainability, and environmental benefits, yet it is mostly taken for granted, and not taken fully into consideration in technical and financial water supply planning.

- ◆ integration of appropriate planning and protection of all municipal groundwater sources into broader urban planning.

In the specific case of Lucknow, a more integrated and harmonized conjunctive use of surface water and groundwater sources should include spreading municipal groundwater extraction to

numerous areas within a radius of 25 kilometers that are experiencing soil waterlogging (as a result of a high or rising water table) and constructing well fields in such areas with delivery of water to the urban distribution system either by pipeline or by augmentation of flows in any conveniently located canals. Both options would have the secondary benefit of improving

land drainage and crop productivity in the corresponding rural areas.

With the worldwide increase in the pace of urbanization, growing dependence of large urban centers on groundwater is now common in most continents. A recent field survey in Metropolitan Fortaleza in Brazil, which is one of Latin America's fastest-growing cities, disclosed an unexpectedly large increase in the number of water wells (from 1,700 in 1980 to about 10,000 currently), with significant capital sunk in private water supply and most of the large abstractors being unregulated (GW-MATE CP-14). The primary driver of this private and informal groundwater use is the unreliability of municipal service provision and periods of extended drought. The accelerated and unregulated increase in groundwater abstractions has raised concerns about seawater intrusion and consequent irreversible damage to the aquifer systems, along with pollution resulting from poor coverage of the sewerage network. Similar issues regarding the sustainability of groundwater use exist in various other cities in Brazil, which has witnessed an increase in its urban population from 37 percent of the total in 1950 to 81 percent in 2000, and which therefore provides an interesting parallel to India's fast urbanization rates.

Another example of the current and future significance of urban groundwater use is illustrated by Greater Nairobi, which primarily relies on surface water supplies from the Tana River basin, but where poor reliability due to drought and the inefficient distribution network has resulted in increasing groundwater use by unregulated private operators (GW-MATE CP-13). Groundwater beneath the city is being pumped from the thick aquifer underlying the Athi River floodplain by industrial enterprises, commercial users, and domestic wells, leading to a gradually falling water table and increased

pumping costs. As the use of groundwater will become more critical in the coming decades to provide adequate service levels for the rapidly growing urban population and as a strategic reserve in times of drought, the urban water supply authority, which is currently relying solely on surface water, is facing the imperative of introducing an element of groundwater planning and management.

For large urban groundwater settings such as Delhi and Lucknow, a success story in groundwater management is provided by Greater Bangkok (Box 2.4), illustrating how a severely deteriorating groundwater overexploitation situation was stabilized by an appropriately empowered and well-organized regulatory agency.

Conclusion: Tailoring groundwater management to each specific typology

This chapter has presented a description of the main typologies of groundwater overexploitation in India, the peculiar dynamics of groundwater use in each setting, and the appropriate management measures. The recommendations on management measures have emerged from a continuous and close dialogue with the various stakeholders, using the available information on the hydrogeological and socioeconomic characteristics for each specific environment. The measures are summarized in Table 2.6, and begin to answer the question of what to do for each typology of overexploited aquifers presented in Table 2.3. The following chapter assesses the strengths and weakness of the institutional framework within which the proposed measures must be implemented, both at the central and state government levels. A detailed discussion of the who and how of implementing the management measures is the substance of the final chapter.

Box 2.4 Stabilizing groundwater use in Greater Bangkok

Greater Bangkok witnessed widespread exploitation of groundwater starting in the 1950s, and by 1980 the abstractions had reached a point where there was evidence of significant land subsidence damaging urban infrastructure and concerns regarding aquifer sea intrusion (GW-MATE CP-20). The initial approach taken by the Metropolitan Waterworks Authority was to eliminate the utility's abstraction in favor of surface water sources, but the increased domestic, commercial, and industrial tariffs for public water supply triggered a massive increase in the drilling of private wells, whose total abstraction reached over 2,000 million liters per day in the late 1990s. Measures such as banning water well drilling in critical areas and licensing and charging for metered or estimated groundwater abstractions were introduced, but took some years to be implemented. During 1995–2005 even stronger measures were introduced and implemented (including raising groundwater use charges and more aggressive application of sanctions on well drilling, supported by public awareness campaigns) to constrain groundwater abstraction within environmentally tolerable limits.

Total abstraction was reduced from 2,700 million liters per day in 2000 to 1,500 million liters per day in 2005, and land subsidence was also significantly reduced. Political protest by users in some districts was addressed by allowing well users to continue using their wells conjunctively for the period up to their next license renewal (up to 10 years) and to retain their wells as a backup supply for 15 years, provided they were adequately metered and open to inspection.

TABLE 2.6 Preferred management approaches under different aquifer and user typologies

Land use	General & specific hydrogeological environment		Resource use	Relevance of management approaches to address overexploitation			
				Policy intervention	Demand management	Recharge	Conjunctive use
Rural	Hard-rock terrains in peninsular India	<i>Widespread weathered hard-rock (basalt or granite) aquifers with shallow, low-storage patchy groundwater bodies</i>	Subsistence and commercial agricultural exploitation, drinking water supply, some industries	Low	High	Medium	Low
		<i>Occasional but important groundwater bodies in coastal or graben fill sedimentary aquifers</i>		High	Low	Medium	Medium
	Major alluvial formations of rural Indo-Gangetic plains	<i>Alluvial aquifers, in plains largely within major irrigation canal commands with naturally shallow water table</i>	Mainly subsistence and commercial agricultural exploitations	Medium	High	Low	High
		<i>Alluvial aquifers in the older elevated alluvial plains, with more limited irrigation canals and deeper water table</i>		High	High	Low	Low
Urban	Urban environment	<i>Weathered hard-rock aquifers with shallow, low-storage patchy groundwater bodies</i>	Individual urban households, water utilities, industries, tourism	Low	Medium	High	Medium
		<i>Major alluvial aquifers in alluvial plains</i>		Medium	Low	Low	High

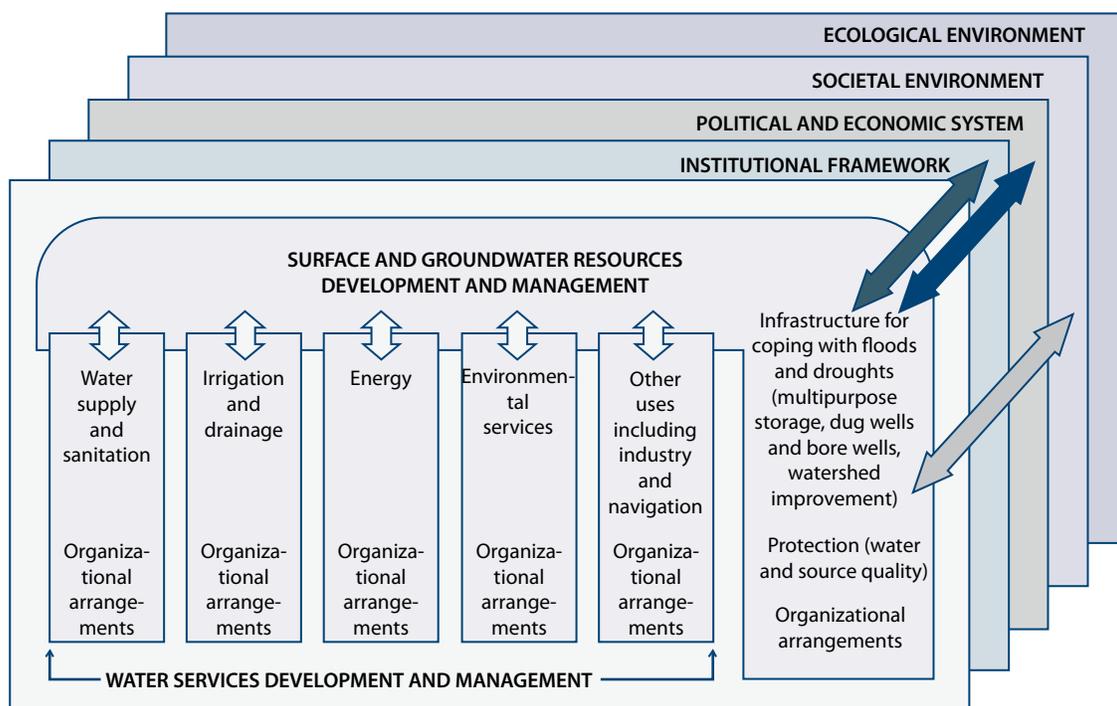
A Semblance of Sufficiency: Institutional Framework of Groundwater Management in India

Introduction

Groundwater overexploitation is a result of millions of individual decisions made at the local level, each arguably rational in its specific local context. Yet, patterns of groundwater use and overuse are nevertheless influenced significantly by a range of macrolevel variables.

Administrative, legal, political, and economic factors are all powerful determinants positively or negatively influencing the decisions of farmers and households, at the individual and collective levels, regarding the use of groundwater. This complexity is illustrated by the well-known water resources management “comb” schematic (Figure 3.1), which shows the surface and

FIGURE 3.1 Contextual environment of water resources and water services



groundwater resources embedded in a set of relevant environments.

The following section introduces the broad categories of instruments used across the world for groundwater management. The institutional environment governing groundwater use in India is then examined in detail, with specific focus on its legislative, organizational, and sector policy dimensions. The appropriateness and applicability of various management instruments for addressing groundwater overexploitation in different settings of India is then assessed in the macro context of this institutional environment.

Types of groundwater management instruments

Groundwater use in India is unique both in scale and characteristics of development, and will therefore require management approaches that not only address the peculiar needs of each groundwater setting (as described in the preceding chapter) but are also adapted to the broader contexts of governance and the political economy in India. A number of countries have faced the challenge of groundwater overexploitation in previous decades, and there now exists a significant body of knowledge on lessons emerging from this global experience. The following broad categories of groundwater management interventions can be identified from this cumulative experience (Shah 2009):

- ◆ **Regulatory measures**, enforced through state administrative mechanisms, mainly aimed at controlling groundwater abstraction through restrictions on digging new wells, well depths, and volumes pumped (pumping quotas); norms for well siting; and well field protection zoning
- ◆ **Economic instruments**, aimed at influencing the behavior of resource users by introducing an economic value to the resource, through water pricing (including taxes and levies on

wells or withdrawal volumes); water resource fees; compensation for reducing groundwater withdrawals; and formal or informal sale and purchase of groundwater

- ◆ **Groundwater property regimes**, aimed at creating private and preferably tradable ownership or usufructory rights, so that incentives for improving productivity and conservation can be created in a system that is otherwise open access and prone to the tragedy of the commons
- ◆ **Community management**, aimed at creating self-governing groundwater user organizations that can be given the responsibility of sustainable management of aquifers, through collective monitoring of aquifers and the behavior of groundwater users

Scholars and policy makers in India have reviewed the international experience with these management interventions, to understand which measures have worked elsewhere and why (Shah 2009; Planning Commission 2007). Prior to assessing their appropriateness and applicability for addressing groundwater overexploitation in India, the following sections present the institutional context of groundwater use in the country.

Groundwater use in India: Legislative environment

Groundwater in the Indian legal system falls within a complex, multilayered framework, consisting of a range of constitutional and statutory provisions at the central and state levels.

The right to groundwater has traditionally been seen as following the right to land, based on the Indian Easements Act of 1882, which gives every owner of land “the right ... to collect and dispose within his own limits of all water under the land which does not pass in a defined channel”. This provision of the Act effectively establishes the right

of each landowner to appropriate all groundwater not flowing in “defined channels” under the land. This long-established “real property” groundwater right is balanced by the emerging public interest dimension of groundwater use. In 1996 the Supreme Court, ruling under the Environment (Protection) Act (1986), instructed the government of India to establish the Central Ground Water Authority to regulate and control groundwater development with a view to preserving and protecting this resource. The decisions made in a more recent case involving the Coca-Cola Company also affirm the government’s right and obligation to protect groundwater under the right to life guaranteed by the Constitution of India.

The Constitution lists “water supplies” (which is understood to include groundwater) under the State List, thereby giving the states jurisdiction to regulate and control groundwater. However, the central government also has a concurrent power to make laws with respect to any matter for any part of the territory of India. One of the functions of the Union Ministry of Water Resources is “overall planning for the development of groundwater resources, establishment of utilizable resources and formulation of policies of exploitation, overseeing of and support to state level activities in groundwater development”.

Accordingly, the central government has sought to support states in a pragmatic way through the issuance of the Model Groundwater Bill. The rationale for the bill is to provide a template for consideration by state governments, which can modify and adopt it according to their needs. The Model Groundwater Bill was first developed in 1970 and has subsequently been revised and circulated many times. Amongst other things the bill recommends the constitution and empowerment of some form of “state groundwater management agency”, and registration and control of at least the larger groundwater users. It is important to note that only a handful of states have enacted groundwater legislation based on

the bill. In the words of the Planning Commission’s Expert Group on Groundwater Management and Ownership, “Despite repeated circulation of the Model Groundwater Bill by the Central Government, states have generally exhibited lethargy in legislating on groundwater” (Planning Commission 2007). Arguably the bill could be further modified to improve the chances of enactment of effective groundwater management legislation by the states. A comparison with global practice in groundwater legislation indicates that some of the salient improvements to the Model Groundwater Bill could include more emphasis on public participation and community management and less dependence on direct top-down governmental control, differentiating between small and large users and between commercial and noncommercial uses of groundwater, and addressing equity issues around groundwater use, including consideration of groundwater users who do not have formal land titles.

Legal remedies that have been proposed for improving groundwater management in India also include changes to the Easements Act, which would involve establishing private property rights in water by delinking water use rights from land rights so that incentives can be created to promote a more efficient and rational utilization of scarce groundwater resources.

The Planning Commission’s Expert Group on Groundwater Management and Ownership has argued that the legislative framework is reasonably robust, in that in principle it enables the groundwater management practices that are likely to be pragmatic and effective in India (Box 3.1). Recent Supreme Court and State High Courts rulings support the principle that private extraction rights can, and should, be curbed by the state if the use of groundwater is considered excessive. The Expert Group has therefore concluded that “no change in basic legal regime relating to groundwater seems necessary” (Planning Commission 2007). An analysis of the

Box 3.1 Adequacy of existing legal framework for effective groundwater management in India

The Planning Commission's Expert Group on Groundwater Management and Ownership (Planning Commission 2007) has framed the legal environment as adequate for groundwater management:

- ◆ It acknowledges that there is sufficient basis for government action, in that "The recent court rulings have held that the Union State has got a duty to protect groundwater against excessive exploitation and the inaction in this regard will be tantamount to infringement of the right to life of the people guaranteed under the Constitution of India."
- ◆ The "Central Government's role emanates from the provisions of the Environment Act, because as overexploitation of groundwater is gaining momentum, environment is increasingly under threat."
- ◆ It realizes the implementation constraints associated with regulatory measures: "Given the enforcement problems relating to prohibitive measures, greater reliance needs to be placed on community management of the resource, supported by adequate technical inputs, complementary institutional changes and appropriate incentives (such as a subsidy regime for micro-irrigation), rather than on 'controls by state'."
- ◆ It advocates selective regulation, establishing that "Should groundwater level fall below the replenishable level in a specific groundwater block, the Central Government should intervene with command and control measures, under the provisions of the Environment Act, by declaring the affected area as 'environmentally threatened'."

administrative and sector policy environments, presented in the following sections, shows that the Expert Group's conclusion is correct, because the problem of groundwater overexploitation does not arise from inadequate legislation and therefore cannot be solved through legislative remedies.

Groundwater use in India: Administrative and organizational environment

India is a federal republic of 28 states and 7 union territories. All states and two of the union territories (including the National Capital Territory of Delhi) have elected governments. Each state or union territory is further divided into districts, of which there are a total of 610 in India, for basic governance and administration. The districts in turn are further divided into blocks and villages.

Under the Indian Constitution, state governments have the primary responsibility for water supply and irrigation. In addition, state legislatures have been given a constitutional mandate to decentralize power, where necessary, to the locally elected panchayati raj institutions, with drinking water and minor irrigation included in the subjects over which

responsibility can be devolved from state to village level. As discussed before, the central government also has jurisdiction over groundwater, but it is the state governments that have the primary jurisdiction and responsibility for controlling and regulating groundwater use.

Through the National Environment Policy and National Water Policy, the central government is expected to play a role in the direction of groundwater development and management in the country. As mentioned earlier, the Central Ground Water Authority is charged with the regulation and development of groundwater as a prime natural resource of national importance. The activities of the Authority include notification of areas for regulation of groundwater development in severely overexploited aquifers, regulation of well drilling and groundwater abstraction in such areas, and building awareness on groundwater issues in the country. The Central Ground Water Authority includes the representative of and is headed by the chair of the Central Ground Water Board, which is a dedicated groundwater research and monitoring agency under the Ministry of Water Resources engaged in hydrogeological surveys and groundwater monitoring nationwide.

In addition to the Central Ground Water Authority and Central Ground Water Board, the various agencies at different levels in the government that are important actors in groundwater development and use are shown in Table 3.1.

