Groundwater Resources of India
Towards a Framework for Practical Management and Effective Administration

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Abstract: This paper is intended as a contribution to the on-going discussion on the development of a framework for appropriate and effective groundwater resources management taking account of the main groundwater settings occurring in India. It is based on the international experience of the authors and informed by on-the-ground work in World Bank-funded projects with the States of Andhra Pradesh, Maharashtra, Rajasthan and Tamil Nadu during 2002-06. The main focus is on the management of ground water in weathered hard-rock aquifers outside the command of major irrigation canal systems, because it is precisely these very extensive areas that are experiencing the most pressing problems. But the differences of approach required for groundwater resource management in other hydrogeologic and socioeconomic settings are also discussed briefly.

GENERAL CONTEXT OF PAPER

Widespread and progressive depletion of groundwater tables in India over the last 10-15 years has become a cause of major concern – in many areas this has occurred more-or-less year-on-year (Fig. 1), except for temporary respite following years of exceptional monsoon rainfall when a partial recovery has been observed.

Worst-affected are the 'hard-rock aquifers' (comprising principally such formations as the weathered Granitic Basement Complex and the Deccan Trap Basalts) outside the command area of major irrigation canal systems. These occupy **very extensive areas of the drought-prone land-mass** of India (Fig. 2) – in effect almost everywhere away from the alluvial tracts associated with the major rivers and coastal belts.

Groundwater resource depletion has already had serious impacts on dry-season cropping and village water-supplies, and in consequence it has received a lot of media publicity and increasing political attention. But much of this has focused on only two facets of what is a more complex problem :

- the provision of free (or highly-subsidised) electrical power for pumping
- the failure to conserve watersheds and encourage groundwater recharge.

In result many regard these as the major or only factors causing groundwater depletion.

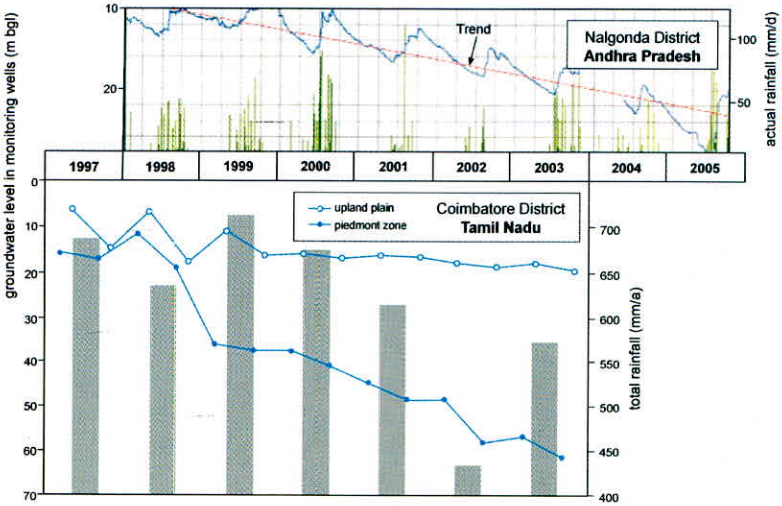

Fig. 1. Typical groundwater level hydrographs for the weathered Granitic Basement Complex aquifer in Andhra Pradesh and Tamil Nadu.

