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**INDIA - WATER RESOURCES MANAGEMENT
SECTOR REVIEW**

**GROUNDWATER REGULATION AND
MANAGEMENT REPORT**

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**Rural Development Unit
South Asia Region
World Bank**

**In Collaboration With the
Central Ground Water Board
Ministry of Water Resources, Government of India**

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ABBREVIATIONS

CADR	Centre for Advanced Development Research
CERC	Central Electricity Regulation Commission
GA	Groundwater Authority
CGWB	Central Groundwater Board
CMNAPP	Common Minimum National Action Plan for Power
CWC	Central Water Commission
GDP	Gross domestic product
GEC	Groundwater Estimation Committee
GMD	Groundwater Management Department
GOI	Government of India
HYV	High-yielding varieties
IRP	Integrated resource planning
KON	Kingdom of the Netherlands
MOWR	Ministry of Water Resources
NABARD	National Bank for Agriculture and Rural Development
NDDB	National Dairy Development Board
NGO	Non-governmental organizations
SEB	State Electricity Board
SERC	State Electricity Regulation Commission
SGWO	State Groundwater Organization
TE	Triennium ending
U.P.	Uttar Pradesh
VOs	Voluntary organizations

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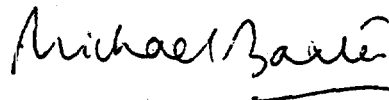
PREFACE

INDIA - Water Resources Management Sector Review Groundwater Regulation and Management Report

Groundwater has played a crucial role in India for food production, drinking water supply, drought mitigation and economic development generally. Due to its relative abundance historically, past emphasis has been on developing its use. As relative scarcity and quality concerns of groundwater have evolved, there is increasing recognition of the need to integrate conservation and resource management.

This report, collaboratively prepared by the Government of India and the World Bank, has emerged from the recognition at policy levels of the need to address groundwater management issues. Together with the technical issues, considerations such as rural power policies, the environment, surface water management and the participatory institutions that compose civil society, which all have implications on India's ability to effectively manage its groundwater resources, have been addressed. By broadening the discussion to encompass economic, legal, environmental and social as well as technical factors, this report goes a long way in enabling the identification of an effective and implementable reform program.

The reform program outlined in the report is ambitious yet practical. Some aspects are innovative and would require testing and refinement through pilot activities prior to widespread implementation. But most recommendations can be broadbased forthwith. The report has admirably achieved its objective of highlighting the basic principles required for groundwater management and of articulating a framework for changes in policy and implementation. The spirit of open dialogue and collaboration that characterized the preparation of this report gives some confidence that the complex challenges inherent in addressing India's groundwater management needs can and will be tackled.



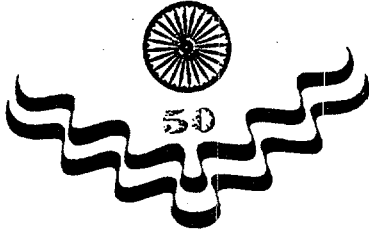
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Preface

This joint report by the Ministry of Water Resources and World Bank highlights many crucial problems facing India as the nation charts future policies for equitable, efficient and sustainable management of its ground water resources. As the report rightly emphasizes, ground water is a vital resource for agriculture, domestic water supply and industry. Agricultural sector productivity, poverty alleviation, rural development and even environment are influenced by the development and management of ground water resources.

Management of ground water resources is a major emerging challenge for India. This report outlines an ambitious but practical reform program that provides a strong starting point for the development of ground water management capacity. Many elements of the reform program will, of course, evolve as they are tested and put into practice. As the report recommends, pilot activities are essential for this evolution to occur. Ground water management necessitates development of practical responses to extremely complex challenges. Needs and management options differ both within and between regions. Effective management requires an information base capable of addressing this diversity. It also requires an appropriate legal framework and a strong, integrated set of organizations capable of implementing management actions at national, state and local levels. People's participation is also important since they are the ultimate users of ground water resources. Pilot activities will provide the practical experience necessary to translate the broad complex policy issues addressed in the proposed reform program into a firm action agenda for the day to day management of India's ground water resources.

This report represents the outcome of a collaborative process between the Government of India and the World Bank. The Ministry of Water Resources' Sub-Group on Ground Water devoted substantial time and resources to compilation of information and preparation of its background report. The staff and consultant team provided by the World Bank contributed substantially to the report. Discussions at the workshop on Ground Water Regulation and Management held in New Delhi on February 18-19, 1997, were open and frank. They also brought in the views of representatives from many non-governmental organizations. The net result is a much broader picture than has previously been compiled of the institutional, economic and technical considerations that must be addressed if India is to manage its ground water resources equitably, efficiently and sustainably.

Some of the management approaches, such as development of water markets, need further evaluation to determine their applicability to India after providing necessary safeguards. While research in India has documented the widespread presence of small scale, local informal water markets, these are acknowledged to be fundamentally different from large scale water markets operating under formal legal and regulatory structures. Encouragement of these large scale formal water markets would be a major step, the potential risks of which would have to be evaluated alongside the potential benefits. Substantial evaluation and identification of practical institutional and regulatory mechanisms to counter the negative impacts (particularly on the poor and under privileged) is a pre-requisite, before a conscious effort is made for experimenting with the concept.



(ARUN KUMAR)

EXECUTIVE SUMMARY

Context

- i. The importance of groundwater to India's economy and development prospects should not be underestimated. The resource is of importance as a source of drinking water and food security for the 950 million inhabitants of India, supplies 80 percent of water for domestic use in rural areas and perhaps 50 percent of water for urban and industrial uses. Over the last three decades, the rapid expansion in use of groundwater primarily for irrigation has contributed significantly to agricultural and overall economic development in India. Groundwater irrigation potential, the number of wells, and the number of energized pump sets have grown exponentially since the early 1950s. With more than 17 million energized wells nationwide, groundwater now supplies more than 50 percent of the irrigated area and, due to higher yields in groundwater-irrigated areas, is central to a significantly higher proportion of total agricultural output. In addition, in drought years, groundwater represents the primary reliable source of irrigation.

- ii This rapid development in groundwater, however, has had a price. In many arid and hard-rock zones, increases in overdraft areas and associated water-quality problems are emerging. Blocks classified as dark or critical increased at a continuous rate of 5.5 percent over the period 1984–85 to 1992–93. At this pace, and without regulatory or recharge measures, over 35 percent of all blocks will become over-exploited within 20 years. Sustainability of the resource base is thus critical for meeting an array of basic needs—from health to economic development.

A. ASSESSMENT AND ISSUES

From Development To Management

- iii. The core groundwater challenge facing India is the shift from development (i.e., additional extraction activities) to management. Concerns of overdraft and a broad array of other management needs are emerging in many areas and are of fundamental importance to resource sustainability. The emphasis on management needs, does not imply that groundwater resources in India are fully developed. Additional extraction could still be supported in a few localities. However, focus on development activities must now be balanced by management mechanisms to achieve a sustainable utilization of groundwater resources.

- iv. At issue also is the appropriate role for the government in the various activities of the sector. Although facilitated by the provision of institutional credit and subsidized energy supplies, most groundwater development has been accomplished successfully through the private investment of millions of farmers (MOWR, 1996). Groundwater development will thus likely continue in most regions regardless of government intervention, due to continued privately funded investments by farmers who now understand the benefits of groundwater irrigation. In contrast, direct government involvement through the development of public tubewells, though costly, has achieved little success and currently contributes a very minor fraction of the total area irrigated with groundwater. While the continued availability of credit may be important to

maintain, particularly for poor farmers who need to replace or upgrade existing wells, large-scale direct government support for groundwater development is largely unnecessary today.

v. Although the private sector will continue its prominent role in groundwater development, private sector initiatives are unlikely to address the many management needs. Protection of drinking water sources, pollution control, groundwater recharge, and environmental concerns such as overdraft and associated water quality problems, are the key issues needing to be addressed. Overdraft is, however, only a fraction of the management challenge associated with groundwater. Large areas, particularly in the command of surface irrigation systems, suffer from waterlogging and problems associated with salinity or alkalinity. Furthermore, the impact of development on the environment and non-agricultural users can be major even where overdraft or waterlogging are absent. Seasonal fluctuations in the water table can affect shallow wells, low seasonal flows in surface streams and pollution loads. This can have a major impact on the availability of drinking water, on the poor, and on the environment. In addition, there is the question of water quality and pollution. Pollution or deterioration in water quality can reduce the availability of water in ways that are far less reversible than overdraft. Non-point-source pollution from agriculture and other sources combined with point-source pollution represents a major challenge for groundwater management (MOWR, 1996). These issues will appropriately require leadership and facilitation primarily from the government. Unless management capacity is developed, the resource base will be undermined, with major impacts on the environment, domestic users, agriculture, and industry. Governmental efforts thus need to shift from development to these far more complex management needs.

vi. The combination of challenges now emerging necessitates a broad-based approach to groundwater management. To date, most management responses to overdraft have focused on supply-side solutions such as groundwater recharge. Although recharge activities are important and should be enhanced, they represent an extremely limited aspect in a much broader array of potential interventions. On the supply side, conjunctive management approaches involving the operation of surface systems can improve the availability of both ground and surface water. Overall, however, demand-side interventions are of equal, if not greater, importance than those on the supply side. Improvements in irrigation efficiency, expansion of low-water-intensity cropping patterns, and encouragement of municipal and industrial water conservation, need to be core components of programs to manage water scarcity. Overall, groundwater management approaches need to focus on the inter-linked hydrologic and use systems as a whole rather than primarily on supply-side aspects.

vii. Similar broad approaches are needed to monitor and address environmental impacts and concerns, such as waterlogging and pollution. These need to be integrated effectively into groundwater development and management approaches. These systemic environmental implications, however, should not be neglected by focusing narrowly on overdraft or waterlogging. In addition, it is important to recognize the high level of variability in management needs, which can differ fundamentally even between adjacent areas. Furthermore, impact evaluation needs to be focused at the system as well as the local level. Pollution is also a major threat at the system level. Where waterlogging is concerned, controlling the inflow of surface supplies may be far more efficient than attempting, as is often done, to pump out excess

groundwater. This is particularly true where groundwater is of poor quality. Likewise, attempts to limit the introduction of pollutants to the hydrologic system through land-use planning and the encouragement of low-fertilizer-and-pesticide-intensity agriculture will be much more effective than efforts to remediate aquifers once polluted.

Institutional Re-orientation

viii. Though groundwater in India is constitutionally a state responsibility, the center maintains equal capability to undertake groundwater activities. Under present arrangements there is substantial duplication of activities between state and central governments, particularly in the area of undertaking broad assessments of recharge and extraction as a basis for targeting development finances. While this is a valuable mechanism for cross-checking data from different sources, it is also a relatively inefficient use of scarce resources. The cost of this is recognized in India, and efforts are under way to minimize expenditures stemming from duplication of water-level measurement (MOWR, 1996). A further and more critical source inefficiency, is the focus of the CGWB on macro-level data and analysis, while state groundwater organizations (SGWOs) focus on micro levels. Effective analysis of hydrologic system dynamics cannot be differentiated into macro and micro components but rather depends on the scale of the system being studied. The consequence of the macro-micro distinction is the perpetuation of development-focused assessments of water balance to the neglect of management capacity development in center and state agencies in activities—such as in scientific research versus implementation—where they have different comparative advantages.

ix. Aside from these issues, existing organizations lack capacity in key management areas. Management is not primarily a technical challenge but depends heavily on social, economic, legal and other considerations. At present, most groundwater organizations are dominated by engineers. Even in the technical arena, most of capacity in the CGWB and SGWOs is concentrated on exploration and basic resource monitoring, not on the types of system analysis essential for management. An additional constraint is the lack of integrated approaches or effective communication between the various water and environmental organizations. Without effective institutional mechanisms to implement an integrated approach, sustainable management will be unattainable.

x. Attempts to regulate groundwater through restrictions on credit and electricity connections—the primary governmental management effort implemented to date—have had only limited success. While there is some evidence from NABARD that withdrawal of credit support for new wells reduces the number of new wells constructed, this will not be sufficient to address existing overdraft concerns. There will need to be initiatives by NGOs and local populations to address groundwater problems and these have begun to emerge in some areas. These indicate local concern and willingness to act in areas where groundwater problems are perceived as urgent. Frameworks need to enable local management initiatives and provide adequate technical support while also enabling government management where locally based approaches are not viable. Frameworks also need to establish a *process* by which management can be initiated and gradually evolve with regard to the issues addressed and tools used. This is essential because as

yet, limited institutional capacity exists for addressing the broader array of groundwater management needs emerging in different parts of the country.

xi. Effective management will also require strong data collection and analytical input. Descriptions of groundwater availability and the functioning of hydrologic systems underpin major investment programs and management decisions. As such, data and analysis are a fundamental tool in political and philosophical debates. With this in mind, there is a need to fill the critical gaps in data availability and assessment, in particular with regard to groundwater pollution, and on hydrologic systems in the hard-rock regions that underlie two-thirds of India (MOWR, 1996). Throughout India, governmental organizations at central and state levels systematically collect large quantities of valuable groundwater data. The monitoring activities focus primarily on groundwater development aspects, and there is a large degree of overlap between different agencies. To facilitate the ability of the organizations involved to build the common social consensus essential for effective management, data collection and analytical systems should be transparent and accepted as reliable by all actors.

xii. While the current data collection and assessment system has served a useful purpose by encouraging the collection of a standard data set, it has had limited practical use. Extraction and recharge estimates developed using MOWR's Groundwater Estimation Committee (GEC) methodology provides little information on groundwater dynamics and interaction with surface water systems. It encourages data processing rather than scientific evaluation. Because it also omits dimensions of water quality and pollution, or the array of environmental and socioeconomic impacts that groundwater development can have long before overdraft conditions occur, it provides limited advance warning of emerging problems. Focusing analysis on hydrologic units such as watersheds and aquifers, rather than on administrative units, would improve the estimates. This is recognized by the CGWB and is likely to be incorporated in ongoing revisions to the GEC methodology. The better approach, however, would be to adopt direct indicators of groundwater conditions, such as long-term trends in the level and quality of water and pollutant concentrations in groundwater which could signal emerging problems—of quality as well as quantity—more reliably and transparently than estimates based on the water balance approach.

Legal and Regulatory Framework

xiii. Systematic approaches to management require a solid legal framework if they are to be implemented. Groundwater legislation will ultimately be essential for management. There is, however, little unanimity regarding the form such legislation should take in order to be effective. As a result, a careful review of legislative issues is essential. Given the wide disparities in opinion in India regarding the appropriate legal frameworks,¹ the review should involve a wide range of participants from both within and outside government, such as non-governmental organizations (NGOs), academics and representatives from different states. Substantial international experience regarding establishing effective legal frameworks for groundwater

¹ For instance, legal approaches proposed by Chhatrpathi Singh (Centre for Environmental Law), Vishal Narayan (Tata Energy Research Institute), and Maria Saleth (Centre for Economic Growth) are quite different from those proposed by the government and outlined in the model bill prepared by the CGWB.

management should be reviewed and could serve as useful examples, although adaptation and possibly extensive modification to reflect the Indian context would be required. Experimentation with alternative management approaches using existing legal avenues and administrative powers may also be important in order to frame appropriate legislation.

xiv. The CGWB has prepared a model legislation for groundwater regulation. Several versions of the proposed legislation have been circulated to state governments, and the latest version is currently under revision. The current version focuses on regulation and addresses management as well as overdraft regulation. Earlier versions advocated establishing a centrally controlled, technically dominated Groundwater Authority in each state. These versions contained no provisions for ensuring the effective participation of local populations in management or regulation. Regulatory or management approaches based primarily on powers vested in state or central government entities face strong opposition at local levels, in academic circles, and in many field and research NGOs.² It is, furthermore, far from clear how implementation could occur.

xv. The recent interim order issued by the Supreme Court establishing the CGWB as a central Groundwater Authority provides an important opportunity for developing and passing effective legislation and corresponding regulatory and management mechanisms at the central and state levels. However, the development of effective management systems will take time. There are no simple solutions. Development will require an energetic and adaptive process that enables piloting and the evolution of management capacity at all levels from the central government to the individual user.

Water Markets

xvi. With increasing scarcity and demands on water resources in India, and the emergence of quality and pollution problems, use of market mechanisms to reallocate water between adjacent farmers or between farmers and urban areas (for domestic or industrial purposes), is evolving and in some areas is becoming prevalent. For the time being, such market activity in India is largely based on groundwater resources. The market is currently informal in that sales occur outside a formal water rights and institutional framework, and thus the ability to regulate not only the sales but also the extent of groundwater extractions is limited if not impossible. Large regulated water markets essential for re-allocating increasingly scarce groundwater and surface water supplies to high-priority uses, have yet to develop.

xvii. To enable the orderly development of markets, the implementation of a regulatory framework will be crucial. Unregulated development of large-scale formal markets for water would have major negative consequences. In the absence of a functioning water rights system and institutional framework for management, water sales would occur with little consideration for third-party and environmental impacts or resource sustainability. Experiences in other countries indicate that these impacts could be significant. Expanding the role of markets into a

² Academic and NGO representatives attending the workshop sponsored by the Government of India and the World Bank on Ground Water Regulation and Management (February 17–18, 1997, New Delhi) strongly criticized the proposed legal frameworks emphasizing governmental regulation as opposed to more participatory strategies.

formal mechanism for water allocation necessitates a reform of the water rights framework, and the development of effective management institutions. Practical approaches to both these aspects represent the major challenge facing the development of markets.

Economic Incentive Mechanisms

xviii. The pace of groundwater withdrawals and use is intimately tied to energy prices. Currently, power is supplied to rural areas at subsidized prices, quoted on a per-horsepower basis of groundwater pumps (i.e., flat rate pricing structure) rather than based on actual quantities consumed. The use of flat rates for electricity, combined with less than fully reliable power supplies, encourage individuals who own wells to maximize pumping of groundwater and sales to neighboring farmers in informal water markets. Where diesel pumps heavily dominate the market, pumping costs and thus water prices in the informal markets are much higher, tending to induce more efficient and sustainable withdrawals and use of groundwater. Energy pricing and other indirect avenues for influencing conditions in informal water markets may represent the most viable avenue for policy action in the absence of, or in addition to, direct pricing of groundwater.

xix. Although energy prices may be one of the strongest levers for influencing the functioning of informal water markets, the question of energy pricing should not be evaluated from a water market perspective alone. An associated problem of subsidized rural power prices are the major financial losses incurred by state electricity boards (SEBs) which range from 5 to 7 percent of total state receipts. A large portion of these losses have been attributed to the agricultural sector, where flat rates are prevalent and collection of electricity charges are low. There is evidence to indicate that agricultural power consumption is far lower than reported by SEBs in all states studied and possibly the country as a whole. Provision of unmetered power to the agricultural sector creates an accountability gap and generates incentives and opportunities for large unaccounted losses to be attributed to agricultural use. Unless the accountability gap is closed, there will be no basis for addressing concerns over SEB finances which will remain precarious.

xx. Cost reflective prices to agriculture based on an efficient cost structure will of course have to be associated with improved quality and reliability of supply. It is unreasonable to expect consumers to pay higher rates for power unless the quality of service improves. Affordability would not be an issue under a regime of cost efficient service delivery. Farmers and other consumers time and again have demonstrated their willingness to pay for quality reliable services.

B. THE REFORM AGENDA

xxi. Resources management requires an integrated approach. Groundwater cannot be managed in isolation of critical considerations such as: integration with surface water; incorporation of water quality, pollution, environment, and health issues; and a broad array of resource allocation, economic and social concerns. Much more attention will also need to be given to end-use efficiency and supply allocation between competing uses. These new challenges require integrated understanding of resource dynamics and more refined approaches

to data collection and analysis. They also require new institutions capable of ensuring the direct involvement of users in the management process. With millions of wells scattered throughout rural India and entrenched traditions of private ownership, user involvement is essential for effective management. Finally, development of effective management systems will take time. There are no simple solutions, and development will require a process that enables piloting and the evolution of management capacity at all levels, from the central government to the individual user. Table I below summarizes the key reform actions. A detailed Matrix of Recommendations is presented in Table 6.1, listing agencies responsible and time frame for action.

Table I. Recommended Plan of Action - Summary

Recommendations

A. REORIENT THE APPROACH TO GROUNDWATER MANAGEMENT

Objective: To achieve a shift in policy and operations from development to management of groundwater resources, including integration of environmental issues.

A.1. *Shift the emphasis from development to management.* The primary challenge facing the organizations dealing with groundwater in India is management, not development. The activities of government organizations and policies affecting groundwater need to reflect this. *Because groundwater management experience is a new area in India and solutions are not clear-cut, pilot management projects will initially be essential to guide the finalization of feasible management options and arrangements.*

A.2. *Integrate Environmental Considerations.* Groundwater development has proceeded with little consideration for environmental implications. These now need to be incorporated through integrated approaches to water management. As a first step toward this, environmental cells should be created in central and state groundwater organizations.

B. CREATE LEGAL AND REGULATORY MECHANISMS.

Objective: Develop legal and regulatory framework that has broadbased community support and is implementable. Utilize pilot management projects to build community support for regulation.

B.1. *Create Legal Frameworks, Institutions and Processes to Enable Management.* In the present context where little unanimity exists on the form that legislation or regulation should take, a broad-based public consultation and review of legislative issues should be undertaken, and pilot projects should be initiated using existing administrative powers to test both the centralized regulatory approach proposed in existing model legislation and the alternative participatory institution-based approaches outlined in this report. These activities will provide a basis for formulating appropriate and implementable groundwater legislation.

B.2. *Evaluate existing and potential roles for water markets.* Informal markets for irrigation and domestic water are widespread. Formal water markets, *if established within an effective rights, institutional and regulatory framework*, could play a major role in addressing water allocation challenges. The impact of policies (particularly regarding energy pricing) on the functioning of water markets needs to be evaluated as part of policy formation. Investigation of rights, institutional and regulatory frameworks is critical for effective implementation of water markets and should be a component in management pilot projects.

Table I (cont.). Recommended Plan of Action - Summary

Recommendations

C. REFORM INSTITUTIONAL STRUCTURES AND OPERATIONS

Objective: Strengthening of Institutional structures and procedures that support the emphasis on management, and the development and strengthening of supporting data and other systems.

C.1. Reorient government organizations. The activities of government organizations involved in groundwater should emphasize participatory management support rather than development. Given the large number of private wells, *community participation is essential, and governmental organizations need to develop capacities supporting this.* Social science, outreach, and education capacities of groundwater organizations should be strengthened. In addition, management requires effective coordination and communication between agencies.

C.2. Create Data and Analytical Tools Essential for Management. High-quality data and scientific analytical techniques are required to meet management challenges. Greater reliance should be placed on direct indicators of groundwater conditions (i.e. water level, point and non-point pollution, and quality trends) combined with detailed hydrogeologic analysis of the aquifers. A two-stage approach to analysis should be adopted in which trends in the water level and quality, water balance estimates using the revised GEC method, and the designation of sensitive zones, are used to target the scientific analysis essential for policy decisions.

D. INTRODUCE TECHNIQUES AND INCENTIVES FOR SUSTAINABLE GROUNDWATER MANAGEMENT

Objective: Providing and strengthening incentives that will induce sustainable extraction and use of groundwater resources.

D.1. Identify Techniques and Programs for Sustainable Groundwater Management. Incorporation of the full range of approaches to groundwater management as core functions of groundwater management organizations is a must. Approaches include: conjunctive management, end-use conservation, land-use planning, agricultural and other pollution-avoidance techniques, and groundwater recharge techniques (both modern and traditional).

D.2. Improving Agricultural Power Supplies and Pricing Structure. An overall program of energy sector reform involving institutional changes, improvements in the quality of supply and price adjustments, is essential to address rural power supply and SEB financial problems. Users should pay the full cost of the energy they consume, but price increases cannot be justified in absence of better quality services. Restructuring of the SEBs per se will not be enough. Commercialization and corporatization of the SEBs will be necessary.³

D.3. Channel Investment to Emerging Needs. Investment programs should reflect the shift in emphasis from development to management. Government support for development is no longer necessary except where: (a) groundwater development levels are low; (b) substantial scientifically-documented groundwater potential exists; (c) additional irrigation is required to raise agricultural productivity; and (d) farmers are unfamiliar with groundwater irrigation or unable to afford new wells. Any government funding, even in the excepted cases above, should be through credit and institutional support to private or cooperative development rather than public wells, and should focus on improvements in energy supply, water conservation, and development of a management information base.

³ Detailed recommendations for power sector reforms are presented in: India Orissa Power Sector Restructuring Project Staff Appraisal Report (PSRP; Report No. 14298-IN), and Haryana PSRP (Report No. 17234-IN).

C. PHASING OF REFORMS

xxii. The ultimate shape of these reforms will evolve out of a long-term process. This shape will reflect experiences gained, needs identified and results achieved in initial phases. Over the short term, therefore, highest priority should go to initiating those activities essential for starting and guiding the overall process of reform. In this context, five sets of activities should be initiated as soon as possible:

- *Establishment of a broad-based public consultation, including NGO and academic representatives, to review legislative issues and guide the design and implementation of pilot groundwater management projects.* Participatory approaches can and need to be developed (in the context of the newly formed Central and State Groundwater Authorities) that draw on the extensive experience of NGOs and other groups working with rural communities. It is only through inclusion of users that many of the problems that have blocked effective management in the past may be overcome. Commencement of the consultation process is, therefore, an important first step.
- *Initiation of pilot projects to test and evaluate management approaches.* Practical experience with many potential groundwater management approaches is lacking in the Indian context. Evaluation of the potential roles for local user-based institutions, water markets, and governmental regulation is essential in order to define long-term management strategies and the reform and legislative foundations they may require. Pilot projects that can be undertaken using existing administrative authority, and used to evaluate and clarify the roles of the various parties, should be initiated in the first phase. Supporting research and evaluation of experiences in other countries, are also important first-phase activities.
- *Initiation of proposed reform of the power sector.* SEB finances and other weaknesses of the electricity sector pose high risk to continued delivery of power services. Incremental improvements to the SEBs will not resolve the problems. SEBs should be commercialized and corporatized (if only initially as public companies). Commencing the process to transform SEBs into business entities will enable the identification and quantification of sources of financial loss.
- *Establishment of an environmental cell in the CGWB and state groundwater boards.* This does not need to be initiated on a large scale during the initial phases of reform. It is, however, important to begin building environmental capacity within groundwater organizations, both to guide the proposed pilot management projects and to assist as data collection systems are expanded to monitor pollution.
- *Design of data collection systems for monitoring groundwater pollution with the intention of initiating pollution monitoring as soon as possible.* Evaluation of pollution problems and management needs requires data. In addition, the ongoing Hydrology Project will provide a vehicle for the development of monitoring systems.

xxiii. Most other activities identified in this report as important for the transition from development to management could be implemented either in the course of ongoing activities or during later phases as results become available. The primary exception is the promulgation of national groundwater legislation. The form legislation should take depends heavily on the results of research and pilot activities. Promulgation should, therefore, occur once results from the first phase are available.

I. THE ROLE OF GROUNDWATER IN THE INDIAN ECONOMY

A. INTRODUCTION

1.1 Groundwater plays a central role in the maintenance of India's economy, environment, and standard of living. It is the primary source of water supply for domestic and many industrial uses. It is also the single largest and most productive source of irrigation water. Yields in areas irrigated with groundwater are higher than in areas supplied by other sources of irrigation, and groundwater plays a critical role in maintaining production during droughts (Dhawan, 1988; Moench, 1992). Competition over available water supplies is growing, however. Urban areas, such as Chennai (formerly Madras), face acute water scarcity for domestic uses, while adjacent agriculture consumes much of the available resource. This is also a concern in rural areas where declines in the water table due to agricultural extraction frequently result in a shortage of drinking water. With India's population growing and expected to pass 1 billion early in the next century, protection and sustainable utilization of India's groundwater resources are essential.

1.2 Over the past three decades, government policies that subsidize credit and rural energy supplies have encouraged rapid development of groundwater resources. These policies have, to a large extent, been successful. In most parts of the country where groundwater resources are available, wells are common and irrigate large areas. Problems associated with rapid development are, however, increasing. Overdraft has become a significant concern in many arid zones and hard-rock regions. It is also a problem in states such as Punjab, Haryana, and western Uttar Pradesh (U.P.) where development levels are high (MOWR, 1996). In addition, in hard-rock areas the specific capacity of wells often declines rapidly after a short period of pumping, indicating limited storage conditions (MOWR, 1996). As a result, depletion often occurs on a seasonal basis even where long-term overdraft problems are not present. Water quality and pollution are also emerging as points of concern in many areas. Finally, waterlogging and associated salinity are major problems in some areas, particularly the command areas of large irrigation systems (MOWR, 1996). These challenges to sustainability are likely to increase as the demand on groundwater resources and competition over available supplies grow.

1.3 Groundwater in India is at a crossroads. Past development efforts have successfully—and in some cases too successfully—led to extensive development of groundwater irrigation. With the exception of improvements in rural electricity supply, most further development can proceed through private initiative. The challenge now is to make the transition from development to sustainable management of the resource base, which is a much more complex task.

B. ECONOMIC IMPACT OF GROUNDWATER

Crop Production

1.4 Groundwater is a significant source of supply for roughly half of India's net irrigated area. Groundwater irrigation (using tubewells, dugwells, borewells, and dug-cum-borewells) began to

expand rapidly with the advent of HYV technology in the second half of the 1960s.⁴ According to some estimates, 70–80 percent of the value of irrigated production in India may depend on groundwater irrigation (Dains and Pawar, 1987). Thus, approximately two-fifths of India's agricultural output comes from areas irrigated with groundwater. Because agriculture and allied activities contribute roughly 30 percent of India's GDP, with crops accounting for three-fourths of this, the contribution of groundwater (with a package of associated inputs) to India's GDP is about 9 percent.