It is clear that the oversight of groundwater issues is institutionally fragmented both within and across different levels of government. Table 3.1 shows more than 15 government agencies with specific mandates associated with groundwater resources and related water services. Given the ubiquitous use of groundwater and its pertinence

to various sectors, this large number of agencies is neither unexpected nor unusual in the global context. However, a large number of agency players impacting a vital resource without effective coordination or regulatory oversight translates into a significant governance challenge for groundwater management in India. The roles and responsibilities between state and central groundwater institutions are not sufficiently defined. The Central Ground Water Authority's groundwater rules for regulation, development, and management are still pending approval and many states have reservations regarding the mandate of the Central Ground

TABLE 3.1 Main government agencies relevant to groundwater

Level	Unit	Main functions	Ground water resources	Water services
Central Groundwater Development & Management	Central Ground Water Authority	Established in 1997, following Supreme Court orders, mainly to regulate, control, manage, and develop groundwater resources in the whole country and support states	○	
	Central Ground Water Board	Established in 1950 for dedicated groundwater research and monitoring, to support overall planning for development of groundwater resources in the country, and to provide support to states	○	
	Central Pollution Control Board	Norm setting on industries' water use and wastewater discharge	○	○
	Ministry of Commerce and Industries	Policy decisions and water use norm setting on water related to industry	○	○
	Ministry of Environment and Forests	Planning, promotion, coordination, and overseeing implementation of environmental and forestry programs and implementing the Environment (Protection) Act 1986	○	
	Ministry of Rural Development	Rural development, land resources, and drinking water supply	○	○
	Ministry of Urban Development	Implementing the nationwide Jawaharlal Nehru National Urban Renewal Mission, with significant interventions in water supply, sewerage and sanitation; Water supply and sewerage for the National Capital Territory of Delhi and the Union Territories	○	○
	National Water Board	Established in 1990 under Ministry of Water Resources, apex organization with responsibility for progress achieved in implementation of National Water Policy and other issues, reports to National Water Resources Council	○	○
	National Water Resources Council	Established in 1983 with prime minister as chair, minister of water resources as vice-chair, and concerned Union ministers/ministers of State, chief ministers of all states, and lieutenant governors of union territories with secretary of Ministry of Water Resources as member secretary	○	○
	Ministry of Water Resources	Setting policy guidelines and programs for development and regulation of the country's water resources, but functions specific to groundwater resources through Central Ground Water Board	○	
	Oil and Natural Gas Commission	Member of Central Ground Water Authority and supplements deep well logging information	○	

Level	Unit	Main functions	Ground water resources	Water services
Central Financing Institutions	Rural Electrification Corporation	Development financing institution that finances and fully coordinates and oversees Special Project Agriculture		○
	National Bank for Agriculture and Rural Development	Responsible for refinancing and standardizing substantial part of private sector groundwater	○	○
State	State electricity boards	Single window to individual farmers for obtaining pump set energization		○
	State government departments	Principally responsible for groundwater use and control, as water is primarily a state subject	○	○
Local	Panchayats	Rural water supply, but to be devolved more water services and water resource management functions	○	○

Water Authority for control and regulation, given that groundwater is primarily a state subject. Although the Central Ground Water Authority and Central Ground Water Board have the potential to become champions of sustainable groundwater management in India, the continued lack of clarity over their status and chronic understaffing means central government institutions cannot properly fulfill their functions and effectively support state agencies.

The institutional and administrative environment also varies considerably between states. A comparative review of organizational structures at state level reveals a very diverse picture. Some states, for example Andhra Pradesh and Maharashtra, have dedicated groundwater authorities, whilst others, such as Haryana, only have small groundwater cells as part of their irrigation departments. In almost all cases, groundwater agencies are not adequately equipped for taking up the role of groundwater management. The major issues pertain to the following:

- ◆ Groundwater agencies are almost nonexistent in many states. In Punjab, a leading agricultural state where 80 percent of groundwater blocks are threatened by overexploitation, groundwater monitoring and management for the 20 districts of the

state is the responsibility of the Groundwater Directorate, which is staffed by only five hydrogeologists. Even in states such as Andhra Pradesh and Maharashtra, which boast the best groundwater departments in the country, staffing strength and profiles are grossly inadequate compared to what is needed. The situation is further worsened by the decades-long hiring freezes resulting in a large fraction of vacant positions and a steady loss of institutional wisdom with the retirement of experienced personnel.

- ◆ Groundwater organizations are generally located at a relatively low level in the state hierarchy, often in the departments whose interest is focused on one of the main water uses, for example irrigation or water supply. Even where they are considered an independent department, they report either to the irrigation or water supply minister, and are a relatively minor part of the minister's charge.
- ◆ The structure, functioning, and staffing of groundwater agencies conform primarily to the long-outdated mandate of surveying and developing the groundwater resource, and are not oriented to paying any attention to the users and the socioeconomic

dimensions of groundwater use. Resource management functions currently receive very scant human and financial resources compared to surveying, monitoring, and development of groundwater.

These shortcomings of the state agencies represent a major implementability constraint for any kind of groundwater management in India. As discussed in Chapter 5, removing this constraint also constitutes a pragmatic and politically feasible first step towards addressing the challenge of groundwater management in the country.

Groundwater use in India: Sector policy environment

In most environments, the modalities of groundwater use are strongly contextual. In agriculture, for example, groundwater use depends significantly on energy options and costs of pumping, availability of surface irrigation, and cropping choices. Similarly, the unreliability of urban domestic and industrial water supplies is the primary driver of self-provision through private wells in urban areas. Table 3.2 presents an overview of these sectoral linkages.

TABLE 3.2 Main groundwater-related policies and scope for coordination and synergy

Policy area	Description	Current situation & action needed
Crop policy		
Food crops procurement	Major impact on cropping patterns due to purchases and price guarantees	Minimum support prices for some water-intensive crops such as paddy are a key constraint for crop diversification in many states
Subsidies on Inputs		
Electricity	Subsidized power at odds with sustainable groundwater management but major burden on state exchequers is the key problem	Free electricity for irrigation pumping in place in several states; high-level dialogue towards effective application of realistic tested measures urgently needed
Micro irrigation	Better if linked to local supply and service network and demand management measures	Programs popular when linked to improvements in crop production and ease of use
Moisture management	Mulching, composting, and improved field irrigation can reduce water consumption	Some projects and pilots support extension services covering soil moisture management
Recharge programs		
Rainwater harvesting and recharge	Potential to increase recharge, but challenge is maintenance, farmers' investment, and link to demand management	States and central government implementing large-scale programs but unlinked to water demand measures
Sand and gravel mining	Sand and gravel loads of rivers key in storing floodwater and in recharge. Sand dams can also harvest sand	Extraction in India is largely uncontrolled and many local river sections are being depleted
Land use planning		
Protection of recharge areas	Designated sensitive areas can help control polluting activities	Not yet common in India, even for urban areas
Road planning	Roads can retain, channel, and recharge water, but inadequate cross-drainage can cause waterlogging	Ambitious yet only partly fulfilled plans to improve the national road network in India. Linkage opportunities should be explored
Housing	Building codes can include rooftop water collection and recharge of aquifers	In place in several major cities. Care is required to ensure harvested rooftop water can infiltrate
Solid waste disposal	Hazardous waste landfills need careful siting and sealing to prevent contamination of groundwater	Proper management strategies and regulation implementation urgently needed to cope with massive widespread problem in India

Policy area	Description	Current situation & action needed
Petrol pumps	Oil and petrol leaks can be major contaminant of groundwater	Hardly any effective regulation
Economic planning		
Tourism	Can place a high groundwater demand, especially in fragile coastal areas	With over 382 million per year, domestic tourism in India is on the increase. Planning of water supply and waste disposal required
Sugar mills	Should be located in areas with ample water supply away from hard-rock aquifers	Several located in fragile groundwater-dependent areas, which need to be avoided
Industrial estates	Encouraging small and medium industries to relocate to industrial estates with local wastewater treatment facilities to avoid dispersed pollution	In several states there is a move to central wastewater processing units on industrial estates. This could be useful but requires careful assessment to avoid concentrating pollution
Industrial planning	High-water-consuming plants should be sited in areas with adequate water supplies	The Coca-Cola bottling factory case in Kerala highlighted the need to make use of the provisions in the relevant state acts (Pollution Control Act, Environment (Protection) Act, Groundwater Act) and couple this with regulatory provision by the local government
Mining	Several areas in India seem to have promising deposits but careful protection is required from pollution from mine tailings, and there is considerable scope for waste-to-resource programs	Groundwater protection around mining areas in India is still in its infancy and more work is required, especially around selected hotspots

There is an extensive and growing body of literature on the evolution of sectoral policies, which have had serious implications for groundwater use in India (Shah 2007; Jha, Srinivasan, and Landes 2007; Molle and Berkoff 2007). Of all these sectoral linkages, the one between groundwater use and policies pertaining to provision of power to farmers is so prominent in India that it is referred to simply as the “energy-groundwater nexus”. Groundwater irrigation is heavily dependent on access to electricity, and is estimated to account for anywhere from 15–20 percent (Shah 2007) to 31 percent (Kumar 2005) of the total electricity consumed in India. Most of the states are providing electricity to farmers at a heavily subsidized flat tariff, whereby farmers are charged a fixed rate (based on the pump horsepower) independent of the actual amount of electricity consumed. Some states are also providing free electricity to farmers, and the promise of free power was a common and popular campaign promise in the last round of elections in many states. Flat rate tariffs and

cheap electricity provide no incentive for judicious use of water and power by farmers, and there is broad consensus that they have contributed to accelerating groundwater use and overexploitation in the country since the 1980s (Narayana and Scott 2004), resulting in an almost steady increase of 5.5 percent per year in the number of critical groundwater blocks across the country. In addition to the perverse incentives it creates for groundwater pumping, free or cheap power is also a severe threat to the bottom line finances of state electricity boards, which are saddled with losses incurred from massive nonrevenue exposure to the agricultural sector.

In the current environment, where in practice no direct legal or administrative control exists on groundwater use, the economic signals contained in the agriculture, power, and other sectoral policies have become the prime determinants of groundwater use, even though these policies were designed without any consideration of their

possible impacts on groundwater use. It is clear that the governments will need to rectify these policy distortions if a sustainable long term solution has to be found for addressing groundwater overexploitation.

However, as described in the following chapters, there are serious political economy obstacles to reforming such sectoral policies in the immediate term. Therefore, an interim “Plan B” is needed whereby the some of the desired objectives of policy reform maybe achievable through innovative technical alternatives that sidestep the politically difficult decision-making process. Gujarat’s experiment with separation of electricity feeders for agricultural power supply (Box 3.2) has been successful in giving the state effective control over electricity and groundwater consumption in agriculture, and can provide at least an interim solution to other states for resolving the hitherto irresolvable energy–groundwater nexus.

Introducing high-level policy reform – to what end?

A discussion of the need for policy reform first requires an identification of instruments of groundwater management that could be considered appropriate for specific settings in India, and that would need to be introduced or strengthened through a legislative initiative. The four main categories of groundwater management instruments presented earlier are now assessed for their potential applicability and effectiveness in physical and institutional settings of groundwater overexploitation in India.

Regulatory measures

Global experience suggests that regulation of groundwater abstraction is a challenging undertaking. Effective regulation needs not only sound legislation and a viable regulatory institution, but also the administrative capacity to readily

Box 3.2 The Jyotirgram scheme in Gujarat

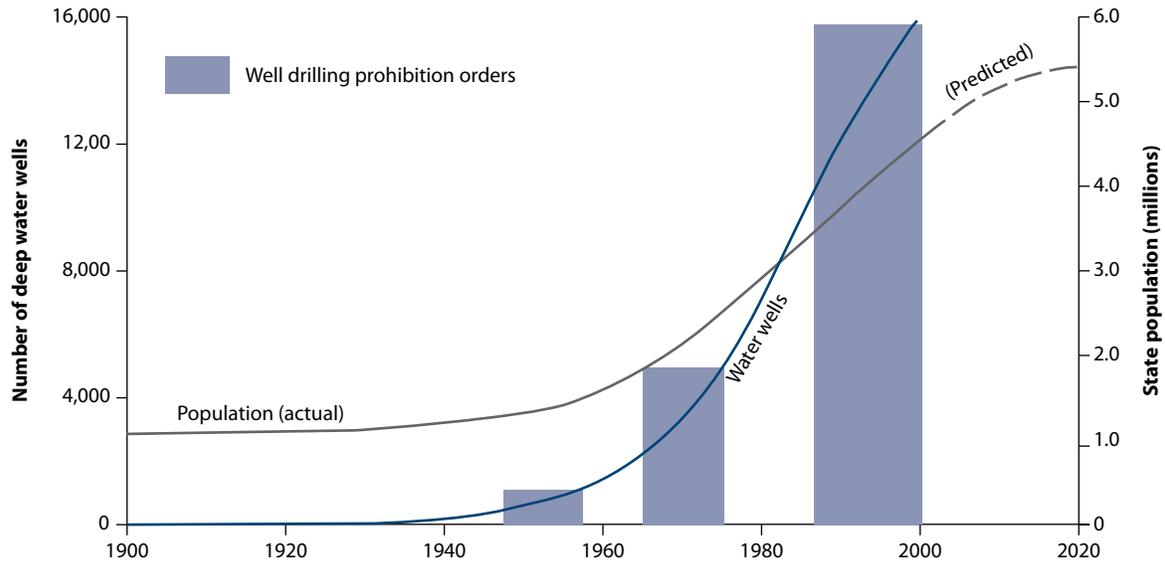
In 2003 Gujarat initiated a statewide scheme for separating the electricity feeders for agricultural power supply from those for nonagricultural use supplies in the rural areas (Shah and Verma 2008). The key objective of the scheme, which was implemented at a cost of US\$260 million, is to provide an agreed amount (8 hours) of high-quality and high-reliability power to farmers, and to provide 24-hour supply to nonfarm uses. The farmers agree to accept de facto rationing because reliable power supply on an announced schedule is preferable even for a limited number of hours during most of the year, as long as demand during the peak irrigation time is also met.

The implementation of this scheme has resulted in

- ◆ significant improvements in village quality of life and in the nonfarm village economy through separation of the rural domestic, industrial, and institutional power supply from the impacts of decisions regarding agricultural power supply;
- ◆ more efficient use of power and groundwater in agriculture, due to the high reliability of power available on a preannounced schedule;
- ◆ 37 percent reduction in aggregate use of power in groundwater irrigation between 2001 and 2006, and a concomitant reduction in groundwater draft.

This measure of separating farm power supply from other uses in rural areas has provided the state with an effective switch with which power and groundwater use in agriculture can be regulated at various levels. The one adverse effect of this intervention has been the loss of water availability to the marginal farmers who relied on informal water markets, which have shrunk significantly due to power rationing. This downside can be addressed and the gains of the intervention further enhanced if the farm power supply can be provided on a demand-adjusted schedule based on identification of farmers’ requirements.

FIGURE 3.2 Increase in water well drillings with increasing regulation in Guanajuato state, Mexico



monitor and enforce rules. This becomes extremely difficult when there are large numbers of very small users. Figure 3.2 illustrates how the number of water wells has grown with increasing regulation in Guanajuato state, Mexico, as people drill wells in anticipation of regularization deadlines after which new wells would be banned in overexploited aquifers. Both in terms of population and water well density, Guanajuato is much smaller than a typical Indian state, but is emblematic of problems faced by a regulatory approach for managing groundwater overexploitation.

India faces even greater monitoring and enforcement challenges, with the number of groundwater structures last counted at 19 million and now estimated to be between 23 million and 25 million. The administrative capacity of regulatory institutions at both the central and state levels is weak. As described earlier, the Central Ground Water Authority is authorized to notify critical groundwater areas where stringent regulations on groundwater abstraction can be imposed. Currently 1,615 groundwater blocks (of a total of 5,723 groundwater blocks in the country) are classified as semi-critical, critical, or overexploited. Of these,

the Central Ground Water Authority has notified 43 overexploited blocks for regulating groundwater exploitation and 65 blocks for registration of abstraction wells.

In these notified blocks, the Central Ground Water Authority has been issuing directives for enforcement of various measures such as registration of groundwater abstraction structures, registration of drilling agencies, and regulation of groundwater development by new users (including industrial users in overexploited and critical blocks). Directives issued to district administrative heads in notified areas permit sealing of the illegal tubewells, seizure of drilling equipment, and disconnection of electricity supply to the energized illegal wells.

Notwithstanding the expansive scope of these regulations, neither the Central Ground Water Authority nor the state groundwater agencies that are supposed to oversee the enforcement of these regulations have the resources and personnel required for the task. Furthermore, the offices of the district commissioner or district magistrate, which have been authorized to take necessary action in cases of violation of Central Ground Water

Authority directives in the notified areas, are the hub of all administrative activity and are unlikely to find the resources to pursue enforcement violations. It is a telling example of the lack of enforcement resources that drilling of wells continues unabated and groundwater tables are falling by as much as 1.5–2 meters annually in the two notified districts of south and southwest Delhi (Times of India 2008), in the immediate neighborhood of the Central Ground Water Authority's office.

The enforceability of the legislation has been a major problem even in those states where it is narrowly focused on protecting drinking water sources. It can be safely concluded that it is practically impossible for the states to marshal the supervisory resources needed for enforcement of command and control measures over millions of wells. Therefore, enacting and enforcing stringent groundwater regulations can be a viable strategy only for protecting severely threatened resources in a relatively smaller number of active management areas, and this is already allowed by the existing legal framework.

Economic instruments

Introduction of pricing provides a substitute to coercive instruments for achieving resource conservation and sustainable management of groundwater, because volumetric charges or resource use fees create incentives for users to move towards efficient allocation of the resource. Groundwater pricing has been attempted and is a part of groundwater governance regimes in many countries, for example China, Israel, Jordan, Mexico, and the United States. A tax or a resource use fee is the more traditional form of pricing, but collection and enforcement of such fees has been found to be difficult where there are large numbers of resource users or poor governance environments (Shah 2009). Pricing has been more successful when used to create incentives for moving water to higher-value uses. Examples include the municipal water utility in Chennai paying farmers to sell borewell supplies

for meeting urban water needs (Briscoe 1999), and numerous European cities paying periurban farmers to adopt agricultural practices that protect the water quality of aquifers being tapped for urban use (Shah et al. 2000).

The debate on introduction of pricing mechanisms for water has often raised equity concerns, focusing on questions about the ability of the poor to pay market prices for a basic need such as water. Hybrid approaches that combine a well-defined, free and universal basic right allocation of water with economic pricing above a threshold quantity have been successfully implemented (for example in South Africa), and could therefore conceptually address such equity concerns (Iyer 2007). However, the main difficulty with pricing mechanisms in settings such as those of rural agriculture in India is that of implementation, because the state agencies simply do not have the administrative resources required for metering and monitoring groundwater use and collecting user fees. This concern of implementability is not always addressed adequately. Maharashtra, for example, is currently considering a groundwater management model that involves regulation of groundwater use from more than 1.5 million irrigation wells in the state, and includes provision of a levy on groundwater use and a ban on deep tubewells. The practicality of such measures appears doubtful when it is considered that merely the registration of users has proved to be a difficult challenge in Mexico and Spain, with a number of wells that is more than an order of magnitude lower than that in India. In order to get an idea of the transaction costs of implementing such measures in India (with close to 20 million wells today), it is helpful to note that it was owing primarily to the difficulties of metering close to 2 million wells that the state electricity boards were forced to switch to flat tariffs in the 1970s.