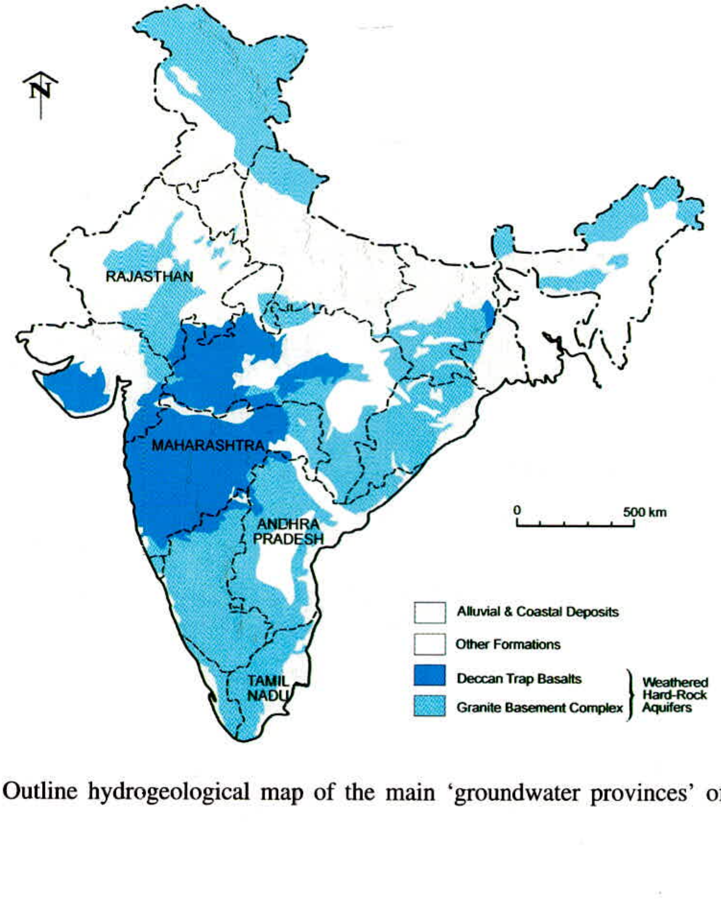

Fig. 2. Outline hydrogeological map of the main 'groundwater provinces' of India.

These authors consider that this is misleading because :

- energy consumption (even without subsidy) represents only a minor proportion of total crop production costs, and where the groundwater table is falling **much larger costs have to be borne by farmers in waterwell deepening and pump replacement** – and in any case the electricity subsidy can (to some extent) be justified as an equity measure, reducing the large price differential in irrigation water-supply cost between groundwater-using farmers (under private initiative) and canal-using farmers (with infrastructure provided by government) – but this is not to say that energy subsidies should not be phased out (because of their impact upon state finances) in favour of other financial support to the poorer farmer to economise on groundwater use.
- the level of current groundwater resource imbalance often exceeds 30% of the total average rate of natural replenishment, whereas **the potential increment of recharge enhancement over natural is unlikely to exceed 10% at best,** because the land area over which groundwater body recharge from monsoon precipitation can be economically enhanced by rainfall harvesting and recharge structures is limited (and even then some of the intercepted runoff may have previously been captured by downstream users) – thus recharge enhancement should not be regarded as a universal panacea to the resource imbalance problem but more of a useful technique for the management of some specific local problems.

So what are the primary causes of groundwater resource depletion? Well, the reality is that the **total available storage of groundwater bodies in hard-rock aquifers is strictly limited by their weathering characteristics and water-bearing properties**. And this storage reduces rapidly as the water-table falls through critical horizons in the weathering zone (usually below the uppermost 2-6 m of fractured bedrock which is typically situated at 5-25 m bgl) (Fig. 3). It can thus be rapidly depleted by heavy abstraction – and intensive uncontrolled waterwell drilling for the supplementary irrigation of wet-season (kharif) crops, and the continuous irrigation of dry-season (rabi) and perennial crops is unquestionably responsible for the hydrological imbalance observed in most groundwater bodies.

The **over-exploitation of groundwater resources has a series of associated impacts** – spiralling costs for waterwell deepening and pumpset replacement, escalating energy consumption and losses in water pumping, serious operating and financial problems for state electricity companies (where rural energy is highly subsidised), reduced availability of electricity and/or groundwater supply for irrigation with damage to dry season crops, and problems with provision of drinking water with reduced well yields and deteriorating quality (excessive fluoride and/or salinity) when groundwater is drawn from greater depth in some aquifers.

Moreover, **over-exploitation first affects the poorer farmers** by:

- putting them in the precarious position of having to purchase water from richer farmers with deeper tubewells (whose water was often produced with free electrical energy)
- forcing them out-of-business completely with migration to the cities.

In turn many 'better-off' farmers find themselves having to negotiate larger-and-larger bank loans in their efforts to deepen waterwells and to 'chase the declining water-table', and simultaneously face decreasing water security and crop yields. Thus although the **initial use of ground water for irrigation generated many benefits for farmers, there are few 'winners' when its exploitation in hard-rock aquifers becomes uncontrolled and excessive**. Such 'winners' would appear to be restricted to waterwell drilling rig manufacturers, owners and operators, together with borehole pump manufacturers and retailers.