1.5 The significance of groundwater in the economy is due to the fact that agricultural yields are generally higher—by one-third to half—in areas irrigated with groundwater than in areas irrigated with water from other sources (Dhawan, 1995). This is primarily due to the fact that groundwater offers greater control over the supply of water than do other sources of irrigation. As a result, groundwater irrigation encourages complementary investments in fertilizers, pesticides, and high-yielding varieties, leading to higher yields (Kahnert and Levine, 1989). In low rainfall regions it is estimated that “a wholly irrigated acre of land becomes equivalent to 8 to 10 acres of dry land in production and income terms” (Dhawan, 1993). This is often called the dynamic effect of groundwater irrigation on crop yields.

1.6 The strong link between groundwater and economic growth has underlain the development strategy of the country. a special agricultural strategy launched for eastern India (comprising eastern U.P, Bihar, West Bengal, Assam, Orissa, and Eastern Madhya Pradesh) in the mid-1980s, for instance, relied heavily on the exploitation of groundwater. Since 1987, free boring for shallow tubewells and subsidies for pumpsets have been provided throughout the region. This approach appears to have paid rich dividends. Rice production, the main foodcrop of this region, increased rapidly and reasonable progress was made on poverty reduction.⁵

Drought Proofing

1.7 Development of groundwater has led to increased “drought proofing” of India's agricultural economy. The importance of this in the Indian context can be gleaned from the impact of droughts. In the 1960s groundwater was a relatively insignificant source of irrigation, particularly in eastern India. In 1965–66, rainfall (June to September) was 20 percent below normal, leading to drought conditions. Foodgrain production declined 19 percent at the national level over the previous year's level (Table 1.1). In contrast, in 1987–88, rainfall dropped almost 18 percent below normal, but foodgrain production declined only 2 percent over the previous year's level. Although the droughts are not directly comparable, the decline in production in 1987-88 was significantly smaller than in 1965/66, and much of this can be attributed to the spread of irrigation in general and of groundwater irrigation in particular.

⁴ The relation between new technology and groundwater development has been two-way. Not only has groundwater irrigation helped to spread new technology, but some of the profits earned through new technology have been plowed back into groundwater development, leading to the well-known “tubewell explosion” in northwest India. This was facilitated by the government's efforts to promote rural electrification and the banking industry's institutional credit support, especially after 1969.

⁵ West Bengal has experienced the fastest growth of rice production in this region, exceeding 5 percent a year for almost a decade. Rice production also grew faster in Bihar than in the nation as a whole. As a result, this region, which was a net importer of rice from the northwest, became more or less self-sufficient, releasing the surpluses from the northwest to be exported to other countries. In 1995–96, India exported more than 5 million tonnes of rice, becoming the second largest exporter of rice in the world.

Table 1.1. Impact of 1965/66 Drought on Grain Production
(’00,000 tons unless otherwise noted)

Region	Foodgrain output			Rice production		
	1964/65	1965/66	Percentage decline	1964/65	1965/66	Percentage decline
India	893.6	723.5	19.04	393.1	304.4	22.56
Eastern India	189.6	125.6	33.76	124.2	71.3	42.59
Eastern U. P.	51.7	35.6	31.4	17.5	8.4	52.00
Bihar	75.3	36.2	51.93	49.1	14.7	70.60
West Bengal	62.6	53.8	14.06	57.6	48.2	16.32

Source: Prasad and Sharma (1991), Table 7.2.

1.8 Droughts have ripple effects throughout the Indian economy. Not only is there the direct loss of production; there are also numerous secondary effects. Vulnerable populations are particularly at risk and are often forced to migrate in search of work. Public expenditures on drought mitigation and food distribution programs also increase substantially. The growth in India’s irrigated area, particularly the area irrigated with groundwater, has greatly reduced the economy’s vulnerability to sharp reductions in rainfall, drought proofing the rural economy in general and the crop sector in particular.

1.9 An analysis of the variance in growth rates of irrigated and unirrigated agriculture for the period after the advent of new technology in the late 1960s, revealed that the degree of instability in irrigated agriculture between 1971 and 1984 was less than half of that in unirrigated agriculture (Table 1.2). The impact of irrigation on stability is much greater in low-rainfall states, especially those served by assured sources of irrigation such as tubewells (Haryana and Punjab), than in high-rainfall states. Bihar and Madhya Pradesh are the only states that exhibit higher fluctuation in irrigated than in unirrigated agriculture.

Table 1.2. Drought Proofing of Indian Agriculture
(standard deviation in annual growth rates, 1971–84)

State	Irrigated agricultural output ^a	Unirrigated agricultural output ^b	Ratio of irrigated to unirrigated output
Andhra Pradesh	13.6	18.8	1.38
Bihar	22.0	17.9	0.81
Gujarat	23.8	86.3	3.63
Haryana	9.3	54.8	5.89
Karnataka	16.7	31.4	1.88
Madhya Pradesh	24.5	23.0	0.94
Maharashtra	17.9	43.8	2.45
Punjab	4.9	19.3	3.94
Rajasthan	11.3	46.9	4.15
Tamil Nadu	19.2	41.6	2.17
U.P.	12.0	40.0	3.33
Average	7.3	19.0	2.60

Notes: a. Agricultural output consists of foodgrains and non-foodgrains. b. Average is of 11 states reported in the table.

Source: Adapted from Rao and others (1988).

Rural Development and Poverty Alleviation

1.10 The impact of groundwater development extends beyond the owners of wells. The importance of groundwater irrigation for farmers who do not own wells was documented in several early studies in Pakistan (Meinzen-Dick, 1996) and in Gujarat and Eastern U. P. in India (Shah, 1993). These studies indicate that farmers who own wells generally achieve the highest yields, while farmers who purchase water achieve higher yields than farmers who depend on canal irrigation alone, but not as high as the yields achieved by the owners of wells (see Tables 1.3 and 1.4). In addition, farmers who purchase water tend to use more fertilizer, labor, and other inputs than those who depend on canal water alone. This stabilizes the demand for these associated inputs and leads to the spread of support services for pumps, wells, and so forth, creating a base for small-scale rural industries. Overall, therefore, the expansion of groundwater irrigation is a major catalyst for rural development.

Table 1.3. Input Use and Agricultural Productivity

Indicator	Canal only	Purchased from tubewell	Own tubewell
Gross crop income (rupees per acre)	3,018	3,475	4,659
Canal water use per acre (acre-minutes)	26.3	26.2	25.2
Tubewell water use (acre-minutes)	0.0	14.2	31.4
Cash input expenditure (rupees per acre)	309	385	388
Labor use (man-days per acre)	73.8	76.2	75.5
Cropping intensity (percent)	160	168	184
Water-consumptive crops (percent)	35	36	45

Source: Meinzen-Dick (1996), citing Renfro (1982).

Table 1.4. Average Yields of Major Crops by Water Source (kilograms per acre)

Crop	Canal only	Public tubewell	Purchased from tubewell	Own tubewell
Wheat	672	747	784	896
Rice	522	709	784	859
Cotton	261	299	373	485

Source: Meinzen-Dick (1996), citing Freeman, Lowdermilk and Early (1978).

1.11 Beyond its role as a key contributor to agricultural GDP and drought mitigation, the spread of groundwater irrigation supports employment generation and thus rural development and poverty alleviation. In India, while 76 percent of the operational landholdings are small and marginal farms (of less than 2 hectares), they operate only 29 percent of the area. They constitute 38 percent of net area irrigated by wells, and account for 35 percent of the tubewells fitted with electric pumpsets (GOI, 1992). Thus, in relation to operational area, small and marginal farmers are well represented in groundwater irrigation. With productivity being much higher on irrigated than on unirrigated tracts, better access to irrigation for small and marginal farmers reduces poverty in rural areas.

1.12 Groundwater development also promotes direct and indirect employment of skilled and unskilled persons. According to the Working Group on Minor Irrigation for Formulation of the Ninth Plan (1997–2002), about 32 percent of the cost of construction in minor irrigation consists of unskilled labor and 12 percent of skilled labor, with total labor accounting for 44 percent of the cost (GOI, 1996b). Using this and the prevailing wage rates, the working group estimates that a target

12 million hectares could be created through minor irrigation (10 million hectares through groundwater irrigation and 2 million hectares through minor surface irrigation), the direct employment in the construction phase itself would be about 2.1 billion man-days. Additional indirect employment created on every hectare of irrigated land through increased agricultural activity would be approximately 45 days per hectare. By the end of the Ninth Five-Year Plan, there would be additional employment of 432 million man-days every year as a result of the 12 million hectares of minor irrigation created during the plan period (GOI, 1996b).

C. EMERGING CONSTRAINTS AND CONSEQUENCES

1.13 Although the development of groundwater irrigation has yielded a variety of benefits for the Indian economy, agricultural growth has been relatively slow compared with the investments made in agriculture, its overall potential, and the levels of growth achieved by other countries (Table 1.5). Over the period 1980–92, for example, agricultural production in India grew at an average annual rate of 3.2 percent compared with 4.8 percent in Nepal, 4.5 percent in Pakistan, and 5.4 percent in China (World Bank, 1994).

1.14 Growth has been slow in Indian agriculture for a number of reasons. These include distortionary trade policies that accord high protection to manufacturing in comparison to agriculture and low investments in research and development⁶ and infrastructure (including irrigation). Mismanagement of the base of water resources and infrastructure for supplying water and energy also has clearly contributed to the slow growth of Indian agriculture, as indicated by the rising level of subsidies compared with gross fixed capital formation (Figure 1.1).

Table 1.5. Public Expenditures on Agriculture and Growth Rates in India and East Asian Economies
(public expenditure as a percentage of agricultural GDP)

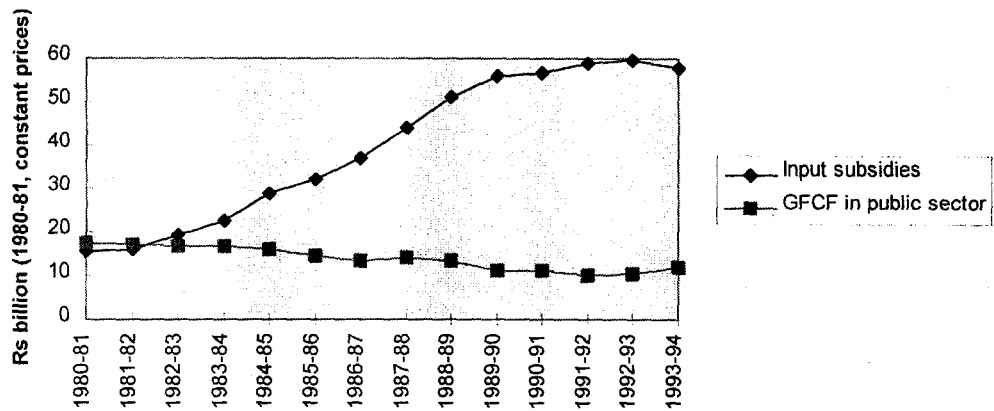
Indicator	India	Indonesia	Malaysia	Thailand
Average Agric. expenditure (1990–1993)	29.1	6.9	10.1	12.9
Avg. annual Agric. GDP growth (1980–93)	3.0	3.2	3.5	3.8

Source: World Bank (1994), Table 4.3.

1.15 The impact of weak groundwater management on India's agricultural development has, however, not been investigated in great detail. Although sufficient data are not available to quantify the impacts, it is clear that there are significant causes of concern regarding the unreliability of highly subsidized power supplies, falling groundwater tables, and deteriorating quality of groundwater. If not checked, these problems have the potential to reduce significantly the beneficial impact of groundwater development on agricultural productivity.

⁶ India currently invests only about 0.3 percent of agricultural GDP in agricultural research as against 0.7 percent in developing countries and 2–3 percent in industrial countries (C. H. Rao 1994).

Figure 1.1. Subsidies and Investments in Indian Agriculture, 1980–94



The Impact of Power Supply Deficiencies

1.16 *Unreliable power supplies.* Despite its phenomenal growth, power still falls short of demand, and the quality of service (reliability and voltage fluctuations) remains poor. Power intensity of Indian agriculture has increased many-fold over the years. From 0.8 kilowatt-hour for every Rs. 1,000 worth of crop output in 1950–51, it reached 2.8 kilowatt-hours in 1960–61 and 94.8 kilowatt-hours in 1991–92.⁷

1.17 Cuts in the power supply and consequent unreliability directly affect the factors that generally contribute to the high productivity of areas irrigated with groundwater. When power supplies are unreliable, farmers have far less control over application of water and associated inputs to their crops. The consequences are much lower yields than would be achievable, due to adverse effect on the viability of investments in complementary inputs such as fertilizers and pesticides. Estimates of the impact of power shortages suggests a cost to agriculture in the range of Rs. 9 to 14 per kilowatt hour in the decade to 1992-93 (Dhawan, 1996).⁸ This is much higher than the actual cost to farmers, which is about 20 paise per kilowatt-hour. Even if one works out the true resource cost of generating and distributing electricity in rural areas, which may come to somewhere between Rs. 3.5 to Rs. 4 per kilowatt-hour, still the opportunity cost is more than double, indicating a very high social benefit-cost ratio of rural electricity supplies. Furthermore, the incentive structure created by an unreliable power supply, its pricing, and absence of any groundwater management framework is a critical constraint on groundwater-irrigated agriculture.⁹

⁷ The dieselization of the rural sector has not been spectacular, despite the dramatic changes taking place during the 1980s: from 6.92 kilograms in 1980–81 to 8.98 kilograms in 1991–92 for every Rs1,000 worth of crop output (Dhawan 1996).

⁸ Dhawan (1996) regressed gross and net values of crop output (at 1980–81 prices) on consumption of electricity in agriculture and rainfall for the period. He found that the coefficient of electricity variability ranged from 2.25 to 3.43, depending on whether the dependent variable was net output or gross output of crop agriculture. Since the prices increased four times during 1980–81 to 1995–96, Dhawan calculated Rs9 for net output and Rs14 for gross output (at 1995–96 prices) as the opportunity cost of every kilowatt-hour of electricity in Indian agriculture (Dhawan 1996).

⁹ For further details, see Annex 3.

1.18 Although the phenomenon of erratic power supplies stretches far beyond agriculture, it is most acute in this sector for several reasons: the overall demand for power far exceeds its supply; the supply lines are poorly maintained, leading to frequent breakdowns; there is a sizable theft of power; and official pricing of electricity for agriculture is very low. Cheap pricing of electricity, particularly on the common flat-rate basis (which depends upon the horsepower of the pumpset) has led to burgeoning subsidies, bankrupting the state electricity boards (SEBs). This adversely affects not only the maintenance of the existing power network but also the further development of this sector.

1.19 Regardless of actual use, power subsidies to agriculture have had a major impact on the SEBs. Where state finances are concerned, the annual share of SEB losses in state fiscal deficits between 1986 and 1995 ranged from 5 to 7 percent (see also Box 1.1). All power users have felt the impact of these deficits. Although this is true to a large extent, it is worth exploring whether the power subsidy to agriculture is really as high as is generally attributed in government accounts. There are indications that a very large portion of the power subsidy intended for agriculture is diverted to other uses (refer para. 5.12). As a result, the contribution of subsidies to agricultural productivity, as with other subsidies to agriculture, has been far less than intended.¹⁰

Box 1.1. Power Subsidy in Indian Agriculture

Of the various subsidies for inputs going to Indian agriculture—fertilizers, rural credit, canal irrigation, and electricity—the single largest subsidy is for power. During the triennium ending (TE) 1994–95, the power share in the four subsidies was as high as 56 percent, followed by fertilizer (16 percent), credit (15 percent), and canal irrigation (13 percent). This is in sharp contrast to a situation existing during the TE 1982–83, when the power subsidy constituted only one-quarter of the total subsidies for inputs to Indian agriculture. The power subsidy for agriculture (in real terms) grew at the rate of almost 20 percent a year during the period 1980–81 to 1994–95. This is much higher than the growth rates registered in subsidies for canal irrigation (6 percent), fertilizer (12 percent), and credit (4 percent; Gulati, 1997). During TE 1982–83, these four subsidies together accounted for 1.3 percent of GDP, which increased to 2.5 percent of GDP during TE 1994–95. The power subsidy alone accounted for a little more than half of this, about 1.3 percent of GDP.

D. IMPLICATIONS FOR GROWTH, EQUITY, AND SUSTAINABILITY

1.21 The economic implications of groundwater management and associated power supply problems are clear:

- *Agricultural growth is constrained.* Unreliable power supplies combined with weak management of groundwater resources greatly constrain the growth of India's agricultural sector. This is because as water tables drop due to unsustainable pumping, farmers are forced to utilize electric pumps of increasingly higher capacity in order to extract groundwater. As a result, farmers become increasingly more dependent on unreliable or rostered electricity supplies thereby risking the viability of their investments in fertilizer and

¹⁰ During the 1980s and early 1990s for example, only 50 percent of the fertilizer subsidy benefited the ultimate consumers (World Bank, 1996).

other inputs. The benefits achieved through groundwater irrigation are likely to decline toward conditions in poorly managed surface irrigation systems or, at worst, rainfed cropping. This will affect yields and the overall productivity of the agricultural sector. Although groundwater is generally the most reliable source of irrigation, unreliability of the power supply and falling water tables erode this core advantage and undermine overall growth rates. In regions where water tables have fallen or rural power supply is unreliable, India's ability to maintain agricultural production during droughts suffers most. This greatly increases the probability that droughts will have major economic impacts at the regional or national levels.

- *Power supply problems have serious ripple effects on commercial and industrial sectors.* The combined effects of unreliability and attempts to cross-subsidize rural power supplies by charging substantially higher rates to industrial and commercial sectors represent a major factor constraining industrial and commercial activity in India. Efficient production and use of capital and labor often depend on reliable power. Although the full impact is impossible to estimate here, cross-subsidies and unreliable power supplies increase costs throughout the economy. For example, unreliable power necessitates investments in captive generation of alternative power sources at all levels of the Indian economy. From the small farmer who chooses to purchase a backup diesel pump to the industry that builds its own power plant, those depending on reliable power supplies must invest in captive generation. This diverts resources that could be applied to other economic activities. As captive generation grows, so does India's dependence on imported fuel. Fuel imports now account for 25 percent of total imports. If the reliability and availability of power continue to decline, oil imports will grow. This increases the vulnerability of India's economy to the global availability and price fluctuations of oil.
- *There is a disproportionate impact on the poor.* In agriculture and industry, the poor bear the greatest burden of groundwater management and power supply problems. Yet the burden extends throughout the economy. The wealthy are able to afford captive generation or diesel pumps; the poor are less able. At a higher level, the overall economic inefficiencies imposed by lack of availability and other factors leave little scope for growth of wages or expansion of the opportunities accessible to the poor.
- *Incentive structures mitigate against effective action.* In nominal terms, farmers receive subsidized power supplies even though, as a result of unreliability of power supplies, the actual per unit cost burden is quite high (refer para. 5.17). For this reason and because they have little confidence that power supply conditions will improve, they oppose changes in the rate structure. At the same time, the lack of accountability in agricultural power supplies, combined with high prices to other sectors, creates both incentives and opportunities for major diversions of power. Interests benefiting from this will oppose effective change. Consumers, particularly farmers, are also likely to oppose change because they have little faith in the government's intentions or capacity to improve service.

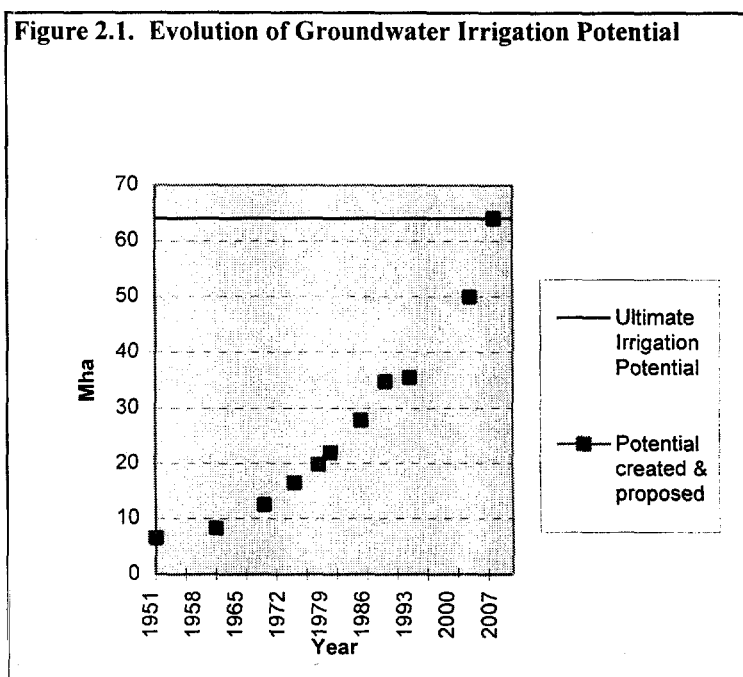
II. FROM DEVELOPMENT TO MANAGEMENT

2.1 Groundwater management rather than development is the major challenge facing water resource organizations in the coming decades. Three factors argue strongly for this shift in focus: (a) the dominance already, and continued strong momentum, toward groundwater development through private initiative; (b) the rapid expansion of groundwater management problems across many parts of the country; and (c) the major organizational and other challenges facing development of effective groundwater management systems.

A. THE MOMENTUM BEHIND DEVELOPMENT

2.2 Groundwater development has been growing at an exponential rate in recent decades. Figures 2.1–2.3 indicate the rapid rate of growth in groundwater irrigation potential and the number of wells and energized pumps.¹¹ Current proposals of the CGWB envision that the rapid pace of development will continue until the full irrigation potential estimated to be available from groundwater is reached in about 2007. Investments are proposed of Rs. 30 billion to Rs. 35 billion per year (Rs. 347.2 billion total) by the government either directly or through NABARD (CGWB, 1996). Energizing the proposed new pumps is estimated to require 33.5 billion kilowatt-hours of electricity and 3.5 billion liters of diesel (CGWB, 1996).

Figure 2.1. Evolution of Groundwater Irrigation Potential

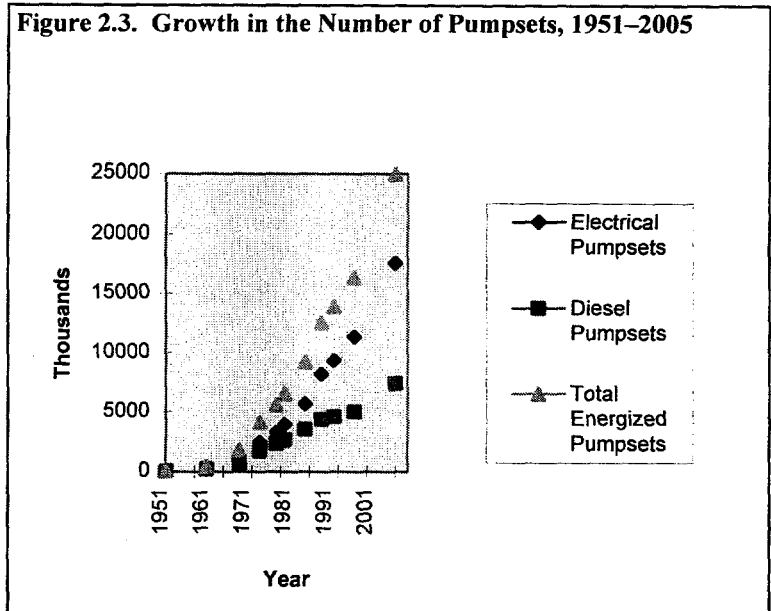
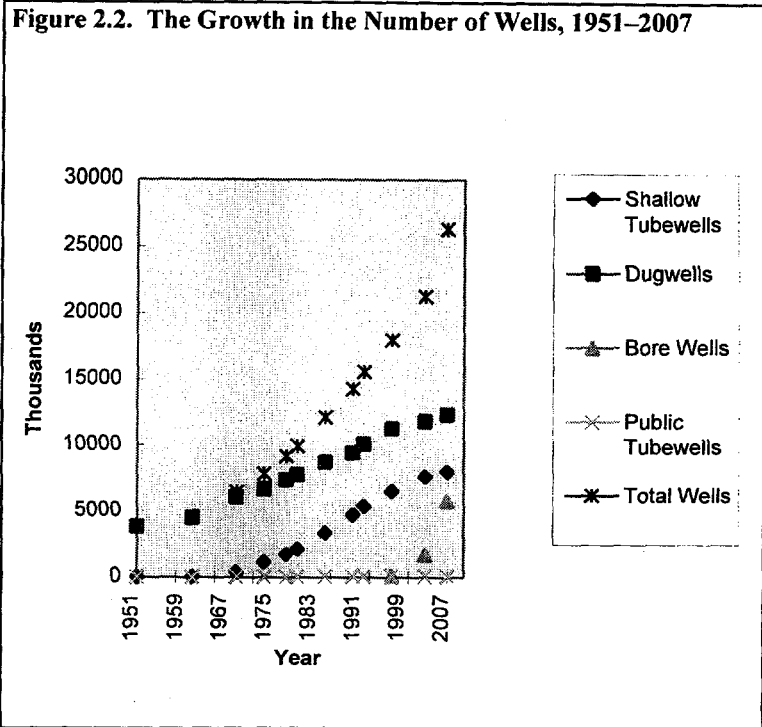


2.3 In addition to governmental support for groundwater development, private investment has been substantial. The degree to which private sector groundwater development has gained momentum independent of government credit subsidies is indicated by the absence of any documented impact on groundwater development rates when those subsidies are withdrawn. Withdrawal of NABARD mechanism used by the government to try to control groundwater extraction in overdraft areas. There appears, however, to be a limited impact on groundwater extraction when credit is withdrawn (Moench, 1991; Vaidyanathan, 1993). Reports from NABARD regional offices indicate that the withdrawal of credit reduces the growth rate of

¹¹ Data for the chart derived from a variety of official sources, including CBIP (1989) and CGWB (1991, 1995, 1996). Statistics after 1993 are estimates, and those after 1997 represent proposals for development prepared by the CGWB (1996).

groundwater exploitation from 1.5–2 percent a year down to 0.3–0.5 percent in dark areas. Although this impact is significant, groundwater extraction is still increasing in dark areas, and existing overdraft concerns persist.

2.4 In some areas, demand for new wells may be declining. Groundwater development in eastern states has been slow, despite the high potential (MOWR, 1996). NABARD officials note that they have had trouble meeting credit distribution targets for new wells in some areas, such as Western U. P., and attribute this to saturated demand. Most credit demand in this area is for rehabilitation of existing wells and pumps. Similarly in these areas, there were insignificant numbers of farmers who lacked access to groundwater irrigation. Although groundwater irrigation is limited in large areas, particularly in the northeast, precipitation is high in many of these areas and demand for irrigation is limited. In sum, although the need to support groundwater development remains in some regions, access to wells is no longer a major issue in areas where returns to irrigation are high and a large groundwater potential exists.



B. RAPID EXPANSION IN PROBLEMS

2.5 With rapid expansion in groundwater extraction, development-related problems have begun to emerge. Official figures on the number of critical and over-exploited blocks are illustrative (Table 2.1). Although the number has declined in some locations, an overall increase of 51 percent has occurred over a period of seven to eight years.

2.6 The number of critical and over-exploited blocks represents a small fraction of the total area irrigated with groundwater in India. This does not reduce the magnitude of the challenge. The change in dark and critical areas between 1984–85 and 1992–93 represents a continuous growth rate of 5.5 percent. If this rate continues, the number of over-exploited and critical blocks will double every 12.5 years. This implies that by the year 2017–18 (25 years from 1992–93), roughly 1,532 blocks, or 36 percent of the 4,248 blocks, in the listed states will be dark or critical. Possible doubts about the accuracy of official estimates notwithstanding, the overall pattern indicates the extent to which overdraft is a growing concern.

Table 2.1. Overexploited and Dark Blocks, 1984–93

State	1984–85	1992–93
Andhra Pradesh	0	30
Bihar	14	1
Gujarat	6	26
Haryana	31	51
Karnataka	3	18
Madhya Pradesh	0	3
Punjab	64	70
Rajasthan	21	56
Tamil Nadu	61	97
U.P.	53	31
Total	253	383

Source: CGWB 1991, 1995.

2.7 Overdraft estimates reflect only a fraction of the problems emerging as groundwater development accelerates. Substantial declines and fluctuations in the water table can occur long before extraction exceeds recharge. This can have major impacts on other users and the environment. Environmental concerns associated with development and pollution are major. Competition between uses is also a substantial point of concern (Box 2.1). In Gujarat, pumping depressions due to agriculture are clearly visible on maps and greatly affect the availability of water for urban areas such as Gandhinagar (see Annex Map A4.1).

2.8 The problem is not limited to urban areas. The impact of agricultural pumping on the availability of rural drinking water has been clearly documented in a few location-specific cases (Wijdemans, 1995). In arid and hard-rock zones, however, the problem is probably much more widespread than the few available research studies document. A sample survey by the Rajiv Gandhi National Drinking Water Mission in 1994 found, for example, that one-third of sample households had experienced seasonal or permanent drops in the water table. Estimates made for the study on rural water supply and sanitation in India suggest that in 1995 perhaps 37 million people lived in areas classified as dark and that this number has increased 2.6 million each year since 1991 (World Bank, 1998). The well networks of state groundwater organizations (SGWO) are heavily dominated by village drinking water wells, which tend to be centrally located, are easily monitored, and generally lack pumps. Interviews with SGWO officials conducted over the past six years in Karnataka, Tamil Nadu, and Gujarat indicate that at least 10 percent (and in some seasons as high as 25 percent) of these wells have gone dry since monitoring was initiated. Although these dug wells are not isolated piezometers, there appear to be no hydrological reasons why they would not serve as reliable indicators of gross changes in water level.