While the challenges of implementation make dim the prospects of setting up formal groundwater pricing in India, informal versions of groundwater

markets are thriving in rural India (Saleth 1994) and cover more than a quarter of the country's irrigated area (Mukherji 2004). Urban areas are also found to be served significantly by informal supply systems based mainly on groundwater (Londhe et al. 2004). Therefore, pricing mechanisms can theoretically be a viable instrument of groundwater management in India, if implemented through community-based approaches.

Tradable groundwater rights

Tradable property rights, if properly implemented, have the potential to alter the nature of the groundwater abstraction game. As shown in a general context (Coase 1960), the existence of well-defined rights is a required condition for resource users to reach socially acceptable and optimal outcomes through a process of negotiation and bargaining.

While the conceptual effectiveness of a tradable groundwater property rights regime is obvious, the real constraint in making it effective lies in the domain of implementation. The foundation of groundwater rights rests on the premise that the rights can be enforced, with transaction costs of enforcement mounting as the number of rights holders increases. The fundamental difficulty with property rights systems is therefore the same as that with regulation and pricing – the very high transaction costs of implementation.

The examples cited in the previous section (the city of Chennai buying water from farmers for meeting urban water supply needs, and European cities paying the periurban farmers for protecting the water quality of aquifers) indicate that introducing an element of pricing can improve allocation efficiency of groundwater. However, it is critical to establish the groundwater

Gram Sabha (village community) meeting with public officials, Pandherwadi village (Satara, Maharashtra)



rights prior to the setting up of pricing and transaction platforms. If quantitative rights are not established and credibly enforced, trading can create incentives for sellers to increase groundwater extraction and worsen the problem of overexploitation.

The scale of the challenge of implementing groundwater property rights is made clear by the experiences of other countries. After 20 years of nationalizing groundwater and instituting a system of groundwater use permits, the recording of groundwater rights remains incomplete in Spain and only less than a quarter of groundwater structures have been registered. Mexico has similarly lagged behind in registering the water rights of the 96,000 tubewell irrigators that account for 80 percent of the total groundwater use in the country (Shah 2009). Measures taken in Australia and the United States have generally been considered successful but involve exempting the relatively small groundwater users for the purpose of reducing transaction costs. Hence, Nebraska targets groundwater wells with a pump capacity of 50 gallons per minute or more, and Australia does not regulate groundwater for those irrigating less than 2 hectares of land. It has been estimated that adopting a similar *de minimis* approach in India would leave more than 95 percent of users outside the system (Shah 2009). If a property rights-based approach were to be developed for managing abstractions by such a large number of small abstractors, it is clear that it could only be implemented by users themselves, which again points to the inevitability of community self-governance models.

Community management of groundwater

Strictly speaking, community groundwater management refers not to a specific instrument but to a means of implementing management interventions. The key is that the resource user community (instead of the state) is the primary custodian of groundwater and is charged with

implementing management measures. Hence, community groundwater management can involve any mix of instruments, including regulation, property rights, and pricing.

As described in the following chapter, many instances of successful community groundwater management in India are characterized by the presence of charismatic leaders or are very location specific, and therefore do not offer a process-based approach or a model that can be implemented at scale. Internationally, the systematic and large-scale experience in community-based groundwater management comes principally from Mexico and Spain, which have adopted community-based models as the central element of their official groundwater governance and management policy. In both these countries, groundwater user associations or aquifer management councils have been statutorily promoted as the institutions for collective and participatory self-governance of aquifers. While these community institutions have been successful in some regards, they have not been able to achieve the basic objective of demand management to ensure sustainable use of groundwater resources. In Mexico, for example, the aquifer management councils (called COTAS) have achieved significant results in raising groundwater user awareness and in promoting watershed conservation (GW-MATE CP-10), but have failed in making any impact on groundwater abstractions. It has been noted that the COTAS have avoided the task of monitoring actual groundwater withdrawals by the farmers, and in general are not likely to survive as sustainable farmer organizations if the National Water Commission were to stop paying their dues (Shah 2009).

Notwithstanding these general experiences with systematic adoption of community-led groundwater management approaches, there are interesting points of light. The Santo Domingo aquifer in Mexico was severely depleted due to excessive abstractions for irrigated agriculture, and regulations were issued in 1992 to address

the problem. When the regulatory measures were found to be having little effect, the COTAS took the lead in designing and implementing incentives for increasing irrigation efficiency, rehabilitating pumping equipment, installing and monitoring groundwater abstraction meters, and monitoring groundwater levels. With strong support from the National Water Commission, these measures resulted in more than 60 percent reduction in groundwater abstractions from 1995 to 2006, with the water table rising from 130 meters to 8 meters below ground level (Cordova Urrutia 2007). While the community management model has obviously succeeded in meeting the basic objective of sustainable groundwater use in Santo Domingo, the secret to this success lay in the fact that the user community for this aquifer consisted of a relatively small number of commercial farmers who could afford to invest in water-saving irrigation and to buy the groundwater rights of those willing to give up irrigated agriculture. The case of the Ogallala aquifer (in the High Plains region of the United States, and accounting for one fifth of the total wheat, corn, cotton, and cattle production of the country) is often offered as another example of successful community-based groundwater management. Since the recharge rates into the aquifer are very small compared to both storage and abstractions, aquifer communities have attempted to undertake, and are succeeding in achieving, a managed depletion rather than sustainable management of the aquifer (Terrell, Johnson, and Segarra 2002).

An assessment of these experiences for possible application in India indicates that merely substituting the community for the state cannot work unless the groundwater management interventions are structured to serve the basic interests of the users, taking into account the socioeconomic realities of each particular groundwater setting (Planning Commission 2007). Therefore, while it is clear that the circumstances of groundwater use in most settings of India necessitate the adoption of community-based

management approaches, the available global experience offers little direction for design of such interventions. Developing a framework for design and implementation of community-based groundwater management in different settings of India is hence the central part of the challenge of addressing groundwater overexploitation, and the following chapter is dedicated to a detailed presentation of lessons from Indian experiences for developing such a framework.

Limitations of standard instruments of groundwater management for addressing overexploitation in India

Even though a difficult political economy is often cited as the primary reason for the infeasibility of legislative reforms to introduce effective regulation, groundwater pricing, or property rights, it is also clear that the appropriateness of these prescriptions is doubtful for most of the groundwater settings in India. Therefore, front-ended policy reform focused on these approaches is not a credible solution to the problem of groundwater overexploitation in India, at least not until the central “how to” challenges of implementation can be resolved. Since it is unrealistic to expect that the state will ever have sufficient administrative resources to directly implement management interventions, community-based management approaches emerge by default as the only viable mechanism, especially in rural agricultural settings with a large number of users. However, it is also clear that there are no templates available for designing community-based groundwater management models, and that India will likely need a home-grown solution.

Conclusion

The review of the formal institutional environment for groundwater use in India reveals that there do not exist credible mechanisms that can directly influence groundwater development and use. This lack of an active and direct management framework

may not be so unexpected, because the explosive growth in groundwater use that is causing the overexploitation of aquifers has essentially been furtive, and continues to happen outside the domain of the government. Groundwater therefore remains essentially ungoverned: the turning on of the borewell pump by a farmer in most of the Indian countryside is an act unfettered by any central, state, or local law or administrative control. The title of a comprehensive account of groundwater use in South Asia aptly refers to the current situation as “anarchy” (Shah 2009), and it is only very recently that the crisis of overexploitation has started to push the issue of groundwater governance into the domain of the state.

An assessment of different groundwater management instruments in the macro context of resource use patterns and the institutional environment in India points to the suitability of community-based groundwater management approaches, which rely primarily on the voluntary action of resource user communities. The next

chapter presents a detailed case study of the Andhra Pradesh Farmer-Managed Groundwater Systems Project (APFAMGS), a community-led groundwater management initiative where hundreds of communities have achieved remarkable results in moving towards sustainable groundwater use. This example, along with the emerging lessons from various other community-led initiatives, indicates that carefully designed community-based approaches hold significant promise for addressing groundwater overexploitation issues, especially in hard-rock aquifers. The example of APFAMGS emphasizes the imperative of defining groundwater management objectives and designing a management approach according to the specific local hydrogeological and water use realities. At the same time, the radical achievements of this initiative challenge some of the underlying assumptions in the discourse and practice of groundwater management in India, especially the notion that legal and policy reform is a necessary first condition for attempting groundwater management in the country.

A Groundswell of Change: Potential of Community Groundwater Management in India

Introduction: The promise of community management

A search for successful examples of community management of water resources in India brings up the names of charismatic leaders who have inspired brilliant action by communities on conservation and stewardship of their local water resources. The sagas of these leaders and communities, scattered across India, are a significant element of the discourse on community management of water resources, because they serve as rare points of light in an otherwise dismal scenario of neglect, mismanagement, and degradation.

Rajendra Singh, proclaimed the “water man of India”, has led numerous rural communities in the Aravali hills of Rajasthan to undertake watershed development, construction and care of traditional water bodies, and formation of local governance mechanisms, leading to tangible improvements in lives and livelihoods and an almost mythical resurrection of dried-up rivers. Anupam Mishra, through his simple book *Aaj bhi khare hain talaab* (“Ponds are still relevant today”), spurred the renewal of interest in community water management systems. The book, which is intentionally not copyrighted but available in 14 languages and one of the most widely

printed books in India, has inspired communities across the country to engage in conservation and revitalization of local water systems. Anna Hazare and his disciple Popat Rao Pawar, both recognized with national awards for their work, have set perhaps the best-known examples of community revival through participatory watershed and water resource management in villages in Maharashtra. Popat Rao Pawar’s village of Hiwre Bazaar presents a shining example of community self-regulation of groundwater, where farmers in a semiarid agricultural setting have voluntarily limited irrigation to dug wells, and where community uptake of government programs on watershed development and groundwater recharge has transformed a village previously stricken by regular droughts and crop failures into one of the most prosperous villages of the country.

Each of these stories is different in its genesis, approach, emphasis of efforts, and resulting achievements, and each is tied uniquely to local natural conditions and social milieu. Collectively, these examples have created within the national discourse constituencies of support for a paradigm that provides an alternative to the state control of water resources. In the context of community groundwater management,

these examples of watershed development indicate that under appropriate conditions and with adequate leadership communities can successfully come together to work on augmenting the supply of local water resources. However, as discussed in the preceding chapters, increased supply cannot address the challenge of groundwater overexploitation in India. Given the widening gap between the actual and sustainable levels of groundwater abstraction, any credible management strategy needs to have at its core demand-side management of groundwater, which remains notoriously difficult to achieve.

Even more importantly, while these examples provide inspiration, they do not come close to providing a model that governments can support and implement at the scale required for managing groundwater overexploitation in the country. The key questions for community management of groundwater are therefore the following:

- ◆ Is there a viable model of demand-side management of groundwater by communities? Can the government engage with communities to facilitate collective action on groundwater management, and if yes, how?
- ◆ Are scale interventions possible? More specifically, for a vast majority of India's 600,000-plus villages, which are often not blessed with brilliant local leadership and the unique natural and social settings enabling that leadership, could there be a process-based approach that can be implemented to address a crisis that deepens with every passing day?

It is against the background of these questions that the experiences of community groundwater management in Andhra Pradesh are presented in the following sections. Most of the presentation is focused on a detailed discussion of the Andhra Pradesh Farmer-Managed Groundwater Systems

Project, which is chosen for illustrating the key emerging lessons on community-based groundwater management.

Background: Groundwater in Andhra Pradesh

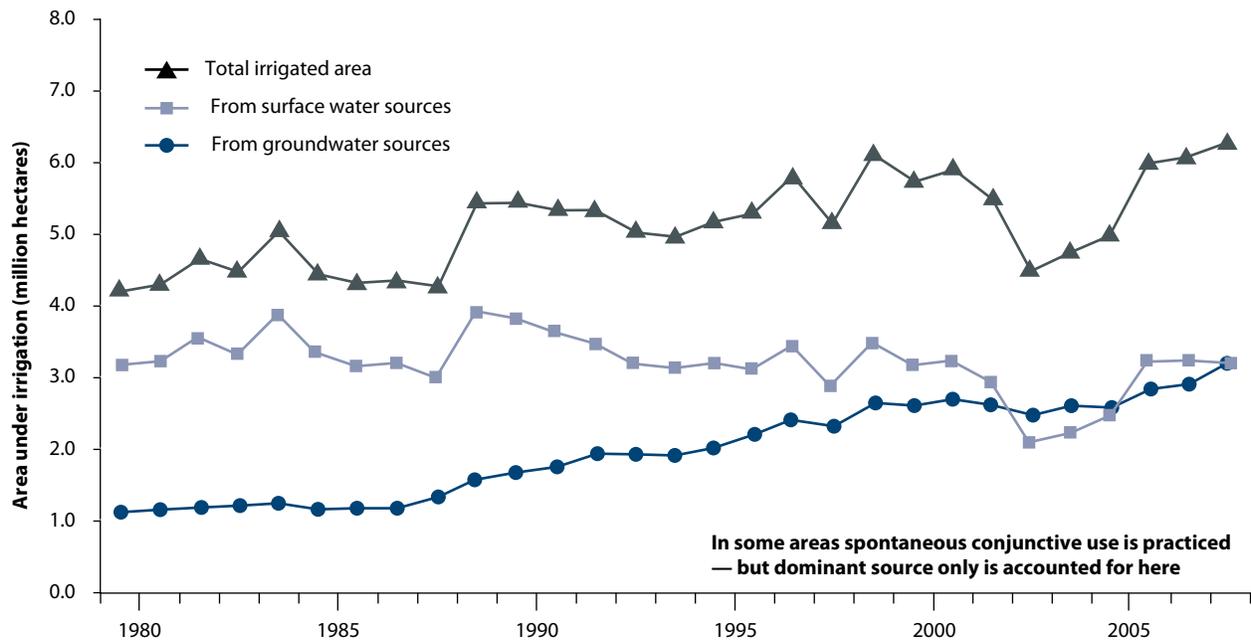
Around 85 percent of the land area of Andhra Pradesh is underlain by hard-rock aquifers. There has been a rapid growth in the number of borewells in the state over the last three decades, to the current estimated total of at least 1.74 million, with depths steadily increasing during this period from about 30 meters to over 60 meters. While this period has seen a twofold-plus increase in the area under groundwater irrigation, with very little public investment in groundwater management, the area under surface irrigation has not increased over the same period (Figure 4.1), despite substantial investments.

But this massive expansion of groundwater use has had serious impacts. In 2008, 300 of the 1,227 groundwater blocks in the state were at critical or overexploited levels, and a further 208 were at the semi-critical level. In groundwater blocks that are outside the command area of canals, average resource use is 78 percent of the total potentially available groundwater replenishment, and in many districts it has risen to above 100 percent.

Andhra Pradesh Farmer-Managed Groundwater Systems Project

The Andhra Pradesh Farmer-Managed Groundwater Systems Project (APFAMGS) is a nationally executed project of the Food and Agriculture Organization of the United Nations (FAO) in India, implemented by a nodal executing agency in seven drought-prone districts of Andhra Pradesh. The objective of the project is to equip groundwater user farmers with the necessary data, skills, and knowledge to manage the groundwater resources available to them in

FIGURE 4.1 Evolution of total areas irrigated under groundwater and surface water in Andhra Pradesh, 1978–2008



a sustainable manner, mainly through managing and monitoring their own demand. Under the present Study and Technical Assistance Initiative on Groundwater Management in India, the World Bank commissioned a farmer survey and remote sensing analysis to assess water use, crop diversification, farmer incomes, and other aspects of the project. APFAMGS also made available its database covering the project physical area and more than 25,000 participating farmer households. Assessments based on these diverse data indicate that more than 500 communities in different agroeconomic settings across the project area have begun to bring their water use in line with groundwater availability, which includes reduction in groundwater abstractions in the years when the recharge is low. The challenge of addressing groundwater overexploitation has seen few successes, especially in developing countries. Although APFAMGS is still ongoing and a final results assessment has not been conducted, these achievements of the project make it stand out as the first global example of large-scale success in community management of groundwater use.

APFAMGS approach

The core concept of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle, and limited availability. In order to achieve this, the project has adopted an approach aimed at demystifying the science of groundwater by translating the scientific concepts of hydrogeology and groundwater management and making them accessible to groundwater users who often have limited literacy skills. The education is participatory and emphasizes nonformal modes of learning.

Unlike the standard practice whereby the targeted community is a mostly passive recipient of technical information on the status of their local resources, the APFAMGS approach engages the farmers in data collection and analysis, thereby building their understanding of the dynamics and status of groundwater in the local aquifers. The project provides farmers with the equipment and skills to collect and analyze rainfall and groundwater data. APFAMGS farmers are measuring and keeping

daily track of rainfall, water levels, and well yields, calculating groundwater recharge from monsoonal rainfall, and estimating their annual water use based on planned cropping patterns. The project is essentially transforming farmers into “barefoot hydrogeologists”. APFAMGS also facilitates access to information about water-saving techniques, improved agricultural practices, and ways to regulate and manage farmers’ own demand for water. The project does not offer any incentives in the form of cash or subsidies to the farmers: the assumption is that access to scientific data and knowledge will enable farmers to make appropriate choices and decisions regarding agricultural practices and the use of groundwater resources.

This assumption holds particularly true for agricultural settings in hard-rock aquifers, because the information on groundwater availability, if and when available, can serve as a very important input into the risk management paradigm of the farmer. The hard-rock aquifers have low storage and fast response times, so they fill quickly during the monsoon and also deplete quickly with use. More importantly, they do not generally have appreciable volumes of deeper long-term storage that can be tapped with benefit, as is the case with alluvial aquifers. As pumping continues during the rabi season, the water levels start falling and wells start going dry, with attendant consequences for standing crops. Therefore, having an estimate of the aquifer budget (available groundwater and projected demand, as explained in the following sections) gives the farmers an important element of information on the risk to their rabi crop, and provides this information in time before the rabi planting. Repeating the experience over years provides a frame of reference for farmers whereby they can correlate aquifer budget numbers in different years with the results of their cropping decisions.