It would appear that the **'no-intervention scenario'** (allowing natural controls to constrain use) **would have unacceptable social costs** as a result of the impacts described above – not to mention a growing crisis in providing minimum drinking water-supply requirements to the rural population and a sub-optimal use of available ground water for agricultural production. Thus ways urgently need to be found of **mobilising and supporting communities in adapting to groundwater resource realities**, by exercising an appropriate level of constraint on dry-season groundwater extraction and new waterwell drilling.

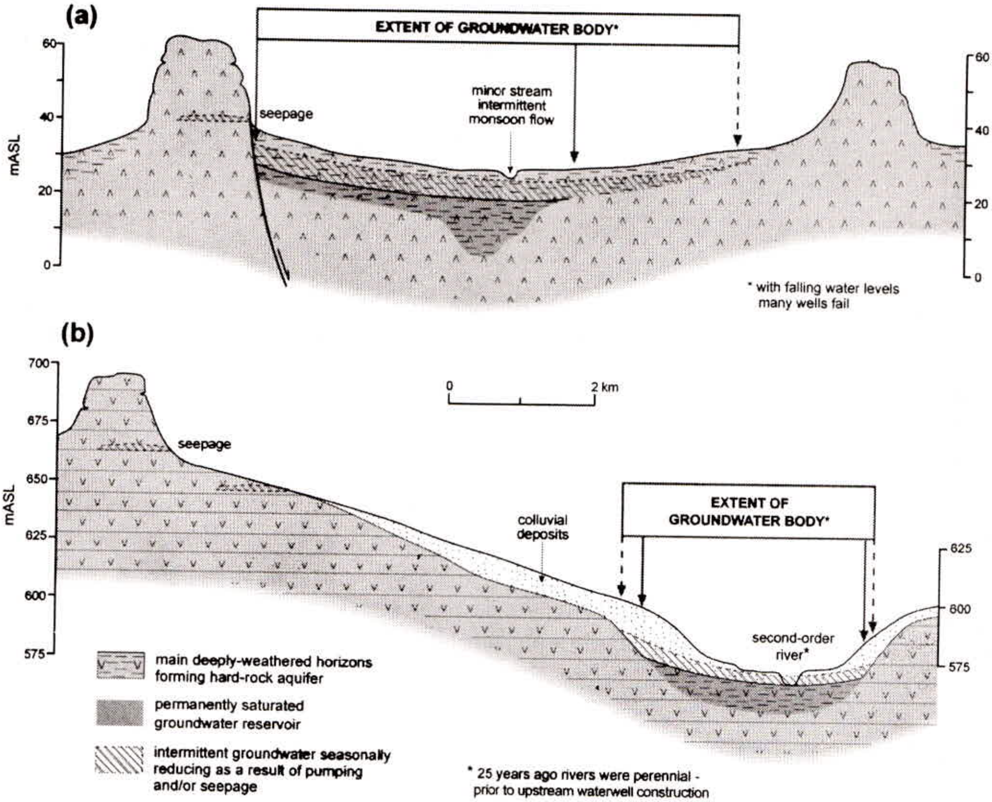

Fig. 3. Hydrogeological cross-sections of the weathered (a) Granitic Basement Complex and (b) Deccan Trap Basalt aquifers to illustrate the structure of groundwater bodies.

ELEMENTS OF THE GROUNDWATER MANAGEMENT FRAMEWORK

Sound groundwater resource governance is an integral part of sustainable and integrated water resource management, and as such is the policy of the Indian Union Government. Good governance requires government bodies responsible for groundwater resources at national and state level to establish an effective policy and legal framework, as well as appropriate institutional arrangements, to allocate and manage the use of ground water in a way responsive to national social and economic needs and to the long-term sustainability of the resource base.