2.9 Competition is not just an issue of availability. The decline in water level can affect the domestic water supply even where there is no real threat of overdraft. Fluctuations in the water table, which are due to groundwater extraction for agriculture, reduce the reliability of shallow wells as sources of drinking water. Even in high-rainfall and recharge areas such as Bangladesh, seasonal fluctuations in the water table can have a major impact on shallow drinking wells (Sadeque, 1996), resulting in major social, financial, and institutional implications. Deeper water

levels necessitate more technologically complex and expensive drinking water systems. The cost differential between simple schemes (based, for example, on shallow hand pumps) and deeper energized pumps could be on the order of 1,000 to 1,500 percent (World Bank, 1998). Furthermore, as the complexity of drinking water systems increases, so do their institutional and fiscal requirements. Drinking water schemes requiring high-capacity energized pumps face institutional challenges similar to those encountered with public irrigation wells.

2.10 Water quality is also a major concern. Increases in fluoride above acceptable levels in drinking water have, for example, been directly correlated with pumping rates and declines and fluctuations in the water level in some projects (KON, 1992). According to the CGWB (1996), "Fluoride levels in the groundwater are considerably higher than the permissible limit in vast areas of Andhra Pradesh, Haryana, and Rajasthan and in some places in Punjab, Uttar Pradesh, Karnataka, and Tamil Nadu." Arsenic is also a critical problem in eight districts of West Bengal (MOWR, 1996). Various other quality problems, in particular iron and salinity, affect large areas.

Box 2.1. Agricultural and Urban Competition

Competition between agricultural and domestic water users is growing. Overdraft in the Jaipur area is also a potential source of tension. In Gujarat, groundwater extraction for agricultural uses is increasing rapidly in aquifers developed to supply 200-kilometer-long rural water supply schemes constructed by the Indo-Dutch project. Rapid drops in the water table and associated increases in fluoride threaten the rural projects (Wijdemans, 1995). Similar issues are present adjacent to urban areas in Rajasthan. Tensions between farmers and Jodhpur municipal authorities over the Rampura-Mathana aquifer have been present for more than a decade (Krupanidhi, 1987; Goldman, 1988a & 1988b).

Tension is not limited to arid areas. Madras urban water shortages are well known. In response, major projects are proposed to transfer roughly 400 million cubic meters of water from Veeranumm tank and the Krishna River. Madras region is, however, not short of water. The Arani-Korteliyar aquifer near Madras has a sustainable yield of approximately 400 million cubic meters, most of which is used for paddy cultivation. Compared with the approximately US\$400 million cost to Tamil Nadu of the Krishna and Veeranumm projects, this water could probably be purchased from current users for less than US\$20 million if water rights systems were allowed. Similar market approaches could help to resolve tensions such as those in Rajasthan and Gujarat.

C. ENVIRONMENTAL CONSIDERATIONS

2.11 Groundwater development can have major environmental impacts, and these are already evident in parts of India. They are elaborated here because emerging environmental challenges associated with groundwater development are significant, particularly in arid areas, are often unrecognized, and even in humid regions could eventually damage the resource base or the water-related environment. Environmentally sustainable management rather than development is the key need.

Environmental Impacts Of Groundwater Extraction

2.12 The need for maintaining in-stream flows is a critical though often unrecognized component of groundwater management, both in India and other countries. Groundwater and surface water are integral parts of the same hydrologic system. Dropping water tables due to

groundwater extraction often have major implications for the base flows of streams. Unless base flows are maintained, downstream users can lose access to water at critical times and pollution of both surface and groundwater is likely to increase. Furthermore, even if base flows in streams can be maintained (for example, through controlled reservoir releases) changes in the water level can have major environmental impacts, directly affecting, for example, surface vegetation ecologies and wetlands. These concerns are well known but rarely receive much attention in India. Their importance is likely to increase.

2.13 Development policies and management approaches must respond to the environmental implications of groundwater development, because groundwater development has implications for the environment beyond those directly associated with agriculture or domestic uses. Groundwater development can have major impacts on flows in surface streams, which in turn impact on quality of the aquifer and the ecology in the contiguous areas of the streams (see Box 2.2). Addressing environmental concerns, therefore, cannot be done effectively in isolation from surface water and dedicated environmental management programs.

Box 2.2. Groundwater Extraction, Pollution, and Instream Flows: The Sabarmati Example

In Gujarat, water levels in Ahmedabad city have been falling at 1.5–2 meters a year over the past few decades (Gupta, 1985 & 1989). As groundwater extraction by the Ahmedabad Municipal Corporation increased in the 1960s and early 1970s, flow in the Sabarmati River, which had been highly correlated with basin rainfall, declined to nearly zero. Surface flows and groundwater are closely connected. Model results suggest that in 1984 roughly 19 percent of groundwater extracted in Ahmedabad was derived from induced seepage from the Sabarmati River (Gupta, 1985 & 1989). Partially due to the low level of flow, pollution in the Sabarmati has increased. According to a comprehensive study by the Central Pollution Control Board, the Sabarmati has become a trunk sewer in the Gandhinagar-Ahmedabad reach, and efforts to restore its quality level will need to ensure minimum flows at all points and at all times in the river” (CPCB, 1989). Groundwater management—in particular, control over extraction—would be central to this objective.

2.14 Modeling activities currently under way in the Ganges basin substantiate the concern that environmental impacts could be far-reaching due to the interconnectedness of the aquifers and interactions between the aquifers and the surface waters (Kahnert and Levine, 1989). Modeling efforts indicate that dry-season flows could decline approximately 75 percent if historical patterns of development continue (Ilich, 1996). Though the modeling is based on limited amounts of hydrologic and geologic data, the results cannot be taken lightly. If they prove accurate, unmanaged groundwater development in the Ganges River basin could have a major impact on instream flows, fisheries, aquatic ecosystems, pollution loads, and water availability for downstream users. Careful management of the aquifer and river system could, however, greatly reduce the potential impacts. Avoiding impacts on instream flows from increased development will require careful basin management. Groundwater extraction needs to be monitored and controlled in areas where hydraulic interconnections to surface water bodies (i.e., rivers, tributaries and wetlands) are strong. Stream flows need to be monitored and, if they approach critical levels, augmented by water released from upstream storage or constraints imposed on pumping.

2.15 Overall, avoiding environmental impacts while increasing groundwater development requires a high degree of information and understanding regarding the dynamics of river and aquifer systems and the ability to manage both surface flows and groundwater extraction effectively. River-aquifer interaction studies are an essential component of this and would provide much of the basic information needed to avoid or mitigate environmental impacts. If developed, this information and management ability would also enable conjunctive management—aquifers could be drawn down in advance of the monsoon, enabling increased recharge during high flows and thus both supplementing the availability of groundwater and reducing waterlogging and flooding.

Waterlogging, Groundwater Quality and Pollution

2.16 Waterlogging represents as important an environmental challenge for groundwater management in India as overdraft. Surface irrigation command areas often experience major waterlogging and associated salinity and alkalinity problems (see Table 2.2). These conditions can exist in close proximity to areas experiencing groundwater overdraft. This is well illustrated in Haryana and Gujarat, where maps show areas with shallow or rising water levels in close proximity to areas with deep, falling water levels (refer Annex Maps A4.1–A4.4). As a result, management needs to be able to respond to substantially different sets of challenges even within relatively small areas. As the maps and table indicate, states such as Gujarat, Rajasthan, Haryana, and Punjab that have large regions affected by overdraft also have major waterlogged areas. Despite the wide variation in estimates, waterlogging and associated salinity and alkalinity clearly pose a major environmental challenge.¹²

2.17 Two points are important with regard to waterlogging and associated water quality problems. First, as with groundwater overdraft, problems caused by rises in the water table necessitate conjunctive management of surface and groundwater resources. Conjunctive management requires more than groundwater development in command areas; it also requires management of surface water inputs. Second, management needs to be flexible and easily adaptable to local conditions. Approaches at the state and local levels should not focus on one aspect of groundwater management to the exclusion of others.

2.18 Groundwater quality is an equally serious environmental concern. As much as two-fifths of India's irrigated area is affected by salinization and alkalinity (Repetto, 1994). Quality problems are greater in some states than others. Roughly 65 percent of the agricultural area of Haryana State is underlain by saline groundwater (Gangwar and Panghal, 1989).¹³ This situation also shows up clearly on maps (refer Annex Map A4.5).

¹² Estimates of the total area affected by waterlogging in India vary greatly. Ministry of Agriculture estimates in 1990 placed the total area affected by waterlogging due to both rises in groundwater and excessive irrigation at 8.5 million hectares in 1990. In contrast, Central Water Commission (CWC) estimates for 1990, which considered only areas affected by rises in groundwater, totaled just 1.6 million hectares (Vaidyanathan, 1994). Estimates compiled for this report indicate a total waterlogged area of 2.5 million hectares (Palinasami, 1997).

¹³ Official figures show 11,438 square kilometers in Haryana are underlain by saline groundwater out of a total area of 44,212 square kilometers for the state (MOWR, 1996).

Table 2.2. Extent of Waterlogging, Salinity, and Alkalinity in Irrigation Projects

State	Number of projects affected	Waterlogging (hectares)	Salinity (hectares)	Alkalinity (hectares)
Andhra Pradesh	4	266,400	5,000	22,040
Bihar	3	362,670	224,300	—
Gujarat	7	89,408	1,214,165	—
Haryana	3	229,840	—	—
J & K	0	1,500	—	—
Karnataka	9	24,543	34,244	—
Kerala	8	11,600	10,610	—
Madhya Pradesh	1	4,260	—	—
Maharashtra	1	6,000	—	—
Orissa	1	196,260	—	—
Punjab	1	200,000	1,008,000	1,211,300
Rajasthan	—	179,500	70,00	—
Tamil Nadu	—	18,000	20,120	27,480
U.P.	—	35,200	483,000	—
Total	—	1,625,181	3,069,439	1,277,990

— Not available.

Source: Vaidyanathan (1994), citing MOWR (1992).

2.19 Water quality also directly correlates with overdraft problems.¹⁴ The correlation is even more striking when one compares blocks classified as “gray” and “dark” with those where quality is poor.¹⁵ This problem is widespread and similar to the following two situations: first, in western Rajasthan water quality is often poor, with electrical conductivities locally exceeding 10,000 micromhos per centimeter at 25°C (Krupanidhi, 1987); and second, in Gujarat, greater than one-third of the groundwater at depths of less than 40 meters contains more than 1,000 milligrams per liter total dissolved solids, and large areas contain more than 3,000 milligrams per liter (Phadtare, 1988; refer Annex Map A4.7). Beyond salinity, naturally occurring contaminants such as fluoride, arsenic, and boron are common and affect the suitability of groundwater for drinking and agricultural uses.

2.20 Groundwater pollution represents one of the challenges in effective groundwater management in India. Pollution poses a serious threat to all groundwater aquifers in India that is virtually irreversible. The central and state pollution control boards focus on hot spots where industrial or municipal effluents have caused major pollution problems. Non-point-source pollution from agricultural fertilizers and pesticides, however, may be an even greater issue, as is already acknowledged. Two decades ago the prospect of groundwater pollution from agricultural chemicals was raised as a pressing issue (Chaturvedi, 1976). At that time, the use of agricultural chemicals in India was a fraction of the use common in western countries. This is no longer the case, and fertilizer use per hectare has been reported to be 60 percent higher than in the United States (Repetto, 1994). Chaturvedi (1976) bemoaned the lack of data on water pollution from agricultural chemicals. This has not changed, though partial information on non-point-source

¹⁴ As can be seen by comparing Annex Maps A4.4 and A4.5, the water level is falling in areas where water quality is good, and the water level is rising in areas where quality is poor.

¹⁵ Refer Annex Map A4.6.

pollution is occasionally available. Although no agency was found to have a systematic program for monitoring potential non-point sources of pollution, the problem is believed to be widespread.

2.21 In coastal areas, saline intrusion related to groundwater extraction is widespread (MOWR, 1996). This often does not show up in official statistics. In Gujarat, for example, saline intrusion is a major problem in Mandvi and Mundra districts, neither of which is classified as containing dark or over-exploited blocks in the CGWB (1995) statistical summary. Large areas in Haryana are also experiencing declines in water quality as over-pumping draws native saline water into freshwater aquifers.

2.22 Groundwater pollution and quality need to be recognized as points of environmental significance. On one level, pollution and quality affect the usability of groundwater resources for domestic, industrial, or agricultural applications. If groundwater becomes degraded, human demands will focus on other resources such as surface streams, with potentially huge secondary impacts. On another level, groundwater quality and pollution have direct implications for the environment. These range from salinization of overlying lands to toxic contamination.

D. THE CHALLENGE OF MANAGEMENT

2.23 Over the coming decades, groundwater management will need to address the broad array of resource and allocation problems now emerging. Overdraft, pollution, poor quality, and the array of impacts that declines (or increases) in the water table have on the environment and third parties, must be addressed. In addition, as urban areas and the non-agricultural economy grows, mechanisms must be found to ensure that water is allocated to high-value, generally non-agricultural, uses. India's ability to feed its rapidly growing population depends on its ability to increase agricultural production and that depends, in turn, on irrigation. Access to groundwater can be a major engine for poverty alleviation and economic development in rural areas. There is a large social value in increasing rural agricultural incomes and slowing migration of the poor to urban areas. Re-allocation must, therefore, not be at the expense of maintaining a viable agricultural economy.

2.24 As India approaches the sustainable limits of groundwater extraction, competition between agriculture and other uses—and within agriculture—will intensify. Solutions to allocation problems will be particularly complicated in areas where overdraft, quality and pollution problems already exist. At least in some areas, current levels of use are being maintained by mining groundwater resources. In these areas, cutbacks in extraction are essential, as are measures to dramatically increase the productivity per use of water. In other areas, the challenge is to maintain extraction within sustainable limits, and to avoid or mitigate the broad array of environmental and social impacts that can emerge with development.

2.25 Given the broad array of problems, uses, and impacts, approaches to groundwater management need to be broadly integrated. Because needs and opportunities vary greatly, often at a local scale, management approaches need to be flexible and capable of adapting to reflect

very local conditions. This is difficult to achieve through centrally controlled programs. Furthermore, the large number of wells, entrenched tradition of private use rights, and limited administrative capacities in many rural areas, mitigate against the success of centralized regulatory approaches. GOI emphasizes the importance of stakeholder participation in the management of wells (MOWR, 1996). Expanding this approach to include mechanisms for effective stakeholder participation in management of the resource base will be critical.

III. STRENGTHENING LEGAL FRAMEWORKS, INSTITUTIONS AND PROCESSES TO ENABLE MANAGEMENT

3.1 Management of India's groundwater will require institutions capable of addressing problems that vary greatly both in character and in scale. Legal frameworks and institutional approaches will need to respond to this variability. They also need to respond to the interests and concerns of local populations. Management often requires actions at the individual level, and the government is unlikely to be able to enforce many of these actions over the objections of local populations. In this context, institutional frameworks that enable effective participation of local users and communities in the management process are essential. Real participation is not a simple process. At its root, participation involves a dialogue between users and government authorities over the nature and goals of management. The balance in this dialogue depends, in turn, on the larger balance of power among participants. Participation rarely occurs unless participants have the power and authority to influence outcomes—in this case, decisions concerning the goals and techniques of groundwater management. Institutional structures must, therefore, provide local communities and users as well as the government with a degree of real power to shape management approaches. Transfer of power to local levels is a key component in the recently revitalized Panchayat Act (the 73rd Amendment to the Constitution). Approaches to developing groundwater management institutions need to reflect this trend and strike a balance between the roles and powers of centralized government organizations and the decentralized roles and powers of local stakeholders. None of this will be simple. Given the complexity, it is important to recognize that effective institutions will not emerge overnight and that processes enabling the development of institutions and capacity are essential.

3.2 These observations are particularly relevant now. The Supreme Court has recently mandated government action to address groundwater overdraft problems and establish the CGWB as a Groundwater Authority (GWA), with a complementary authority in each state. At the same time, current and proposed legal frameworks—the Maharashtra Water Act, Madras mini-act, Gujarat amendments to the irrigation act, and the model bill circulated by the CGWB—have typically been impossible to implement and provide, at best, a partial framework for management. The CGWB in its capacity as GWA has prepared and is refining a framework inclusive of rules and regulations to reflect both the Supreme Court decision and larger management needs. In order to identify effective approaches, this chapter reviews the current legal framework, recent developments stemming from the Supreme Court decision, and proposals for change.

A. CURRENT SITUATION

3.3 Under common law in India (derived from English common law), groundwater extraction rights are chattel to land (MOWR, 1996). Extraction of percolating waters with no limit on quantity is the right of every landowner (Sinha and Sharma, 1987; Jacob, 1989; Singh, 1991). Water rights cannot be transferred to other users except by transferring the dominant heritage—

the land. These statutory rights reflect customary practice. Landowners generally regard wells as theirs own and view others, including the government, as having no right to restrict or otherwise control their “right” to extract water. Furthermore, with water rights tied intimately to land, there has been no opportunity to develop water markets beyond those in which individual landowners sell water to adjacent agricultural users or, on more limited basis, to neighboring towns and urban centers.

3.4 Despite the well-established common law position, the legal position of groundwater has never been fully clarified. The easement and irrigation laws, for example, “proclaim the absolute rights of government in all natural water” (Singh, 1990). In addition, there are constitutional questions over central versus state roles. Although ultimate ownership of water is a sovereign attribute of the nation as a whole, with the exception of interstate rivers, water is a state subject. Entry 17 of List II of the Constitution of India allocates states full authority over water within their borders, including groundwater, except in the case of interstate rivers and basins. In addition, the Supreme Court has interpreted several constitutional provisions as having implications for groundwater management. These include Article 21 concerning the right to life, Article 48A directing the state to “endeavor to protect and improve the environment,” and Article 51A(g) stating that “it shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes and rivers.”

3.5 In 1985 the Supreme Court passed a judgment requiring the government through the Ministry of Environment and Forests to address groundwater overdraft problems.¹⁶ In response, the Ministry of Environment and Forests issued a notification on January 14, 1997, creating the central Ground Water Authority, and designating the CGWB to have administrative responsibility of the GWA mandate for regulating and controlling groundwater extraction.¹⁷ Complementary authorities have subsequently also been created at state level. The GWA has a board chaired by the Chairman of the CGWB. With the exception of one other member of joint secretary rank to be appointed by the central government, all other board members are drawn from the CGWB. The Authority was established provisionally for a year, with the following powers and functions: to issue directions and take measures pertaining to Sub-section 2 of Section 3 of the Environment (Protection) Act; to resort to the penal provisions contained in Sections 15–21 of the Environment (Protection) Act; and, to regulate indiscriminate boring and withdrawal of groundwater in the country and issue necessary regulations with a view to preserving and protecting groundwater.

3.6 The implications of the Supreme Court ruling and creation of the Ground Water Authority have yet to emerge. Furthermore, the practical mechanisms through which the CGWB and SGWOs could regulate well boring and groundwater extraction are far from clear. Viable approaches enabling the new authority to fulfill its mandate will need time to evolve. At the same time, the powers granted the Authority allow it flexibility to test different approaches using existing administrative, powers without the need to pass legislation. In this context, the various attempts by states to regulate groundwater and the history of centrally sponsored management

¹⁶ Supreme Court of India, Civil Original Jurisdiction, I.A. no. 32 IN W.P. (C) no. 4677 of 1985.

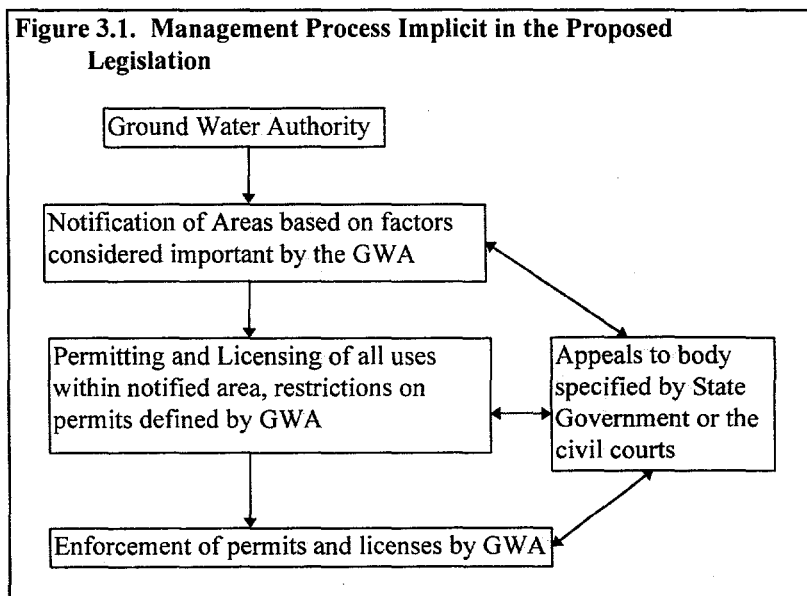
¹⁷ Gazette of India: Extraordinary, part II, sec. 3, subsec. ii, no. 30, New Delhi, Tuesday, January 14, 1997.

legislation proposals are directly relevant. Various states have passed legislation intended to enable groundwater regulation. These are summarized in Table 3.1. These approaches are fragmentary and focus on management by technical agencies. Although some approaches, such as the mini-Act for Madras, have had some success, in most cases legislation has yet to prove effective.

B. THE PROPOSED LEGISLATION

3.8 Although the results of recent action by the Supreme Court may change this, the legal and legislative role of the central government has been limited to developing model groundwater legislation and encouraging states to adopt it. Model legislation prepared by the CGWB proposes a highly centralized approach to groundwater management. According to the CGWB, this model legislation is being revised to incorporate management as well as regulatory functions. The current version envisions creation of ground water authorities at the state level. Each state authority would be led by a chairman “to be appointed by the state government” (Section 3[2.a]). Members of the authority would consist of “representatives of the departments which are concerned with survey, exploration, development, management, and protection of groundwater to be appointed by the state/union territory government” (Section 3[2.b]) and “such number of other members who, in the opinion of the government, have special knowledge or practical experience in matters relating to groundwater to be appointed by that government” (Section 3[2.c]). In essence, the state Ground Water Authority is intended to function as a technical wing of the state government and to act under the control and direction of existing state agencies and the overall guidance of the CGWB and the central Ground Water Authority. Figure 3.1 shows the management process proposed in current versions of the model legislation.

3.9 Two sets of issues are not addressed in current versions of the model legislation. The first relates to the regulatory structure, whether the centralized regulatory approach likely to be effective. The second concerns content, i.e. the numerous groundwater management needs that the proposed regulatory structure may not address—waterlogging, pollution, quality, and conjunctive management. Both sets of issues could be addressed in the revision proposed by the CGWB.



State	Status of Legislation	Focus	Implementing Authority	Powers	Key Provisions
Gujarat	Passed by Legislative assembly in 1976 as amendment to Bombay Irrigation Act. Notified in 1988 but never published in Gazette so may not actually be in force. ⁱⁱ	Applicable to 9 districts in Gujarat (Ahmedabad, Banaskantha, Baroda, Broach, Gandhinagar, Kaira, Kutch, Mehsana, Sabarkantha). Designed for overdraft regulation.	State Government has power to notify areas and appoint "Regional Canal Officers" as implementation and enforcement agents.	Restricts construction of tubewells, bore wells or artesian wells exceeding 45 meters in depth. Anything deeper subject to licensing. Canal officer has discretion to conduct inquiries.	No bar on civil courts. Sanctions limited to Rs. 500/- or imprisonment for six months. Appeal is to the "prescribed authority"
Haryana	Various drafts, most recent in 1996. None passed	Regulation and Control of Groundwater Development, Prevention of waste of groundwater.	"Ground Water Authority" with a chairman appointed by the state and representatives of many departments on an apex body. ⁱⁱⁱ	Notification of areas, regulation of groundwater development. Permits for new wells except domestic users with wells less than 45 meters depth. Registration of existing wells and uses within notified areas. Allows GA to cancel permits. Requires license for businesses involved in sinking wells within notified areas. Requires Electricity Board to obtain NOC from Authority before issuing new electricity connection.	Limits courts inferior to those of Metropolitan Magistrate from trying offenses. Bars jurisdiction of civil courts. Enables penalties of Rs. 500 (first offense) and Rs. 1000 and/or six months imprisonment (second and subsequent offenses). Individuals constructing new wells or running well construction businesses subject to additional penalty of Rs. 500/day for on-going offenses.
Tamil Nadu	Drafted several versions of general groundwater/water resource legislation, none passed yet. ^{iv} Passed Madras Metropolitan Area - Groundwater Regulation Act, 1987 (Tamil Nadu Act 27 of 1987).	Original draft of general legislation essentially the same as 1970 Model Bill. Madras Act focused on groundwater regulation in Chinglepattu District.	For general legislation, currently envisioned as the Ground Water Directorate to be established as part of the Tamil Nadu Water Resources Organization.	Original draft the same as Model Bill. Madras Act, powers for registration of users and licensing extraction, transport and use.	Madras Act regulates transport of groundwater. Draft Act version in 1990 would authorize cutting off of electricity connections. ^v

Table 3.1 (cont.). Status of State Ground Water Legislations ^{vi}					
State	Status of Legislation	Focus	Implementing Authority	Powers	Key Provisions
Karnataka	First draft in 1985, Subsequent communications with the Central Government but bill never enacted.	Groundwater overdraft, similar to 1970 Model Bill. Also prevention of "waste" of groundwater.	Ground Water Authority	Regulates construction of new wells other than those used for domestic purposes	Defines groundwater as state property Provides for fines of up to Rs. 1,000 for first offense, up to Rs. 2000 or one year imprisonment for second offense.
Maharashtra	Maharashtra Groundwater (Regulation for Drinking Water Purposes) Act, 1993. Enacted in 1993. Implementation rules circulated March, 1995. Technical Guidelines also circulated	Regulation of groundwater extraction to protect drinking water sources	Designates District Collectors as the "appropriate authority" for implementation. Other officials not below the rank of Deputy Collector may be appointed by the state.	Requires permission for sinking of wells within 500 meters of public drinking water sources. Enables the Appropriate Authority to declare water scarcity areas and regulate groundwater extraction if public drinking water sources likely to be affected. Enables the Appropriate Authority to declare watersheds as overexploited and, following due process, regulate or close wells.	Provides for compensation in cases where (1) standing crops are damaged by closure or regulation of wells; and (2) wells are permanently closed. Provides for appeals to the Commissioner (if the Appropriate Authority is the Collector) or the Collector if he is not already the Appropriate Authority. Provides for fines of not less than Rs. 2,000 and not more than Rs. 5,000 and/or imprisonment of two months to one year. For continuing offenses permits fines of Rs. 100/day
Madhya Pradesh	Madhya Pradesh Peya Jal Parirakshan Adhiniyam, 1986	Regulation of tubewells and non-domestic uses of water in order to protect domestic uses.	Collector	Declaration of "water scarcity areas" for any period of time. Within scarcity areas, collector has power to grant or deny permission for non-domestic uses and tubewell construction.	Appeal to Commissioner of Division. Rules contain provision forbidding sale of water.

ⁱ Compiled from the relevant Acts, draft Acts and (Bushan, 1996).

ⁱⁱ Numerous differences of opinion exist between authorities on groundwater regarding whether or not this act is actually in force.

ⁱⁱⁱ Haryana State Minor Irrigation and Tubewell Corporation and Agriculture Department (Ground Water Cell) each trying to have themselves identified as the core "Ground Water Authority."

^{iv} Groundwater regulatory unit attached to office of Chief Engineer, Ground and Surface Water Resources Data Centre to prepare new version of general legislation (WB, 1995). UNDP included groundwater regulation as part of a proposed overall water resource law UNDTCD.

^v Government of Tamil Nadu (1990), *Ground Water Development and Management Act*. Draft Act.

^{vi} Compiled from the relevant Acts, draft Acts and Bushan (1996).

Issues Pertaining to the Regulatory Structure

3.10 Where structural issues are concerned, the approach and technical nature of the authority preclude effective involvement of local populations in groundwater management. Groundwater management, although it can require a sophisticated technical understanding of resource dynamics, is *not* primarily a technical subject. Identification of management approaches that can be implemented is, rather, more of a political, economic and social organization exercise. Because regulation will prove intrusive (i.e., shutting down or limiting new and existing uses), opposition from local populations will be strong. The absence of an effective role for local populations in the decision making process will intensify opposition. In addition, if local populations are not involved, opportunities will be missed for the development of management approaches reflecting local interests and considerations. Over the past two decades, discussions of groundwater regulation have deadlocked over two issues: (i) how regulation could be enforced given the huge number of privately owned wells and wide variation in needs and (ii) how the political will could be created to enforce regulations (Dhawan, 1989a; VIKSAT, 1993). Although the recent order by the Supreme Court gives the CGWB the mandate and authority to regulate groundwater, it does not change the basic factors that have blocked effective regulation in the past.

3.11 *Centralized regulation may be essential in some, or possibly most, instances. Given, however, the potential opportunities missed and inherent tendency toward conflict, centralized regulation should be held in reserve in case other management approaches prove ineffective.* The recent Supreme Court decision, while mandating regulation of groundwater extraction and indiscriminate boring, does not specify how that should be implemented. Legal documents, such as new versions of the proposed legislation, could be used to create a flexible framework enabling different approaches to be tried at the state level before resorting to newly established centralized regulatory powers. Although the proposed legislation could be revised rapidly, it might be more productive to use the Supreme Court mandate and existing administrative authorities to initiate pilot management projects first. Experiences gained in the course of these pilot activities could then form a more productive basis for developing new model legislation.