APFAMGS process

The two principal processes employed by the project are participatory hydrological

monitoring and crop water budgeting. The core organizational component of the project is the groundwater management committee, a village-level community-based institution comprising all groundwater users in the community, particularly men and women farmers. The groundwater management committees of all the villages sitting atop an aquifer are federated into an aquifer-level institution called the hydrological unit. The project has established 555 groundwater management committees falling under 63 hydrological units, and it is through these institutions that the communities in the project areas are collecting and analyzing data, and managing and implementing decisions for sustainable groundwater management.

At first glance, the complex hydrogeology of hard-rock aquifers and the limited literacy of the population engaged make participatory hydrological monitoring seem too ambitious. However, keeping focus on education as the core objective of the project and employing creative nonformal modes of learning has made this not only possible but also successful in achieving unprecedented outcomes in groundwater management.

Across the project area, approximately 7,000 farmers have been trained to collect data that are important for understanding the local aquifers. Farmers donate the land for installation of rain gauges, and at each of the 203 rain gauge stations a farmer records, every day, the rainfall at 8:30 a.m. At more than 2,100 observation wells, farmers carry out daily and fortnightly measurements of groundwater levels, and also conduct fortnightly measurements of pump well discharges. In all, more than 3,500 farmers, men and women, are voluntarily collecting data in 650 habitations across the project area. The data are maintained in registers kept at the groundwater management committee offices and are also entered on village display boards. At the aquifer level, hydrological unit members are trained to use these data for estimation of groundwater recharge into the aquifer following the end of the



Sarojamma (center, holding the instrument) with other women farmers, using a water level indicator to measure groundwater level in an observation well. Sarojamma is data collection volunteer for Muthayalapadu village (Kurnool district, Andhra Pradesh)

summer (southwest) monsoonal rains. Owing to significant variations in local hydrogeology, the calculations are specific for each aquifer and follow the standard methodology developed and used by the Central Ground Water Board.

The complement to participatory hydrological monitoring is crop water budgeting, whereby the quantity of water required for the proposed rabi (winter) planting is assessed at the aquifer level, and compared with the amount of groundwater actually available. The proposed water use is derived by aggregating the information collected from farmers on their intended rabi planting. The comparison of proposed water use with the available groundwater reserve gives the aquifer budget, which permits the groundwater users to see the net balance of water. Crop water budgeting is a process bound in time, starting at the end of the summer monsoon and culminating before the rabi planting in an aquiferwide meeting at which the budget is produced with thousands of

farmers in attendance. Carrying out this process at the aquifer level is consistent with the physical scale of the challenge, and also becomes a vehicle for creating an aquifer community. Well-trained facilitators manage the exercise, and the result of the crop water budgeting is reported back to all habitations. The groundwater budget, arrived at through broad-based collective action in the aquifer community and disseminated similarly through the community, crystallizes in one number the state of the aquifer and the gap between what is available and what is cumulatively desired.

The awareness of this number brings into the decision-making world of each individual farmer the knowledge of the status of aquifer reserves, something that has historically been a black box for the farmers. Around the world, farmers have learned to look at the sky, soils, and perhaps the possibility of profit in the local market before deciding what crops to plant, but for the first time now farmers can take into account the availability

of water in the shared aquifer, and plan their risk accordingly. It is important to note that unlike most other attempts at community groundwater management APFAMGS does not seek an agreement from communities to reduce their water use, and the farmers are free to make crop planting decisions and extract groundwater as desired. The project therefore relies solely on the impact of groundwater education to influence the individual decisions of thousands of farmers regarding which crops and how much of each crop to grow in the postmonsoonal season.

The main vehicle for education and capacity building in APFAMGS is the farmer water school, a meeting of around 25–30 farmers once every 15 days, with the learning process grounded in the farmers' own fields. Following the hydrological cycle centered around the monsoons, the farmer water school runs from June to May. In addition to education on groundwater (participatory hydrological monitoring and crop water budgeting), the curriculum includes exposure to techniques and interventions that can enable farmers to get higher returns from agriculture by switching crops, improving yields, and reducing input costs. The farmers accordingly learn about vermicomposting, green manuring, biofertilizers, mulching, intercropping, improved irrigation methods, and the system of rice intensification for

paddy (which can double the yields with only half as much water). The farmer water school employs multiple learning cycles, and trained farmers learn further by becoming farmer facilitators and instructors for the school in their respective habitations. The farmer water school has made organizers, planners, and advocates out of farmers (FAO 2008). The project has trained 1,700 farmer facilitators, 33 percent of whom are women, and the total outreach of the program is estimated at 1 million farmers.

APFAMGS outcomes: Demonstrating the potential of community management

The project outcomes presented here are from a collation of sources, including the 900-plus farmer sample survey and remote sensing analysis of selected project areas conducted for the World Bank by the University of Hyderabad (Box 4.1); the APFAMGS project database; and remote sensing analysis of project areas. The project is currently ongoing, and therefore the results are preliminary at this stage.

The data indicate that in a majority of the project areas, the interventions have succeeded in beginning to build a link between water availability and water use for agriculture. The core message of the project, that groundwater abstraction over the

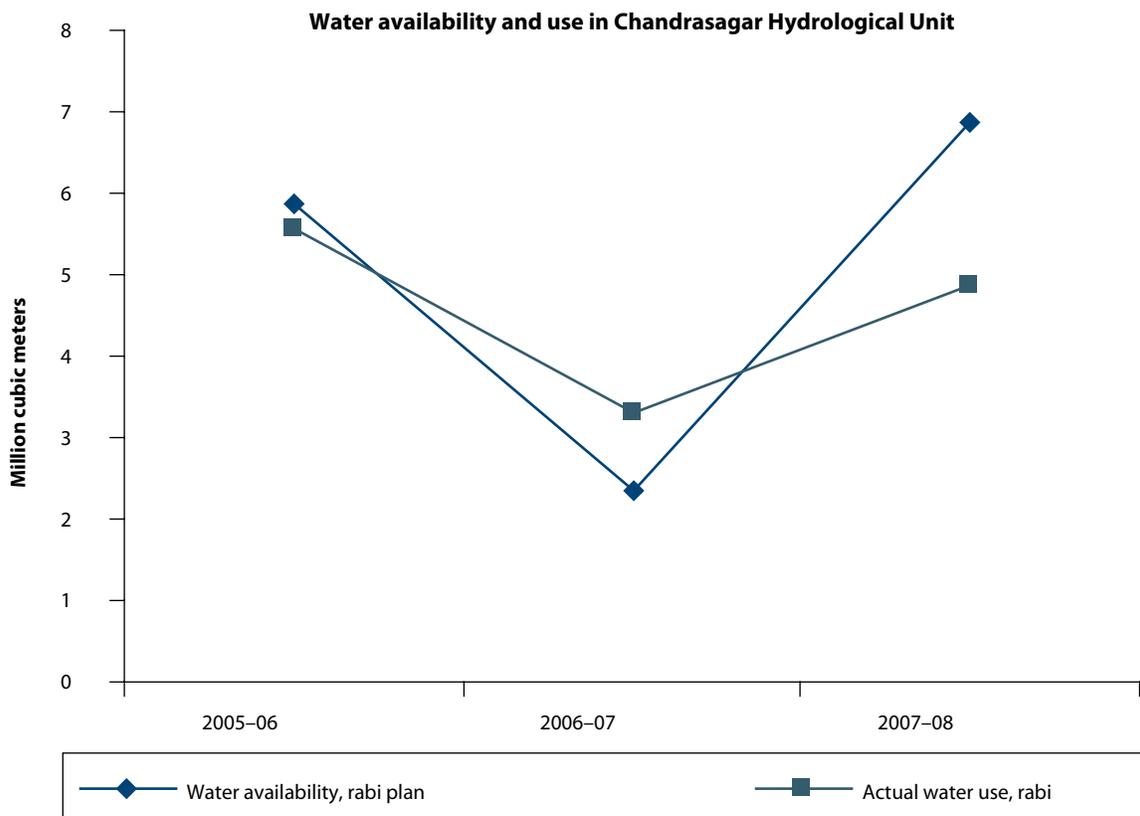
Box 4.1 Farmer survey and remote sensing to assess early results of APFAMGS

The main objectives of the farmer survey and the remote sensing analysis were (a) to compare the agricultural scenario and groundwater use patterns of farming households before and after the implementation of the project; and (b) to compare the current agricultural scenarios of groundwater user households in the project area with their counterparts in the nonproject areas. The remote sensing analysis was added to corroborate the APFAMGS data on cropping patterns in the project areas, and to establish a fast and robust technique for assessing cropping pattern differences in space and time.

The farmer survey covered more than 900 farming households in both project and nonproject areas. The survey covered 8 hydrological units with predominantly field crop areas and 2 hydrological units with predominantly horticultural areas, out of a total of 63 project hydrological units.

The surveys were conducted in the late rabi season of 2007–08, and the survey questionnaire covered a number of quantitative and qualitative dimensions of crop planning, farm economics, groundwater use, and farmer decision making. The remote sensing images of selected project areas during the rabi season in different years were used to independently establish the extent of crop pattern shifts.

FIGURE 4.2 Emerging evidence of APFAMGS communities aligning groundwater use with availability

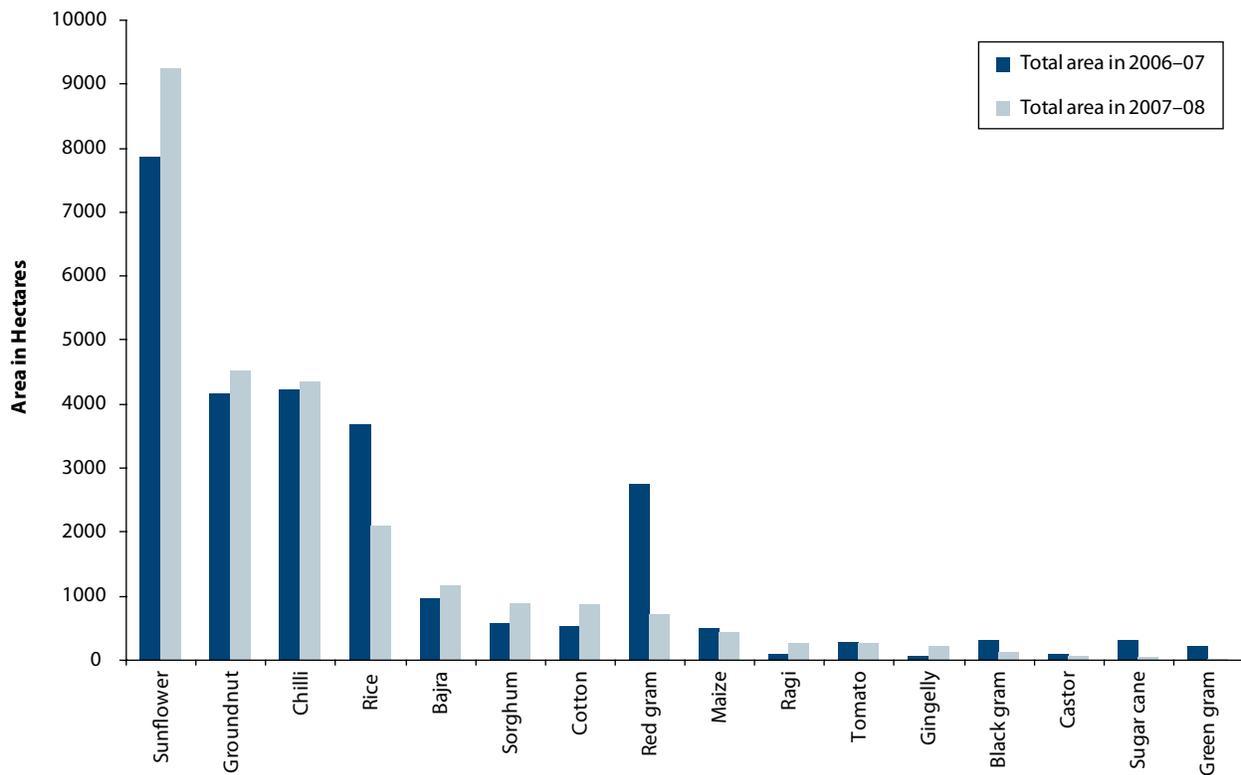


long term needs to be aligned with water availability, is taking hold. This is suggested by the emerging positive correlation between water availability and water use in a number of project hydrological units. In the years when water availability is low at the beginning of the rabi season (either due to low rainfall and consequently low recharge, or due to high groundwater abstractions in the kharif season decreasing availability for the rabi season), groundwater use is reduced in these aquifers (Figure 4.2). This dynamic is counter to the normal behavior whereby water availability in the aquifers is not a factor influencing groundwater use, and aquifer depletion often worsens in drier years. This path-breaking achievement is beginning to emerge in a number of hydrological units under the project, and is likely to result from the impact of groundwater availability information on farmer decision making, as agriculture accounts for the

largest fraction of groundwater withdrawals. Survey results from the project areas show that of the 14 possible factors influencing rabi cropping decisions, information on groundwater availability is the factor reported most often by farmers.

The reductions in water use in these areas are achieved by a combination of crop diversification and water-saving irrigation methods. Six of the eight hydrological units sampled in the farmer survey reported a reduction in the area under high-water-use crops (crops with more than 800 millimeters water requirement), with 50 percent reductions from baseline over two years in some cases. The cumulative changes by crop in the total project area over a recent two-year period are depicted in Figure 4.3. The changes have been accompanied by a significant (43 percent) reduction in rabi paddy area. In contrast, the total area under rabi paddy

FIGURE 4.3 APFAMGS: Shift in cropping patterns 2006–07 to 2007–08



in Andhra Pradesh continued to follow an upward trend, increasing by 5 percent in this period.⁴

Remote sensing analysis was used to conduct spot corroboration of crop pattern data in one selected hydrological unit (Yerravanka). The analysis is based on identifying the remote sensing signature of the high-water-use crops group (> 1,000 millimeters, including paddy, turmeric, banana, and sugar cane) and distinguishing it from that of the low-water-use crops group (< 375 millimeters, comprising black gram, green gram, gingelly, and millet), and then deducing the area under each group from satellite images during different seasons. The analysis indicates that the area under high-water-use crops in Yerravanka decreased by almost 11 percent from 2004–05 to 2007–08, whereas the area under the low-water-use crops increased by roughly the same amount.

⁴ Personal communication with Department of Economics and Statistics, Government of Andhra Pradesh, 2008.

It is important to note that farmers have not sacrificed profitability to reduce water use. Survey results show that project area farmers have consistently improved their profitability, with the net value of outputs nearly doubling during the project period, with inferior and more erratic results in similar nonproject areas (Table 4.1).

In terms of cumulative water abstractions, 42 percent of the hydrological units have consistently reduced the rabi draft over the three years of project operation, while 51 percent have reduced the draft intermittently, and only 7 percent have witnessed an increase in groundwater draft during this period (Figure 4.4). This impact is unprecedented, in terms of reductions actually being realized in groundwater draft, and in terms of the geographic extent of this impact, covering dozens of aquifers and hundreds of communities (Figure 4.5). While these results are preliminary and pose a number of questions on how exactly this impact has been achieved,

TABLE 4.1 Net value of outputs for project and nonproject areas

Hydrological unit/type of area	Net value of outputs per acre (rupees, current year prices)		
	Current year	Base year	% change
Project areas: field crops			
Chandrasagar	16,838	8,987	87.35
Mallapavagu	9,884	5,835	69.39
Nakillavagu	13,339	6,301	111.72
Narsireedypallyvagu	11,208	8,378	33.78
Erravagu	7,042	5,317	32.43
Peetheruvagu	7,583	7,124	6.44
Vajralavanka	18,051	9,420	91.62
Nonproject areas: field crops			
Nonproject areas near Chandrasagar	4,348	6,415	-32.22
Nonproject areas near Mallapavagu	3,491	2,605	34.01
Nonproject areas near Peetheruvagu	2,500	5,173	-51.67

they do indicate that the APFAMGS project, with an estimated outreach of 1 million farmers, may be the first example globally of large-scale success in groundwater management by communities. Furthermore, the approach is quite economical, with the average cost per village community estimated at US\$ 2,000 (Rupees 100,000) per year.

Unpacking the magic: Success in community management of groundwater

This section presents a deeper examination of certain salient aspects of the design of APFAMGS, as a case study in the “how-to-do” of community-based groundwater management. The “what-to-do” elements for successful community action on groundwater management are broadly known, and are often encapsulated in a three-pronged approach: (a) availability of actionable local-level information on groundwater; (b) social mobilization and organization for community action; and (c) provision of incentives to facilitate change, for example credit and extension services and market linkages. As illustrated below, the details of how these three elements are designed determine to a very large extent the success or failure of community groundwater management efforts.