In this context a **'Groundwater Management Model Bill'** has been prepared by the Indian Union Government as a basis for State Governments to adopt, legislate and implement groundwater resource management and protection with appropriate adaptation to local circumstances. To date only four States are understood to have enacted a full 'groundwater management law' (Andhra Pradesh, Goa, Kerala and Tamil Nadu), while in two States (Madhya Pradesh and Maharashtra) 'groundwater acts' are limited to protecting drinking water sources. The Model Bill (and some of its State adaptations) is discussed (vis-a-vis international practice) in Table 1.

Table 1. Analytical matrix of the Indian Model Groundwater Development & Management Bill and some of its state adaptations

Components According to International Practice	*MB*	*AP*	*MH*	*TN*
Groundwater Property				
Planning & Management				
• aquifer planning/management and interaction with river basin/surface water				
• relationship of groundwater resources and land use planning		X		
• groundwater bodies classification according to their use and quality				X
• allocation priorities (drinking water, environment, economic activities)				
• measures/allocation priorities to face scarcity/over-exploitation of public drinking sources	X	X	X	X
• conjunctive surfacewater/groundwater use				X
• modification to groundwater regime due to mining activities				X
• well inspection and abstraction metering	X		X	X
• illegal wells shall not be supplied with electrical energy				X
• conflict resolution				
Water Rights System				
• abstraction permits	X	X		X
• power to amend/cancel permits	X			X
• water rights reallocation/transfer (including market) mechanisms				
• groundwater surveying permits prior to abstraction permits				
• licenses to drillers and driller duties	X	X		X
• permits to discharge waste onto soil or into aquifers and links to abstraction permits				
• rights and duties of users and waste dischargers	X			X
• exemption of permits to abstract and discharge to certain users	X			
• bases to formalize pre-existing users	X			
• relationship with customary water use and land use rights				
Groundwater Conservation & Protection Measures				
• establishment of special management areas in rural and urban settings	X	X	X	X
• measures to control water and land use in special management areas	X	X		
• measures to protect well heads and drinking water sources				
• pollution control, treatment, reuse and recycling of wastewater that threaten aquifers		X		
• effects of sanitation measures on groundwater				
• rain water harvesting and aquifer recharge	X	X		

(Contd.)

Table 1 (*Contd.*)

	MB	AP	MH	TN
Institutional Arrangements & Stakeholder Participation				
• powers, duties and autonomy of national, state, watershed & local management	X	X		X
• inter-institutional coordination mechanisms				
• legal/institutional coordination mechanisms for inter-state/country aquifers				
• duties of municipal water and irrigation providers to conserve/protect groundwater		X		
• mechanisms for social participation in groundwater management & protection				
Information Systems				
• groundwater databases	X			
• users, uses, waste discharge inventories/profiles				
• water abstraction registry (whether or not in area and/or subject to permit)	X	X		X
• well information system	X			
• waste discharge registry (whether or not in area and/or subject to permit)				
• water quality & quantity monitoring				
Economic Instruments				
• water resource use/pollution charges/levies		X		
• economic incentives for efficient use water quality protection/control				
General Implementation Provisions				
• law enforcement and sanctions	X	X	X	X
• compensation to water users	X	X	X	
• power to remove difficulties during a certain period after commencement	X			X
• appeal procedures	X	X		X
• power to make rules	X		X	X

MB Model Bill AP Andhra Pradesh MH Maharashtra TN Tamil Nadu

Components (according to international practice) where the MB and/or state adaptations are silent

- international practice is not necessarily best practice, but filling a number of gaps in the MB, could enhance groundwater resource management and protection
- comparative analysis of the Model Bill, and those already enacted by some state legislations, could shed light on possible improvements

However, the real challenge is not drafting a 'perfect groundwater law' but implementing it. To assess the feasibility of a 'groundwater bill' being capable of successful implementation, it is advisable to undertake an assessments of 'institutional feasibility' and 'regulatory impact' – if these prove the bill too ambitious then capacity building and/or legal adjustments must be considered to give implementation a chance.

Rationale for State-Level Groundwater Management Agencies

Given the very large number of individual groundwater users in most Indian states an **essential component of any groundwater management initiative will be to facilitate community participation,** and there is an associated rationale for decentralisation of the responsibility of most aspects of resource governance to state level. But to facilitate the effective resource management it will also be essential to address the **macro institutional and economic framework required to facilitate local actions.** An indication of the respective key functions and duties of a decentralised institutional scheme for groundwater resource management is given in Table 2.