Content Issues

3.12 The observations with respect to regulatory structure apply to content as well. At present, the legislation does not address large classes of management needs. It is designed primarily as a mechanism for regulating extraction to address overdraft and associated concerns. Waterlogging, water quality, water pollution, end-use efficiency, allocation and environmental considerations represent equally important management challenges. Furthermore, although current versions of the proposed legislation do not preclude integrated water management, neither do they encourage it. Existing versions focus narrowly on permitting and registering existing wells and do not enable many types of management interventions. In addition, members of the Ground Water Authority are to be drawn from departments focused on groundwater, not surface water, pollution control or end users. Given strong departmental affiliations, this arrangement will likely fragment water management.

3.13 Addressing management challenges will ultimately require a much more comprehensive approach to groundwater legislation. Integration of activities to address these management needs is, however, relatively new in India. In addition, many of the activities could be initiated through existing programs and administrative mechanisms. As a result, *it may be more productive to initiate a series of management pilot projects and use the experience gained as a basis for developing new legislative instruments.* This approach could also be used to test the array of alternative management proposals that have been emerging on the basis of NGO activities, academic research, and international experiences with groundwater management. Core components of these alternative proposals are outlined below.

C. ALTERNATIVE APPROACHES

3.14 Calls for reform of the legal framework governing groundwater and surface water rights and regulatory proposals have become increasingly frequent (Moench, 1994a; Chandrashekhar, 1995; Sharma, 1995; C. Singh, 1995; K. Singh, 1995; MOWR, 1996; Saleth, 1996). Some advocate full governmental control; others advocate management by local populations.

Rights Framework

3.15 Saleth and others have proposed the adoption of public trust concepts as the basic element defining the rights and duties associated with sovereign “ownership” of water resources (Moench, 1994a; Saleth, 1996). Public trust concepts would define the state as holding water as an inalienable trust for current and future generations and would imply that the state has a duty to protect the resource base as part of its obligation. They would also limit private use rights to situations not conflicting with trust obligations.

3.16 Reform of common law rights under which groundwater is a chattel to land has also been proposed. Transferable rights to groundwater could, in theory, encourage efficiency and enable the use of market mechanisms for allocating water to high-value uses. The main stumbling block has been identifying practical mechanisms for defining and administering private rights under Indian conditions. Theoretical proposals exist that could address some of these practical challenges. These have never been tested in India, and pilot activities would be essential to evaluate and, if possible, identify approaches that are practical under conditions in India. Other countries (Mexico and Chile, for example) have successfully reformed water rights. The numerous challenges should not be viewed as a reason to delay experimentation and pilot activities in India.

Management Framework

3.17 In addition to rights reform, administrative and management frameworks are needed. Before recommending specific frameworks and processes, it is important to identify the underlying principles. Key principles include:

- *Create an institutional framework that enables rather than specifies.* Groundwater management needs and options vary between areas and change over time. The institutional framework should recognize the broad nature of management needs and the great variation in local conditions, and should be designed in a way that encourages management to evolve its response.
- *Design frameworks to include rather than exclude options.* Local institutions and communities represent a wealth of initiative. There is, however, no guarantee that they will prove capable of addressing emerging problems; nor is there a guarantee that government will prove any more capable. Given the potential for opposition if local populations are excluded, the framework should encourage local management. If that proves ineffective, processes need to be in place that trigger higher-level management initiatives.
- *Separate institutions with responsibility for generating information from those with management functions (regulatory, resource provision, and so forth).* Pressures to justify political or other positions are inevitable. These are likely to be most intense when information is generated by institutions with management and regulatory responsibilities.
- *Create processes that encourage systematic, integrated approaches to identifying management problems and options in participation with local communities.* Integrated resource planning (IRP) frameworks are being used in other parts of the world as mechanisms to ensure consideration of a broad array of factors in the development of management systems (See Box 3.1). IRP processes are designed with explicit outreach mechanisms to ensure stakeholder participation. *In the Indian context, frameworks need to ensure integration of surface water, water quality, environmental, economic and use allocation considerations. They also need to provide clear avenues for the involvement of local communities, NGOs and other stakeholders (corporations, urban areas, states, and government agencies) in management decision making.* In the case of government agencies, participation in a planning process may prove more effective than the current practice of inclusion on joint committees.

Box 3.1. What Is IRP?

Integrated resource planning (IRP) processes have been used by the electricity industry in the United States for more than a decade and are now being adapted by organizations such as the Metropolitan Water District of Southern California as an ongoing basis for water planning. IRP has several key features:

- Equal attention to demand as well as supply management
- Extensive involvement of all stakeholders (environmental, NGO, and government) in the planning and decision making process
- Integration in planning of a broad array of social objectives and the factors affecting them
- Iteration—the “plan,” while providing a basis for action, is continuously reevaluated as experiences, options, and new issues emerge.

- *Develop institutions that enable the use of conjunctive management approaches.* The largest opportunities for making water available for different uses in the future are likely to be through improved management of hydrologic systems rather than new development. Conjunctive management opportunities represent a case in point. In India, discussions of conjunctive use have generally been confined to debates over wells in canal command areas (MOWR, 1996). This conceptual approach is limited. Water availability depends on consumptive use, and water quality changes with each application. Designing conjunctive management approaches so that groundwater aquifers can be operated as an integral part of a sequential water supply, storage, delivery and use system, can greatly increase the availability of supply (Box 3.2). A similar approach is important with quality management.

Box 3.2. Conjunctive Management: The Western US Example

In the western United States, conjunctive management of surface and groundwater resources is emerging as a major water management technique. Unlike in India, conjunctive management in the US does not focus on the use of wells in the command of large irrigation systems, although broader concepts of conjunctive management are recognized by GOI (MOWR, 1996). Instead it implies an integrated approach in which surface and groundwater are managed together as part of a single water supply system.

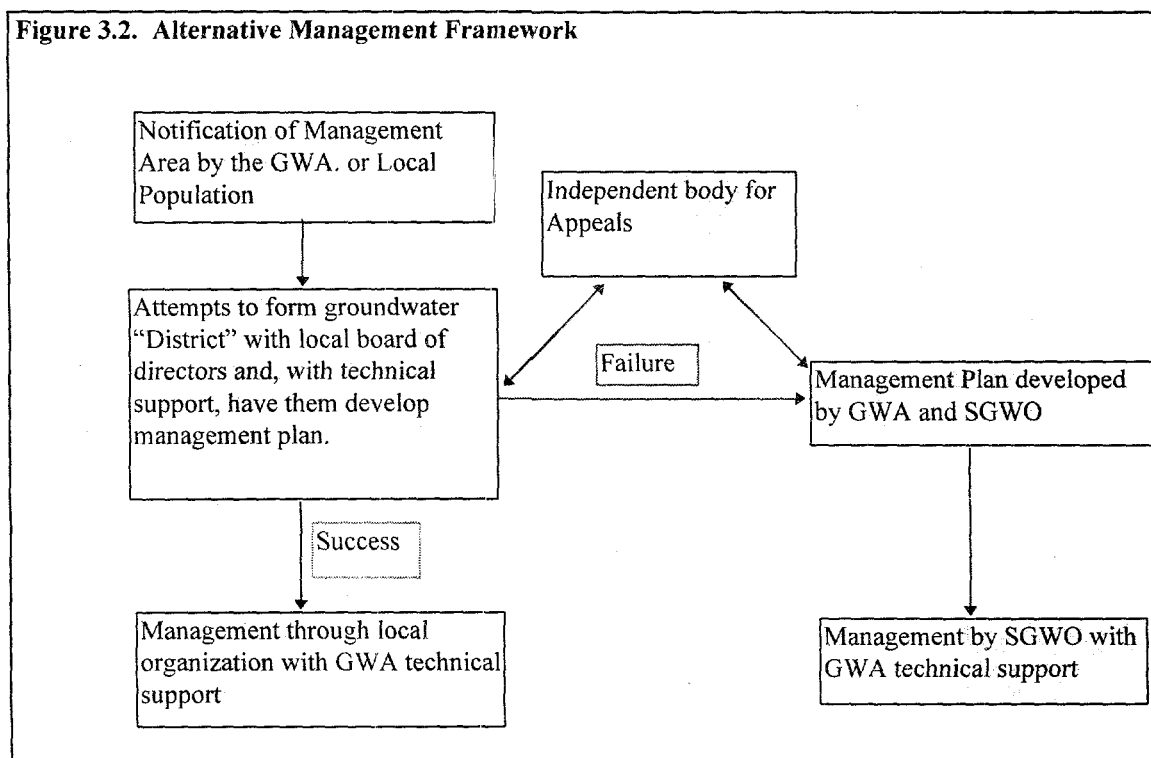
In California, recent studies indicate that conjunctive management could make water more available in the Central Valley by 1 million–1.4 million acre-feet per year (NHI, 1995). This new yield would be captured by reoperating surface and groundwater reservoirs. Water in surface reservoirs would be transferred to aquifers for underground storage in advance of the rainy season. This would free reservoir space and enable greater capture of peak flows. Water stored in aquifers could be accessed as required through wells. The net effect would be equivalent to constructing numerous major new surface reservoirs but would require far less construction or environmental disruption (NHI, 1995). Recent analyses of the US Bureau of Reclamation and Fish and Wildlife Service identify conjunctive management as the least-cost mechanism for increasing yields in the Central Valley (US Department of the Interior, 1995).

Conjunctive management in the western United States is not just a governmental activity. More than 61 districts governed by locally elected boards of directors undertake conjunctive management of ground and surface water in California alone (according to a survey conducted in 1994–95 by the Natural Heritage Institute).

- *Include checks and balances as part of framework and process design.* Management cannot be effectively enforced by the government. As a result, local populations must view management proposals as legitimate reflections of their interests. At the same time, there is no assurance that local populations will act in a manner compatible with the interests of society. As a result, the government must have the power to intervene where larger interests are threatened.

3.18 An alternative management framework to that which is implicit in the Model Bill prepared by the CGWB is outlined in Figure 3.2. This framework could be implemented either through legislation or through administration. Although further investigation is required, the

directives emanating from the recent Supreme Court decision give the CGWB the authority to implement this type of framework through administrative mechanisms.



Notes: GWA = Ground Water Authority; SGWO = State groundwater organization.

3.19 Successful implementation of the management framework proposed above would depend heavily on the process for (i) notification of areas, (ii) education of the local population and formation of local management districts, and (iii) resolution of conflicts. One potential process is outlined in detail in Moench (1996). This framework has been included to demonstrate how the alternative framework might be implemented in practice; it is not intended to be prescriptive. Substantial experience exists in other parts of the world with implementing frameworks similar to this and with designing legislation to support them (see Box 3.3).

3.20 Two key components in the proposed framework may not be evident from the diagram. First, in order for the local management organization to be viewed as legitimate, the board of directors needs to be composed of local representatives. This board would, however, draw on professional sources of advice in developing a management plan. Second, the development of a package of incentives encouraging local management could be important for encouraging the formation of institutions. This package would include credit, technical support for management, and other forms of support for water conservation and other technologies (provided through NABARD). It could also include sanctions such as the closure of government development support in areas experiencing groundwater problems but unwilling to initiate management activities.

Box 3.3. Districts—An Emerging Management Framework

Groundwater districts governed by an elected board of directors, supported by a competent technical staff, and working in conjunction with state government organizations, are being used in many areas to address management needs. Districts are well established in the western United States and are currently being established in Mexico. Similar user organizations also play a large role in water management in Chile (Rosegrant and Schleyer, 1994). Moench (1996) illustrates, using the cases of Kansas and Texas, how areas have successfully addressed major challenges in groundwater management—in the Texas case, major overdraft problems have been addressed using an approach based primarily on education, extension and crop system economics. In the Kansas case (also outlined in some detail below), progress has been achieved through development of broad locally governed management capacity including regulation and land-use zoning.

The Case of Kansas

The Kansas Groundwater Management Districts (GMD) Act is the enabling legislation for all groundwater management districts in Kansas. This act stipulates the process required to form a GMD, the funding and operational authorities, and both the specific and general direction for all activities either required or eligible to be undertaken. This act makes it a policy of Kansas that local landowners and water users be allowed to determine their own destiny in regard to groundwater management issues as long as they do so from within a legally formed and operated GMD.

The basic requirement for a local GMD is the existence of an aquifer system of sufficient size to support a district that is experiencing groundwater problems related to quantity or quality. If an area of the state demonstrates such a viable hydrologic community of interest, a local GMD can be formed. To date, five districts have been formed. The GMDs are operated under the direction of a locally elected board of directors from within the district, the only requirement being that all board members must be eligible voters as defined by the act.

In order to operate, Kansas GMDs must adopt a management program, set an operational budget, and then collect its fees. The management program is locally written and then reviewed and approved by the Division of Water Resources, State Board of Agriculture, which checks local policy for consistency with the Kansas Water Appropriation Act. In this way, local GMD programs are coordinated with state activities regarding groundwater management. To fund the districts, Kansas GMDs can levy land charges not to exceed 5 cents per acre of land and water-use charges not to exceed 60 cents per acre-foot of water. Except for outside grants, gifts, or contracts obtained or negotiated, Kansas GMDs are entirely funded by local revenues.

Districts have the authority to: (i) sue and be sued; (ii) maintain, equip and staff an office; (iii) hold and sell certain property and water rights; (iv) construct and operate works for drainage, storage, distribution or importation of water; (v) levy water-use charges and land assessments, issue bonds and incur indebtedness; (vi) contract with persons, firms, associations or agencies of state or federal government or private entities; (vii) extend or reduce district boundaries; (viii) conduct research and demonstration projects; (ix) require installation and reading of meters or gauges; (x) provide assistance in the management of drainage, storage, recharge, surface water and other problems; (xi) adopt, amend and enforce by suitable action, policies relating to the conservation and management of groundwater; (xii) recommend to the chief engineer (a state official) rules and regulations necessary to implement and enforce board policies; (xiii) enter private property to determine conformance with policies; (xiv) seek and accept grants or other financial assistance from federal, public or private sources; and (xv) recommend to the chief engineer the initiation of proceedings to establish an intensive groundwater-use control area. Under the act, the chief engineer may also, as a result of his own investigations, initiate formation of an intensive groundwater control area. Once established, the state has full regulatory authority in these areas.

Source: Note prepared by the Kansas Groundwater Management Districts Association, 1991.

Proposals

3.21 The broad proposals outlined in the preceding section will require substantial refinement and testing before any approach can be finalized. Two steps should be taken. First, international experiences should be reviewed with regard to legal frameworks and management through district-type structures and their potential applicability to India. The review should also evaluate existing customary law within India and identify those aspects that, if formalized, could support management. Finally, the review should draw on existing preliminary efforts to draft alternative groundwater management legislation suitable to India (see Moench, 1995a, for a preliminary outline of enabling legislation for Rajasthan). The objective of this review should be to identify potentially implementable approaches and to draft one or several versions of new model legislation. In order to ensure the incorporation of a broad base of views, the review should involve a wide spectrum of NGOs, academics, and legal experts. It should not be conducted or controlled primarily by government agencies. Second, once identified, approaches should be tested through pilot management projects. Refinement can best be done on the basis of experience. In many cases, it may be possible to test potential legal, institutional, and process frameworks using administrative mechanisms. Furthermore, there are numerous areas where emerging groundwater problems demand immediate attention, and approaches could be tested and refined. Pilot projects to test groundwater management through district-type structures would be an appropriate way of doing this. Experiences from pilot projects implemented through existing administrative powers could provide the experience and insights necessary for drafting appropriate groundwater legislation.

3.22 The United Nations Development Program (India) is planning to allocate resources to groundwater management pilots as part of a participatory water management program under its Food Security and Nutrition Program. Similar initiatives are being planned under World Bank-funded projects; for instance, the piloting of groundwater districts under the proposed Rajasthan Water Resources Consolidation Project. This could provide a mechanism for developing and implementing pilot projects. Pilot projects to test approaches could be implemented in the Vaigai basin, the area surrounding Chennai (Madras), Hyderabad, and cities in Rajasthan and Gujarat.

Implementation

3.23 The approach proposed here seeks to address some of the social factors that have, so far, blocked effective management. Specific components that may help are:

- *Establishment of a process that includes education and involvement of local stakeholders in the identification of management needs and options.* This should help to build a constituency supporting management.
- *Initial emphasis on management through creation of a local institution governed by a local board of directors.* Stakeholder participation and management should be maximized in such local institutions. This should reduce the apprehension that local

communities feel about regulation and, therefore, their opposition to passage of groundwater legislation.

- *Presence of an independent water tribunal.* As with the initial emphasis on local management, this should reduce the apprehension of local communities that regulation will be imposed whether or not they initiate sincere management efforts.
- *Creation of a package of incentives and disincentives to assist notified areas.* Local communities are far more likely to initiate management efforts if they perceive the benefits of doing so.

D. THE POTENTIAL ROLE OF WATER MARKETS

Informal Markets For Irrigation Water

3.24 Informal water markets—the sale of water by owners of wells to local users—are ubiquitous. They are generally highly localized (e.g., sales to adjacent farmers), are based on short-term transactions between individuals, and involve no transfer of underlying rights. Although these informal markets are indirectly influenced by government policies (energy pricing can, for example, have a large impact), unlike formal water markets they function on a customary basis outside any formal framework of rights, laws or institutions. They have emerged with no support or intervention from the government, and, being based on numerous transactions between scattered individuals, they would be extremely difficult to regulate directly. In contrast, formal water markets—markets functioning within clearly defined rights and institutional frameworks and involving either the transfer of large volumes of water between applications or the transfer of underlying water rights—do not currently exist in India.

3.25 In general, informal irrigation water markets enable resource-poor farmers to obtain access to groundwater and more well-off farmers to afford the high cost of owning a well. There is, however, a great deal of variability in the functioning of informal water markets. Most commonly, informal water markets have positive equity impacts, at least for the current generation (Moench, 1994c). In some cases, however, they exist as part of interlinked factor markets and tend to become instruments of “power and accumulation” (Janakarajan, 1994). In the absence of controls over extraction, informal markets can encourage groundwater overdraft.

3.26 The breadth of water markets (the number of buyers and sellers) tends to vary relatively systematically with groundwater conditions, the density of wells and the availability of power. Water market breadth tends to be limited in situations where: groundwater quality is poor; water availability in wells is limited to the point where owners of wells have little surplus beyond that required for their own irrigation needs; power supplies are limited and diesel pumps are not feasible due to the depth of the water table; and, the density of wells is sufficiently high so that few farmers need to purchase water. Water market breadth is enhanced where: groundwater quality and well yields are high; power supplies are reliable or the water table is within reach

using diesel pumps; and, well densities are high enough to permit farmers to buy or sell but not so high as to permit all farmers to have a well on all plots.

3.27 In many water markets, particularly where diesel pumps face significant competition from electric pumps, sellers provide water at rates below those required to recover capital and variable costs fully. In Eastern Uttar Pradesh, for example, water prices ranged from 35 to 116 percent of the full cost of pumping, with prices exceeding costs in only one location. This situation is, however, far from universal. In Gujarat, water market prices are well above the cost of supply and vary greatly between villages.

3.28 In general, irrigation prices in water markets are heavily influenced by variable costs, particularly power rates. High flat annual or monthly rates for electricity combined with abundant power and high yields from wells encourage owners of wells to maximize water sales, thus capping water prices in the market as a whole. This enables farmers who depend on purchased water—typically poor, smaller farmers—to obtain access to irrigation at a cost close to or, in some cases, below that of their more wealthy counterparts. Flat rates for power therefore tend to enhance the equity and efficiency of water markets as long as sellers are not constrained by limitations on the availability of power or water. By the same token, groundwater overdraft, where present, is exacerbated due to incentives to maximize sales and therefore extraction.

3.29 Where diesel pumps heavily dominate the market (or water is scarce), water prices range up to three times variable costs. In this situation, buyers tend to apply substantially less irrigation water than sellers. In U.P., however, water buyers apply lower levels of irrigation and achieve lower yields, but cropping patterns and cropping intensity are not greatly different from those of sellers (Shah, 1996a).

3.30 These patterns indicate the importance of power pricing for the equity and efficiency of informal water markets. Since informal water markets represent a major mechanism through which many small farmers obtain water, the impacts on informal markets should be considered when formulating policies for pricing and supplying electricity. There is, however, a great deal of variability in the functioning of informal water markets, and the effect of power pricing and supply policies in different social and physical contexts remains poorly understood. As a result, additional research on informal water markets is essential for informed policy development.

Formal Water Markets: The Larger Potential

3.31 Markets are emerging as a major allocation mechanism in a number of countries, when utilization of water in an aquifer (or river basin) has progressed to the extent of the available rechargeable resources. As previously noted, formal water markets can enable efficient reallocation of scarce supplies to high-value uses while compensating existing users. For this to occur without major third-party and environmental impacts, water markets must function within a clearly defined framework of rights and institutions. This type of rights and institutional foundation does not currently exist in India. Although conceptual proposals for rights reform and institutional development exist, these proposals have yet to be tested. Furthermore, many essential operational details will only become evident in the course of implementation. As a

result, if formal water markets are to develop as a mechanism for allocating supply in India, *pilot projects are needed to start the process.*

3.32 Chennai (formerly Madras) is a potential location for pilot activities. There, water sales by agricultural users adjacent to urban areas could provide a low-cost mechanism for resolving urban water shortages (see Box 3.4). Estimates suggest that up to 400 million cubic meters of water could be purchased from farmers for less than US\$20 million. This compares with the US\$400 million cost to Tamil Nadu of the proposed Krishna and Veeranam projects that would supply a similar amount of water to Madras city. Similar opportunities are present in other locations such as Jaipur and Hyderabad.

3.33 The establishment of water rights and the development of management institutions represent the largest challenge to the development of formal water markets. Although testing and refinement would be required, substantial background work has already been done in India. Institutional possibilities were discussed in detail above (refer paras. 3.14-3.23). Where rights are concerned, theoretical proposals exist for defining government ownership of water resources and management duties under public trust concepts (paras. 3.15-3.16). This could be accompanied by a system of individual rights. For sustainability, rights need to reflect the volume of water available. Metering groundwater extraction is, however, broadly viewed as problematic under conditions in India. Transferable rights could be defined based on current patterns of use, sustained yield of the aquifer, and traditional concepts of sharing. It may be possible to measure and monitor rights based on crop areas and water duties (Moench, 1995a).

3.34 Although instituting a system of water rights would be possible, implementation would face major challenges (MOWR, 1996). Aside from the political and social challenges, practical methods for quantifying rights under Indian conditions have yet to be tested. Measurement, monitoring and enforcement of extraction rights would represent a major administrative challenge. The obvious challenges inherent in implementing a transferable system of

Box 3.4. The Madras Pilot Proposal

Madras city faces major water shortages over coming decades despite new supplies of 930 Mld from the Krishna River (Briscoe, 1996). Additional supplies from external sources such as the Cauvery River via Veeranam tank are prohibitively expensive, costing roughly Rs. 16 per cubic meter. Supplies are, however, locally available from Chembarambakkam tank and potentially from the Araniar-Kusaithaliayar aquifer if water can be transferred from existing agricultural users.

According to Metrowater officials, procedures exist for purchasing water from agricultural users, and the necessary actions to do this have been initiated in Chembarambakkam tank. The potential for transfers from the Araniar-Kusaithaliayar aquifer depends on reevaluation of aquifer yields. If yields are sufficient, Metrowater officials see few impediments to purchasing customary water rights from farmers who are willing to sell. Water from this source would cost roughly Rs. 2 per cubic meter, far less than the Rs. 16 per cubic meter estimated for water from external sources. International experiences indicate that creation of a formal water market requires establishment of tradable water rights. Effective management of the aquifer would also require land-use planning and establishment of a groundwater management district.

In the Madras case, pilot activities could involve formation of a management district and the testing of different mechanisms for defining water rights. Although this requires confirmation, existing administrative powers would probably be sufficient for implementing a pilot project.

groundwater rights should not, however, be used as an argument against pilot projects with the ultimate objective of developing such a system should it prove feasible. Other countries such as Mexico and Chile have implemented water rights systems (see Box 3.5), and water rights transfers are a common mechanism for addressing water allocation needs in the United States.

3.35 Given the potential utility of water markets as an efficient allocation mechanism, however, this investigation and piloting should be undertaken before final mechanisms can be instituted. Pilot projects of the type proposed for Madras should be undertaken there or in other areas—such as Hyderabad, the Vaigai basin in Tamil Nadu (Oblitas, et. al., 1996), or cities in Rajasthan or Gujarat—to acquire lessons and gain practical experience. These pilots should involve formation of a local management institution and evaluation of mechanisms for quantifying and administering groundwater rights (through metering or indirect measures such as cropped area and crop water duties). They should also identify and evaluate both the benefits from market-based water transfers and any social, economic or environmental externalities associated with those transfers.

Box 3.5. Water Rights Reform—The Cases of Chile and Mexico

Chile and Mexico have recently established tradable water rights. Under the old system of water law, users (predominantly farmers) had precarious rights to water and no say in its distribution and management. Establishment of tradable rights was seen as a major benefit by farmers and also by those sections of the government bureaucracy affected by water policy but not directly involved in water development. The main advocates of slow or limited change were the bureaucracies directly controlling water management.

In both Chile and Mexico, the initial allocation of water rights was based on existing patterns of use. Although both countries focus attention on surface water rights, Chile's water code has a chapter on underground water. This enables the government to establish the rights to groundwater in a manner similar to the rights to surface water. It also enables the government to reduce the rights of all users proportionately where necessary to protect aquifers from over-exploitation.

According to some reports, the establishment of tradable water rights in Chile has encouraged efficient agricultural use and increased agricultural productivity per unit of water by enabling the development of water markets. It has also improved urban water and sewerage services (Rosegrant and Schleyer, 1994). Recent reports indicate, however, that the model encountered problems as well as successes (Bauer, 1997a & 1997b). Although benefits have accrued, significant negative impacts have been felt by farmers unfamiliar with legal processes or lacking the money to participate in markets for water (the poor). Significant conflicts have also emerged between different groups of users, and many social and environmental externalities have yet to be addressed. These reports emphasize the importance of the legal and institutional framework for how a market works (Bauer, 1997b) and the difficulty of setting up water markets, even in the fairly simple arena of irrigation transfers (Bauer, 1997a).

IV. REORIENTING THE GOVERNMENT INSTITUTIONS

A. ROLE OF GOVERNMENT ORGANIZATIONS

4.1 The Central Ground Water Board (CGWB), the National Bank for Agricultural and Rural Development (NABARD) and state groundwater organizations (SGWOs), form the core governmental entities directly concerned with groundwater. These are loosely connected with a wide range of other governmental organizations whose actions affect groundwater management. The core organizations were set up and designed to promote groundwater development. They were not designed to undertake many of the management functions required to address emerging problems nor to support local management institutions of the type proposed in Chapter III. Finally, weak links with other governmental organizations fragment understanding and management initiatives.

The CGWB and SGWOs

4.2 The CGWB's mandate is to develop and disseminate technologies and monitor and implement policies for the scientific and sustainable development and management of India's groundwater resources including their exploration, assessment, conservation, augmentation, protection from pollution, and distribution based on principles of economic and ecological efficiency and equity (Naidu, 1995).

4.3 As the report on re-organization of the CGWB states, "The task now to be achieved, besides scientific and sustainable development, is managing the resource, augmenting its availability, conserving it for future use, and protecting its quality from damage consequent to the actions of man" (Naidu, 1995). Meeting this objective and mandate requires a substantial change from the historical focus of the board and a strengthening of staff capabilities in the social, economic, and institutional as well as technical aspects of management.

4.4 The capacity of the CGWB to undertake basic research should be enhanced to fill its recommended role as the primary organization supporting management and providing policy analysis. Because management depends heavily on social, economic, legal, and other considerations, capacity enhancement should equally emphasize social and physical science aspects. Specific roles envisioned by the MOWR for the CGWB include (i) compiling and analyzing groundwater and related data at the national level, including cross-checking; (ii) developing and refining analytical methods; (iii) undertaking basic scientific research and location-specific field studies on water resource dynamics, quality, pollution, and the natural environment with particular reference to groundwater aspects; (iv) undertaking social science research and policy studies on water management with particular reference to groundwater aspects; (v) providing technical support to SGWOs and local organizations in areas where management initiatives are under way; and (vi) educating policy makers and the general public.

4.5 In order to ensure effective integration of groundwater and other water resource-related activities, effective mechanisms should be established for ensuring communication and

integration among the CGWB, SGWOs, and other water-related organizations. This is essential not just to address emerging problems but also to take advantage of the opportunities created by conjunctive management.

4.6 Aside from these issues, existing organizations lack capacity in key management areas. Management depends heavily on social, economic, legal, and other considerations, yet groundwater organizations are staffed primarily by engineers. Even in the technical arena, capacity in the CGWB and SGWOs is concentrated largely on exploration and basic monitoring of resources, not on the types of system analysis essential for management. Technical strengthening of management aspects is important. Equally important are the social, economic, and institutional aspects. Participatory strategies are emphasized in many documents, including the Eighth and Ninth Five-Year Plans. Groundwater organizations, however, substantially lack in-house capacity to guide development and implementation of these approaches.

4.7 The capacity of CGWB and SGWOs to act as management support and implementation organizations should be enhanced. Giving SGWOs a broad mandate, possibly under a unified water resources organization (rather than one narrowly focused on agriculture or irrigation) is essential if these organizations are to develop effective management capabilities. Although SGWO capacity for management support and implementation should be increased, *this does not imply that they should have a direct role in groundwater development*. Experiences with public tubewells have been extremely disappointing, and recent reviews have strongly advocated reducing direct government involvement and turning management over to farmers (World Bank, 1991). Where social dimensions are concerned, enhancement should address the participatory, social, economic, and legal dimensions of management. To do this, it may be necessary for groundwater organizations to create in-house cells having these capacities. To be effective, officials from these cells would need to play a central role in policy development, project development, and implementation activities as well as education and outreach. Given the degree of public support needed to implement groundwater management, *education and consensus building are key skills for any institution charged with groundwater management in the next century*.