Passive versus participatory education

A comparison between APFAMGS and the community groundwater management pilots ongoing under the World Bank-supported projects in Maharashtra illustrates two different approaches for making groundwater information available to communities. In the Maharashtra pilots, the Groundwater Survey and Development Agency conducts the technical assessment of groundwater availability and use. The support agency recruited

FIGURE 4.4 Changes in groundwater draft in APFAMGS hydrological units

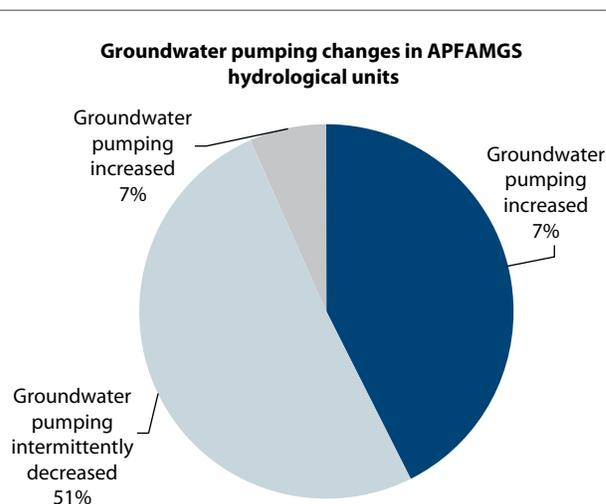
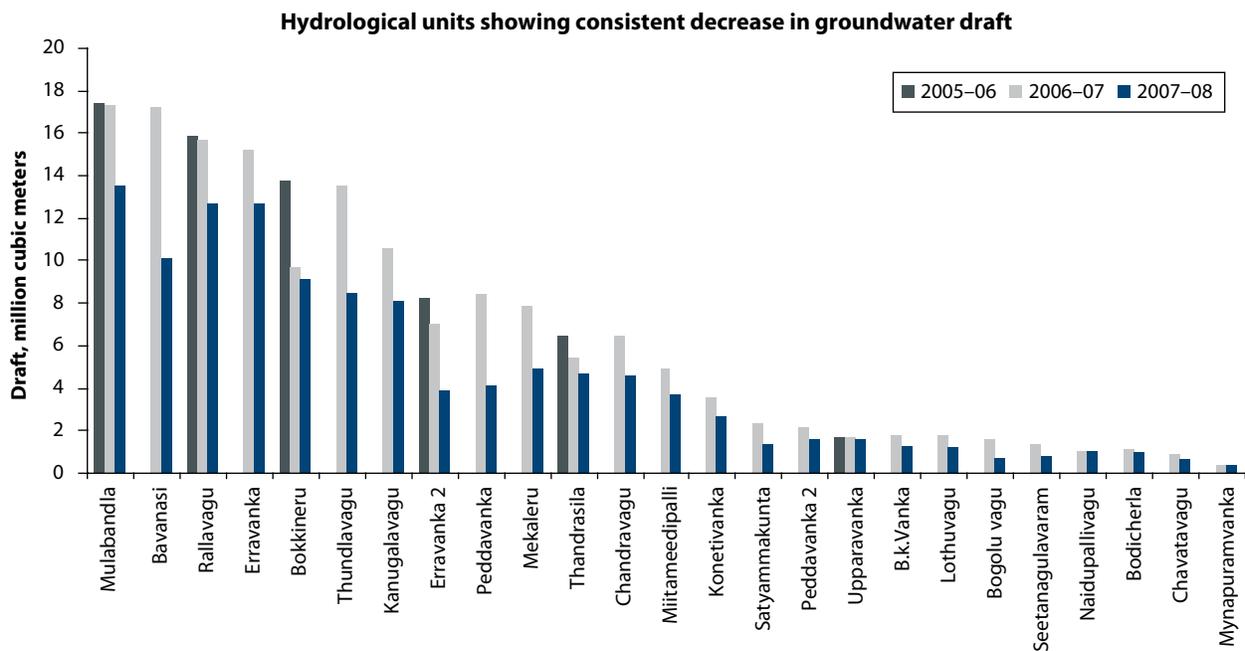


FIGURE 4.5 APFAMGS hydrological units showing consistent reductions in groundwater draft



for the aquifer pilot implementation then organizes dissemination of this information in the aquifer communities. In contrast, APFAMGS communities generate the information themselves – they are the “barefoot hydrogeologists” engaging in and effectively leading the processes of data collection and analysis, as described earlier. Whereas in one case the community tends to accept the numbers of the groundwater budget with bemused indifference, in the other case the community is engaged to the extent of not only learning to use but also improvising the tools, templates, and techniques for estimating water availability and water use. In a telling incident in Cuddapah district, the district hydrogeologist from the Andhra Pradesh Groundwater Department acknowledged that the group of barely literate women standing in the field and explaining the local groundwater dynamics almost rivaled his professional staff in their knowledge of the subject.

The project approach is based on nonformal means of education, and echoes seminal thinking in the pedagogy for empowering people. The focus is on the triggering of a critical consciousness, which

allows people to “emerge as conscious makers of their own culture”, and to “reject their role as mere objects in nature and social history and undertake to become subjects of their own destiny” (Freire 1973).

Engaging the community

Of the APFAMGS budget, 98 percent is dedicated to education and building community processes, while less than 2 percent is spent on supply augmentation (through groundwater recharge structures). APFAMGS has succeeded in establishing strong community processes by formally engaging all groundwater users and using traditional and well-established vehicles of community mobilization. The project is rooted in a strong participatory, capacity-building, and gender equity approach. It is significant that more than 2,000 women farmer volunteers are engaged in data collection, and fully one third of the 1,700 farmer facilitators are women. The culmination of crop water budgeting, at an aquifer-level meeting in autumn before the rabi planting, is a big affair, with thousands of farmers in attendance as the final budget is calculated. The final budget number has great significance for

the communities, but this significance owes more to the process that produces this number than to the number itself. The project's success comes in big part from its clear emphasis on community institutions, education, and capacity building, and from its recognition that these dimensions are challenging enough to merit focusing a significant proportion of the resources on them. In contrast, while community participation and awareness are theoretically recognized as crucial elements in most pilots, the budgets devoted to them (rarely more than 10–20 percent of the total) betray the actual degree of emphasis and attention.

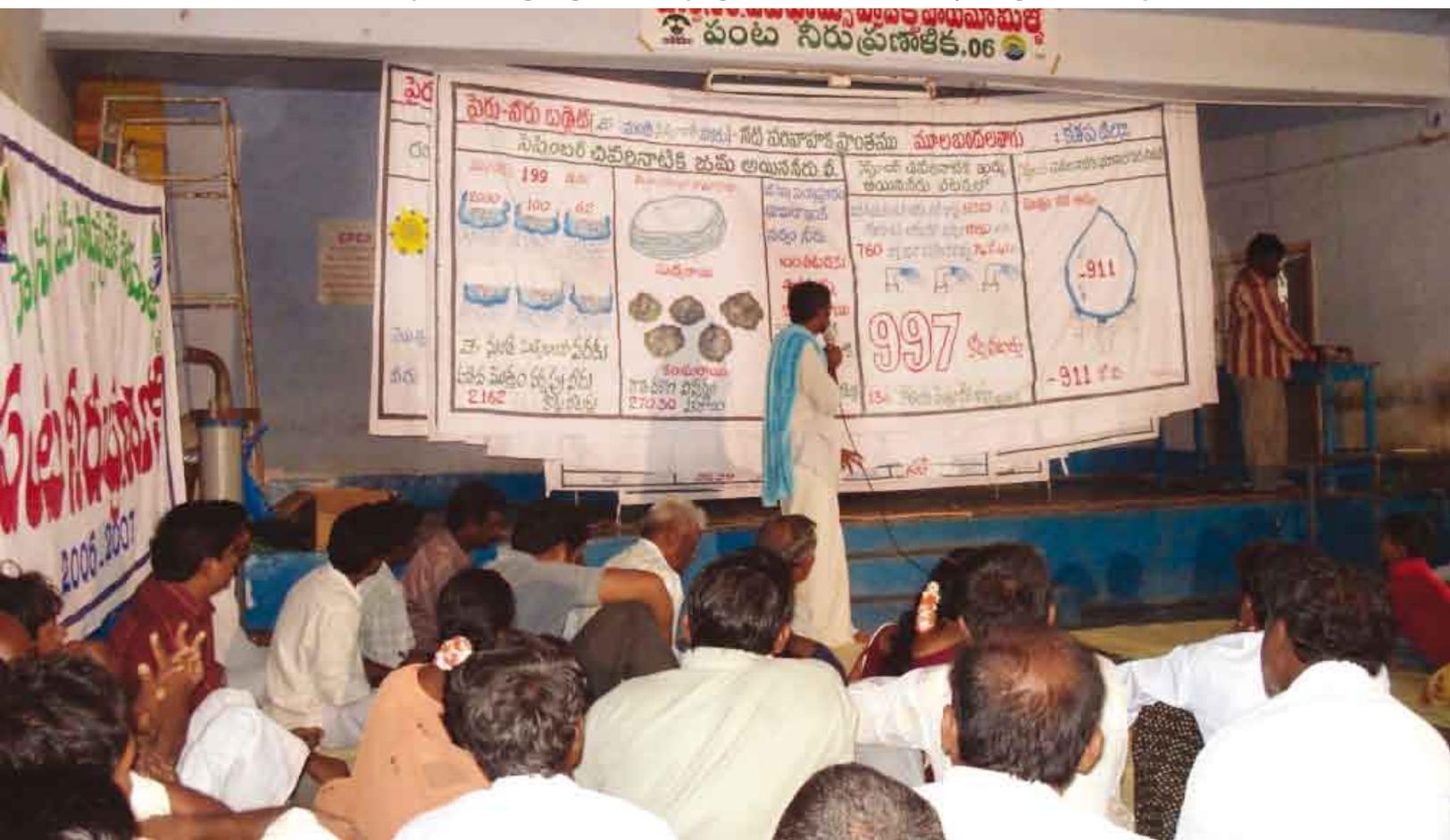
Another significant design feature of APFAMGS is that it engages the farmers around a crucial element of information that is vital for planning the agricultural operations. As explained earlier, in areas with limited-storage hard-rock aquifers, having an estimate of the water availability in the aquifer at the time of dry season planting gives the farmers extremely valuable information on the risk to their crops. The history of farmers' familiarity with borewells spans barely three decades, and

participation in the project promises to the people a reliable understanding of this critical resource. This is a powerful hook for enlivening the practice of groundwater management, as is borne out by the results of the farmer survey, which showed that for a large majority of surveyed APFAMGS farmers, factors pertaining to profitability of crops, availability of groundwater, and knowledge of improved agricultural techniques are the primary determinants of project participation.

Fighting the right battle on collective action

While APFAMGS has achieved notable success in achieving collective action in project communities, it is important to note the aspects where collective action is sought in the project, and even more importantly, where collective action is not sought. As described in preceding sections, the project has established a robust and vibrant process that through collective action in aquifer communities generates knowledge of the balance between groundwater availability and its use. However, the project does not seek collective action on reducing

Crop Water Budgeting exercise in progress for Mulabandhala Hydrologic Unit (Kadapa district, Andhra Pradesh).



groundwater abstractions. The communities do not set collective targets for crop diversification or water use reduction, and the individual farmers are free to plant what they want and pump as they desire. This is in stark contrast to other attempts at community water management of groundwater, where the ultimate objective is to get communities to agree on reducing excessive abstraction and to ensure that the agreements are implemented. Such collective compacts, even when agreed, are notoriously difficult to implement because the farmers always have the incentive to derive extra benefit by cheating or free riding. Even in cases where charismatic leaders and communities led by them have created “islands of salvation”, a deeper look reveals a very complex dynamic of culture, tradition, charisma, coercion, and in some cases, absolute authority, that make such compacts work (Sharma 2006).

The fact that APFAMGS is achieving water use reductions without seeking or building collective compacts on water use reduction is explained by an interesting combination of factors. The limited storage and the absence of deeper and abundant water-bearing layers in hard-rock aquifers create a condition where, with some exceptions, sinking a deeper well to pump out more water is not necessarily a successful strategy. With experience, farmers are learning that it is more prudent to plan according to estimated groundwater availability and to focus on protecting the planted crop. Farmers indicate clearly in interviews that with the knowledge of the groundwater budget from the crop water budgeting exercise, their rabi planting decisions are not affected by the possibility of other farmers’ using more water-intensive crops. “It doesn’t bother me, but *he* will need to borrow more from the moneylender next year”, one farmer commented when asked to respond to the possibility of another farmer deciding to grow more paddy in a year with especially scarce groundwater. It is evident that the reductions in groundwater draft in APFAMGS are not coming

from an altruistic collective action, but from the individual risk management decisions of thousands of farmers. This makes the APFAMGS model robust and replicable, since no authoritative leadership is required for enforcement of compacts.

Emphasis on increasing farmer incomes

Convincing farmers to reduce water use is the most difficult part of groundwater management, because without adequate mitigating measures this necessarily equates with diminished returns from agriculture. Exhortations to use less water are therefore met with skepticism from farmers, especially those working on precarious margins in dryland areas. There are some examples where a powerful charismatic leader (such as Popat Rao Pawar in Hiwre Bazaar) has convinced the community to undergo a temporary sacrifice of water use reductions to achieve long-term improvements, but in general, a message heavy on reducing groundwater abstraction is a kiss of death for community-based groundwater management. Figuring out how to sweeten the bitter pill of demand-side management holds the key to unlocking its potential.

With emphasis on improved farming and irrigation techniques, and with the use of innovative and radically effective communications on groundwater status, APFAMGS primarily taps the farmers’ incentive to save their dry season crops and to improve crop yields. Instead of coaxing farmers to adopt water-saving measures with the objective of reducing groundwater use, APFAMGS encourages farmers to select cropping patterns and irrigation interventions that minimize risk and maximize return. With reductions in water use following organically from the profit-oriented decisions of thousands of individual farmers, APFAMGS has found a very attractive horse to pull the wagon of reducing groundwater use.

That reductions in groundwater abstraction can be combined with increased agricultural

Box 4.2 Economic modeling of groundwater resource use behavior in rural India

The International Food Policy Research Institute (IFPRI) was commissioned under this initiative to develop a linked agricultural-hydrological model that could capture the essential interactions between groundwater availability, agricultural production, and resource use behavior in rural India. The key components of the exercise were (a) constructing an adequate representation of economic behavior with respect to crop production and water usage by farmers; (b) creating an adequate representation of the hydrological characteristics and dynamics of the aquifer; and (c) creating a linkage between the modeling components in (a) and (b), such that the effects of various factors (such as crop profit values and penalties for irrigation demand) could be observed on farmer welfare and behavior, as well as on the natural resource base. While farmer behavior may generally be characterized to be of the noncooperative type, the modeling objective was to discern and quantify incentives or disincentives that could bring about a shift towards cooperative behavior.

The crop production model developed for this exercise incorporated both economic and agronomic dimensions for determining crop production response to policy- and environment-driven factors. The groundwater resource usage and aquifer dynamics were simulated by assuming a two-cell aquifer model. The necessary agronomic and aquifer data were collected from the two distinct settings of hard-rock aquifers in Maharashtra and Andhra Pradesh respectively.

production in the hard-rock aquifers of India is also substantiated by farmer behavior modeling simulations conducted by the International Food Policy Research Institute under commission from the World Bank (Box 4.2). The simulations model the rational profit-maximizing behavior of farmers situated within the given hydrological and agro-economic environments, comprising cropping options, crop yields, input and output prices, and aquifer characteristics. A coupled agricultural production and groundwater use model was developed, and two separate simulations

conducted with the detailed data obtained from two villages – Hiwre Bazaar (Maharashtra) and Siddypalli (under APFAMGS in Andhra Pradesh). The model realistically captures the cropping and pumping dynamics of communities, as illustrated in Figure 4.6, which shows the derived demand for water, indicating the value per hectare of irrigation across seasons. Figure 4.7 shows the difference in net benefits between a myopic groundwater abstraction scenario and the optimal groundwater abstraction scenario, demonstrating that the initial gain in net benefit enjoyed in the

FIGURE 4.6 Per hectare demand for water in kharif and rabi seasons in Hiwre Bazaar

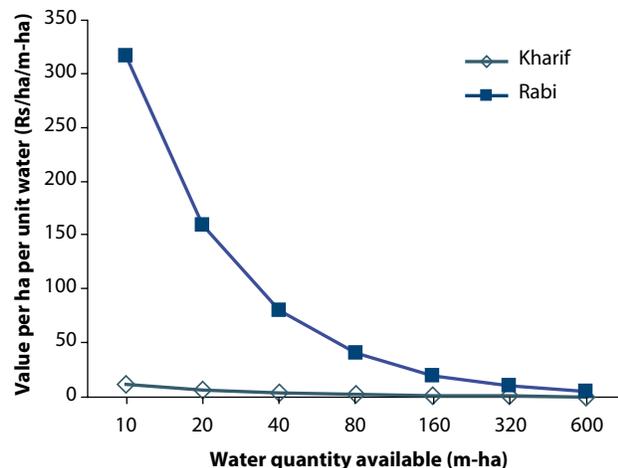
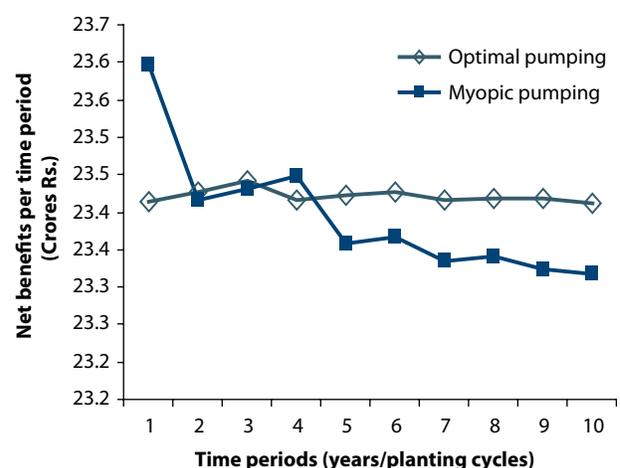


FIGURE 4.7 Net benefits under optimal and suboptimal groundwater extraction in Hiwre Bazaar



myopic extraction case is quickly dissipated as the groundwater table drops and higher pumping costs are incurred.

The empirical evidence from Andhra Pradesh is also substantiated by the behavior modeling simulations for Siddypalli village. In this case, simulations of crop areas were conducted under different combinations of crop profit and irrigation demand penalty values, where the latter parameter is introduced to make water demand reduction an element of the objective function of the farmer. While it is intuitively clear that APFAMGS farmers respond to crop profit signals, Figure 4.8 shows that significant crop pattern shifts do not come about unless water demand reduction is strengthened as a part of the objective function.

The main lesson here, therefore, is that community-based groundwater management programs should be designed with a shared focus on improving agricultural productivity, incomes, and water conservation, and that water use reductions should not be explicitly sought but realized by aligning efficient irrigation interventions with farmer incentives for higher profits.

More points of light: Community-led groundwater management in other initiatives in Andhra Pradesh

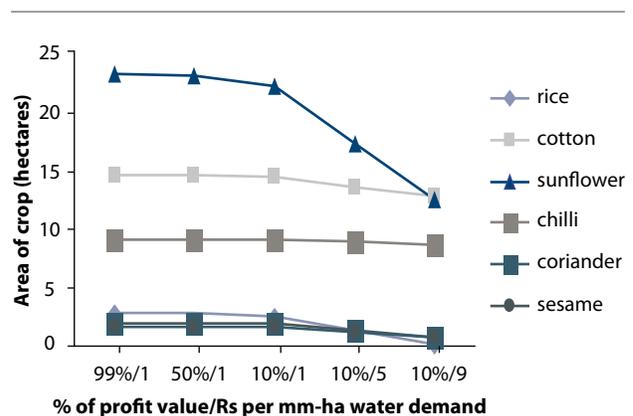
In addition to APFAMGS, community-based groundwater management approaches have been pioneered in Andhra Pradesh through other projects such as the Andhra Pradesh Groundwater Borewell Irrigation Schemes (APWELL), the Andhra Pradesh Community-based Tanks Management Project, and the Andhra Pradesh Drought Adaptation Initiative.