In the Indian context state-level agencies have some major advantages when it comes to promoting groundwater management on-the-ground, since they are best able to facilitate cross-sector dialogue on groundwater resources at the all-critical (state) levels and allow closer government-stakeholder interaction (especially considering that most state government departments have operational offices at 'district-level' where many of the local management measures will need to be taken).

Table 2. Key responsibilities of Union and State Government agencies in a decentralised scheme of groundwater resource governance

Union Government	*State Government*
• facilitating the decentralisation of, and providing an overall framework for, the groundwater management and protection process, including 'best practice' in monitoring and assessment	• definition of specific groundwater bodies capable of and requiring systematic resource management, those requiring conjunctive management with surface water and those areas with only minor groundwater resources that can be dealt with through simpler administrative rules
• promoting appropriate management and protection oriented teaching and research in universities	• keeping updated inventory of groundwater use/user profiles in main groundwater bodies to establish basis for social participation
• benchmarking the progress of state groundwater management agencies, and based on this provide advice to those experiencing problems	• provision of groundwater management-related information
• having an overview function in relation to the field evaluation, development strategy and management measures for trans-state aquifers	• improved monitoring of status of groundwater bodies (at present water-table monitoring is usually good, groundwater quality somewhat lacking, and abstraction/use measurement poor and recharge assessment inadequate)
	• support to local communities in adapting livelihoods to groundwater resource realities (eg. in preparation of crop-water budgeting plans, the provision of loan-finance for water-saving irrigation technology, the promotion of markets for alternative crops, etc)
	• providing an enabling environment for voluntary compliance of agreed rules for community groundwater management
	• establish a 'government lighthouse' for monitoring groundwater management initiatives (aided by NGOs if required) and thus ensure that they do not fail because of lack of support and control (because it will take some years for the community to become leaders of an environmentally-sustainable development process

But for successful decentralisation of the groundwater resource management function there will be a substantial challenge in terms of setting the corresponding responsible agency at appropriate level in the state government hierarchy, of staffing it with appropriately-trained professionals, and of defining the relation with the surfacewater resource administration.

The key factors which need to be taken into consideration by state-level groundwater management agencies when trying to establish the applicability and feasibility of resource management approaches are (a) the **definition of groundwater bodies,** (b) the **issues and conflicts for management action,** (c) **the institutional capacity to promote and administer participatory management,** (d) **effective social approaches to stimulate collective community action** and (d) **groundwater user willingness and ability to participate and comply with the agreed regulations.**

A particularly critical issue will be how to address heterogeneity amongst the groundwater 'users profile' in rural areas between the very large number of subsistence farmers and the smaller number of commercial farmers. The state-level groundwater management agency will thus need to appraise the scope for regulatory measures such as groundwater use rights (abstraction permits) at aggregate village level, with separate ones for major commercial and industrial abstractors – but they will have to ensure community support and enforceability.

The benefits, feasibility and rules for formal 'groundwater rights systems' and 'community-based groundwater management' according to some Indian authors are shown in the upper part of Table 3, whilst observations and recommendations of the present authors on the situation in four states are given in the lower part of Table 3, concluding that :

- where options for increasing recharge and water productivity have been exhausted, it seems that only external regulation or physical failure of waterwells will restore the resource balance
- a socially-enforced two-pronged regulatory framework will be preferable with (a) local community arrangements for smaller users and (b) statutory regulations for larger commercial users, in order to address users asymmetry.

Definition of Groundwater Bodies

In India the main groundwater bodies can be usefully classified (in order of decreasing importance):

- shallow hard-rock aquifers (mainly the Granitic Basement Complex and Deccan Trap Basalts) but only where they have significant inter-annual storage due to deep weathering and locally with overlying colluvial deposits
- major alluvial, deltaic or coastal unconsolidated formations
- deeper sedimentary aquifer formations.