4.8 Beyond the overall status of groundwater organizations, there is substantial duplication of activities at state and central government levels. Both levels of government conduct broad assessments of recharge and extraction as a basis for targeting development finances. This is a valuable mechanism for cross-checking data from different sources but represents a relatively inefficient use of scarce resources. Its cost is recognized, and efforts are under way to minimize expenditures (MOWR, 1996). The inefficiencies stemming from duplication are compounded by the CGWB's focus on "macro"-level data and analysis, while SGWOs focus on "micro" levels. This distinction reflects the fact that most water-related topics are state subjects under the constitution. At the same time, the distinction inhibits the development of management capacity. Management requires understanding the dynamics of hydrologic systems, not just assessing water balances. Effective analysis of system dynamics cannot be differentiated into "macro" and "micro" components; rather it depends on the scale of the system being studied. As a result, the macro-micro distinction tends to perpetuate the use of development-focused water balance assessments and does not encourage state and central organizations to develop capacity—for

example, in scientific research versus implementation—where they have different comparative advantages.

4.9 Where technical aspects are concerned, the “macro-micro” distinction between SGWO and CGWB roles should be de-emphasized. Instead, emphasizing functional distinctions—with SGWOs focusing on management implementation and CGWB focusing on basic science, data analysis, and national policy—would be better suited to current needs. This recommendation is consistent with the difference in organizational activities that already exists in most cases. In general, the CGWB has a much stronger technical staff than most SGWOs. It has also been involved to some degree in basic hydrological work and is relatively well connected with national hydrologic training and research institutions. In contrast, most SGWOs are heavily involved with implementation. With few exceptions, they undertake little basic research. In recognition of this functional distinction, the CGWB mandate may need to be reduced to eliminate responsibilities for implementation.

4.10 The Naidu report on re-organization of the CGWB emphasizes that the “State Ground Water Organizations’ main charge will be to formulate area-specific groundwater schemes and extend custom services for site location, design and construction of abstraction structures, and also selection and installation of pumping devices.” Moreover, the “CGWB’s role in the development and management of groundwater should normally be to undertake applied research and adaptive trials and to formulate overall policy and give guidelines and direction in program implementation to the states” (Naidu 1995, p. ES7). These recommendations are compatible with the emphasis on strengthening the functional distinction between the CGWB and SGWOs, while de-emphasizing the macro-micro distinction.

4.11 The proper liaison and coordination between state and central groundwater organizations and their counterparts working with surface and other water issues needs to be established. Currently, high-level staff in the MOWR, CWC and state governments dealing with water resources are drawn from organizations whose activities focus on surface water, including the implementation of management information programs. Furthermore, only engineers from organizations concerned with surface water are working in MOWR on policy, planning and implementation. Being a scientific cadre, CGWB officials are poorly positioned to engage in dialogue with higher-ranking counterparts in state organizations. As a result, the groundwater specialists have little scope for policy input despite the dominant role of groundwater as a source of irrigation, domestic and industrial water supply. This inhibits consideration of groundwater management issues at the national level. Similar considerations affect the ability of CGWB and SGWO officials working at the state level, a contributory factor being that senior SGWO officials generally have lower rank than senior surface water officials (MOWR, 1996).

4.12 Low official position is not the only factor constraining communication and integration. Groundwater considerations need to become an integral part of the planning and implementation of irrigation, drinking, and other water management or development projects and policy. Liaison activities through working groups, though useful, rarely ensure integration. To ensure integration, groundwater officials should be involved in design and implementation teams for water resource projects and water policy development.

NABARD

4.13 The National Bank for Agriculture and Rural Development is the primary governmental channel for directly subsidizing groundwater development and other rural credit. Major proposals exist to continue this. The CGWB has proposed, for example, a program to invest 3,500 crore per year (US\$1 billion) for the next ten years in the construction of new wells through NABARD (CGWB, 1996). In discussions held in October 1996, NABARD officials and technical officers expressed caution about this program, pointing out the “overly optimistic assessment of groundwater availability in order to justify investments.” According to NABARD, demand for financing of new groundwater structures is declining in many states, such as U.P., because most of the land is already irrigated. At the same time, in areas such as Rajasthan, Madhya Pradesh, and Gujarat, demand for water conservation technologies is growing rapidly.

4.14 Given emerging management needs, the capacity of NABARD to support related investments and to monitor their effectiveness should be enhanced. Credit for investments in water conservation technologies (such as drip irrigation or sprinklers) and water harvesting should be given more importance than credit for new wells. Financing for alternative energy sources such as solar and wind is also needed (MOWR, 1996). If local organizations become involved in distributing electricity through single-point metering, they may require credit for a wide range of activities (such as pump rectification programs, enhanced distribution networks, and individual meters). Overall, NABARD’s capacity to support and monitor these types of activity should be enhanced. A new initiative at NABARD is the Rural Infrastructure Development Fund. Although most of the initial round of financing has been to develop water resources, NABARD officials noted the potential for using this fund to support investments in groundwater recharge and other management activities.

B. CREATING THE DATA AND ANALYTICAL TOOLS FOR MANAGEMENT

4.15 Data and analytical techniques underpin major investment programs and management decisions. As such, data and their analysis are a fundamental tool in political and philosophical debates. If data collection and analytical systems are transparent, they can form a “level playing field” for guiding development debates according to a common understanding of the system’s physical characteristics. Where data collection and analytical systems are less transparent, they are easily manipulated and become tools for achieving political ends (Moench, 1994b). The importance of data collection and analytical procedures should not be underestimated.

Current Practices

4.16 In India, governmental organizations at the central and state levels systematically collect groundwater data. This has produced considerable information and documentation. Data collection focuses on exploration, groundwater-level monitoring, and determination of basic quality (in particular salinity). In general, more attention is given to routine data processing than to

scientific analysis. Although this satisfies operational needs, scientific analysis is indispensable to understanding hydrologic systems and identifying management options.

4.17 Systems for collecting and analyzing data in national (CGWB), state (SGWOs), and public water supply organizations are similar, resulting in significant duplication as mentioned above (see Annex 1). Currently, groundwater data are mainly used to guide development. Uses include site determination, design of wells, and projections of groundwater development potential. Potential estimates generated through a standard groundwater estimation methodology are used to allocate subsidies and loans for new irrigation wells. This procedure enables limited management by linking development funds with the condition of the groundwater resource. However, groundwater management is not yet a primary goal of efforts to collect and analyze groundwater data.

Groundwater Estimation Methodology and Its Application

4.18 The methodology of the Groundwater Estimation Committee (GEC) plays an important role in the estimation of groundwater potential. A brief description of this methodology is presented in Annex 2. This water balance methodology focuses on extraction and recharge. SGWOs update extraction and recharge estimates regularly for all development units (blocks, taluks, mandals, or watersheds) in the state. The methodology provides a clear framework for collecting and processing data and contributes to the continuity of nationwide and systematic data collection programs. The estimates of average annual recharge and groundwater draft produced using the GEC methodology, although they are useful and enhance understanding of groundwater conditions, should not be used to calculate the level of development or to guide development finances and abstraction regulation. Conceptual flaws and limited accuracy cast serious doubt on the suitability of the estimates for these purposes.

4.19 An important conceptual weakness is that the methodology treats development units as independent. Dynamic interactions between units, which especially in larger aquifer systems may be very important, are completely ignored. The method is static in other respects as well: for example, it allocates a fixed percentage of the recharge to unrecoverable losses and nonagricultural use without relation to real groundwater conditions and water requirements (which are likely to change over time). Furthermore, it uses assumptions on the seasonal variation of groundwater levels rather than measured information.

4.20 A fundamental flaw in the methodology is the implicit objective of full development of the groundwater resources: that is, it assumes that the total recoverable recharge in individual development units should be captured. The general validity of this principle can be severely criticized. It neglects, again, the dynamics of groundwater systems and completely ignores their interaction with environmental and socioeconomic systems. Base-flow depletion, saline water intrusion, and declines in groundwater level may all reach unacceptable levels long before total recharge is captured. Furthermore, the amount of water required may in some areas be significantly less than the amount of water available.

4.21 Based on analysis of computational instructions and assessment of the accuracy of field data, block-level recharge and draft estimates have likely errors on the order of 25 percent or greater. The estimated “level of groundwater development” derived from these estimates therefore has an even larger probable error, some 30 to 40 percent (attempts to estimate 90 percent confidence intervals on extraction and recharge at the block level indicate even larger potential errors; Moench 1991). The “level of groundwater development” as calculated by the GEC is therefore not suitable as a single criterion for planning development or regulating abstraction.

Proposed Improvements

4.22 New guidelines have been proposed, amending GEC methodology. They include significant improvements: the bias toward agricultural groundwater use (irrigation) has been removed; the selection of watersheds as units for assessment in hard-rock areas mitigates the methodological flaw regarding groundwater dynamics; subdivision of units is proposed to reduce averaging effects; nonagricultural water is allocated according to needs; fieldwork is recommended to determine area-specific values of relevant parameters; and, last but not least, the long-term trend in groundwater level has been adopted as a second indicator complementing slightly modified estimates of the stage of groundwater development.

4.23 In spite of improvements, the proposed guidelines, while useful as a component in a more comprehensive approach, cannot be considered as a fully satisfactory basis for planning groundwater development. A two-stage approach is recommended for improvements. The first stage would be to score each development unit based on a set of indicators. Provisionally, the set might consist of (i) stage of groundwater development; (ii) trends in groundwater level and quality; and (iii) evidence of a special problem or sensitivity (pollution risk, salt water intrusion) or a special interest (urban water supply well field, wetland nature reserve). Each of these indicators has its shortcomings, but together they should provide a reliable indication of management needs. The second stage would focus on units with likely management needs. Detailed scientific studies accounting for the physical and socioeconomic context and using numerical modeling tools should form the basis for planning and management in these units. These detailed studies should evolve over time into full-fledged groundwater resource management studies.

Informational Requirements For Resource Management

4.24 Current data collection activities are extremely limited in relation to these issues. Consequently, management faces an enormous data gap. In addition, there is substantial duplication in data collection and analysis between organizations. Diversification of tasks and mandates would increase efficiency. It would also promote scientific analysis and enable responses to emerging issues.

4.25 *Addressing the Data Gap.* Data gaps cannot be eliminated rapidly. Priorities have to be defined and the process of narrowing the data gap started. *Perhaps the most critical data gap is related to groundwater pollution.* Pollution of groundwater is virtually irreversible, and there is ample evidence that pollution poses a serious threat to all water table aquifers in India. Special monitoring networks need to be installed to monitor industrial, urban, and agricultural pollution

systematically. Inventories and studies of the main sources of pollution, including non-point sources such as agriculture, are also essential. The resulting information will reveal which pollutants are encroaching and thus how to target pollution control activities. Beyond pollution, data are required on the dynamics of hydrologic systems. Key steps in this direction include:

- *Observations.* Increasing the frequency of observation (monthly) of the groundwater level, conducting time-series analysis in the context of explanatory variables, and locating monitoring stations within groundwater systems would substantially improve the understanding of groundwater regimes.
- *Hydrochemical data processing.* Numerous hydrochemical analyses have been completed but never used beyond general water quality evaluation. Available hydrochemical data would allow much more to be done. Time-series analysis and 3-D mapping of hydrochemical facies¹⁸ are recommended. Mapping has proven elsewhere (for example, in the Netherlands) to be a powerful technique for understanding the interaction between groundwater and surface water.
- *Computer-based data processing and storage.* Computer technology makes data processing more efficient, enables detailed analysis, and improves access to groundwater information. Proper design of data bases is key. Data standardization, quality checks, and interface with processing and analysis software are fundamental considerations. Furthermore, systems should be flexible to accommodate new types and functions of data.
- *Basic research on the hard-rock aquifers that underlie a large portion of India* (MOWR, 1996). Worldwide, most groundwater models and analytical techniques have been developed for use in porous media, such as sediments. Hard-rock aquifers are dominated by flow through fractures and secondary porosity. This difference has fundamental implications for development and management. Conducting more basic research is, therefore, important to ensure sufficient scientific understanding to meet management needs.

4.26 Other priorities for data collection may vary from state to state. In general, it is important to define procedures for processing and analysis simultaneously. Otherwise, the data might end up in data graveyards and fail to contribute to the management of groundwater resources. Capability in data collection, processing and sharing is being supported by the World Bank-Netherlands supported Hydrology Project.

¹⁸ The term facies is commonly used in geology and hydrology to describe a mass of material (in this case water) that is different in one or more respects from adjacent material. A hydrochemical facies is a groundwater boundary (or change in the nature of the groundwater) that can be distinguished on the basis of changes in water chemistry.

V. TECHNIQUES AND INCENTIVES FOR SUSTAINABLE GROUNDWATER MANAGEMENT

5.1 Beyond information, the shift from development to management necessitates a shift in emphasis on techniques and technologies. Although skills in designing wells and pumps will not lose relevance, a much broader array of end-use and land-use planning, operations, and recharge technologies or techniques will become of central importance. Overall, management techniques are likely to be of far greater importance than the limited array of structural technologies used in association with them.

A. DEMAND-SIDE MANAGEMENT AND POLLUTION AVOIDANCE TECHNIQUES

5.2 In many arid zones the critical technological challenge is to use less water more efficiently to produce the same or greater benefits. According to NABARD officials, demand for loans to purchase piping and complete drip and sprinkler systems is growing rapidly. Field observations suggest that much of the demand for these higher-level technologies is coming from wealthy farmers growing cash crops. Private sector involvement in irrigation efficiency is already widespread with companies such as Jain Irrigation supplying pipes, drip irrigation, and sprinkler equipment. Given extensive private sector involvement, the primary role of government may be to ensure that credit is available for purchasing equipment and to investigate mechanisms for encouraging the adoption of such technologies by lower-income sections of the population.

5.3 However, demand-side management is not only a question of irrigation technologies. The spread of low-water-intensity cropping systems is equally, if not more, important. Attempts to regulate cropping patterns in surface irrigation systems have been widespread and generally ineffective. The development of marketing networks and other agricultural support systems has, however, had a major impact on cropping systems in some states. Examples are the spread of oilseed and milk production in Gujarat as a result of National Dairy Development Board support and the cultivation of sugarcane in Maharashtra with the support of the sugar cooperative. Both are examples of the impact of marketing organizations on crop production, though the sugar example is encouraging higher rather than lower water usage. Education could also play a significant role. Detailed studies evaluating the potential for this type of approach in India are not available. Research is needed both to estimate the extent to which shifts in cropping patterns could reduce the agricultural demand for water and to determine the mechanisms through which appropriate shifts could be encouraged.

5.4 Demand-side management is also important with regard to emerging pollution problems. International experience indicates that pollution avoidance is far more effective—and less expensive—than remediation. From a groundwater perspective, the identification and encouragement of low-chemical-intensity agricultural practices could be a core management technique. Pollution could also be avoided, as a number of countries are beginning to do,

through land-use planning. This would involve, for example, limiting the extent of pollution-generating activities in recharge areas and other locations where hydrological conditions produce aquifer contamination. In a similar manner, many waterlogging and salinity problems may be better controlled by ensuring that excess amounts of surface water are not delivered for irrigation rather than by pumping excess water out once water tables have risen. The report of the Sub-Group on Ground Water emphasizes the vertical and lateral drainage responses in areas where water levels are rising (MOWR, 1996).

B. CONJUNCTIVE MANAGEMENT AND GROUNDWATER RECHARGE

5.5 In addition to demand-side interventions, conjunctive management techniques are becoming more important. India can no longer continue to plan to utilize surface and ground water resources almost in isolation from each other (MOWR, 1996). Conjunctive use can be an effective technique for addressing waterlogging and salinity problems in the command of major surface irrigation systems. In addition, MOWR notes that augmentation wells are constructed to supply water to surface systems when flows in rivers are limited. Ideally, conjunctive management techniques should be defined much more broadly. Internationally, conjunctive management is being viewed as the integrated operation of surface and groundwater systems to optimize the availability of water (refer Box 3.2). Wider conceptions of conjunctive use are also growing in India.

5.6 The modified draft guidelines issued by the MOWR recognized an array of objectives for conjunctive use in irrigation projects (MOWR, 1991). A summary of these objectives is outlined below: (i) increase the total available supply; (ii) improve the regulation of the combined system, using the storage volume of the aquifer; (iii) phase the development of water supply or irrigation projects by using groundwater first and later diverting stream flows; (iv) reduce evaporation losses from surface reservoirs; (v) increase the flexibility of supply in relation to demand by pumping groundwater as needed to even out variations in stream flow; (vi) reduce salinity by mixing water of different quality; (vii) reduce capital investments and operational expenditures by shortening conveyance distances for surface water; (viii) induce groundwater replenishment from streams by extending the duration of stream flow by means of releasing water from dams or retarding the flow with levees; (ix) augment low flows in rivers by recharging the aquifer, raising water levels, and, thus, increasing groundwater contributions to the base flow; (x) arrest groundwater depletion in areas not being served by surface irrigation projects by introducing surface irrigation from small rivers to displace existing demands on groundwater resources and increase recharge.

5.7 These objectives and the implementation guidelines that follow them fully recognize the importance of taking an integrated approach to the design and operation of surface irrigation-groundwater systems. They also begin to address conjunctive management possibilities outside the context of surface irrigation systems (particularly regarding the last three objectives).

5.8 Recharge is an important component of groundwater management (MOWR, 1996): the CGWB has extensive experience in implementing recharge projects, and the Eighth Five-Year

Plan proposes initiating recharge projects in 200 gray, dark, and over-exploited blocks, transferring surplus monsoon runoff between sub-basins within river systems, and storing the water in available aquifers. Recharge activities are, however, not just a governmental initiative. NGOs in many arid sections of the country support active and often very innovative projects for groundwater recharge (Moench, 1995b). In Rajasthan, many local communities have well-established traditions of water harvesting and groundwater recharge that are of direct relevance to current needs (Khan, 1995; Rosin, 1995). Furthermore, there are large-scale farmer-based movements in areas such as Saurashtra in Gujarat for recharging groundwater by diverting monsoon runoff into existing dug wells. The recharge activities being undertaken by the government and through private sector initiative along with the more pro-active components in the guidelines for conjunctive use planning represent a foundation for building systems for integrated conjunctive management of water resources.

5.9 Ideally, conjunctive management of water resources in India would involve the *integrated operation of surface and groundwater systems to meet an array of context-dependent social, environmental, and other objectives*. Surface water systems—reservoirs, rivers, irrigation canals, and other storage and conveyance facilities—would be operated in conjunction with activities to recharge and manage groundwater aquifers. The objective might, in some cases, be to maximize the availability of water. In other cases, reliability and environmental values such as instream flows may have greater importance (as they do, for example, in the western United States).

5.10 Implementation of conjunctive management approaches in India is hindered by the strong bureaucratic divisions among organizations involved with surface and groundwater. For conjunctive management to move beyond the simple expansion of wells in the command of surface irrigation projects to the integrated operation of surface and groundwater systems, these bureaucratic divisions need to be overcome at all levels. Detailed information on the geological and hydrological situation is essential for implementation. Given the complexity of conjunctive management, the information requirements, and the institutional obstacles that need to be addressed, pilot projects are essential to gain practical experience. For this reason, it is strongly recommended that pilot conjunctive management projects be initiated. In addition, a high-level group containing user and NGO representatives should be formed to guide, support, and document conjunctive management initiatives. This is important in order to ensure that pilot projects can proceed smoothly with participation from both local communities and relevant government agencies.

C. AGRICULTURAL POWER SUPPLY AND PRICING STRUCTURE

5.11. The pace of groundwater withdrawals and use in India is intimately tied to energy prices. A critical factor in achieving efficiency and sustainability of groundwater use is the quality and price of power supplies to the agricultural sector. Most electricity delivered to the agriculture sector is used to pump groundwater for irrigation. A combination of poor quality and unreliable supplies provides no incentive for efficient use of groundwater. The long range implications point to a deteriorating sustainability of groundwater resources over time. Currently, power is supplied to rural areas at subsidized prices, quoted on a per-horsepower basis of groundwater

pumps (i.e., flat rate pricing structure) rather than based on actual quantities consumed. The use of flat rates for electricity, combined with less than fully reliable power supplies, encourage individuals who own wells to maximize pumping of groundwater and sales to neighboring farmers in informal water markets. Where diesel pumps heavily dominate the market, pumping costs and thus water prices in the informal markets are much higher, tending to induce more efficient and sustainable withdrawals and use of groundwater. Energy pricing and other indirect avenues for influencing conditions in informal water markets may represent the most viable avenue for policy action in absence of, or in addition to, direct pricing of groundwater (MOWR, 1996).

5.12. Although energy prices may be one of the strongest levers for influencing the functioning of informal water markets, the question of energy supply and pricing should not be evaluated from a water market perspective alone. An associated major problem of subsidized rural power prices are the financial losses incurred by state electricity boards (SEB) which ranged annually from 5 to 7 percent of total state receipts between 1986 and 1995. A large portion of these losses have been attributed to the agricultural sector, where flat rates are prevalent and collection of electricity charges are low. There is evidence to indicate that agricultural power consumption is far lower than reported by SEBs in all states studied and possibly the country as a whole. Provision of unmetered power to the agricultural sector creates an accountability gap and generates incentives and opportunities for large unaccounted losses to be attributed to agricultural use. Unless the accountability gap is closed, there will be no basis for addressing concerns over SEB finances which will remain precarious.

5.13. Restoration of power sector financial viability through appropriate pricing as a first step will be essential for sustainability of groundwater. Cost reflective prices to agriculture based on an efficient cost structure will of course have to be associated with improved quality and reliability of supply. It is unreasonable to expect consumers to pay higher rates for power unless the quality of service improves. Affordability would not be an issue under a regime of cost efficient service delivery. Farmers and other consumers time and again have demonstrated their willingness to pay for quality reliable services.

Power Use And Prices In Agriculture

5.14. SEBs report official figures on energy use in agriculture based on their estimated deliveries to the sector. Demand can also be calculated based on pump energy use, hours of operation, and number of pumps. When this is done, major gaps emerge between official and academic estimates. This situation is a common feature in all states. Total consumption by pumps in Uttar Pradesh, for instance, were estimated at 1.5 billion units in 1993–94 (CADR, 1995), which was slightly less than 17 percent of the 9 billion units reported by the Uttar Pradesh State Electricity Board (UPSEB) for the same period (UPSEB, 1996). Various calculations made for this review place the level of agricultural electricity demand in Uttar Pradesh between 10–20 percent of officially reported figures. Similar percentages are obtained for Gujarat, and just slightly higher for Haryana (Table 5.1). Only under intentionally *unrealistic* assumptions—that pumping hours match those required for an “ideal” cropping pattern, that the lowest pump efficiencies are encountered, and that the maximum number of wells is functioning—do energy

consumption estimates approach official UPSEB figures. Even so, this represents only 80% of the official estimate.

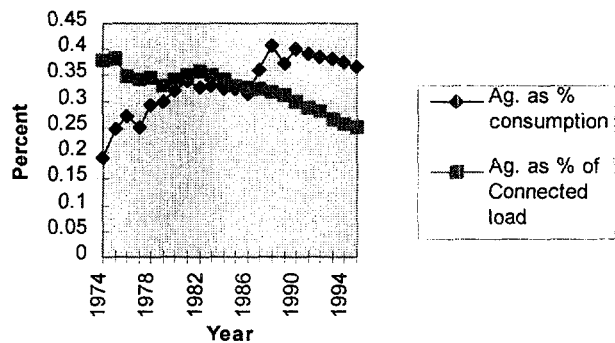
5.15. Official statistics also contain contradictions. They indicate, for example, that agricultural load has been declining as a percentage of total connected load, while agricultural consumption has been increasing as a portion of total consumption (Figure 5.1). If accurate, this would suggest increasing use of existing pumpsets at rates substantially above improvements in capacity utilization in the rest of the economy. Given the widely reported decline in the quality of rural electricity supply,¹⁹ however, this appears unlikely to be accurate. In large areas of Eastern and Central Uttar Pradesh, for instance, virtually all farmers have disconnected their electrical wells in favor of using diesel power to operate their pumpsets. A similar process is underway in other states such as Haryana and Gujarat (K. N. Bhatia and M. R. Chaudhary, 1996; and Shah, 1996a).

5.16. The general validity of these estimates is supported by national trends in connected load. Nationwide, although agricultural energy consumption is officially reported to have increased as a percentage of total consumption, connected load in agriculture has remained roughly constant as a proportion of total connected load (Table 5.2). Connected load could, in theory, be increasing at a slower rate than consumption due to a variety of factors, including increased use of connected capacity or less-efficient equipment. Rural electricity supply problems have increased dramatically in recent years. As a result, the number of hours that farmers with electric wells are able to pump groundwater has declined in most areas, implying that capacity utilization

Table 5.1. Share of Non-Official to Official Estimates of Agricultural Energy Demand, Selected States

U.P.	10-20 %
Haryana	38-52 %
Gujarat	20 %
Sources: Moench (1996); Shah (1996b); CADR (1995)	

Figure 5.1. Power Consumption and Connected Load in Uttar Pradesh, 1974-94



Source: Calculated from UPSEB 1996, Tables 5.3 and 5.4.

Table 5.2. Electricity Connected Load, 1970-92
(thousands of megawatts)

Year	Agriculture	Total	Agriculture as a percentage of connected load
1970/71	6,224.8	26,230.2	23.73
1979/80	15,247.4	56,123.4	27.17
1984/85	21,255.2	81,234.3	26.17
1986/87	24,286.9	92,244.6	26.33
1987/88	26,105.0	98,932.8	26.39
1988/89	28,466.1	105,955.7	26.87
1989/90	30,590.6	114,099.2	26.81
1990/91	32,511.5	120,901.2	26.89
1991/92	34,562.3	135,664.9	25.48

Source: TERI 1995, Table 4.3.30, p. 121, compiled from Central Electricity Authority, various issues.

¹⁹ Voltage fluctuations cause pumps to burn out twice a year on average in Haryana (Bhatia and Chaudhary, 1996).

has declined. Connected load should, therefore, be increasing more rapidly than, actual consumption. Since agricultural electricity consumption is not metered, estimates of agricultural consumption are derived as a residual by deducting metered domestic and industrial consumption. Reports on Haryana, for example, noted the “probable exaggeration of consumption by the flat-rate users” and “deflated...figures on consumption by the metered users due to unrecorded power theft and meter tampering” (Yoshida, 1994). The potential for large non-technical losses is certainly great given the absence of metered supply to agricultural consumers.

5.17. Most of the differences in estimated energy consumption are due to differences in the number of pumping hours assumed by the SEBs and the number measured in field surveys. Because electrical pumps are unable to operate for long hours, the effective price of the electricity actually consumed is relatively high under the flat-rate system (Table 5.3).

Table 5.3. Implicit Prices for Electricity under a Flat-Rate System

<i>Location</i>	<i>Annual power consumption per pumpset (kilowatt-hours)</i>	<i>Annual flat-rate charge per horsepower</i>	<i>Implicit price of electricity (rupees per kilowatt-hour consumed)</i>	<i>Source</i>
<i>Uttar Pradesh</i>				
Western U.P. (only irrigation)	1,438	3,750 @ Rs.50 per month; 3,000 @ Rs.40 per month	2.09–2.53	Shah based on CADR (1995)
Central U.P. (only irrigation)	1,214	3,750 @ Rs.50 per month; 3,000 @ Rs.40 per month	2.47–3.09	Shah based on CADR (1995)
Eastern U.P. (only irrigation)	1,062	3,750 @ Rs.50 per month; 3,000 @ Rs.40 per month	2.82–3.53	Shah based on CADR (1995)
U.P. general (all agricultural operations)	2,566	3,750 @ Rs.50 per month; 3,000 @ Rs.40 per month	1.17–1.46	CADR (1995), p. 40
<i>Haryana</i>				
Karnal Haryana (5-horsepower average pump)	4,313	3,900 @ Rs.65 per month	0.90	Palanisami (1996)
Bhiwani Haryana (7.5-horsepower average pump)	6,230	5,850 @ Rs.65 per month	0.94	Palanisami (1996)
<i>Gujarat</i>				
Gujarat (5-horsepower pump)	1,388	1,800 @ Rs.360 per year	1.3	ORG (1992) consumption
Gujarat (7.5-horsepower pump)	2,150	2,700 @ Rs.360 per year	1.26	ORG (1992) consumption
Gujarat (7.5-horsepower pump)		2,700 @ Rs.360 per year	1–2	Shah (1996a), p. 49

Implications

5.18. The results have two major implications for attempts to resolve SEB financial problems. First, if energy consumption by agriculture is anywhere close to the range indicated, SEBs will not be able to become financially viable unless they address the large unaccounted losses currently attributed to agricultural consumption. Second, because agricultural users are paying a relatively high rate for the power they *actually* consume, metered prices in the Rs. 0.5 per kilowatt-hour range could actually decrease SEB collections, even without considering the costs of metering. Third, under the current poor rural power supply environment, higher flat-rate charges to agricultural users are likely to induce further conversion to diesel-powered pumpsets wherever technically feasible (conversion would probably not occur if users were assured of good-quality power supplies). Furthermore, NABARD is encountering a large demand for diesel-generating sets to run electrical pumps where water tables are deep. As a result, conversion could occur on an even larger scale.