The primary objective of APWELL was to trigger groundwater development for poverty reduction in the drought-prone districts of Andhra Pradesh, but the project efforts were also dedicated towards developing community-based approaches for

ensuring the sustainability of groundwater use. The development of the concept and practice of participatory hydrological monitoring was a key innovation of APWELL, which in many ways was the precursor of APFAMGS. Working through technical as well as social interventions, the project achieved significant outcomes in improving the efficiency of groundwater use in agriculture, crop diversification with increasing crop yields and agricultural incomes, and associated socioeconomic and environmental benefits.

The ongoing World Bank-financed Andhra Pradesh Community-based Tanks Management Project has a dedicated groundwater management component, focused on implementing community-based groundwater management in an essentially conjunctive use setting by targeting groundwater users within the command and influence zones of irrigation tanks. The groundwater-related activities under the project include delineation of the groundwater influence zone of irrigation tanks through participatory field surveys, organization of groundwater user groups in the influence zone of the tanks, and representative co-option of groundwater users from outside the command area into the command area water user associations. The project is adapting and implementing the

FIGURE 4.8 Crop areas in Siddypalli under different combinations of crop profit value and irrigation demand penalty



APFAMGS approach of participatory hydrological monitoring and crop water budgeting in order to meet the objectives of improving groundwater management and increasing agricultural productivity and incomes.

The Andhra Pradesh Drought Adaptation Initiative is a pilot program supported by the World Bank that is being implemented in two districts of Andhra Pradesh by the Department of Rural Development. Five shared-groundwater pilots are being implemented under this initiative, whereby individual borewell owners are collectively agreeing to reduce groundwater demand through use of water-saving methods (such as a shared pipeline network for drip and sprinkler systems), crop pattern shifts, and a ban on new well drillings. A key element of the Drought Adaptation Initiative is to develop and pilot implementation arrangements whereby a nodal nongovernmental organization can coordinate the multisectoral inputs required from various state departments and agencies in support of community groundwater management and other objectives.

Situating the challenge: Groundwater as a common property resource

The design of sustainable groundwater management approaches can be rigorously undertaken by considering groundwater as a common property resource, whereby the possibilities of successful collective action are determined by a range of factors pertaining to the relationship between the community and the resource (Ostrom 2001). Accordingly, the likelihood of communities evolving and maintaining regimes of common property resource management depends on the following characteristics of the resource:

- ◆ **Feasible improvement.** The resource is not so degraded that users perceive no benefit from collective action; nor is it so underutilized that users perceive little need for action.

- ◆ **Availability of indicators.** Reliable and valid indicators of the existing state of the resource can be provided.
- ◆ **Predictability.** The yield of the resource can be predicted.
- ◆ **Spatial extent.** The physical expanse of the resource is such that the dependent users can meaningfully come together for collective action.

In addition, the following characteristics of the resource users themselves are also important:

- ◆ **Salience.** The users have a significant level of dependence on the resource.
- ◆ **Common understanding.** The users share a common understanding of the resource dynamics and how their actions can influence the resource.
- ◆ **Low discount rate.** The users anticipate significant reliance on the resource continued into the future.
- ◆ **Trust and reciprocity.** The user community has the ties and connections that facilitate collective action.
- ◆ **Autonomy.** Resource users have control over the resource.
- ◆ **Prior organizational experience and local leadership.** The users have experience and skills of organization and leadership required for collective action.

When the challenges of community management of surface water irrigation and groundwater irrigation are compared in this context (Schlager 2007), it becomes evident that the special nature of groundwater makes the latter a much harder problem to solve. The physical extent of aquifers is often too large to easily create a user community; the resource is unseen and its state is often hard to assess; and the complexities of

hydrogeology make common understanding of resource dynamics difficult to achieve. Given these challenges, and the insights from the common property resource school, it is clear that the design of a community groundwater management approach needs to go beyond the familiar domains of hydrology, regulation, and economics, and to incorporate the elements of social capital formation, behavioral psychology, nonformal education, communication, and leadership development, which are all crucial for successful community action. APFAMGS provides evidence that this can be done, and of what can be achieved if it is done.

At the same time, APFAMGS provides an interesting twist to the common property resource perspective on groundwater. The collective action in the project is limited to building a common understanding of the groundwater dynamics, and aligning groundwater use with availability is actually achieved through individual profit-motivated decisions of farmers without any collective agreement. As described above, the particular hydrogeology of hard-rock aquifers allows APFAMGS to sidestep the more difficult issue of creating and implementing a collective compact on water use reduction. Hard-rock aquifers underlie 65 percent of India's land, and APFAMGS provides a demonstrated approach for tackling groundwater overexploitation in these areas. It is not clear whether such a model would work in alluvial aquifers, where storage is many orders of magnitude higher than the annual recharge, and where the gloomy scenario of chasing the water table down to economically punishing depths can run unabated over much longer periods. The key lesson, however, is that the quest for successful community action on groundwater management is not necessarily futile, and tangible improvements are possible if "contrary to a mechanistic belief, the need to fully integrate the human dimension is highlighted" (Kemper 2007).

Conclusions: Emerging directions for community-based groundwater management

The lessons emerging from the cumulative experience in community groundwater management in India point to the following guiding principles:

1. **Community-based groundwater management should not require sacrifice.**

An important lesson from the experience so far is that there is no need for a sacrificial attitude to groundwater management, as groundwater demand management encourages changes in cropping patterns, irrigation techniques, and soil moisture conservation that can also lead to improved water productivity and farmer returns. The fact that agriculture in large parts of India is operating far below optimal productivity is therefore an opportunity in disguise, because the baseline of relatively inefficient water use and low crop yields means that there is ample scope for improving profits and reducing water use at the same time, and that sustainable groundwater management need not come at the price of sacrificing gain in agricultural incomes.

2. **Participatory engagement should be the core focus of community-based groundwater management investments.**

Community-based groundwater management primarily entails building a social process that can enable groundwater users to manage their interactions with the resource. Making visible the otherwise invisible resource of groundwater is a prerequisite for engendering collective action. APFAMGS employs the best nonformal techniques for educating nonliterate groundwater users, and has effectively created a popular science movement encompassing multiple

dimensions of water use and agriculture in the project areas. This focus on participatory engagement in generating and sharing knowledge on local resources is in stark contrast with most community-based groundwater management initiatives, where a majority of resources and efforts are concentrated on supporting physical works (for augmenting groundwater recharge) and on incentives such as subsidies for water-saving irrigation techniques. For community management efforts to succeed, it is clear that information, education, and social mobilization need to be recognized as core objectives, and supported by adequate resources.

3. Community-based groundwater management needs state engagement.

Groundwater overexploitation is a widespread problem in India. With an ever-increasing number of aquifers facing overexploitation, the challenge can only be addressed through systemic action by the state. In addition to the scale issue, communities need time and continued investments in capacity building before they can become genuinely capable of creating and leading sustainable groundwater management. This highlights the need for the state agencies to take on a “lighthouse” function in order to ensure that community-based initiatives do not fail because of lack of support and control, and to make sure that experiences from successful interventions such as APFAMGS remain available for replication.

4. Pragmatic policies can strengthen community-based groundwater management.

The bottom-up approaches stemming from on-the-ground community action can be complemented by top-down measures that can create an enabling environment at the local level. Examples of

possible policy measures that are pragmatic and can strengthen community groundwater management include endorsement of community groundwater management institutions, and improving institutional coordination amongst the various panchayati raj institutions dealing with different aspects of water resources at the village level.

5. Limitations of community-based approaches need to be recognized.

The successful experiences of community-based groundwater management owe much to their design being particularly suited to the peculiar physical and socioeconomic settings of groundwater use. The APFAMGS model, for example, seems to be well adapted to the recharge and emptying dynamics of hard-rock aquifers, which, as mentioned earlier, cover approximately two-thirds of India’s aquifer settings. While APFAMGS could provide a model for other hard-rock settings, it is not likely to work in geographically vast alluvial aquifers with significantly larger storage. Also, Andhra Pradesh has a particularly high density of social networks and a strong history of progressive social change in rural areas; it is probable that the APFAMGS model would be significantly challenged in settings with different social dynamics (lower social capital or larger asymmetries in user populations, for example). Finally, it needs to be noted that the lessons emerging from the Andhra Pradesh experiments with community-based groundwater management are preliminary, since the projects are still ongoing and there is no hindsight to assess the long-term sustainability of the results achieved. Therefore, the available models of community groundwater management would need careful and innovative piloting before they can be replicated and scale interventions become possible.

Pragmatic Approaches for Managing Overexploited Aquifers in India

Introduction

There is an urgent need to change the status quo. The rapidly falling groundwater tables in many parts of India present serious and immediate human development and economic challenges. Groundwater overexploitation is threatening India's ability to meet the drinking water-related Millennium Development Goals in rural areas; it is affecting the livelihoods of a large number of largely poor subsistence farmers; and it is endangering the sustainability of agriculture and the long-term food security of the country.

Given these pressing needs, the central and state governments in India are seeking to identify effective and politically feasible approaches for addressing the problem. The efforts in the World Bank's groundwater management initiative have accordingly been focused on identifying management strategies for promoting sustainable groundwater use within a systematic, economically sound, and politically feasible framework. As discussed in the first chapter, the objective was to develop a "Plan B" for groundwater management in India: given that the usual prescriptions of high-level policy reform (for example groundwater pricing and tradable property rights) may be neither appropriate for groundwater management

in India nor feasible in the current political economy, pragmatic approaches that can start addressing the challenge now and largely within the existing legislative framework need to be developed and identified. Plan B, therefore, is essentially a game-changer, which, through measures that are effective yet of low political cost, can shift the dynamic from a continuing debate on institutional issues to taking concrete actions on the ground.

Conceptual basis of Plan B

Even with the political economy considerations set aside, India – with the largest withdrawal of groundwater in the world, through a number of wells (approximately 20 million) that is orders of magnitude higher than in other countries, and with almost no correlation between groundwater availability and groundwater use – presents a unique case for groundwater management. For example, nowhere else in the world do hard-rock aquifers, which represent close to two thirds of India's land area, see the rates of exploitation and heavy dependence that are common in India. Furthermore, as described in Chapter 2, there is a plurality of contexts of groundwater overexploitation in India, and therefore the management solutions need to be developed specifically for each of these contexts.

The classical institutional framework emerging from the global discourse on and experiences in groundwater management has four broad categories of instruments and measures: regulatory measures, economic instruments, groundwater property rights, and community groundwater management. The applicability of these approaches in Indian contexts is discussed in the preceding chapters, along with comparative global experiences. Large-scale regulation of groundwater use, for example, does not have any successful examples except in China. Groundwater pricing and property rights, which often constitute the core policy prescriptions for groundwater management in the global discourse and which have been implemented with varying degrees of success in some countries, suffer from the same weakness that is fatal in most Indian contexts – the astronomical transaction costs of implementation with millions of small users spread over very large areas. There is also the question of whether the statutory implementation of such high-level policy reforms for groundwater management will actually change the situation on the ground. Profound gaps between the de jure and de facto realities are not uncommon in India. With a diffuse public good such as groundwater, whose development and management has remained for the most part in the private domain, governments in India may have the statutory authority to decree reforms but not the capacity to actually implement them. Community management therefore offers an alternative mechanism to state enforcement for groundwater management, and, as discussed in the previous chapter, there is now a critical mass of experience for designing models that could be viable at least for the hard-rock settings in India.

Sector policies, for example agricultural power pricing and minimum support prices for crops, have emerged as powerful drivers of groundwater use, and some of the conceptually clearest interventions recommended for groundwater management involve correcting the incentive distortions regarding groundwater use in these

sector policies. However, an analysis of the politics around reform proposals such as increasing irrigation power tariffs indicates that they are widely unpopular with farmers. Contrary to the claim that resistance to reform comes from affluent large farmers who benefit disproportionately from the power subsidies, there is growing evidence that energy costs to farmers have grown to become significant across the board in recent decades, and increasing power tariffs would land a serious blow to small and marginal farmers (World Bank 2001; Dossani and Ranganathan 2004; Dubash 2007). Free or nominal-cost power for irrigation should be recognized as the political solution to the politically charged issue of equitable government support to both farmers in canal command areas and groundwater-dependent farmers outside the commands, with the former benefiting from free provision of irrigation infrastructure and much-below-cost tariffs for surface irrigation water, while the latter have to make entirely private investments for irrigation. The case for interventions such as rationalized power tariffs has to be made in the larger current picture of an anemic agricultural sector in the country, which, in its contrast with the rapidly growing industrial and service sectors, is cleaving India into two disparate worlds – one that is urban, globalized, and increasingly affluent; and the other that is largely rural, poor, and agrarian, perceived to have been “left behind”, and iconized poignantly in the spate of farmer suicides in recent years in different states of the country. Reforms with significant impacts on agriculture will need to be sold to the constituencies in this second India, which is close to 60 percent of the total population. This is the inescapable burden of democracy, and the common arguments that attribute failure to implement a policy reform agenda to a “lack of political will” in decision makers ignore this essential requirement of building constituencies of popular support.

It is clear that in the long term policy distortions introduced by highly subsidized electricity will need to be corrected to find a sustainable solution

to the groundwater overexploitation problem. However, in purely practical terms, it needs to be noted that the political actors who have attempted to withdraw the provision of free or cheap power to farmers have either lost elections or have had to quickly revise their positions (Shah et al. 2007). With this record, any groundwater management approach that requires unpopular front-ended policy reform, no matter how sensible, will not have any takers in the current political economy. It has therefore been suggested that for the time being it seems sensible “to take the nature of the state as given rather than assume the nature of the state will change to resolve water sector problems” (Shah 2005, cited in World Bank 2005).

In an assessment of Indian democracy, Dreze and Sen distinguish between ideals, institutions, and practice, and find that the main limitations relate to the quality of democratic practice (Dreze and Sen 2002). Drawing upon this analogy, it may be said that the biggest constraints impacting groundwater management in India today pertain to the practice of groundwater management, which arguably does not exist, despite the significance of groundwater as a critical resource for the country. Establishing and strengthening this practice through ground-level management interventions needs to be the first priority for governments, and there is ample support in the current institutional environment for the needed interventions.

Elements of Plan B: Building a practice of groundwater management

The findings of the World Bank’s groundwater management initiative, drawing from analytical work and implementation experiences in different states, point towards a menu of pragmatic management interventions. These interventions can be implemented through a number of possible entry-points, including state groundwater agencies, other line departments, or groundwater users themselves. The targeted and flexible nature of these measures means that they can be highly

context specific, and can be selected and adapted to the varied contexts of intensive groundwater exploitation in India. Together, these interventions can be seen as the building blocks of Plan B – a game-changing action plan that comprises effective yet low-political-cost interventions, and that can shift the dynamic from a continuing debate on institutional issues to taking concrete actions on the ground. This approach should not be mistaken for an easy way out; it would still require significant institutional effort, change, and also addressing vested interests.

The recommended management interventions fall into three broad categories: (a) community-based groundwater resource management; (b) targeted regulation; and (c) sectoral policy interventions and coordination. As their success will be determined in large part by the ability of the state groundwater agencies to provide effective support, the organizational improvement, strengthening, capacity building, and relocation of these agencies is identified as the core cross-cutting intervention and is presented first.

Implementation action 1: Building capacity and adjusting the role of state groundwater institutions

States have the primary responsibility for managing and ensuring the sustainability of groundwater resources. In addition to their constitutional mandate, state agencies have an advantage in promoting groundwater management on the ground, because they are in a better position to:

- ◆ facilitate cross-sectoral coordination of groundwater resources at the most critical (state) level;
- ◆ promote government–stakeholder interaction (especially considering that most state government departments have operational offices at district level, where many of the local management measures will need to be taken);

- ◆ design groundwater management approaches specific to the typologies and user needs of local aquifers.

However, groundwater agencies in the states are not adequately equipped for taking up these roles. As described in Chapter 3, groundwater agencies are located at relatively lower levels in the state hierarchy and tend to have much less clout than their counterpart departments focused on one of the main water uses, for example irrigation or water supply. In many cases, there is no dedicated state groundwater agency. The organizational structure, resources, and staff skill sets continue to be oriented primarily towards groundwater development rather than management.

Groundwater management is more about enabling the users to manage interactions among themselves, and with the aquifer, than about top-down managing of a natural resource, and a transformational shift would be needed to reflect this in the functioning of state groundwater agencies. The task of addressing

these shortcomings in the state agencies is not a politically sensitive “hot potato”, and could therefore be addressed as priority. Maharashtra provides a good example of taking the initiative on this front: the technical resources and staff competencies of the state Groundwater Survey and Development Agency are being strengthened through various programs, including support from World Bank-financed projects.

The capacity of state groundwater institutions will need to be developed to ensure that they can perform the key functions of providing information and technical support, enabling community management, and enforcing regulatory measures. The structure of state groundwater development and management agencies should derive from these key functions. Table 5.1 presents a broad outline of how these functions could be formalized in a state groundwater institution.