But in the case of the first and geographically-dominant category (which is the primary concern of this paper) **only some parts of these extensive aquifer systems** have sufficient saturated thickness and hydraulic continuity to be considered as significant storage reservoirs in the dry season and thus **form 'groundwater bodies' that are capable of being managed as a 'water reservoir'** with allocation constraints and priorities. It is important that the areal extent of these groundwater bodies is adequately defined (Fig. 3).

Areas with only very limited thickness or absence of deeply-weathered and/or well-fractured layers would not be included within a 'groundwater body' so defined. This will exclude substantial areas of the Deccan Trap Basalts and the Granitic Basement Complex as very 'minor aquifers' (with only small

Table 3. Groundwater rights systems or community-based management to address progressive depletion of groundwater table in Indian hard rock aquifers

Groundwater Rights Systems	*Community-based Groundwater Management*
Potential Benefits • public decisions in the allocation or formalization of initial water rights at the regional, state, sectoral, river basin, groundwater body, large village or water user association level • social control at the small village or individual user level through decentralized private decisions at the stage of reallocation and actual use of water • providing water security for private investors and inputs for food and livelihoods for the poor **Implementation Feasibility** • already exist in implicit and informal form both at the macro and micro levels – the issue is formalizing and making them explicit and transparent • costs of establishing system similar to those of other water sector reforms, but present social benefits far higher and would grow as water scarcity increases in future • most states can produce first technical requirement, namely water balance and alternative use scenarios for each groundwater body • however, implementation difficulties due to millions of users, institutional weakness and corruption **Framework for Enforcement** • conflict resolution among states, users or uses • water rights markets, which in some cases may increase economic efficiency	**Potential Benefits** • general setting rather than regulatory frameworks to underpin local management • takes advantage of local champions, movers and shakers • facilitates awareness building • facilitates bridging the knowledge gap between hydrogeologists and users • in a number of successful cases no users forced to give up pumping or reduce farm business – only supply augmentation and/or efficiency improvement in water use implemented **Implementation Feasibility** • a fair amount of institutional potential at grassroots level exist (community-based groundwater management groups and markets estimated to be up to 50% of the total gross irrigated area) • however such systems are vulnerable, particularly when they try to regulate demand **Simple Informal Rules** • waterwells – separation restrictions, banning certain types, no drilling beyond a certain depth, banned zones, wells for drinking water only, no irrigation well to be deeper than a drinking water well and crops — discouragement of water-intensive crops, high water demand crops only with drip irrigation

On-the-ground Situation & Recommendations

AP	*MH*	*RN*	*TN*
• successful Participatory Hydrological Modelling plus agricultural extension services; challenge is sustainability and scaling-up • given very large numbers of individual users self-regulation, plus statutory measures for large users, only feasible where enforcement capacity is advisable	• given intense competition between rural drinking water and water for irrigation, a fined tuned balance of community-based regulation and some statutory measures required to address: • user equity where a large number of small subsistence farmers and few large commercial users abstract water from the same groundwater body • empowerment of people that have no water use priority for small drinking water volumes in relation to large irrigation, municipal, industrial demands	• in 2000, a decision was taken not to enact the draft groundwater bill, because it would be impossible to enforce its provisions without first securing the support of groundwater user communities. • since there are no legal water rights, the relationship between the village authority, groundwater users associations and the Groundwater Department could be sanctioned in a formal agreement, but this alone would not protect against excessive withdrawals outside these areas	• Tamil Nadu Groundwater Act was adopted in 2003, but full implementation has not yet begun and some farmers have shown disagreement, in part as a result of lack of public discussion before the bill was enacted. • it appears best to treat groundwater as a 'common pool resource' and place it under community management, delineating priority groundwater bodies, forming user groups, formulating rules for use and conservation and creating conflict-resolution mechanisms, with support at state level

occurrences of usable groundwater but no consistent storage) justifying only basic groundwater exploration, use administration and land conservation but not systematic 'resource management'.

Issues to be Addressed by Management Actions

The **level of groundwater management attempted should also relate to existing/potential issues requiring action/resolution,** which will vary widely with hydrogeologic and socioeconomic settings.