5.19. SEB finances must be made viable. This will require (a) charging prices for power that accurately reflect the cost of supply and (b) collecting applicable charges from all power users. In addition, given the decline in rural power supply conditions, serious consideration must be given to alternative sources of energy. Rehabilitation of the rural energy supply network will be hugely expensive. This investment is unlikely to be viable unless the institutional sources of loss can be addressed. Current supply and pricing policies, in which nonagricultural sectors face high metered rates and the agricultural sector faces unmetered rates, create large opportunities and incentives for non-technical losses, which SEBs acknowledge are significant. Because agricultural power consumption is not metered, however, it is impossible to determine the extent to which the gap between the official figures for agricultural power consumption and estimated consumption reflects legitimate losses. As workshops held by the Power Finance Corporation concluded, “it is difficult to determine the revenue recovery that would be realized through the implementation of various proposals (on metering and billing) because presently there is no way to reliably apportion the amount of unbilled kilowatt-hours between unmetered services, stolen power, and technical line losses” (PFC, 1993, cited in Shah, 1996a).

5.20. Unless the accountability gap can be closed, mechanisms for equitable or transparent electricity pricing and for control of losses cannot be developed. Closing the accountability gap requires accurate measures of consumption in all sectors. For this reason, *power consumption in the agricultural sector must be metered*. As SEB officials emphasize, however, the original shift from metered to flat charges in agriculture reflected real administrative problems (related to reading meters, collecting charges, and tampering by officials and farmers). These problems continue in areas, such as Haryana, that are attempting to reintroduce metered power supply. There, farmers contacted in our survey indicated that they chose to remain on the flat-rate system—despite substantially higher total charges than they would face if they accepted meters—in order to avoid conflicts with SEB staff (Palanisami, 1996).

D. CHANNELING INVESTMENT TO ADDRESS EMERGING NEEDS

5.21. Analyses discussed in this report and in the background papers prepared for this review have major implications for the directions that governmental investment should take. First, although scope remains for further development in some areas, private sector initiative appears to be sufficient in most cases and large-scale programs to subsidize new wells are no longer needed. Most groundwater development has occurred through private initiative, and subsidies have often benefited primarily the relatively wealthy sections of the population. There is substantial momentum behind private investments in groundwater extraction: restrictions on the availability of credit have had minimal impact on the construction of wells in dark areas. Furthermore, in most areas, access to wells is no longer an issue. Overall, large-scale programs to subsidize the construction of new wells are no longer needed to encourage groundwater development. Targeted assistance may, however, be appropriate in limited areas where (i) substantial groundwater resources exist; (ii) large sections of the population lack access to irrigation; and (iii) increases in irrigation would significantly improve yields.

5.22. Second, improvements in the availability and reliability of rural electricity supply represent the primary point where investment is required to encourage groundwater development in areas with substantial untapped groundwater resources. This should be done only if pricing and accountability systems can be implemented that enable full cost recovery. Unless power supply conditions are improved, local populations are unlikely to accept metering or higher prices for power. If metering and pricing policies are implemented without improvements in the power supply, shifts to diesel (or to diesel-powered generating sets) will expand. Given the magnitude of investment required to rehabilitate rural electricity supplies, alternatives such as continued expansion of diesel pumps or shifts to solar- or wind-powered irrigation should be given serious consideration (MOWR, 1996).

5.23. Third, significant investments are essential to improve the availability of data, scientific understanding, and policy analysis. The World Bank/Netherlands-assisted Hydrology Project represents a partial start in this direction. Developing management systems capable of ensuring the sustainability of resources requires substantial improvements in the availability of basic data and scientific understanding. This includes both technical (pollution, hydrological, geological, and environmental) and social (economic, institutional, and cultural) aspects. Management is information-intensive. Although it is less easy to calculate the returns to investments in information than to investments in physical infrastructure, these returns are nonetheless major. In many cases, the full value of previous investments—for example in wells—will be lost if groundwater becomes irreversibly polluted, water quality declines, or water tables fall due to lack of investment in information.

5.24. Fourth, investments to improve the end-use efficiency of water and power are essential. Investments that reduce demand for energy or water should be compared with the marginal cost of producing new supplies. Pump efficiency in India is very low. It may cost far less to reduce the demand for energy by rectifying irrigation pumpsets than it would to produce an equivalent amount of new energy by investing in generation and distribution. The importance of efficiency improvements and the high cost of rural electrification are fully recognized by government

officials dealing with groundwater (MOWR, 1996). Metering of electricity supplies would create strong incentives for rectifying these losses. The economic returns from energy saved should be included when evaluating the cost of metering. A similar argument applies to irrigation technologies and other mechanisms for conserving water.²⁰ Investments are recommended that encourage this (for example, credit for efficient irrigation and water harvesting technologies through NABARD and pump rectification schemes).

²⁰ In the western United States, the High Plains Underground Water Conservation District has managed to reduce groundwater extraction by 50 percent over the past 20 years while increasing crop yields substantially. This was achieved by investments to improve water-use efficiency. In addition to increasing yields, the investments significantly reduced costs.

VI. THE REFORM AGENDA

A. REORIENT THE APPROACH TO GROUNDWATER

Shifting From Development To Management

- *Groundwater-related policies need to shift from the historical focus on resource development to management.* Groundwater development is occurring primarily through private initiative. The private sector is, however, unlikely to address many management needs alone. Governmental initiatives in groundwater management are essential.
- *Management approaches need to be integrated.* Groundwater cannot be managed in isolation from surface water, water quality, pollution control, and the environment. Institutions are required that enable effective integration. This could be achieved by establishing local watershed or aquifer management districts with jurisdiction over all these aspects in areas where emerging problems indicate that management is required.
- *Management requires stakeholder participation.* Given the large number of wells and entrenched traditions of private use, the government's ability to enforce regulations and overcome political opposition is limited. For these reasons, effective mechanisms and processes for involving local populations in management are essential.
- *Management approaches must address growing competition and the needs of multiple users.* Although agricultural uses are dominant nationwide, domestic and industrial uses are growing and may exceed agricultural demands in some areas. The environmental impacts of development must also be recognized.

Integrating Environmental Considerations

- *Development of groundwater management approaches that are both environmentally sustainable and possible to implement are essential.* Central to this are institutional arrangements that enable surface and groundwater resources to be analyzed and managed in an integrated conjunctive manner and that ensure that water quality and pollution considerations become an integral part of the evaluation and planning of groundwater resources.
- *A comprehensive approach toward environmental impact assessment and monitoring should be developed.* As a start, environmental monitoring can be improved by (i) monitoring direct indicators including water table trends, water quality trends, pollution, and stream flows; (ii) designating sensitive zones including areas near surface streams, recharge areas, and wetland or vegetation communities dependent on high water tables; (iii) continuing to refine water balance estimates as warning indicators; and (iv) applying state-of-the-art analytical techniques where indicators suggest that problems are likely. These measures are a package, and no one is sufficient on its own. The World

Bank/Netherlands-assisted Hydrology Project will provide a solid set of data and analytical tools for this.

- *Establishment of an environmental technical cell within groundwater departments is suggested in order to implement the previous two recommendations.* This cell should be responsible for evaluating the environmental implications of management or development proposals and should have sufficient authority to ensure that environmental concerns are adequately addressed.
- *Better links for operational activities, data sharing, analysis, and policy development need to be established between groundwater organizations and those dealing with surface water, pollution, and the environment.* Operations and research central to the environment (for example, the study and management of stream-aquifer interactions) depend on the coordination of operations and data between organizations.

B. CREATING LEGAL AND REGULATORY MECHANISMS

Creating Legal Frameworks, Institutions, and Processes to Enable Management

- *A consultative process on legislative issues, with participation including representatives from different states, NGOs, users and the CGWB is needed to design new model groundwater legislation.* The recent orders of the Supreme Court establishing the CGWB as a Ground Water Authority (GWA) at the central government level and state GWBs as GWAs at the state level, represents an opportunity to promote the establishment of legal frameworks for management. At present, however, there is little unanimity regarding the design of appropriate legal frameworks. In particular, centralized command-and-control approaches are generally viewed as unworkable.
- *An international review of groundwater legislation should be undertaken to provide examples of approaches with potential relevance for India.* A wide variety of legal frameworks have been developed around the world for groundwater regulation and management. These may contain ideas and approaches useful in developing legislation suited to the Indian context.
- *Development of an institutional framework and capacity building process that enables community participation and the evolution of management institutions suited to local conditions.* The recommended approach involves designating local management areas or “districts” to address local or regional needs. The proposed framework encourages management control by local representatives while enabling government action in cases where local governance proves ineffective. The approach could be piloted through administrative mechanisms and, if successful, could provide a starting point for developing new model legislation.

- *Pilot projects to test participatory management approaches and concepts should be initiated.* United Nations Development Programme (India) anticipates allocating resources to groundwater management pilots as part of a participatory water management program under the Food Security and Nutrition Program. The Bank-assisted Water Resources Consolidated Project in Rajasthan will directly pilot several locally-managed groundwater management districts. Individuals at US Agency for International Development have also expressed an interest in pilot management activities.
- *Options for establishing formal groundwater rights should be investigated.* The reform of water rights combined with the development of effective management institutions could enable the use of market mechanisms for allocating water to high-priority sectors while compensating existing users. Public trust concepts could clarify states rights and duties with regard to sovereign power over water resources.²¹ Public trust concepts could also provide a basis for regulation. Development of viable approaches requires research and experimentation on the legal and practical aspects of implementation.

Evaluating The Role Of Water Markets

- *The possibility of developing water markets into a mechanism for intersectoral allocation within an effective rights and institutional framework should be investigated and tested through pilot projects.* The reform of water rights and the development of an institutional framework for administering transfers and avoiding negative impacts are essential for this. Effective institutional and water rights frameworks must be developed if markets are to become a significant tool for allocating water. Pilot projects in locations such as those proposed in Madras and other cities should be supported.
- *Impacts on the functioning of informal water markets in rural areas should be considered when formulating policies for rural energy pricing and supply.* Small-scale informal water markets (the selling of water by owners of wells to adjacent users) often enable poor farmers to obtain access to groundwater resources and more well-off farmers to afford the high cost of owning a well. Water prices in these informal markets tend to be lower when power is charged on the basis of a flat rate (horsepower per month) and when power and water supplies are reliable. This often enables farmers who do not own wells to obtain water at a cost lower than farmers who do. Where groundwater resources are limited, however, informal water markets can encourage overdraft.
- *Additional research is needed on the nature of informal water markets.* Key topics include (i) the extent and characteristics of intersectoral water transfers through informal markets, particularly in periurban areas; (ii) the implications of informal agricultural water markets for equity, efficiency, and sustainability under a variety of resource, social,

²¹ The concept of the “public trust” is found in many western legal systems. It represents the state’s obligation to protect the interests of its citizens in common-pool resources by defining those interests as held “in trust” for the “public” by the state. Public trust obligations are often defined as an aspect of state sovereignty.

and policy conditions; and (iii) avenues for management of informal markets where that appears essential to address major social or resource concerns.

C. REFORMING INSTITUTIONAL STRUCTURES AND OPERATIONS

Reorienting Government Organizations

- *Strong functional linkages between the CGWB, SGWOs, and other organizations involved in water management should be created to ensure effective integration of groundwater and other water resource–related activities.* One way to do this would be to involve groundwater officials as an active part of design and implementation teams for water resource projects and overall water policy development at the state and central levels.
- *A commissioner of groundwater at the joint secretary rank should be established in MOWR, and scientists and hydrologists from the CGWB should be positioned in the ministry.* At present, only engineers from organizations concerned with surface water are working in MOWR on policy, planning, and implementation, including implementation of management information programs. Groundwater specialists have little scope for policy input despite the dominant role of groundwater as a source of irrigation, domestic, and industrial water supply. This is a significant factor inhibiting consideration of groundwater management issues at the national level. Possibilities for increasing the rank of senior CGWB officials in regional offices to a level equivalent to that of their counterparts in other state organizations should also be investigated. As a scientific cadre, CGWB officials are poorly positioned to engage in dialogue with higher-ranked counterparts in state organizations (a CGWB director is, for example, of lower rank than a chief engineer in a state cadre).
- *The importance given to “macro-micro” distinctions between CGWB and SGWO roles should be de-emphasized.* Except for cross-checking data and estimates, the utility of macro-micro distinctions is unclear. Macro-micro distinctions also undermine development of information on hydrologic systems. Functional distinctions, with SGWOs focusing on implementation and the CGWB focusing on basic science, data analysis, and national policy appear more important. The centralized data storage and retrieval aspects of the Hydrology Project represent a step in this direction.
- *The capacity of the CGWB to undertake basic research should be enhanced in order for it to fill its recommended role as the premier groundwater science and policy organization.* Since management is not just a technical challenge but depends heavily on social, economic, legal and other considerations, capacity enhancement should equally emphasize social and physical science aspects. At present, there is no in-house capacity to operationalize participatory integrated approaches. The Rajiv Gandhi Groundwater Training and Research Institute to be established in Raipur with support from the

Government of the Netherlands represents an important step in strengthening the technical aspects. Social and participatory aspects need similar strengthening.

- *The capacity of SGWOs to act as management support and implementation organizations at the state level should be enhanced.* As with the CGWB, enhancement should address the social, economic, and legal as well as the technical dimensions of management. At present there is no in-house capacity to operationalize participatory integrated approaches. To do this, it may be necessary for groundwater organizations to create in-house cells having these capacities. Given the degree of public support needed to implement groundwater management, education and consensus building are key skills for any institution charged with groundwater management in the next century.
- *The capacity of NABARD to support groundwater management investments and to monitor their effectiveness should be enhanced.* Credit for investments in water conservation technologies and water harvesting should increase in importance relative to credit for new wells. If local organizations become involved in the distribution of electricity, access to credit may be needed.
- *Direct government involvement in groundwater exploitation through public tubewells should be eliminated, and existing public tubewells should be turned over to users.* Public tubewells have performed poorly, and, given the highly successful private sector initiatives in groundwater development and the success of the program to handover management of public wells to farmers in West Bengal (under the World Bank financed West Bengal Public Tubewells Project), direct governmental involvement is unnecessary.

Creating The Data And Analytical Tools Essential For Management

- *Monitoring of the CGWB and SGWO groundwater observation well networks should be revised in order to reduce the degree of duplication and to ensure optimal sampling in time and space.* The cost of this is recognized, and efforts are under way to minimize expenditures due to duplication of water-level measurement. Network monitoring could be undertaken either by SGWOs or by the CGWB as long as standard procedures are followed and data collection is given high priority. The Hydrology Project represents a major move in this direction.
- *The scope of groundwater monitoring should be widened to address management information needs, in particular by establishing systematic groundwater pollution and quality monitoring networks.* Pollution monitoring should include non-point-source agricultural residues as well as point-source municipal and industrial effluents. Quality monitoring should include fluoride, arsenic, and boron as well as total dissolved solids.
- *The importance given to estimating recharge and extraction using the GEC methodology should be greatly reduced.* Conceptual flaws in the method and large errors in estimated

quantities suggest that the calculated outcomes should be viewed as a useful indicator rather than as a reliable single criterion for managing groundwater resources.

- *A more comprehensive, two-stage analytical framework is recommended to guide groundwater resources management.* The first stage would involve a combination of measures including (i) designating sensitive environments where problems are likely to emerge;²² (ii) monitoring water level, water quality, and pollutant trends; (iii) conducting estimates based on a refined version of the GEC methodology; and (iv) creating a citizens notification system through which local problems could be brought to the public's attention by groundwater organizations. The second stage would involve detailed scientific studies in sites where these indicators suggest the presence of management needs.
- *Further basic research is required on hard-rock aquifers.* The hydrologic characteristics of hard-rock aquifers are poorly understood, particularly in relation to management needs. Because these aquifers underlie roughly two-thirds of India, scientific understanding is central to managing a large portion of India's groundwater resources.

D. TECHNIQUES AND INCENTIVES FOR SUSTAINABLE GROUNDWATER MANAGEMENT

Techniques and Programs for Sustainable Groundwater Management

- *Demand-side management through the spread of efficient irrigation technologies such as piping, drip irrigation, and sprinklers is essential in order to address many emerging groundwater problems.* Although much of this can be achieved through private sector initiative, it is important to ensure the availability of credit for purchasing equipment. In addition, mechanisms for encouraging adoption by lower-income groups should be investigated.
- *Opportunities for and constraints on the spread of low-water-intensity cropping patterns should be investigated as a component of demand-side management approaches.* Choice of crop may ultimately play a larger role in water demand than irrigation technology.
- *Opportunities for avoiding pollution through land-use planning and development of low-chemical-input agricultural practices should be identified.* Pollution avoidance is generally far less expensive than attempts at aquifer remediation.
- *Conjunctive management and recharge should be central to groundwater management (MOWR, 1996).* Ideally, conjunctive management of water resources in India would

²² Sensitive environments could include those where interactions with streams or other surface water sources are likely, areas where recharge is low, coastal and other areas where there is substantial variation in water quality, areas where there is a high potential for pollution, and areas where demands are growing rapidly.

involve the integrated operation of surface and groundwater systems to meet an array of context-dependent social, environmental, and other objectives.

- *Pilot conjunctive management projects should be initiated to gain practical experience.* In addition, a high-level group containing user and NGO representatives should be formed to guide, support, and document conjunctive management initiatives. This is important to ensure that pilots can proceed smoothly with participation from both local communities and relevant government agencies.

Agricultural Power Supply And Pricing Structure

- *Institutional mechanisms are required that eliminate the SEB financial losses while, if possible, enabling the rate structures to be flexible at the local level.* This will be possible only through commercialization and corporatization of the SEBs. During the transition to corporatization, and until investments in metering all connections is complete, SEBs can make single-point metered supplies available to groups (panchayats, cooperatives, or private distributors). Because this approach has not been tested, piloting would be required prior to broad implementation. In particular, mechanisms would be needed to enable disconnection of service to local distribution entities if users do not pay their bills.
- *Measures should be taken to ensure that all users pay rates for power that reflect the cost of supply.* Improvements in the rural supply of electricity are essential. This will not be possible unless costs can be recovered. If power were reliably delivered in rural areas, current tariffs would be highly subsidized. At present, due to the limited number of hours that power is actually delivered and the flat horsepower-based tariffs, the effective rates faced by agricultural users are substantially higher than generally believed and often equivalent to or above those paid by users in other sectors. Metered tariffs equivalent to those in other sectors could result in lower total charges to agricultural consumers, who would only pay for power actually consumed.
- *Changes in the power tariff need to be linked directly to improvements in the quality of service as part of the reform of the electricity sector in rural areas.* Changes in tariffs are unlikely to be acceptable to consumers unless accompanied by substantial improvements in service.
- *The use of non-conventional energy sources (solar and wind) for groundwater pumping should be investigated in detail and, where economic, expanded.* Studies are also needed to evaluate the economics of diesel pumps from a national accounting perspective and to evaluate options for improving the efficiency of diesel pumps. Rehabilitation of rural electricity distribution systems will be both expensive and slow. In many cases, alternative energy sources could be less expensive and made available for use much more rapidly.

Channeling Investment To Address Emerging Needs

- *Large-scale programs to subsidize new wells are no longer needed.* Although scope remains for further development in some areas, private sector initiative will be sufficient in most cases. Credit is, however, essential for rural inhabitants to maintain existing groundwater infrastructure, and maintaining their access to credit should have a high priority.
- *Improvements in the availability and reliability of rural electricity represent the primary point where investment is required to encourage groundwater development in areas where substantial untapped groundwater resources remain.* Given the very high costs inherent in improving rural electricity supplies, alternatives should also be investigated. In specific, the economics of alternative energy sources (solar, wind, and possibly diesel) should be investigated in detail. If these prove economic from a national accounting perspective, it may be more efficient to direct investments toward them than toward rural distribution of electricity.
- *Significant investments to improve data availability, sharing of the data and information with the public, scientific understanding, policy analysis, and management capacity are recommended.* Management systems capable of ensuring resource sustainability require substantial improvements in the availability of basic data and scientific understanding. This includes both technical (pollution, hydrological, geological, environmental) and social (economic, institutional, cultural) aspects.
- *Investments should be directed to developing management capacity at local, state, and central levels.* At present, there is a “software-hardware mismatch.” Most investment proposals are directed toward physical works rather than to participation, institutional capacity building, and the information essential to management. Funding for management activities can be increased at the expense of funding for groundwater development.
- *Investments that encourage end-use efficiency of water and power are essential if India is to increase food production and maintain its resource base.* If these investments can be targeted to recipients, investments could take the form of credit for efficient irrigation and water harvesting technologies through NABARD.

E. DETAILED MATRIX OF RECOMMENDATIONS

Table 6.1. Detailed Matrix of Recommendations

No	Recommendations	Implementing Agencies	Time Frame
A. Reorient the Approach to Groundwater Management			
<i>Objective:</i> To achieve a shift in policy and operations from development to management of groundwater resources, including integration of environmental issues.			
A1. Shift the emphasis from development to management			
	<ul style="list-style-type: none"> • Develop effective mechanisms and processes for involving local populations in management • Reduce programs that directly or indirectly subsidize groundwater development • Develop mechanisms for integrating groundwater, surface water, pollution, irrigation and municipal water supply data collection, planning and management. Mechanisms for closely coordinating the activities of all government organizations dealing with water should be established. • Develop groundwater management support capacities in government groundwater organizations. Capacities needed include: economic analysis, legal and institutional development, community relations & participation, education and outreach. In addition, technical skills in hydrologic data monitoring, analysis, modeling and presentation should be strengthened. • Identify and further develop legal and regulatory frameworks for management 	<p>SGWOs, CGWB</p> <p>Central and State Governments SGWOs, Drinking Water agencies., IDs, CGWB CGWB, SGWOs, NABARD</p> <p>MOWR & CGWB in collaboration w/ Legal Specialists, Academics/NGOs.</p>	<p>Begin immediately and sustain Within 1 year</p> <p>Within 1-2 years</p> <p>Initiate within 1 year and sustain</p> <p>Immediate. Evaluate and develop as pilots occur</p>
A2. Integrate Environmental Considerations			
	<ul style="list-style-type: none"> • Create environmental cells in state and central groundwater organizations • Establish effective mechanisms for environmental policy and implementation coordination both among government organizations and between government organizations and NGOs. • Undertake environmental impact analyses for all groundwater development and management programs • Establish comprehensive approach to environmental impact assessment and monitoring based on: (a) monitoring of direct indicators (water level, quality and pollution trends and instream flows); (b) designation of sensitive zones; (c) continued refinement of water balance methods; and (d) application of state of the art analytical techniques where indicators suggest problems are likely. 	<p>CGWB, SGWOs CGWB, SGWOs, CPCB, SPCBs, MoEF CGWB, SGWOs, CPCB & MoEF CGWB & SGWOs</p>	<p>Within one year Within one year</p> <p>Begin within 1 year and sustain Begin process immediately</p>

Table 6.1 (cont.). Detailed Matrix of Recommendations

No	Recommendations	Implementing Agencies	Time Frame
	<p>B. Create Legal and Regulatory Mechanisms. <i>Objective:</i> Develop legal and regulatory framework that has broadbased community support and is implementable. Utilize pilot management projects to build community support for regulation.</p>		
	<p>B1. Create Legal Frameworks, Institutions and Processes to Enable Management</p>		
	<ul style="list-style-type: none"> • Form a broad based working group containing NGO, Academic and Government representatives to review legislative and regulatory issues and to guide pilot projects. • Undertake international review of groundwater legislation to identify models with potential relevance for India. • Develop management institution process and framework enabling community participation • Initiate pilot projects using existing administrative powers to test management options, including: formation of aquifer management organizations (or districts) that combine local governance and participation with professional guidance, centralized regulation and water market approaches. • Investigate avenues for groundwater rights reform that could improve water market functioning while allowing social and environmental concerns to be addressed. • Implement legal, institutional and process reforms on the basis of pilot project and evaluation results 	<p>Academic Orgs, NGOs, CGWB, SGWOs, NABARD Working group</p> <p>Collaboration among the above SGWOs w/ support from research orgs., NGOs & CGWB</p> <p>Research orgs., & CGWB</p> <p>State & Central Governments</p>	<p>Immediately.</p> <p>Complete within 2 years</p> <p>Complete within 2 years</p> <p>Initiate immediately for duration of 1-5</p> <p>Complete within 2 years</p> <p>Intermediate term.</p>
	<p>B2. Evaluate existing and potential roles for water markets</p>		
	<ul style="list-style-type: none"> • Investigate the potential for developing formal water markets and the institutional and water rights structures they require through pilot projects, evaluation of international experiences, through study tours, consultancies and workshops. • Undertake detailed evaluation of the impact of energy pricing and other government policies on existing informal water markets and the role energy pricing plays in water market functioning. Incorporate results of evaluations in policy decisions. • Additional research on the nature and functioning of informal water markets including: (a) intersectoral transfers; (b) equity, efficiency and sustainability implications under an array of resource, social and policy conditions; (c) avenues for management of informal water markets where major social or resource concerns exist. 	<p>SGWOs & other state agencies, supported by academic/research organizations with management skills.</p> <p>Academic/research orgs., with implementation by State/Central gov'ts</p> <p>Academic and research organizations</p>	<p>Implement pilots, & begin studies & research within one year.</p> <p>Begin studies and research within 1 year</p> <p>Begin studies and research within 1 year</p>

Table 6.1 (cont.). Detailed Matrix of Recommendations

No	Recommendations	Responsibility	Time Frame
	C1. Reform Institutional Structures and Operations <i>Objective:</i> Institutional structure and procedures that support the new emphasis on management (as opposed to development), and the development and strengthening of supporting data and other systems.		
	C1. Reorient government organizations		
	<ul style="list-style-type: none"> • Shift focus of government groundwater organizations away from development and exploration to management support. • Strengthen social science, education and outreach capacities of government groundwater organizations <i>in ways that strongly support community participation.</i> • Establish strong functional linkages between government agencies by involving groundwater officials in the design and implementation of all water resource projects and giving officials from groundwater organizations equivalent official positions as counterparts in surface water organizations. • De-emphasize “micro-macro” distinction between CGWB and SGOs • Enhance CGWB capacity to undertake basic hydrologic and management research • Enhance capacity of SGOs to act as management support and implementation organizations at the state level with particular focus on education, consensus building and institutional support as well as technical. • Increase NABARD capacity to support groundwater management investments such as water conservation technologies and water harvesting. Reduce NABARD support for new wells. • Eliminate direct government involvement in groundwater exploitation through public tubewells and turn public tubewells over to users. 	CGWB & SGOs CGWB & SGOs CGWB, SGOs, IDs, CPCB, SPCB, Municipal Supply Organizations, etc. CGWB & SGOs CGWB SGOs NABARD State & Central Governments	Begin immediately Begin immediately Begin within 1 year Begin immediately Begin & Sustain Begin & Sustain Begin immediately Over one year
	C2. Create Data and Analytical Tools Essential for Management		
	<ul style="list-style-type: none"> • Continue and expand the hydrology project • Revise CGWB & SGWO well networks & monitoring activities to reduce duplication & ensure optimal sampling. • Develop monitoring systems for and collect point and non-point data on pollution. • Develop two stage approach to groundwater condition monitoring in which water level, quality and pollution trends along with crude GEC estimation procedures are used as warning indicators to target the detailed scientific studies essential for policy decisions • For the first level of monitoring, increase reliance on direct measures of groundwater conditions (water level, quality and pollution trends) & decrease emphasis on GEC water balance data. Eliminate use of GEC water balance calculations as a basis for policy decisions. • Undertake further basic research on the hydrology of hard rock aquifers 	CGWB and SGOs CGWB and SGOs CGWB, SGWO PCB CGWB and SGOs CGWB and SGOs CGWB and SGOs	Sustain Within 2-3 yrs Within 2-3 yrs Over next 2-3 years Over next year Begin & sustain

Table 6.1 (cont.). Detailed Matrix of Recommendations

No	Recommendations	Implementing Agencies	Time Frame
D. Introduce Techniques and Incentives for Sustainable Groundwater Management			
<i>Objective:</i> Providing and strengthening incentives that will induce sustainable extraction and use of groundwater resources.			
D1. Identify Techniques and Programs for Sustainable Groundwater Management			
	<ul style="list-style-type: none"> • Planning, implementing and developing policies for conjunctive management, end-use conservation, land-use planning, pollution avoidance and groundwater recharge should be core functions of groundwater management organizations. Capacities should be developed for this. • Conjunctive management and recharge should be emphasized as central to effective groundwater management. Pilot projects on this should be initiated. • Ensure credit availability for water conservation technologies • Support investigation of low water intensity cropping systems • Investigate opportunities for pollution avoidance through land use planning and development of low chemical input agriculture 	<p>CGWB and SGOs with IDs</p> <p>CGWB and SGOs</p> <p>NABARD Agriculture Depts. CGWB, SGOs, PCBs, MOEF</p>	<p>Begin & sustain</p> <p>Begin & sustain Pilots within 2 years</p> <p>Begin & sustain Begin & sustain Within next 2-3 years</p>
D2. Improving Agricultural Power Supplies and Pricing Structure			
	<ul style="list-style-type: none"> • Initiate institutional reforms to close the SEB "accountability gaps" through pilot projects for rural power delivery such as through high quality, single point metered supply to local organizations such as panchayats, user groups or small scale distribution companies. • Link power tariff changes to increases in the quality of service as part of rural electricity sector reform. • Reform energy prices so that users pay rates that reflect the cost of power consumed. • Conduct detailed studies to further quantify power consumption, the financial and economic costs of power delivered and the prices users actually pay for power in the agricultural sector. • Investigate the use of non-conventional energy sources for groundwater pumping. 	<p>Central and State Governments</p> <p>Central and State Governments, SEBs</p> <p>Central and State Governments</p> <p>Academic and research organizations</p> <p>DNES, SEBs, Academic orgs.</p>	<p>Begin immediately and sustain</p> <p>Begin and sustain</p> <p>Within two years</p> <p>Begin immediately</p> <p>Begin sustained research and development program</p>

Table 6.1 (cont.). Detailed Matrix of Recommendations

No	Recommendations	Implementing Agencies	Time Frame
D. Introduce Techniques and Incentives for Sustainable Groundwater Management (cont.)			
D3. Channel Investment to Emerging Needs			
	<ul style="list-style-type: none"> • Investments should focus on development of the information base essential for management, conjunctive management, end-use conservation, pollution control, groundwater recharge and other management needs. Investments in energy supply improvements may also be important. • Large scale governmental support for groundwater development, such as the subsidy programs run through NABARD, no longer appear necessary except where: (1) groundwater development levels are low; (2) substantial scientifically documented groundwater potential exists; (3) additional irrigation is important for improving agricultural productivity; and (4) farmers are unfamiliar with groundwater irrigation or unable to afford the cost of new wells. • Improvements in rural electricity supplies is the primary point where investments are required to encourage groundwater development in areas where substantial untapped resources remain. • The potential for investments in non-conventional energy sources for pumping should be investigated in detail. • Significant investments to improve data availability, scientific understanding, policy analysis and management capacity are required at central, state and local levels. • Investments to encourage end-use efficiency of water and power are essential. 	<p>Central and State Governments, NABARD, SEBs, CGWB, SGOs.</p> <p>Central & State Governments, NABARD</p> <p>SEBs, State Governments DNES</p> <p>Central and State Governments, CGWB, SGOs NABARD</p>	<p>Begin immediately</p> <p>Sustained reductions in over next 5 years. Very small program remaining.</p> <p>Over next 5 years.</p> <p>Invest gradually as programs are developed.</p> <p>Sustained, planned investment</p> <p>Sustained major drive as programs develop.</p>

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**Annex 1. Groundwater Data Collection, Processing and Analysis
in Haryana, Uttar Pradesh, Tamil Nadu and Gujarat**

A1.1. Interviews were conducted in October 1996 with officials of national and state groundwater related organizations in Haryana, Uttar Pradesh, Tamil Nadu and Gujarat. One of the main objectives of these interviews was to get an impression of state-wide groundwater data collection activities and practices. The organizations visited for this purpose were: the Central Groundwater Board North-West India, the Groundwater Directorate of Haryana State Minor Irrigation and Tubewell Organization, the Groundwater Cell of Haryana State Department of Agriculture, the Haryana State Public Health Department, the Haryana State Pollution Control Board, the Central Groundwater Board Northern India, the Uttar Pradesh Groundwater Department, Jal Nigam (Uttar Pradesh), the Central Groundwater Board Tamil Nadu, the Tamil Nadu Groundwater and Surface Water Data Centre, the Tamil Nadu Water Supply and Drainage Board, the Tamil Nadu Pollution Control Board, the Central Groundwater Board West Central India, the Gujarat Water Resources Development Corporation, the Gujarat Water Supply and Sewerage Board and the Gujarat Pollution Control Board. The state pollution control boards were included to find out whether or not they would have any activities related to groundwater pollution.