With community groundwater management emerging as the most viable model, at least in

TABLE 5.1 Suggested missions and functions for individual units within a state groundwater management agency

Organizational unit/mission	Main functions
Information and planning unit <i>Keeping updated resource and user status aimed at contributing to sustainability, replicability, and scaling up of groundwater management initiatives</i>	Delineation of main groundwater bodies and priorities for promotion of community-based groundwater management (including relationship with watersheds) Hydrogeological and socioeconomic planning framework for replication and scaling-up strategy and identification of new community-based groundwater management initiatives, distinguishing essentially drinking water from resource management needs Identification of critically endangered groundwater blocks to be notified Evaluation of resources of main groundwater bodies, in the form of information to community organizations, state government, and local authorities Establishing permanent policy dialogue with agricultural, land use planning, and urban, rural, and industrial state agencies Serving as a “lighthouse” to permanently monitor groundwater management initiatives for issues that put sustainability at risk Overall planning Preparation of procedures, guidelines, and standards State databasing, groundwater allocation, and granting of entitlements to selected users Conducting capacity-building and awareness-raising programs for groundwater users, nongovernmental organizations, stakeholders, politicians, bureaucrats, professionals, and technicians

<p>Survey, development, and demand management unit</p> <p><i>Ensuring that groundwater supply development, recharge enhancement, and demand management measures are scientifically sound, economically reasonable, follow best professional practice, and are properly linked to irrigation and water supply service providers</i></p>	<p>Traditional hydrogeological surveying and improved groundwater quantity and quality monitoring</p> <p>Keeping updated groundwater user inventory and profiles of groundwater uses</p> <p>Ensuring quality control and quality assurance of construction, operation and maintenance, and agricultural and irrigation (and generally demand management) activities and outputs</p> <p>Undertaking permanent critical, technical, and economic assessment and obtaining field evidence for updating guidelines for recharge enhancement measures</p> <p>Ensuring formal linkages with irrigation and water supply projects</p>
<p>Community management enabling unit</p> <p><i>Contributing to communities in community-based groundwater management initiatives becoming leaders of sustainable development processes</i></p>	<p>Keeping links with relevant panchayats</p> <p>Coordinating community-based groundwater management pilot projects and establishing a nursery for community-based groundwater management initiatives</p> <p>Keeping the necessary links with other government agencies and external support agencies to ensure that groundwater users have access to inputs for making efficient and beneficial use of the resource</p> <p>Maintaining linkages with and capacity building of stakeholder organizations (first supporting design and implementation of community-based groundwater management initiatives, and later as part of lighthouse outreach capacity)</p> <p>Keeping a benchmarking system aimed at constructive competition among community-based groundwater management projects</p>
<p>Regulatory unit</p> <p><i>Supporting local authorities in dealing with critically endangered groundwater blocks</i></p>	<p>Traditional hydrogeological surveying and improved groundwater quantity and quality monitoring</p> <p>Keeping updated groundwater user inventory and profiles of groundwater uses</p> <p>Keeping links with and capacity building of relevant panchayats, local authorities, and district comptrollers</p> <p>Establishing agreements with local authorities to decentralize nonauthority enforcement functions</p> <p>Undertaking regulatory enforcement</p>

the hard-rock areas, it is important to ensure that community-based initiatives get the required support from the state groundwater agencies during the time that it takes for the communities to genuinely become capable of managing sustainable groundwater management regimes, and that they are permanently monitored for issues that put sustainability at risk. Therefore, the community management enabling function is the most critical enhancement needed for the state groundwater agencies.

Recent experience from community groundwater management pilots being implemented under two World Bank projects in Maharashtra (Box 5.1)

highlights the importance of expanding the skills profile in the state groundwater agency by going beyond the technical and monitoring functions to include a management enabling function. More importantly, this example demonstrates that with the right support these internal organizational changes can be readily implemented and can produce tangible results.

Although dedicated state groundwater management agencies are desirable, this may not be possible in many states. A pragmatic and organic approach would be needed to ensure that the key functions are performed through organizational arrangements appropriate to

Box 5.1 Supporting effective groundwater agencies: Lessons learned from World Bank projects in Maharashtra

The results of the technical assistance provided under this initiative to the Maharashtra Rural Water Supply and Sanitation Project and the Maharashtra Water Sector Improvement Project highlight the importance of the enabling and nurturing role of state government agencies.

Both projects include investments to support community aquifer management pilots in selected aquifers, with the Groundwater Survey and Development Agency as a key implementing agency. The Rural Water Supply and Sanitation Project was the first project to design and implement the aquifer management pilots, and while its core focus area (rural water supply and sanitation) was very different from that of the Water Sector Improvement Project (irrigation), the groundwater pilots supported through the latter project can be considered second generation in that they were designed with the benefit of learning outcomes from the Rural Water Supply and Sanitation Project.

Under the Rural Water Supply and Sanitation Project groundwater pilots, the role of the Groundwater Survey and Development Agency was confined to technical assessments, with the responsibilities of delineating and surveying pilot aquifers and preparing water budgets comparing water availability with water use. The awareness building and mobilization in aquifer communities around this information was conducted entirely by nongovernmental organizations contracted directly by the project implementation unit, which also managed the overall implementation of groundwater pilots. As the groundwater component was a very small fraction (less than 2 percent) of overall project activities, and as the Groundwater Survey and Development Agency was not directly involved, the implementation of groundwater pilots was slow and poorly integrated.

The groundwater pilots of the Water Sector Improvement Project were explicitly designed with the lessons from the Rural Water Supply and Sanitation Project in mind. The Groundwater Survey and Development Agency is responsible for leading all aspects of the aquifer management pilots of the Water Sector Improvement Project. The agency receives funds directly from the central project implementing unit and is responsible for all procurement processes, including the hiring of nongovernmental organizations as support organizations for facilitating community-level organizational arrangements. Key agency staff are responsible for overall implementation of the pilots, with a nodal team leader at the state level complemented by pilot team leaders who actively participate in the establishment and functioning of village-level groundwater management committees and aquifer-level groundwater management associations. While the project is still under implementation, it is clear that expanding the role of the Groundwater Survey and Development Agency beyond its traditional mandate of providing technical support, and providing support for it to take up groundwater management functions, are proving beneficial to the implementation of the groundwater pilots.

each state's local context. For example, in Andhra Pradesh, the Department of Rural Development, with its track record of success in community development initiatives, could work closely with the Groundwater Department for facilitating community groundwater management.

Where the groundwater agency is located in the state hierarchy is another crucial element of the solution. It is of foremost importance that the state groundwater agency be located at an appropriate level in order for it to participate in and influence the dialogue on the important aspects of state (and even national) policy on irrigation, agriculture, energy, land planning, and rural and urban development. Since surface water and groundwater are intimately

connected through the hydrological cycle in each river basin, planning and management of surface water and groundwater should be closely integrated through a focus on conjunctive use. The proposal currently under consideration in Maharashtra to bring surface water and groundwater under the purview of the state water resources regulatory authority is a welcome example in this regard, as long as the state groundwater agency is located at the appropriate level as described above.

Implementation action 2: Community-based groundwater management

The "what-to-do" elements of successful community action on groundwater management



Women's Self-Help Group in Tahwapur village (Barabanki, Uttar Pradesh). The group is active on water management issues, and also rents agriculture equipment to farmers.

are broadly known, and consist of actionable resource information, social mobilization, and incentives to facilitate change. However, the apparent simplicity of this prescription is deceptive, given the fact that there are very few examples of programs or projects anywhere in the world that have succeeded at scale in achieving sustainable groundwater management on a systematic basis, especially through demand-side management with a large number of users. There has, therefore, been a notable lack of proven models for community-based groundwater management, which is the main reason why governments have so far not attempted to implement and invest in community-based initiatives, even in areas facing serious groundwater crisis.

This report begins to address this gap. The potential of community-led initiatives is illustrated through a detailed assessment of an innovative community-based groundwater management project under

implementation in Andhra Pradesh, presented in the previous chapter. With a total outreach close to 1 million farmers and early results showing hundreds of communities beginning to align their water use with groundwater availability, this initiative may be the first example globally of success at this scale in groundwater management through demand reduction by communities. Therefore a promising model for community-based groundwater management is available for hard-rock aquifers and could be the basis for replication and scaling up. This and other community initiatives undergoing pilot-level implementation are also beginning to define the key requirements of designing community-based groundwater management programs:

1. Community-based groundwater management should not require sacrifice.

Demand management will not be successful unless farmers are provided with cropping and irrigation options that reduce risk and

increase profits. At the same time, providing these options to farmers without generating awareness about the status of local groundwater resources will also be ineffective. Low agricultural productivity in large parts of India is an opportunity in disguise, because the baseline of relatively inefficient water use and low crop yields means that there is ample scope for improving profits and reducing water use at the same time, and that sustainable groundwater management need not come at the price of sacrificing gain in agricultural incomes.

2. Participatory engagement should be the core focus of community-based groundwater management investments.

Generating information, education, and social mobilization are the core elements of community-based groundwater management, and the resources dedicated to these activities should be commensurate with their importance.

3. Community-based groundwater management needs government support.

Community groundwater management needs capacity building and significant hand holding in its early years. Given the current widespread need for groundwater management and the increasing number of areas threatened by overexploitation, it is clear that systemic nationwide action is needed, and government support for implementation will be crucial.

4. Pragmatic policies can enable community-based groundwater management.

State governments can take policy action to facilitate formation of local groundwater user institutions and to ensure institutional coordination amongst different water- and groundwater-related departments at the aquifer level.

5. Community-based groundwater management models need to be adaptable

Village Community members showing the rain-gauge installed in a farmer's house in Vardhangarh (Satara, Maharashtra). Rainfall measurements are recorded daily.



to local settings. The approaches would need to be tailored specifically to the characteristics of local aquifers, resource use, social dynamics, and history of collective action.

Implementation action 3: Sector policy interventions and coordination

Because of groundwater's ubiquitous use, policy measures focusing directly and explicitly on groundwater are rarely sufficient for ensuring adequate management, and often prove to be less important than linkages with other sectoral policies and programs (public as well as private, and at national, state, and municipal levels) that have a large impact on groundwater. Pragmatic interventions on key issues such as agricultural power pricing and conjunctive use in agriculture and urban water supply are presented below.

Implementation action 3.1: Promoting conjunctive use in agriculture

In the irrigation canal commands of the Ganga and Indus river systems, heavy depletion of aquifers often exists in close proximity to problems of waterlogging and salinization arising from canal leakages and excessive use of surface water in high-water-table areas. As explained in Chapter 2, more optimized conjunctive use (with improved surface water distribution and more rational groundwater use) could increase the cropping intensity from generally below 150 percent to well over 200 percent in the Ganga plain commands without compromising groundwater resource sustainability. To achieve this, the social and economic obstacles facing implementation would need to be overcome by pursuing a management action plan based on identifying different microplanning and management zones in the command areas. Groundwater use within the microzones would need to be incorporated more fully and realistically into the planning and implementation of irrigation water management. State financial investment, user incentives, and management procedures would need to be

mobilized in line with this vision of conjunctive use, and the tasks would include

- ◆ completing bank sealing and desedimentation of major irrigation canals;
- ◆ implementing and improving existing operational codes for the distribution of canal water;
- ◆ extending rural electrification and promoting the construction and use of tubewells (if necessary through subsidy) in high-water-table areas;
- ◆ long-term campaign to educate farmers on the benefits of managing conjunctive use of groundwater and canal water through microzone planning.

Implementation action 3.2: Integrating groundwater in urban water supply planning

The dynamics of groundwater use are significantly different between cities that are located on major alluvial aquifers and those that are underlain by hard-rock aquifers, as described in Chapter 2. However, in both hydrogeological settings, it is common to find that there are no systematic studies of urban groundwater. Water utilities are practically blind to the role of groundwater in their existing supplies and the corresponding socioeconomic benefits, potential health risks, and management needs. Data on resource availability and quality are often deficient, dispersed, or nonexistent, and technical and financial water supply planning at municipal or state levels is almost entirely restricted to consideration of large new capital investments for the development of new surface water sources.

This omission cannot continue if climate-robust and cost-effective solutions to the major challenges of urban water supply in most parts of India are to be found. With rising demand, scarce additional surface water supplies, and increasing frequency and severity of drought predicted in many climate change scenarios, the role of urban groundwater resources and reserves will become all the more

critical in the future. Thus there is an urgent and general requirement to move from opportunistic exploitation of groundwater resources to more systematic evaluation of the status of urban groundwater use and the option it presents to contribute to meeting future demand, together with the integration of this important resource into overall urban development plans.

Specifically, for municipal agencies in cities on alluvial aquifers, more robust urban water supply solutions with sustainable groundwater use would involve

- ◆ planned conjunctive use wherever exploitable surface water resources are available;
- ◆ development of more easily protected and managed peripheral municipal well fields to spread groundwater capture over a large area (through appropriate arrangements with the rural communities);
- ◆ integration of appropriate planning and protection of all municipal groundwater sources into broader urban planning.

For cities situated on hard-rock aquifers, extensive private water well construction and groundwater dependency is likely to stay on as a coping strategy to reduce dependence on the purchase of much more expensive tanker-based water supply. This existing private access at moderate cost to in situ groundwater will inevitably be a key factor affecting the cost recovery potential for major new urban water supply schemes based on costly transport and treatment of supplies from distant surface water sources. Municipal agencies would therefore need to develop a more integrated vision of, and balanced policy between, utility infrastructure provision (both water supply and sanitation) and private self-supply.

Implementation action 3.3: Technical and political solutions to agricultural power pricing

The advent of unmetered and cheap or free power to farmers in India in the 1970s and 1980s

owes to a combination of populist politics and the high transaction costs of metering millions of wells in the countryside. However, over time, the introduction of free or flat rate power has proved to be a one-way ratchet measure, fostering a culture of agrarian entitlement to free electricity and creating serious political costs associated with reverting to metering or introducing rational increases in tariffs. The burgeoning consumption of free or subsidized power in agriculture also poses a survival challenge for the state electricity boards, which are posting unsustainable losses, putting considerable burden on state budgets. Therefore, a resolution of the energy-groundwater nexus is important for ensuring the viability and sustainability of both groundwater-based agriculture and the electricity sector in India.

As discussed earlier, it is clear that the economically rational solution of power metering coupled with a reintroduction of sensible tariffs is unviable in the existing political environment. However, the impracticality of overt reform does not preclude the possibility of designing technical interventions that are able to achieve the basic objectives of reform, but without having to present the decision makers with suicidal political choices. Gujarat's experience in regulating agricultural power supply by installing separate electricity feeder systems for tubewells is an example of such an intervention, providing 24-hour power supply for domestic, institutional, and industrial use in villages, with the farmers getting eight hours of improved quality and reliable power on an announced schedule that can be designed to match the periods of moisture stress. It has resulted in significant improvements in quality of life and economic productivity in the villages and a de facto reduction in farm power subsidy, and has provided the state with a macrolevel on-off switch to control electricity consumption and groundwater use in the agricultural sector, without any political difficulties. Punjab, now a state with fairly entrenched policies of free agricultural power supply, is also attempting

with success a similar approach for regulating electricity and groundwater use in agriculture. The concept is replicable across different parts of India, and could provide a much-needed interim solution for addressing the energy–groundwater nexus in other states.

In the long term, however, the low-level, high-cost equilibrium of the energy groundwater nexus has no technical fix, and can be escaped only by consciously following a political path out of the situation (Dubash 2007). This would involve serious efforts at deepening the understanding of farmer perspectives; negotiating through multistakeholder dialogues that engage organized farmer interest groups, utilities, and government representatives (instead of only policy elites and experts); transition steps to move out of the current stalemate; and crafting an implementation strategy that combines economic, administrative, technical, and institutional solutions, and that meets social and economic objectives in a politically acceptable manner.

Implementation action 4: Targeted regulation of groundwater use

Instruments for controlling abstraction of groundwater from designated aquifers can include, among other measures, allocation of permits, selective credit controls, restrictions on electricity connections, and restrictions on borehole locations and licensing. As discussed in Chapter 3, global experience suggests that regulation of groundwater abstraction is a challenging undertaking. Given the large number of users of this highly decentralized resource, which has been developed almost entirely by private initiative, regulation will be of limited use in most of India. However, a selective command and control approach would be needed in the limited number of critically endangered aquifers:

- ◆ In the case of urban settings seriously threatened by overexploitation, there is no

alternative in the immediate term to the enforcement of regulations for protecting groundwater resources, although systemic reform in water supply would go a long way towards addressing the underlying causes of the problem.

- ◆ In the case of overexploitation of major alluvial aquifers a two-pronged approach may be required, whereby a few of the largest users (whether commercial farms, industry, or urban water utilities) could be given individual groundwater allocations, to be enforced by local authorities through statutory but socially acceptable measures.

Implementing even this limited regulatory agenda would require building the capacity and adjusting the role of central and state agencies and providing them with the resources required, including staffing and budgets, to deliver on the mandate of enforcing regulations. The success of this command and control approach is, however, likely to be diluted if expanded to other overexploited aquifers. Regulation would be particularly inappropriate in hard-rock aquifers, where there is very limited potential for unsustainable groundwater mining and where monitoring costs would be prohibitive, owing to the extremely large number of small individual subsistence farmers.

Pragmatic menu of implementation actions for overexploited aquifers

The pragmatic implementation actions discussed in the preceding sections need to be selected and carefully tailored to the local contexts of groundwater overexploitation. Based on the typologies of overexploited aquifers presented in Chapter 2, the combinations of actions that can be both effective and viable in different settings of groundwater overexploitation in India are summarized in Table 5.