In the rural environment the main actors or stakeholders will be subsistence agriculture, commercial agriculture, rural drinking-water and some village industries. And for the weathered hard-rock groundwater bodies remote from the main irrigation canal command areas (the main concern here) the policy options for addressing the groundwater resource imbalance will in most cases include :

- reduction in land area irrigated in the dry season, with concomitant increases in the productivity of dryland crops, the level of livestock rearing and the development of small-scale industries
- elaboration of village crop-water plans that maximise farmer incomes whilst reducing groundwater use, by increasing use productivity with the introduction of higher-value crops
- specific measures to help conserve drinking water sources, in terms of restrictions on the construction and operation of irrigation waterwells in their vicinity, the implementation of recharge enhancement measures where appropriate, and measures to avoid their pollution from land-use practices.

Clearly, all of the above require cross-sector approaches (including agriculture, energy and perhaps trade policy interventions), since the water-sector does not have a mandate to address these issues alone.

Local Groundwater Management Partnerships

An 'enabling environment' for local community participation (at groundwater body or micro-watershed level) needs to be created which will involve bringing together a number of state government departments (usually with local offices at district level). The Groundwater Department will need to be re-focused and strengthened around a management (as opposed to development) agenda, and to promote the sort of actions summarized in Table 4 – with particular emphasis on providing authoritative information on groundwater resource status to both the state political and policy level and to the local groundwater user community.

It will be essential for this 'lead department' to be proactively involved in defining the level of delegation for resource management to the community, and in advocating and supporting macro-economic reforms to facilitate the groundwater management process such as :

- defining clear incentives to reduce (or placing actual constraints on) the cultivation of high water-demand crops (such as rice paddy and sugar cane)
- establishing greater incentives (including support prices), readily-accessible low-cost credit and commercial infrastructure for the cultivation of low water-demand crops
- re-directing the use of the electrical energy subsidy to support the provision of seeds, the purchase of improved irrigation technology and the marketing of lower water-use crops
- developing a feasible model of crop/income insurance.

The 'lead department' will also need to **work closely with the Agriculture and Irrigation Ministries** in crop-water planning so that these take full account of the availability of groundwater storage at the

Table 4. General scheme of groundwater management interventions, processes and measures

Objective of intervention	*Management processes & measures*
Develop a shared vision of groundwater resource availability and use priorities	• boundaries of groundwater body and any external influences • average order of annual groundwater replenishment • concept of available storage at onset of dry season • potential for artificial recharge enhancement • protection of quantity and quality of village water-supply • implications for crop irrigation availability
Ensure sustainable community participation	• establish community groundwater management committee with village-level reps, respecting local traditions/leaders • facilitate women's participation • involve community in data gathering • ensure two-way communication based on agreed information
Set-up flexible management plan with achievable goals	• define an agreed participatory groundwater management plan, incorporating consideration for improving groundwater productivity and making real groundwater resource saving • promote grants/subsidies for approved real water-saving measures • remove subsidies for the growing of high water-use crops in dry season (eg, sugar cane, rice, bananas, maize) • periodically monitor groundwater resource status (quantity/ quality)
Establish enforceable rules/regulations	• define realistic water-user entities (individual or aggregate depending on user profiles) • establish a comprehensive groundwater users inventory with active collaboration of community • identify acceptable proxy controls on groundwater use in situation when water abstraction metering is not feasible • introduce (and enforce with community support) indirect controls on groundwater abstraction in heavily-committed aquifers (through ban on new well drilling, restrictions on well spacing and constraints on electricity connections) • enforce reductions on groundwater use and irrigated area (with community support) in situations where subsidies have been provided to improve irrigation water-use efficiency and productivity)

end of the monsoon recharge period, provide required technical support and extension services and **empower District Inspectors and Village Panchayat Leaders** to sanction those who persistently violate the established local rules for groundwater development and use. And early consideration will need to be given to the formation of a **'groundwater body management committee/organisation'**, with appropriate representation of village reps (VPs) and any major individual users, and on priority activities for attention and finance.