A1.2. A summary of the main groundwater related field activities is presented in Tables A1.1 through A1.8. Only a few comments will be made here. First, there is a *rather high degree of similarity* of the groundwater data collection programs, both if one compares between states and between the main groundwater related organizations active in each of the states visited. Differences in performance, however, do exist for a variety of reasons. Second, there is a *considerable overlap of activities*, especially as regards state-wide monitoring of groundwater levels and of groundwater quality. In spite of differences that are present as well, there is obviously scope for reducing duplication and using the capacity thus made available for more differentiation in groundwater activities. Third, *groundwater pollution monitoring is completely missing*; the same is true for state-wide groundwater pollution surveys. Groundwater organizations are not yet equipped for the special requirements of groundwater pollution monitoring. Pollution Control Boards feel, however, that groundwater pollution monitoring is beyond their scope of activities.

A1.3. Similarities were also observed in data processing and analysis, and in the presentation and use of the information. Groundwater investigation activities in general reflect operational information needs for groundwater development - and not yet those for groundwater resources management. Production of maps and updating the classification of blocks according to their 'level of development' (see the GEC methodology in Annex 2 below) are important goals that will answer practical questions regarding local groundwater development conditions. Lack of

computer facilities results in only limited processing and even less analysis of the data. The hydrochemical data would, in particular, reveal much more if they were more thoroughly analyzed. Little attention is given to time series analysis, to links between ground and surface water systems and the environment, or to the variation of groundwater conditions with depth. Numerical simulation models or other techniques that focus on the physical processes behind groundwater quantity and quality are not yet in common use at the organizations visited. Data are still predominantly stored on paper.

A1.4. Obvious suggestions for improvement are: (a) reducing the duplication of activities; (b) widening the range of variables to be monitored, in particular initiating state-wide groundwater pollution activities; (c) enhancing processing, analysis and storage of the data by introduction of computers; and (d) more attention to scientific analysis of groundwater quantity and quality processes (e.g. by time series analysis, 3D mapping and model simulations).

Table A1.1. Groundwater monitoring activities in Haryana

	CGW-NWI	GWD-HSMITC	GWC-HSDoA
Groundwater levels number of sites frequency of observation remarks	358 dug w. + 165 piezometers 4/year	1650 (50% are 'key wells') 2/year (key wells: 1/month) mainly dug wells used	1857 (mostly dug wells) 3/year (Jan-June-Oct) monthly data for 108 wells a few recorder-equipped wells
Groundwater quality number of sites frequency of observation remarks	358 dug w. + 165 piezometers 1/year (pre-monsoon) in gr.water level monit. wells	1650 (50% are key wells) 2/year (pre-& post-monsoon) in groundwater level monitoring wells	unknown number unknown frequency 10000 water analyses targeted for 1996/97 (limited number of parameters)
Groundwater abstraction number of sites frequency of observation remarks	none	only DIT and ATW annual draft recorded	selected sites monthly for determining unit draft
Groundwater pollution number of sites frequency of observation	none	none	none

Notes: CGW-NWI: Central Groundwater Board, Region North-West India
 DW-HSMITC: Groundwater Directorate of Haryana State Minor Irrigation and Tubewell Corporation
 WC-HSDoA: Groundwater Cell of Haryana State Department of Agriculture

Table A1.2. Other systematic groundwater data acquisition activities in Haryana

	CGW-NWI	GWD-HSMITC	GWC-HSDoA
Remote sensing	on very limited scale	no	no
Resistivity surveying	yes (4 or 5 sets)	occasionally, on request	yes (8 sets)
Exploratory drilling	yes	last 3 years no activity (no budget)	no
Geophysical well-logging	yes (2 loggers - 600 m)	yes (4 loggers)	yes (1 logger)
Chem. analysis of groundwater	yes (own laboratories)	yes; in own laboratories	yes; in own laboratories (10)
Pumping tests: step-testing in wells aquifer testing in wells	yes yes (computer-aided interpretation)	in all DIT and ATW only in exploration boreholes	yes (40-50/yr) yes (40-50/yr)
Well counts	no	no	annual village-wise census
Unit well draft surveys	each year some 15 % of total	ad-hoc surveys	yes
Other field data acquisition activities	some magnetometry		network of 40 rain gauges

Notes: CGW-NWI: Central Groundwater Board, Region North-West India
 GDW-HSMITC: Groundwater Directorate of Haryana State Minor Irrigation and Tubewell Corporation
 GWC-HSDoA: Groundwater Cell of Haryana State Department of Agriculture

Table A1.3. Groundwater monitoring activities in Uttar Pradesh

	CGWB-Northern Region	Ground Water Department -Uttar Pradesh	Jal Nigam
Groundwater levels number of sites frequency of observation remarks	1495 (1446 dug wells + 49 piezometers) 4/year (Jan-May-Aug-Nov)	4000 (800 piezometers + 3200 dug wells) 6/year (key wells: 1/month) 99% of dug wells are without a pump	none
Groundwater quality number of sites frequency of observation remarks	1595 1/year (?) samples from groundwater level monitoring wells	no formal monitoring	none
Groundwater abstraction number of sites frequency of observation remarks	none	none	?
Groundwater pollution number of sites frequency of observation remarks	none	none	none

Table A1.4. Other systematic groundwater data acquisition activities in Uttar Pradesh

	CGWB-Northern India	Ground Water Department -Uttar Pradesh	Jal Nigam
Remote sensing	on very limited scale	on limited scale	co-operation with State Remote Sensing Agency
Resistivity surveying	yes (2 sets)	on request, for site selection	yes (4 sets)
Exploratory drilling	yes (2 DTH and 9 rotary rigs)	currently no activity (no budget)	yes, carried out by Mechanical Wing
Geophysical well-logging	yes (1 logger - 1000 m)	yes (4 loggers)	yes (3 loggers - max. 600 m)
Chem. Analysis of groundwater	yes (own laboratory)	yes; in own laboratories (1000 samples/yr, randomly sampled)	yes, in own laboratories
Pumping tests: step-testing in wells aquifer testing in wells	yes yes (20-25/yr)	in private tubewells in private tubewells	yes no
Well counts	no	no (?)	no
Unit well draft surveys		surveys in all grey and dark blocks (once in three years)	no
Other field data acquisition activities	groundwater pollution sampling in problem areas		

Table A1.5: Groundwater monitoring activities in Tamil Nadu

	CGWB-Tamil Nadu	Tamil Nadu Groundwater and Surface Water Resources Data Centre	TWAD Board
Groundwater levels number of sites frequency of observation remarks	782 (684 phreatic, mostly dug wells and 198 deeper, mostly tubewells) 4/year (Jan-May-Aug-Nov)	2500 (some 2400 are dug wells) monthly mostly dug wells without a pump, around 100 boreholes with recorder	1286 (incl. 330 open wells) 2/yr (Jan and May) most wells 50-60 m deep, drilled in a grid pattern of 10 km to 10 km
Groundwater quality number of sites frequency of observation remarks	782 1/year samples from groundwater level monitoring wells	2500 2/year (Jan - July)	1286 2/yr (Jan and May)
Groundwater abstraction number of sites frequency of observation remarks	none	none	none
Groundwater pollution number of sites frequency of observation remarks	none	none	none

Table A1.6. Other systematic groundwater data acquisition activities in Tamil Nadu

	CGWB-Tamil Nadu	Tamil Nadu Groundwater and Surface Water Resources Data Centre	TWAD Board
Remote sensing	on very limited scale ?	in cooperation with IWS	systematic satellite aided hydrogeological mapping
Resistivity surveying	yes (4 sets)	yes (19 sets)	yes (about 100 sets !)
Exploratory drilling	yes (2 DTH and 2 rotary rigs)	yes (20 rigs; some 180 boreholes/yr)	yes (about 10,000 wells/year)
Geophysical well-logging	yes (1 logger - max. 1000 m)	yes (4 loggers)	yes (4 well-loggers)
Chemical analysis of groundwater	yes (own laboratory)	yes; in own laboratories	yes (HQ and district laboratories)
Pumping tests: step-testing in wells	?	yes	yes
aquifer testing in wells	?	yes	yes
Well counts	?	no (?)	no
Unit well draft surveys	?	?	no
Other field data acquisition activities	electromagnetic surveys	electromagnetic surveys (3 sets)	electro-magnetic surveys (2 sets)

Table A1.7. Groundwater monitoring activities in Gujarat

	CGWB-West Central India	Gujarat Water Resources Development Corporation	Gujarat Water Supply and Sewerage Board
Groundwater levels number of sites frequency of observation remarks	approx. 100 (mostly dug wells) 4/year (Jan-May-Aug-Nov)	about 2000 (mostly open wells) 2/yr (May and October)	400-500 wells 2/yr (pre- and post-monsoon)
Groundwater quality number of sites frequency of observation remarks	approx. 100 (mostly dug wells) 1/year (May) large backlog in analysis due to limited laboratory capacity	about 2000 2/year (May and October) only EC, Cl, pH, TDS; complete analysis every 2 or 3 years. special network in coastal zone (800 wells)	400-500 wells 2/yr (pre- and post-monsoon)
Groundwater abstraction number of sites frequency of observation remarks	none unit draft surveys in systematic surveys	none continuous village well census since 1976	none
Groundwater pollution number of sites frequency of observation remarks	none	none	none

Table A1.8. Other systematic groundwater data acquisition activities in Gujarat

	CGWB-West Central India	Gujarat Water Resources Development Corporation	Gujarat Water Supply and Sewerage Board
Remote sensing	yes, for drilling site selection (aerial photos and satellite images)	yes (IRS images)	yes (photos and satellite images)
Resistivity surveying	only one old equipment	yes (around 20 sets)	yes (10 sets)
Exploratory drilling	yes (2 combination and 5 rotary rigs)	yes (22 rigs; some 30-35 boreholes/yr)	yes
Geophysical well-logging	yes (1 logger - max. 600 m)	yes (3 loggers)	yes (4 well-loggers, max. 300 m)
Chemical analysis of groundwater	yes (own laboratory; limited capacity)	yes; in own laboratories	yes
Pumping tests:			
step-testing in wells	?	yes	?
aquifer testing in wells	yes	yes	?
Well counts	to a limited extent	no	no
Unit well draft surveys	yes	no	no
Other field data acquisition activities		previously also magnetometry	

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**Annex 2. The Groundwater Estimation Methodology
of the Ground Water Estimation Committee**

A2.1. The groundwater estimation methodology outlined by the Groundwater Estimation Committee (GEC) in 1984 is based on water balance concepts: groundwater draft estimates are compared to groundwater recharge estimates in order to judge whether the existing draft in a development unit (block, taluk) is sustainable and to assess the scope for additional groundwater development for irrigation. An important feature of the methodology is that neighboring development units are assumed to be hydraulically isolated from each other, i.e. cross-boundary flows are considered to be non-existent.

A2.2. The methodology can be schematized to a number of consecutive steps, carried out for each of the development units or areas (block, taluk) considered: (i) calculation of the average annual groundwater recharge; (ii) calculation of the potential recharge; (iii) calculation of the total groundwater resources for water-table aquifers; (iv) calculation of the utilisable resource for irrigation; and (v) calculation of the "level of groundwater development". These are described in turn below.

Calculation of the average annual groundwater recharge.

A2.3. The recharge is thought to be composed of rainfall recharge and recharge from surface water sources (seepage from influent rivers, canals, tanks, ponds and lakes, and percolating irrigation water). Two alternative methods are given for this step: (a) the so-called 'ad-hoc method' which uses empirical 'rainfall infiltration coefficients' to estimate rainfall recharge from rainfall figures and geological conditions; and (b) the 'water level fluctuation method' which bases the groundwater recharge estimates primarily on observed groundwater level rise during the monsoon period. The latter one is recommended for (and only applicable to) the monsoon part of the year, whenever there are sufficient data. Estimates of recharge from surface water sources are calculated in both approaches by relying on assumed unit rates and on the surveyed extent of surface water bodies and irrigated areas.

Calculation of the potential recharge

A2.4. This comprises the currently 'rejected' recharge from shallow table areas and the recharge by flooding of flood-prone areas. The former one is assumed to be equal to the increase in groundwater storage capacity if the water table would decline to 5 m below ground surface. Estimates of the potential recharge in flood prone areas are based on assumed unit rates and on the surveyed extent of this type of area.

Calculation of the total groundwater resources for water-table aquifers

A2.5. This quantity is defined as the sum of the average annual recharge and the potential recharge.

Calculation of the utilisable resource for irrigation

A2.6. This is obtained after subtracting 15 percent from the total groundwater resources, to allow for non-agricultural water uses--drinking and industrial--and for irrecoverable losses.

Calculation of the "level of groundwater development"

A2.7. Assigning a value to this indicator is the ultimate aim of the methodology. It is calculated by computing the ratio of net groundwater draft over utilisable resource and converting it to a percentage. A block (i.e. administrative jurisdiction within a district) with a development level under 65 percent classifies as a "white" block, between 65 percent and 85 percent it is a "grey" block, and above 85 percent it is a "dark" block.

A2.8. The methodology is described in full detail in the brochure titled "Ground Water Estimation Methodology" (GOI, 1984). Recent discussions on the methodology have resulted in recommendations for 'new guidelines', which still have to be approved. Both the original methodology and the proposed new guidelines have been commented upon in the Base Report "Groundwater Information for Groundwater Resources Management in India", prepared by GOI in December 1996 as part of the Water Resources Management Sector Review jointly undertaken by the World Bank and the Government of India.

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Annex 3. Perverse Incentives for Groundwater Management

A3.1. The incentive structure created by an unreliable power supply, its pricing, and absence of any groundwater management framework is central to understanding the emerging constraints on groundwater-irrigated agriculture.

A3.2. *User level.* Groundwater is an “open access” resource. At present, individual landowners can drill wells and pump as much as they are able with no thought of the impact on other farmers or the resource base. There is thus little incentive for individuals to use water efficiently except where supplies are limited (see Box A3.1). Contrast the situation of an individual owning land over a deep, highly productive, but overdrafted aquifer and another individual owning a dug well in which sufficient water accumulates each day to allow 3–4 hours of pumping. The first individual has no incentive to use water efficiently because any well he owns will yield the same amount regardless of how many

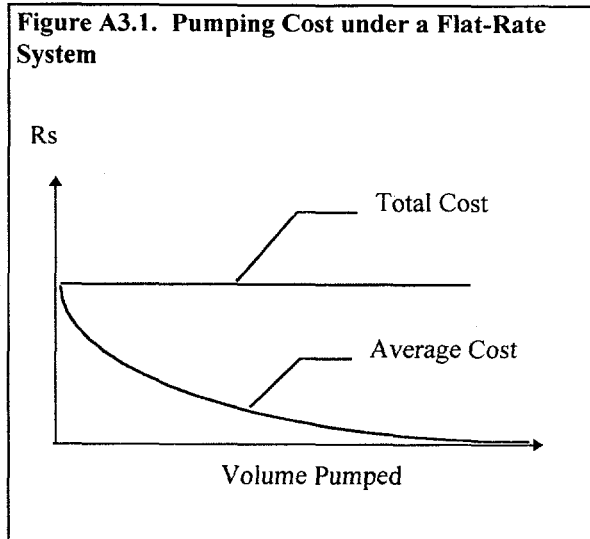
Box A3.1. Pumping Incentives

The deep-aquifer situation characterizes many of the alluvial or sandstone aquifers of northern India—the Gangetic and Indus basins plus much of Rajasthan and Gujarat. In this situation, flat-rate power prices create strong economic incentives for owners of wells to maximize extraction. This is illustrated in Figure A3.1. Under the flat horsepower-based rate system, the total energy cost is independent of the volume pumped, average costs decline continuously, and, once the fixed annual cost is paid, marginal energy costs of pumping are zero. In this context, farmers have little incentive to save energy or pump water at an optimal (i.e. sustainable) rate. The effects of this are readily observable in field locations. Studies in Gujarat indicate that the energy efficiency of pumpsets is very low, often 13–25 percent. Another study in Punjab revealed that farmers’ tubewells operate at a low thermal efficiency of 26–58 percent, and farmers have little incentive to invest in improvements. It is not clear, however, how much flat-rate energy prices affect the incentives to use water efficiently. Informal water markets are widespread, and prices are generally substantially higher than necessary to cover energy costs alone. As a result, both farmers who own wells and individuals who purchase water from them face prices that reflect use.

hours he pumps. Furthermore, because other users also have no incentive to conserve, the first individual is unable to reserve anything for future use if he reduces current extraction. In the second situation, the individual owning a well may have a strong incentive to use water as efficiently as possible. With only 3–4 hours of pumping possible, he is directly affected by the overall scarcity of water. At the same time, as in the alluvial aquifers, he has little incentive to conserve the resource base as a whole. He may use the water that accumulates in his well as efficiently as possible but, because of the common-pool, open-access characteristics of the resource, he has little incentive to invest in management of the resource base.

A3.3. Incentives to maximize extraction contribute to overdraft problems in low-recharge areas. Furthermore, the flat-pricing system masks water resource scarcity and contributes to inefficient selection of crops. Both effects have been clearly documented in Gujarat and other areas. In

Mehsana district of Gujarat, for example, farmers grow wheat in an arid climate with water pumped from depths of roughly 150 meters. Although this region has major overdraft problems, wheat is a logical supplementary crop because the marginal cost of water is close to zero. Equally important, flat-rate pricing masks the true cost of power to users. When unreliability of power is factored in, most pump owners probably incur unit power costs of Rs. 1–3 per kilowatt-hour for the power they receive. This is much higher than intended under current subsidized rate structures and is often equivalent to that paid by industrial and commercial users. From a political-economic perspective, the flat-rate structure enables the state to give the impression of providing subsidized power to the large rural voting population whether or not that population actually receives the intended subsidy.



A3.4. The unreliability of electricity supplies probably contributes as much to inefficient water use as does energy pricing. Unreliability gives farmers a strong incentive to pump water for irrigation whenever power is available, whether their crop needs it or not. It makes sense to irrigate as much as possible given the uncertainty about whether water will be available at a later stage. Furthermore, if power comes at inconvenient times, such as during the night, efficient irrigation practices are difficult to implement. The degree to which these incentives contribute to over-extraction has never been investigated in detail. The incentives to use groundwater resources inefficiently are, however, clear.

A3.5. In addition to incentives for inefficient use, unreliable power supplies create a strong incentive for individuals to use diesel pumps. Although diesel prices in India are roughly at parity with international prices (World Bank, 1996), the type of diesel pumpset common in India is notoriously inefficient. In addition, the shift to diesel pumps has major equity implications. For example, informal water markets tend to function more efficiently and to supply individuals who do not own wells with reasonably priced water when numerous electrical pumps and reliable power supplies are present. Beyond this, however, only wealthy sections of society are able to afford both diesel and electrical pumps. As a result, when power supplies are unreliable, only the wealthy are able to keep several pumps and use low-cost electrical power when it is available. Where this happens, the wealthy capture the benefits of power subsidies.

A3.6. **Group level.** At the group level, the same lack of institutional incentives for resource conservation applies as at the individual level. Because individuals have the right to pump as much as they wish from their own wells, groups have no more direct incentives to manage the resource base than individuals do. Beyond management of the resource base itself, the falling water tables and the current power supply context have major implications at the group level.

A3.7. Falling water levels and unreliable power supplies generally reduce the degree of equity in groundwater access, particularly the degree of reliability with which persons who do not own wells can purchase water. Although informal water markets are common in most agricultural areas, owners of wells tend to sell only their excess supplies. Having invested in fertilizer and other inputs, they have a strong incentive to ensure that their fields are irrigated before they sell any water. As a result, they meet their own water needs first and meet the demands of buyers only when excess water is available. This pattern has been broadly documented across South Asia (Meinzen-Dick, 1996).

A3.8. When power or water supplies are unreliable, purchasers are in a much more uncertain position than owners of wells. Although available data are limited, this uncertainty probably ripples through to decisions on investments in fertilizers and other inputs. The risk is disproportionately higher for the poor. This translates into lower yields and less water-intensive cropping patterns for the poor. Data from three major studies in Pakistan show that farmers purchasing water have consistently lower yields and grow less water-intensive crops than their counterparts who own wells (Meinzen-Dick, 1996). In addition, farmers who own wells are often able to grow more valuable crops, such as vegetables, that are particularly dependent on assured water supplies. As power supply constraints increase and the water table continues to decline, the differential in access to groundwater resources between water buyers and sellers is likely to increase as well. The poverty alleviation benefits associated with groundwater will, therefore, erode.

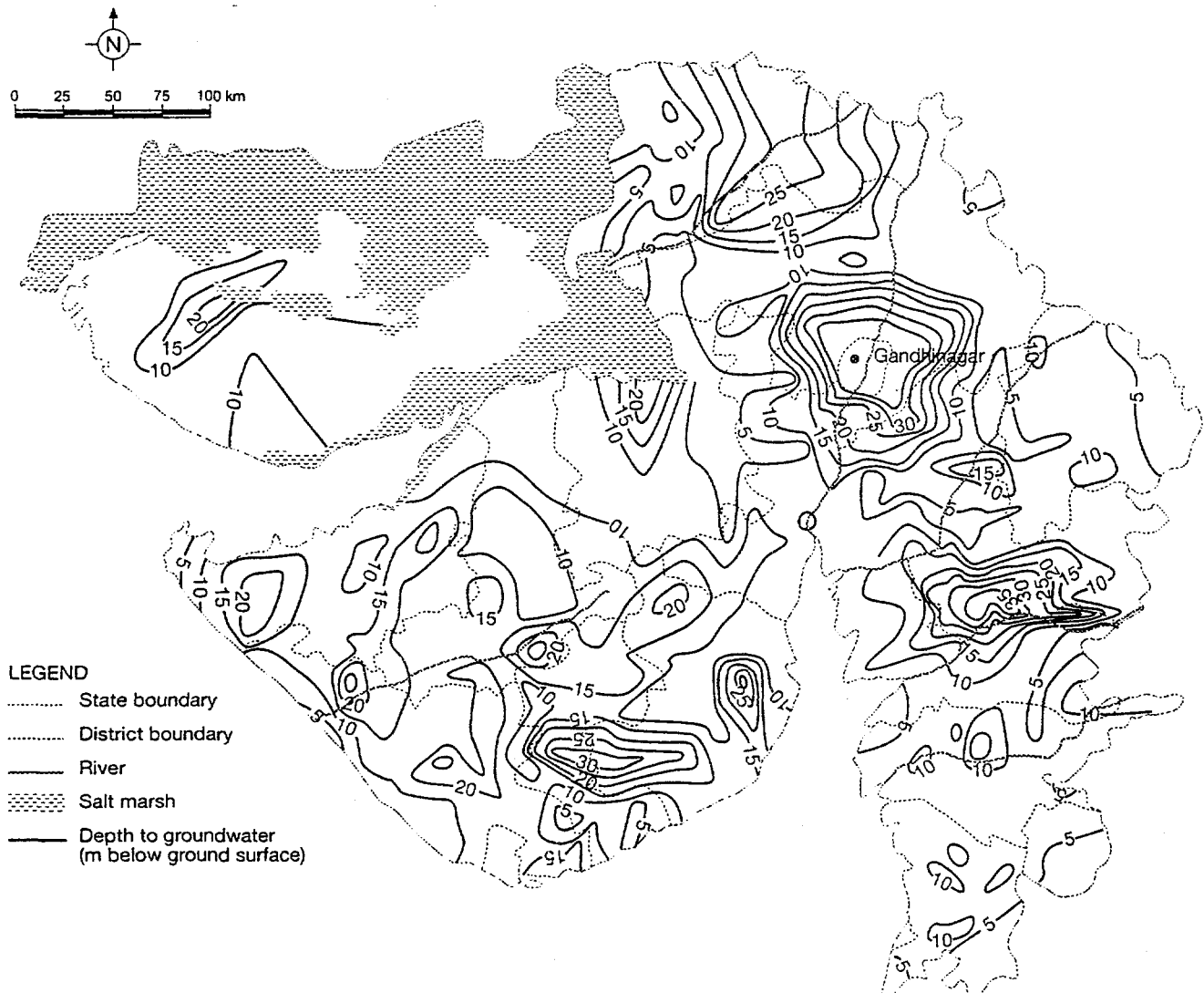
A3.9. State level. At the state level, the incentive structure created by current power pricing and supply policies generates substantial disincentives for effective action. From a political perspective, the provision of subsidized power to the agricultural sector is highly popular. Furthermore, the demand for increased power supplies at subsidized rates is likely to increase as water tables drop. Farmers need to pump water from deeper levels to maintain existing patterns of agricultural production. To do this, they require more power. In addition, as the quality of electricity supplies declines, farmers become less and less willing to pay for the power they receive. Pressure for subsidies therefore increases, creating a vicious cycle in which fewer resources are available for upgrading the electricity system, power is less available, and willingness to pay declines.

A3.10. Disincentives for effective action are also likely to exist in nonagricultural sectors. The inability to account for energy used for agriculture leaves major gaps in the ability of SEBs to account for the power delivered. Combined with high metered tariffs to industrial and commercial sectors, this creates both the incentive and the opportunity to divert power supplies. Some interests benefit within organizations (the SEBs) and consumer groups (agricultural, industrial, or commercial). Unless the power supply becomes so poor that benefits erode, these vested interests are likely to oppose effective change.