TABLE 5.2 Recommended implementation actions for different settings of groundwater overexploitation in India

Land Use	General & Specific Hydro-Geological Environment	Resource Use	Implementation Actions
Rural	Hard-rock terrains in peninsular India	<i>Widespread weathered hard-rock (basalt or granite) aquifers with shallow, low-storage patchy groundwater bodies</i>	<ol style="list-style-type: none"> 1. Enable and nurture community-based groundwater management, strongly complemented by availability of demand management interventions 2. Encourage artificial groundwater recharge 3. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping
		<i>Occasional but important groundwater bodies in coastal or graben fill sedimentary aquifers</i>	<ol style="list-style-type: none"> 1. Enable and nurture community-based groundwater management, strongly complemented by availability of demand management interventions 2. Encourage artificial groundwater recharge 3. Explore conjunctive use management 4. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping 5. Maintain regulation in most critical aquifers
	Major alluvial formations of rural Indo-Gangetic Plains	<i>Alluvial aquifers, in plains largely within major irrigation canal commands with naturally shallow water table</i>	<ol style="list-style-type: none"> 1. Major emphasis on microzone-based conjunctive use management (in canal head: seal canal breaches, groundwater pumping, sodic/saline land reclamation; in tail end: promotion of water-efficient high-value crops) 2. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping 3. Maintain regulation in most critical groundwater blocks
		<i>Alluvial aquifers in the older and elevated alluvial plains, with more limited irrigation canals and deeper water table</i>	<ol style="list-style-type: none"> 1. Major emphasis on microzone-based conjunctive use management (in canal head: seal canal breaches, groundwater pumping, sodic/saline land reclamation; in tail end: promotion of water-efficient high-value crops) 2. Support technical interventions for demand-side management in high-water-use crops 3. Explore technical interventions (e.g. separate agriculture electricity feeders) to indirectly control energy costs and groundwater pumping 4. Maintain regulation in most critical groundwater blocks
Urban	Urban environment	<i>Weathered hard-rock aquifers with shallow, low-storage patchy groundwater bodies</i>	<ol style="list-style-type: none"> 1. Assess the extent of prevalent private self-supply through groundwater and account for it in planning and costing of new water supply augmentation schemes 2. Promotion of urban demand-side management 3. Promotion of household rainwater harvesting measures 4. Maintain regulation in most critical groundwater blocks
		<i>Major alluvial aquifers in alluvial plains</i>	<ol style="list-style-type: none"> 1. Plan conjunctive use where exploitable surface water supplies are available 2. Spread groundwater capture over a large area by developing easily manageable and protected peripheral well fields 3. Integrate groundwater development and management into overall urban planning

Epilogue: Summing up

Groundwater is now arguably the most critical water resource of India. In a vast majority of settings in urban and rural India, it underpins agricultural production, livelihoods depending on the rural agrarian economy, and urban and rural water supplies. The resource development has been explosive over the last four decades. This growth in groundwater use has been driven not only by its superior virtues of widespread access and control over the quality and timing of supply, but has also resulted from the mass exit of users in response to the poor quality of public surface water supplies. The explosive growth in groundwater use has also been furtive in its nature, as a result of millions of private well drillings unfettered by any direct law or management framework. As aquifers in an increasingly large number of areas are threatened by overexploitation, India faces a unique challenge in managing its groundwater use, which:

- ◆ in its aggregate quantum ranks as the highest in the world;
- ◆ is being pumped by a similarly unrivaled high number of groundwater users spread across large tracts of the country;
- ◆ has developed without much consideration of the actual groundwater potential of aquifers;
- ◆ has been only marginally governed, if at all, and is a subject of welfare as well as populist politics.

While the international experience in groundwater management provides helpful insights into what may or may not work in the particular settings of groundwater overexploitation in India, there is a lack of groundwater management models that would be suitable for these settings. The approaches based on state-enforced regulation, pricing, and property rights systems have a mixed record of success at best, and have performed well only in authoritarian governance environments or

in situations characterized by a formalized water economy and a comparatively small number of users.

While these instruments may be adapted for some specific situations (for example regulation in urban environments or groundwater allocations for organized user groups), the transaction costs of implementing them for millions of wells and users make them impractical for state enforcement in most of the groundwater settings in India.

This absence of appropriate and credible models of groundwater management is one reason why state action has been limited to rather ineffective attempts at regulating groundwater use in critically threatened areas. Some of the policy measures needed for addressing the problem (such as removing the perverse incentives for groundwater pumping inherent in the provision of cheap agricultural power) are highly unpopular and therefore unviable in the current political environment. Between these “not appropriate for India” prescriptions and “sensible but infeasible” recommendations, the groundwater overexploitation crisis has continued to grow deeper in India.

The premise and mandate of the World Bank’s study and technical assistance initiative on groundwater management was to accept as given the political economy and identify pragmatic options for groundwater management that can be implemented largely within the existing institutional framework. The key emphasis was on praxis, namely the translation of ideas into plans for management action. The activities under this initiative were therefore deliberately structured to draw lessons from the analytical work as well as from the technical assistance provided to implementation of groundwater management interventions in different states of India.

Based on these analytical findings and lessons from the ground, a menu of pragmatic management

interventions has been developed for the main settings of groundwater overexploitation in India:

- ◆ The recommendations comprise specific and practical actions to start managing groundwater here and now, and also include innovative technical measures (such as separating tubewell power feeder systems to exercise control on electricity and groundwater use in agriculture, and groundwater recharge through existing dug wells to make it more cost-effective) that can sidestep political difficulties or enhance potential results.
- ◆ The menu is not uniformly rich while the significant demand management results achieved by an innovative community-based groundwater management initiative in Andhra Pradesh point to a viable model for community management in hard-rock areas of India, no similar solutions can be recommended for the alluvial aquifers.

- ◆ The menu is practical, and unlike a number of classical recommendations, does not propose options that appear to be political suicide to the decision makers.
- ◆ The confidence in the recommended actions comes from extensive consultations with and support from a broad range of stakeholders on both the technical and political economy aspects of implementation.

Together, the proposed set of interventions sets the basis for changing the game on groundwater management in India, from one that presently consists of either inaction or waiting for champions who can push through unpopular reform interventions, to one where diligent implementation of interventions within the current framework can start producing immediate management results on the ground. For India today, groundwater is too critical a resource to continue to be left unmanaged, and it is hoped that the findings of this report can inspire an action agenda for moving swiftly to protect the vital but ever-declining aquifers of the country.

Sahebrao Nikam of Pandherwadi shows his “water account passbook”, containing the details of the groundwater budget for the local aquifer (Satara, Maharashtra).



Glossary

alluvial aquifer: Water storage system in unconsolidated geological materials (sand, gravel, cobbles, and thin beds of silty clay) deposited by a stream and retaining a hydraulic connection with the depositing stream.

cropping intensity: Number of croppings on a given piece of agricultural land per year. *Double cropping* occurs when two crops are planted sequentially with no overlap in the growth cycle.

evapotranspiration: The process by which water is transferred to the atmosphere through both transpiration from plants and evaporation from soil and plant surfaces. *Beneficial evapotranspiration* is evapotranspiration of moisture that has already been utilized by the crop; *nonbeneficial evapotranspiration* is evapotranspiration of moisture that has not contributed to crop production (for example from soil, weeds, or surface water).

graben: A depressed segment of the earth's crust that has slid downward between two faults and is bounded by them.

graben fill sedimentary aquifer: An aquifer based in the sediment that is deposited by a river flowing in the graben.

hard-rock aquifer: Water storage system in the crystalline basement complex and metamorphic rocks typical of peninsular India, including those areas underlain by ancient volcanic rocks, such as the basalts of western India (Deccan Traps).

headwater zone: Upper reaches of canal system.

kharif: The agricultural season that commences with the onset of the monsoon (June/July) and continues until October; also referred to as the "monsoon crop" or "autumn harvest crop".

nonrecoverable fraction of irrigation water: That part of irrigation water that seeps into water storage systems from which it cannot be recovered, for example saline water bodies.

rabi: The agricultural season spanning approximately the period from October to March/April; also called the "winter crop" or "spring harvest crop".

tailwater zone: Lower reaches of canal system.

References

- Agarwal, A., and S. Narain. 1997. *Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems*. New Delhi: Centre for Science and Environment.
- Bhatia, Ramesh. 2005. *Water and Growth*. Background Paper. Washington, DC: World Bank.
- Briscoe, J. 1999. "The Financing of Hydropower, Irrigation and Water Supply Infrastructure in Developing Countries." *Water Resources Development* 15(4):459–91.
- Central Ground Water Board. 2005. *Master Plan for Artificial Recharge to Ground Water in India*. New Delhi: Government of India, Ministry of Water Resources (<http://cgwb.gov.in/documents/MASTER%20PLAN%20Final-2002.pdf>, accessed May 16, 2009).
- Central Ground Water Board. 2006. *Dynamic Groundwater Resources of India (as on March 2004)*. New Delhi: Government of India, Ministry of Water Resources.
- Coase, R. H. 1960. "The Problem of Social Cost." *Journal of Law and Economics* 3:1–44.
- Cordova Urrutia, J. 2007. *An Aquifer in Equilibrium*. Presentation by COTAS President in Comondu, Irrigation District 066, Santo Domingo Valley (Baja California Sur, Mexico) in the National Meeting of COTAS, Guanajuato, Mexico, September 19–21, 2007.
- Dossani, R., and V. Ranganathan. 2004. "Farmers' Willingness to Pay for Power in India: Conceptual Issues, Survey Results and Implications for Pricing." *Energy Economics* 26:359–69.
- Dreze, J., and A. Sen. 2002. *India: Development and Participation*. New Delhi: Oxford University Press.
- Dubash, N. 2007. "The Electricity-Groundwater Conundrum: Case for a Political Solution to a Political Problem." *Economic and Political Weekly* December 29, 2007.
- FAO (Food and Agriculture Organization of the United Nations). 2008. *Andhra Pradesh Farmer Managed Groundwater Systems: Evaluation Report*. APFAMGS-GCP/IND/175/NET.
- Freire, P. 1973. *Education for Critical Consciousness*. New York: Seabury Press.
- Government of India. 2005. *Net Area Irrigated from Different Sources of Irrigation and Gross Irrigated Area in India during 1950–1951 to 2000–2001*. New Delhi: Government of India, Ministry of Agriculture.

- GW-MATE (Groundwater Management Advisory Team). BN-2. *Characterization of Groundwater Systems: Key Concepts and Frequent Misconceptions*. Briefing Note 2. Washington, DC: World Bank (http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1210186362590/GWM_Briefing_2.pdf, accessed May 16, 2009).
- GW-MATE (Groundwater Management Advisory Team). CP-6. *Integrated Approaches to Groundwater Resource Conservation in the Mendoza Aquifers*. Case Profile 6. Washington, DC: World Bank (http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1210186345144/GWMATE_English_CP_06.pdf, accessed May 16, 2009).
- GW-MATE (Groundwater Management Advisory Team). CP-7. *Yacambu-Quibor: A Project for Integrated Groundwater and Surface Water Management*. Case Profile 7. Washington, DC: World Bank (http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1210186345144/GWMATE_English_CP_07.pdf, accessed May 17, 2009).
- GW-MATE (Groundwater Management Advisory Team). CP-10. *Mexico – The “COTAS”: Progress with Stakeholder Participation in Groundwater Management in Guanajuato*. Case Profile 10. Washington, DC: World Bank (http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1210186345144/GWMATE_English_CP_10.pdf, accessed May 17, 2009).
- GW-MATE (Groundwater Management Advisory Team). CP-13. *The Role of Groundwater in the Water Supply of Greater Nairobi*. Case Profile 13. Washington, DC: World Bank (http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1210186345144/GWMATE_English_CP_13.pdf, accessed May 17, 2009).
- GW-MATE (Groundwater Management Advisory Team). CP-14. *Groundwater Use in Metropolitan Fortaleza, Brazil*. Case Profile 14. Washington, DC: World Bank (http://siteresources.worldbank.org/INTWAT/Resources/GWMATE_CP_14.pdf, accessed May 17, 2009).
- GW-MATE (Groundwater Management Advisory Team). CP-20. *Controlling Groundwater Abstraction and Related Environmental Degradation in Metropolitan Bangkok*. Case Profile 20. Washington, DC: World Bank (http://siteresources.worldbank.org/INTWAT/Resources/GWMATE_CP_20_Bangkok.pdf, accessed May 17, 2009).
- Jha, S., P.V. Srinivasan, and M. Landes. 2007. *Indian Wheat and Rice Sector Policies and the Implications for Reform*. Economic Research Report No. 31. Washington, DC: United States Department of Agriculture, Economic Research Service.
- Kemper, K. E. 2007. “Instruments and Institutions for Groundwater Management.” In *The Agriculture Groundwater Revolution: Opportunities and Threats to Development*, ed. M. Giordano and K. G. Villholth. Comprehensive Assessment of Water Management in Agriculture Series. Wallingford, United Kingdom: CABI Publishing.
- Kumar, M. D. 2005. “Impact of Electricity Prices and Volumetric Allocation on Energy and Groundwater Demand Management: Analysis from Western India.” *Energy Policy* 33:39–51.
- Kumar, M. D., A. Patel, R. Ravindranath, and O. P. Singh. 2008. “Chasing a Mirage: Water Harvesting and Artificial Recharge in Naturally Water-scarce Regions.” *Economic and Political Weekly* August 30, 2008.
- Londhe, A., J. Talati, L.K. Singh, S. Dhaunta, B. Rawlley, K. K. Ganapathy, and R. Mathew. 2004. *Urban-Hinterland Water Transactions: A Scoping Study of Six Class I Indian Cities*. Paper presented at Annual Partners’ Meet of the IWMI–Tata Water Policy Program, February 2004, Anand, Gujarat.
- Maria, A. 2006. “The Role of Groundwater in Delhi’s Water Supply: Interaction between Formal and Informal Development of the Water System,

- and Possible Scenarios of Evolution." In *Urban Groundwater Management and Sustainability*, ed. J. H. Tellam, M. O. Rivett, R. G. Israfilov, and L. G. Herringshaw. Dordrecht: Springer.
- Massachusetts Institute of Technology. 2008. *Climate Change Could Dramatically Affect Water Supplies* (<http://www.sciencedaily.com/releases/2008/12/081217190435.htm>, accessed May 15, 2009).
- Molle, F., and J. Berkoff. 2007. *Irrigation Water Pricing: The Gap between Theory and Practice*. Comprehensive Assessment of Water Management in Agriculture Series, No. 4. Wallingford, United Kingdom: CABI Publishing.
- Mukherji, A. "Groundwater Markets in the Ganga Brahmaputra Meghna Basin: Theory and Evidence." *Economic and Political Weekly* 39(31): 3514–20.
- Narayana, P., and C. Scott. 2004. *Effectiveness of Legislative Controls on Groundwater Extraction*. Paper presented at Annual Partners' Meet of the IWMI–Tata Water Policy Program, February 2004, Anand, Gujarat.
- National Advisory Council. 2008. *Drinking Water Security in Rural India*. Concept Paper. New Delhi: Government of India (http://pmindia.gov.in/nac/concept%20papers/rural_water.pdf, accessed May 15, 2009).
- NSSO (National Sample Survey Organization). 2005. *Situation Assessment Survey of Farmers: Some Aspects of Farming. 59th Round, January–December 2003*. Report 496 (59/33/3). New Delhi: Government of India, Department of Statistics.
- Ostrom, E. 2001. "Reformulating the Commons." In *Protecting the Commons: A Framework for Resource Management in the Americas*, ed. J. Burger, E. Ostrom, R. B. Norgaard, D. Polikansky, and B. D. Goldstein. Washington, DC: Island Press.
- Planning Commission. 2007. *Report of the Expert Group on Groundwater Management and Ownership*. New Delhi, Government of India, Planning Commission.
- Ray, S., and M. Bijarnia. 2006. "Upstream vs Downstream: Groundwater Management and Rainwater Harvesting." *Economic and Political Weekly* June 10, 2006.
- Sakthivadivel, R. 2007. "The Groundwater Recharge Movement in India." In *The Agriculture Groundwater Revolution: Opportunities and Threats to Development*, ed. M. Giordano and K. G. Villholth. Comprehensive Assessment of Water Management in Agriculture Series. Wallingford, United Kingdom: CABI Publishing.
- Saleth, R. M. 1994. "Groundwater Markets in India: A Legal and Institutional Perspective." *Indian Economic Review* 29(2): 157–76.
- Schlager, E. 2007. "Community Management of Groundwater." In *The Agriculture Groundwater Revolution: Opportunities and Threats to Development*, ed. M. Giordano and K. G. Villholth. Comprehensive Assessment of Water Management in Agriculture Series. Wallingford, United Kingdom: CABI Publishing.
- Shah, T. 2005. "Groundwater and Human Development: Challenges and Opportunities in Livelihoods and Environment." *Water Science and Technology* 8: 27–37.
- Shah, T. 2007. "The Groundwater Economy of South Asia: An Assessment of Size, Significance and Socio-ecological Impacts." In *The Agriculture Groundwater Revolution: Opportunities and Threats to Development*, ed. M. Giordano and K. G. Villholth. Comprehensive Assessment of Water Management in Agriculture Series. Wallingford, United Kingdom: CABI Publishing.
- Shah, T. 2008. "India's Master Plan for Groundwater Recharge: An Assessment and Some Suggestions

- for Revision." *Economic and Political Weekly* 43:51.
- Shah, T. 2009. *Taming the Anarchy: Groundwater Governance in South Asia*. Washington, DC: Resources for the Future.
- Shah, T., D. Molden, R. Sakthivadivel, and D. Seckler. 2000. *The Global Groundwater Situation: Overview of Opportunities and Challenges*. Colombo: International Water Management Institute.
- Shah, T., C. Scott, A. Kishore, and A. Sharma. 2007. "Energy-Irrigation Nexus in South Asia: Improving Groundwater Conservation and Power Sector Viability." In *The Agriculture Groundwater Revolution: Opportunities and Threats to Development*, ed. M. Giordano and K. G. Villholth. Comprehensive Assessment of Water Management in Agriculture Series. Wallingford, United Kingdom: CABI Publishing.
- Shah, T., and S. Verma. 2008. "Real-time Co-management of Electricity and Groundwater: An Assessment of Gujarat's Pioneering Jyotigram Scheme." *Economic and Political Weekly* 43(7): 59–66.
- Sharma, M. 2006. "The Making of Moral Authority: Anna Hazare and Watershed Management Programme in Ralegan Siddhi." *Economic and Political Weekly* May 20, 2006.
- Sharma, S. K., and M. Mehta. 2002. *Groundwater Development Scenario: Management Issues and Options in India*. Paper presented at IWMI/ICAR/Colombo Plan-sponsored Policy Dialogue on Forward-Thinking Policies for Groundwater Management: Energy, Water Resources, and Economic Approaches, India International Center, New Delhi, India, September 2–6, 2002.
- Terrell, B. L., P. N. Johnson, and E. Segarra. 2002. "Ogallala Aquifer Depletion: Economic Impact on the Texas High Plains." *Water Policy* 4(1):33–46.
- Times of India*. 2008. "Groundwater Continues to Plummet in South Delhi." New Delhi: Times of India July 9, 2008 (http://timesofindia.indiatimes.com/Delhi/Groundwater_continues_to_plummet_in_S_Delhi/articleshow/3212798.cms, accessed May 17, 2009).
- World Bank. 2001. *India: Power Supply to Agriculture*. Washington, DC: World Bank.
- World Bank. 2005. *India's Water Economy: Bracing for a Turbulent Future*. Washington, DC: World Bank.



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