The provision of **clear information at village level on the status of groundwater** and the availability of resources at the onset of the dry (rabi) season (and not just the trend of groundwater table levels) has to be a central initial element in any community participation in groundwater management strategy – authoritative and intelligible data not only on groundwater level trends but also on groundwater body distribution/boundaries, available groundwater resources at the end of the dry season (and the implications for crop planning), consequences/costs of excessive abstraction are required. Such action is essential to counteract 'the pedlers of false hope' and their vested interest in continuing the vicious circle of further expenditure on waterwell drilling and deepening.

To advance further a **balanced partnership between groundwater users** (subsistence farmers, commercial irrigators, village panchayat leaders representing drinking water interests and any industrial users), **local administration** (district inspectors, revenue officers, etc) **and state government** (groundwater departments) **will be required** to provide solid advice and practical support on the most sustainable and profitable use of available groundwater resources to enable village livelihoods to be maximised. In this context the promotion of community groundwater user (or aquifer management) organisations will be an important step to develop a structured dialogue and collaboration with those either owning or operating waterwells.

SPECIAL CONSIDERATIONS IN OTHER SETTINGS

The Urban Environment

Groundwater use is extremely important in most Indian cities and large towns, since self-supply from private waterwells (at individual house, apartment or urbanisation level, not to mention industrial sites) plays a critical role in urban water-supply security, given the inadequate service levels provided by most public water utilities. Moreover, all the principal stakeholders in urban water-supply in general should be concerned about groundwater resource management, although this is not normally the case through lack of public information on the status of the resource.

The use of groundwater in the urban environment poses a rather different set of issues such as :

- the interrelation between the unrestricted access to groundwater for self-supply and the provision of mains water services
- concerns about groundwater pollution impacts and water borne disease outbreaks.

In many cases urban groundwater resources requires urgent management action, but of necessity they require a different management approach. This is likely to include improved planning and integration of direct self-supply from groundwater with main water-supply services, guidelines for waterwell design and protection, and community mobilisation to ensure more sustainable and safe utilisation and protection of urban groundwater resources.

Major Irrigation Canal Command Areas

Major irrigation canal command areas occupy not only the alluvial tracts of many of the large river valleys but also occupy weathered hard-rock terrain in some areas where major rivers cross such areas. Both terrains behave similarly from the point-of-view of water management, except that the weathered hardrock aquifers are more patchily distributed and often split into small sub-basins with intervening uplifted hills.

For the most part (and except at the 'tail ends') groundwater resources in this environment are 'under-utilised' for agricultural irrigation – and this has two serious consequences:

- rising water-table, soil water-logging and salinisation in upstream parts of command areas
- sub-optimal utilisation of surface water with inadequate service levels to downstream users, who then often over-develop local groundwater.

The principal reason for this appears to be that the irrigation water cost (both capital and revenue), as paid by the farmer, is many times higher for groundwater (for which only electrical energy costs for pumping are subsidised) than for surface water (for which the entire infrastructure and sometimes maintenance costs are met by government) – thus there is only an incentive for groundwater use in those parts of the command where the supply of surface water is highly unreliable.

Groundwater management approaches in these areas needs to look at ways of:

- stimulating groundwater use for irrigation supplementary to surface water – to achieve improved soil drainage and greater availability of surface water for downstream irrigators
- constraining groundwater use in downstream areas where there is risk of aquifer deterioration.

Deep Sedimentary Aquifers

Deep sedimentary formations, which have sufficient water transmission and storage properties to form major aquifer systems are of relatively localised occurrence in India, but those that are present can be of actual or potential strategic importance for supplementing urban water-supplies.

They often have uncertain recharge regimes and relations with overlying shallow aquifers, and thus require cautious and carefully-monitored development. Moreover, their occurrence often has inter-state implications and in such circumstances sound protocols for shared utilisation and protection will be required.

FINAL REMARKS

A preliminary literature survey undertaken to prepare this paper, coupled with the authors overall experience both internationally and in India suggests that:

- there are enough cases of both success and failure in groundwater management in India to inform future activities which should be based on a deeper understanding of the hydrogeological setting, improved user profiles and the institutional framework – but measures at state level need to be taken to ensure sustainability and make scaling-up feasible
- a more systematic on-the-ground analysis of past experiences and on-going groundwater management projects could inform an improved groundwater management and protection policy at Union level, which in turn could shed light on the need to improve further the legal and institutional framework.

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