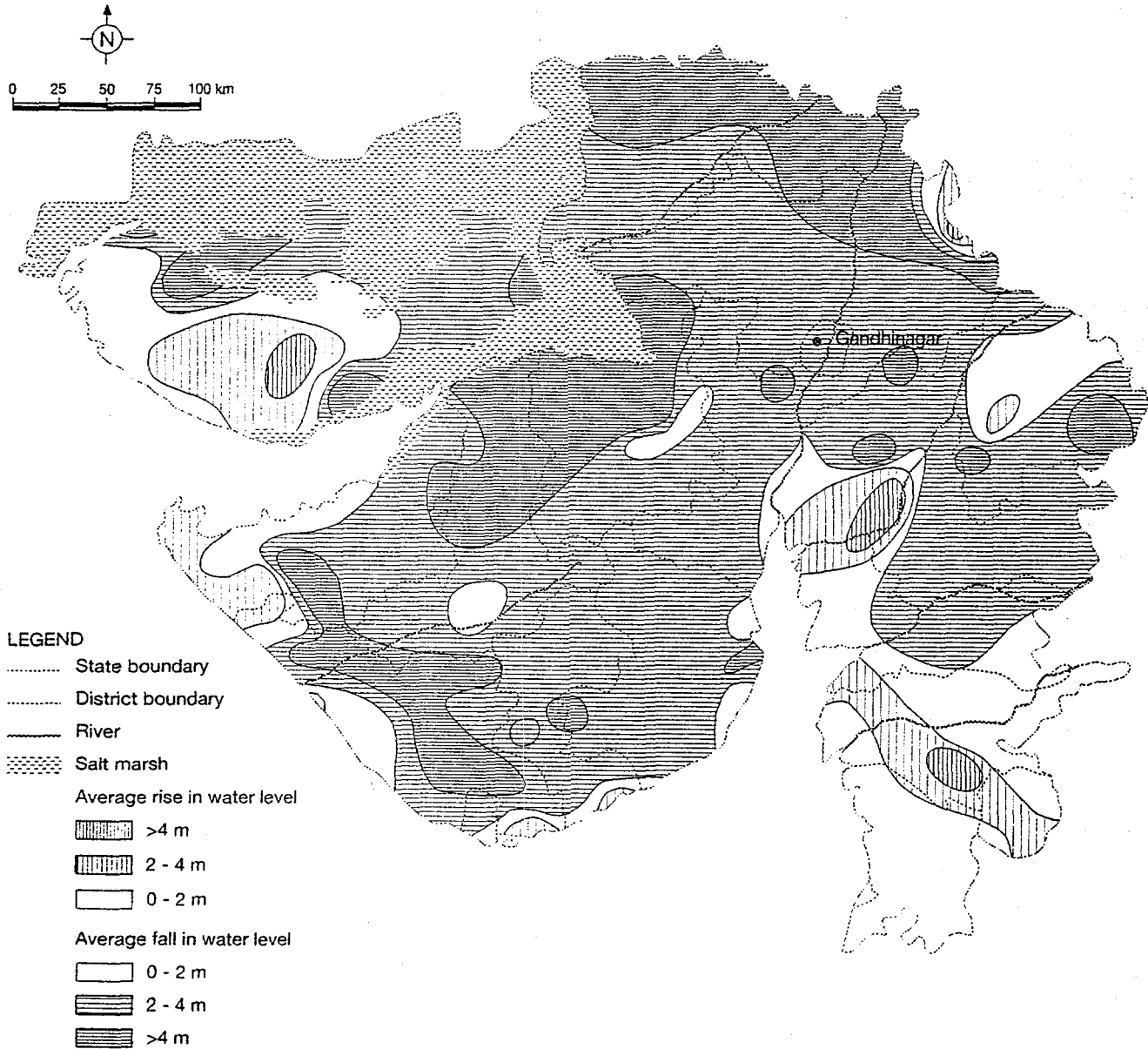
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Annex 4. Groundwater Level and Quality Contour Maps

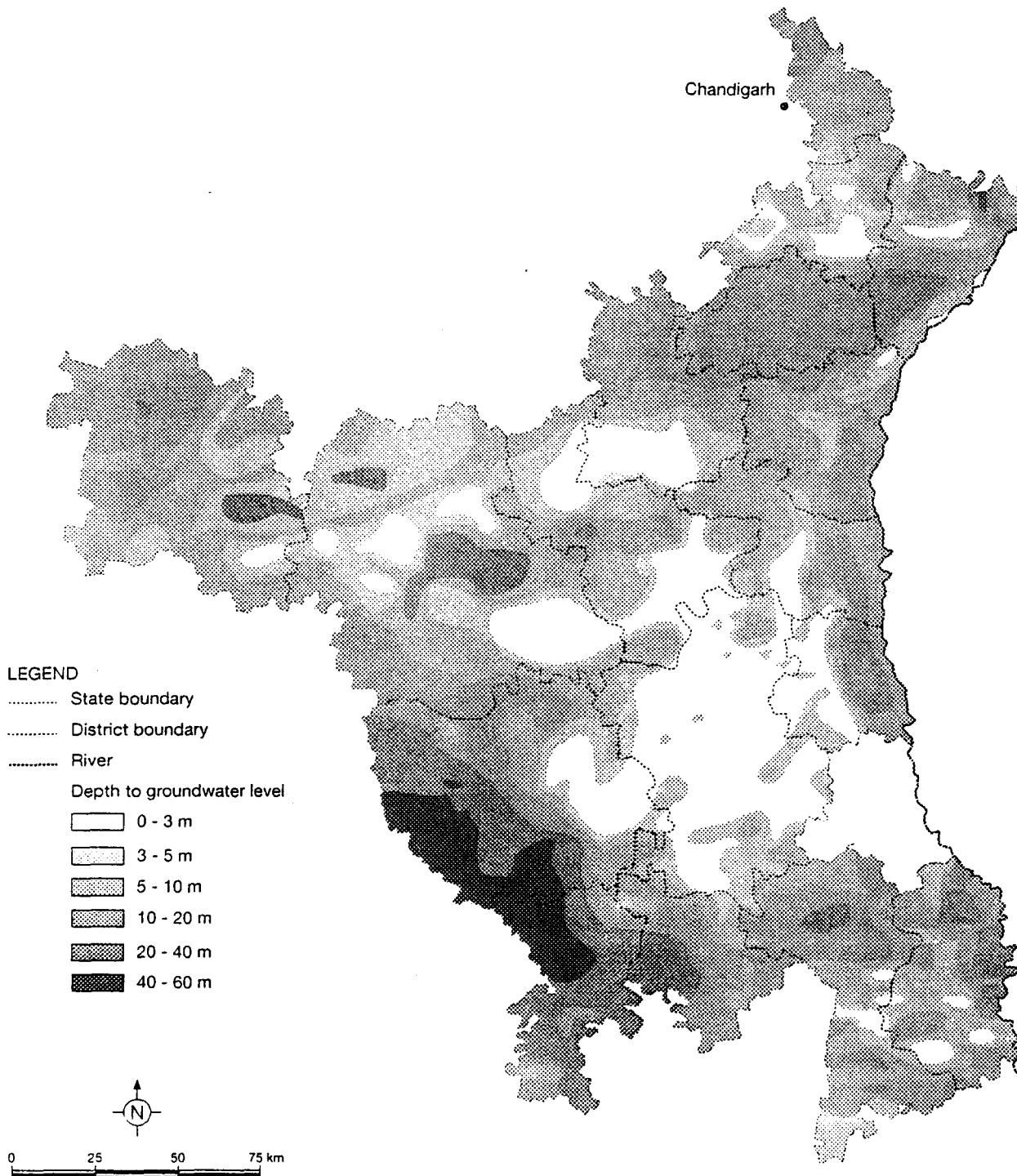
Map A4.1. Depth to Groundwater in Gujarat, May 1991



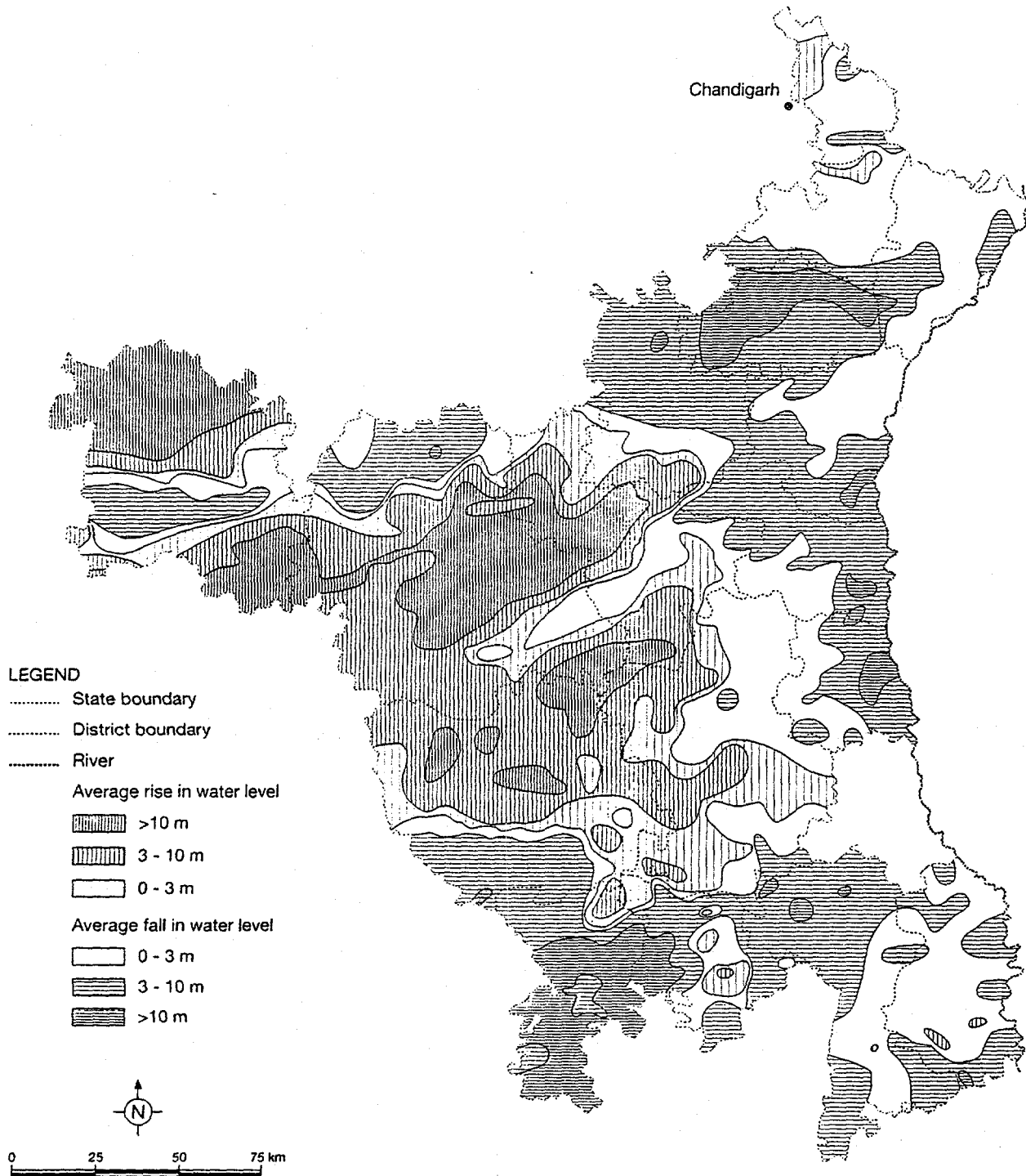
Map A4.2. Change in Water Table in Gujarat, April 1979–May 1987



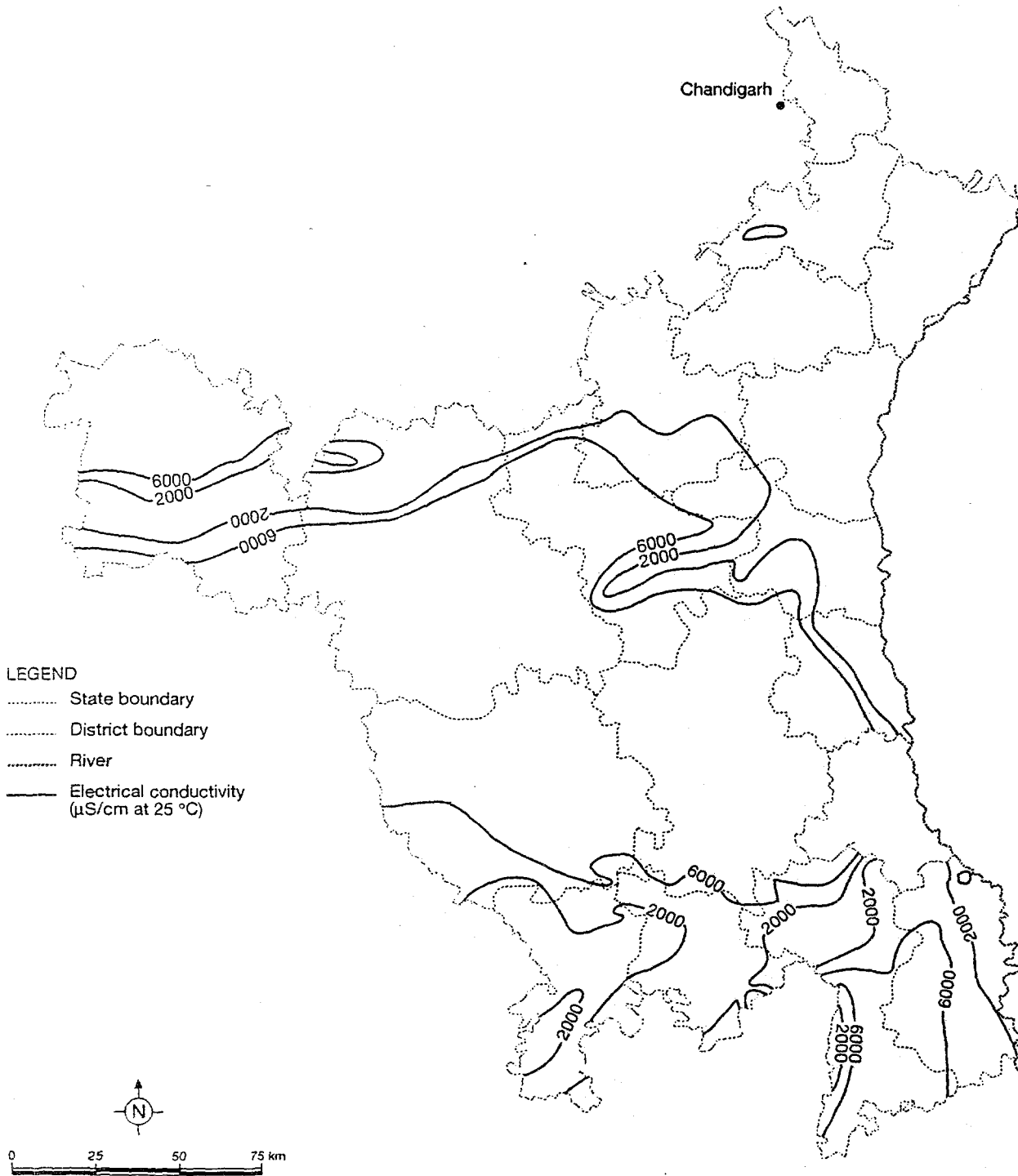
Map A4.3. Depth to Groundwater in Haryana, October 1995



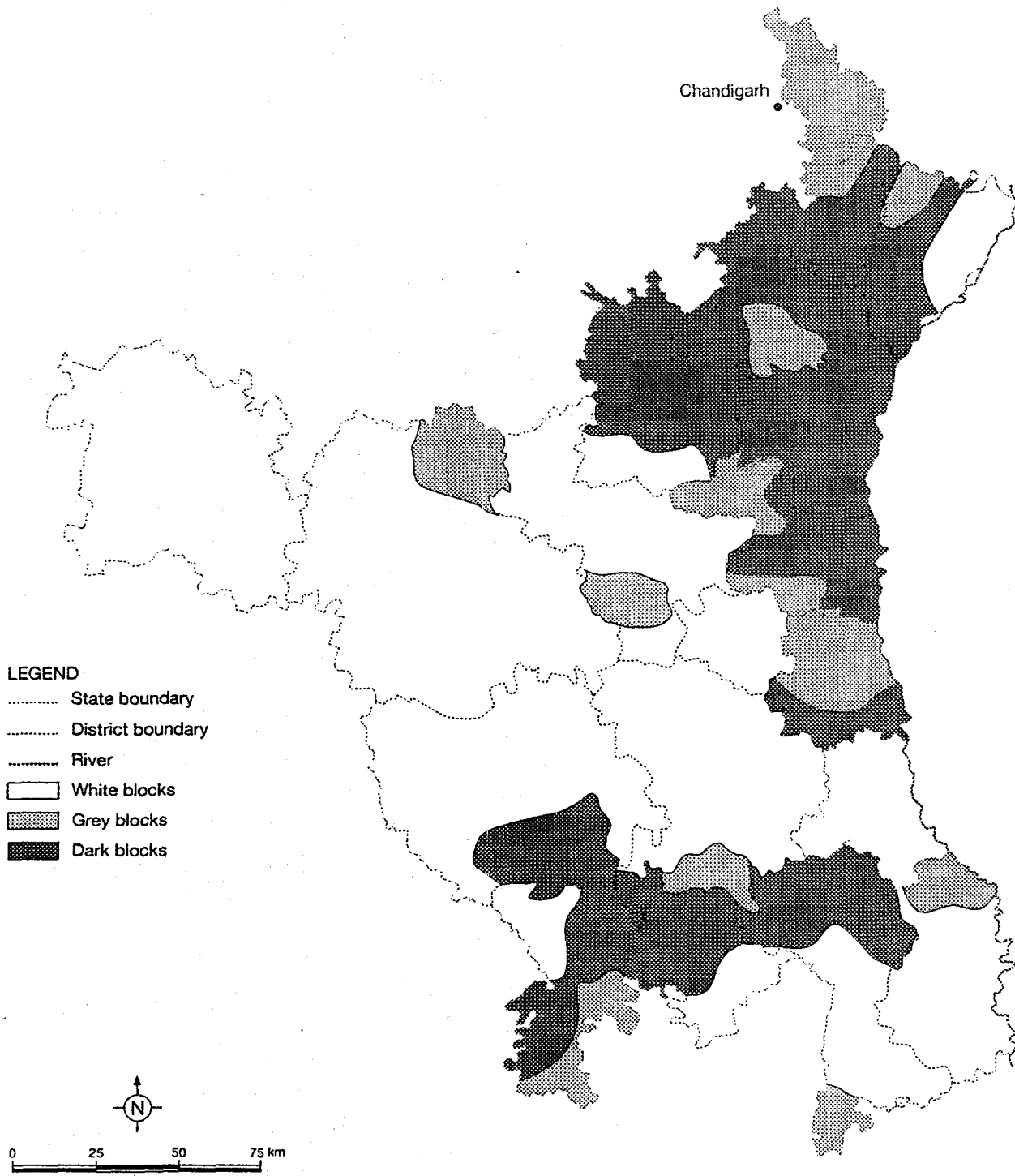
Map A4.4. Change in Water Table in Haryana, June 1974–June 1995



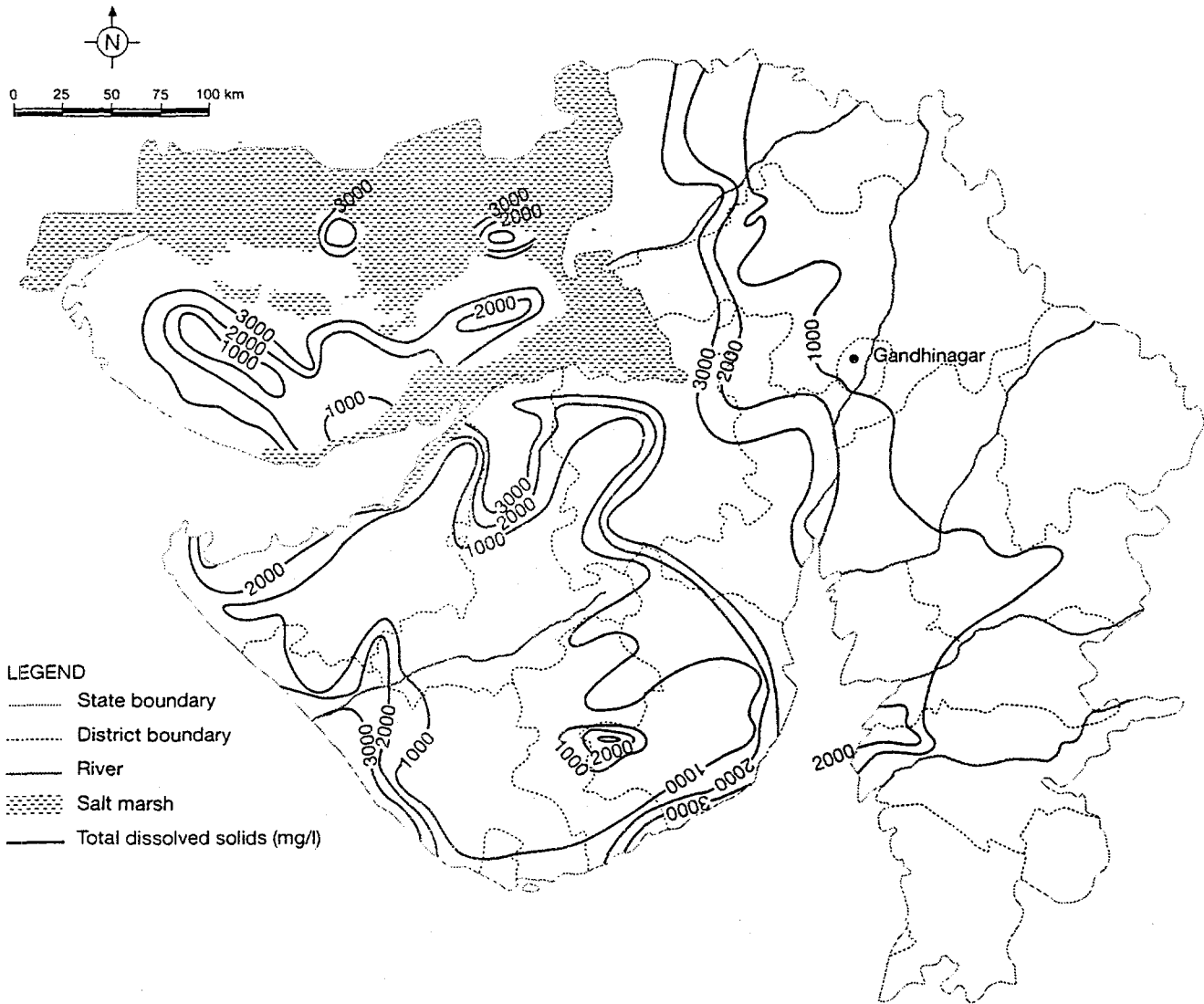
Map A4.5. Electrical Conductivity of Shallow Groundwater in Haryana, 1993



Map A4.6. Level of Groundwater Development in Haryana, 1994



Map A4.7. Total Dissolved Solids in Groundwater in Gujarat



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**Annex 5. Recommendations from the
Workshop on Groundwater Management, February 1997**

Theme 1. From Groundwater Development to Management: Momentum Behind Development, Rapid Expansion in Problems, The Challenges of Management and Channeling Investment to Emerging Needs.

Recommendations:

1. Formation of Ground Water Authority for sustainable development and management of groundwater resources.
2. Identification of critical areas involving government technical and non-technical agencies, users' groups for protection conservation and regulation of ground water.
3. Formulation of groundwater development strategies based on sound technical, environmental and economic criteria.
4. Need based sustainable development of ground water in areas with large potential but presently having low stage of development with due protection and priority to drinking water sources.
5. Lay down guidelines for dissemination, design and construction of wells and installation of pumpsets for different hydrogeological environments.
6. Periodical evaluation of socioeconomic and environmental impacts of ground water development should be done to know the changes between pre and post implementation of groundwater schemes.
7. SGOs and CGWB to earmark adequate allocations on groundwater development for R&D activities.
8. Strengthening of water level & water quality monitoring networks for acquisition of micro-profile information.
9. Noting that NABARD has a critical role in institutional financing of groundwater development schemes, it should shift emphasis from groundwater development to groundwater management. It may enlarge its activities covering fields of micro-irrigation involving animal draft and manual energy besides solar and wind pumps in villages not

electrified as yet. In this context the role of industries using groundwater for financing groundwater augmentation schemes for achieving sustainable development in over exploited/dark areas may also be explored.

10. Diagnosis and rehabilitation of sick wells.
11. Dissemination of available hydrogeological information to planners, decision makers and users preferably in local language.
12. Census of groundwater extraction structures once in five years.
13. Viable rain water harvesting and other groundwater augmentation programs should be given high priority for sustainable development of groundwater.
14. There is a need for inter-departmental co-operation with concerned Ministries/ Departments for proper implementation of all schemes related to groundwater development and management at the national, state and grass-root levels.
15. Groundwater development in and neighborhood of saline groundwater zones should be regulated by restricted pumping and appropriate spacing of wells.
16. Monitoring of groundwater extraction by those using large pumps should be carried out.
17. Program for replacing and rehabilitation of ground water structures, pumps which have outlived their utility, should be planned in advance.

Theme II. Sustainable Development and Environmental Management: Protection from groundwater depletion and pollution, conjunctive use, water conservation, groundwater augmentation, identification of data gaps and assessing additional information needs for efficient and effective resource management, and appropriate groundwater technology.

Recommendations:

1. To maintain the environment for an optimum ecosystem, guidelines on the tapping of river waters should be adhered to. Some quantity of water from reservoirs/barrages needs to be released in river channels to maintain environment.
2. Strengthening of the data base including base flow measurement, parameters now missing to ascertain the figures on sustained yield of aquifers, basins or areas faced with problems of groundwater level fluctuations, pollution, etc..
3. Development of an intensive program to monitor water quality for both point and non-point sources of pollution.

4. Need to encourage alternative practices to control pollutant.
5. Adaptation and use of aquifer simulation, conjunctive use and pollution transport models including modeling of saline freshwater interface in coastal areas for controlled management in critical areas.
6. The CGWB and SGOs need to be strengthened to take up pilot project studies in the field of groundwater management, conservation and pollution and to prepare guidelines/manuals for implementation.
7. The present groundwater estimation methodology needs revision. Computed estimates should match with the observed changes in ground water regimes based on direct indicators like water level and quality.
8. The community organizations and NGO/VOs should be involved in the management activities related with ground water.
9. Necessary mechanism should be evolved for effective inter-agency coordination.
10. There is a need for standardization and modernization of chemical laboratories for assessment of ground water quality, pollution, etc..
11. There is a necessity for laying standards for construction of wells and specifications and installation of pumps and equipment of appropriate type and size compatible with the water yielding capacity of the aquifers. For this purpose the State Organizations should be strengthened including provisions for extension services.
12. Along with the sustainable development including environment more emphasis should now be directed to management aspect. Wherever there is rise in groundwater, augmentation from groundwater to surface water should be done under public sector.
13. With a view to have a proper development and management of groundwater, it is necessary to undertake intensive model recharge studies. Aquifer recharge and water storage therein would also be subject to permit requirement and other regulatory provisions for maintaining the ground water quality.
14. There is necessity to create awareness about the groundwater quality through multi-media programs in view of the pollution, depletion and rise in water table.
15. Training on different aspects of ground water development and management should be provided to functionaries and farmers.

Theme III. Creating Legal Frameworks, Institutions and Processes to Enable Improved Management: Institutional, Legislative and Regulatory Framework at National and State Levels for Managing Ground Water Management and Development.

Recommendations:

1. For regulation and management of ground water development, it is necessary at first to prioritize the ground water use according to National Water Policy.
2. Areas to be notified will be identified by a technically competent authority based on management need indicators such as:
 - Long term water level trends (either increasing or decreasing beyond acceptable levels)
 - Water quality trends
 - Water pollution
 - Water balance estimates (improved GEC estimates)
 - Sensitive area designation
 - Problems identified by local communities (such as drying of drinking water wells during summer season)
3. The notified area should be declared by way of publication in local vernacular dailies.
4. Transparency has to be maintained while developing notified area by giving full justification.
5. There will be constituted an administrative authority to monitor and supervise plan and other actions in the notified area and to take appropriate action as needed.
6. Within notified areas a planning process will be initiated to identify appropriate actions (such as artificial recharge, conjunctive use, irrigation techniques, regulation etc..) to address development and management needs and who will implement the actions identified.
7. The planning process will involve representatives of the central and state groundwater organizations. It also needs to involve local communities (such as panchayats), non-government and voluntary organizations wherever possible. The resulting plan (both appropriate actions and who is to implement them) will be certified as capable of addressing water management problems in the notified area by a technically competent authority (CGWB or SGWO – to be decided).
8. Plan implementation will be monitored by the technically competent authority. This authority will also certify progress toward plan objectives. Should progress prove unsatisfactory, the technically competent authority may require plan revisions.

9. The exercise on management and regulation should start in a limited pilot basis under different hydrogeological, use conditions.
10. Peoples' awareness to understand and appreciate need of protecting and conserving groundwater is essential to the regulative measures effective for ground water development and management.
11. All the existing ground water structures shall have to be registered with the competent authority within one year of notification.
12. Priority on regulation should be given for groundwater development and management in coastal aquifers to check and arrest saline water ingress.
13. Water level and other related data should be regularly published for the notified area.
14. The infrastructure and the laboratories of the concerned SGOs and Central Departments should be strengthened to achieve refinements regarding ground water quality and to ascertain pollution level of groundwater.
15. The establishment of strong data base is needed to deal with ground water development and management aspects in concerned SGOs and Central Departments to facilitate data storage retrieval as well as data transfer through satellite.

Theme IV. Energy Pricing and Groundwater Markets

Recommendations:

1. Government policy should encourage development of water markets, back stopped by regulatory mechanisms as needed to avoid over-exploitation.
2. It is recognized that formalized water markets at inter-sectoral levels should be encouraged. However, pilot programs should first be taken up in the higher potential areas.
3. Ground water markets need supplementing through monitoring (of both quantity and quality) and appropriate regulatory measures.
4. Instead of public owned/managed tubewells, encourage privately or cooperatively owned/managed tubewells.
5. It is recommended that the price of power should reflect the cost of supply.

6. Applicable charges for power should be collected from all power users. Marginal cost pricing for power would be ideal, subject to affordability.
7. Institutional mechanisms for distributing electricity need to be tailored to local conditions.
8. Experiment with pilot single point metered supply to user groups (Panchayats, Cooperatives or private distributors).
9. Power tariff charges need to be linked with improvement in the quality of service as part of an overall package to effect rural electricity sector reform.
10. Detailed studies are needed to further quantify power consumed, the financial and economic costs of power delivered and the prices users actually pay for power in the agricultural sector.
11. Pilot scheme on utilization of non-conventional sources of energy such as biogas, solar, wind and mini/micro hydel plants should be taken up.
12. Wherever viable, water saving techniques such as micro-irrigation through sprinklers or drip systems should be encouraged especially in water scarce areas.
13. Encourage changes in cropping patterns and diversification from high water intensive to less water consuming crops, especially in water scarce areas.
14. Most of the existing agricultural pumpsets are operating at low efficiency. There is a possibility of improving efficiency levels by 25-30 percent. Metered power provisions would create incentives for farmers to improve their pump efficiencies.