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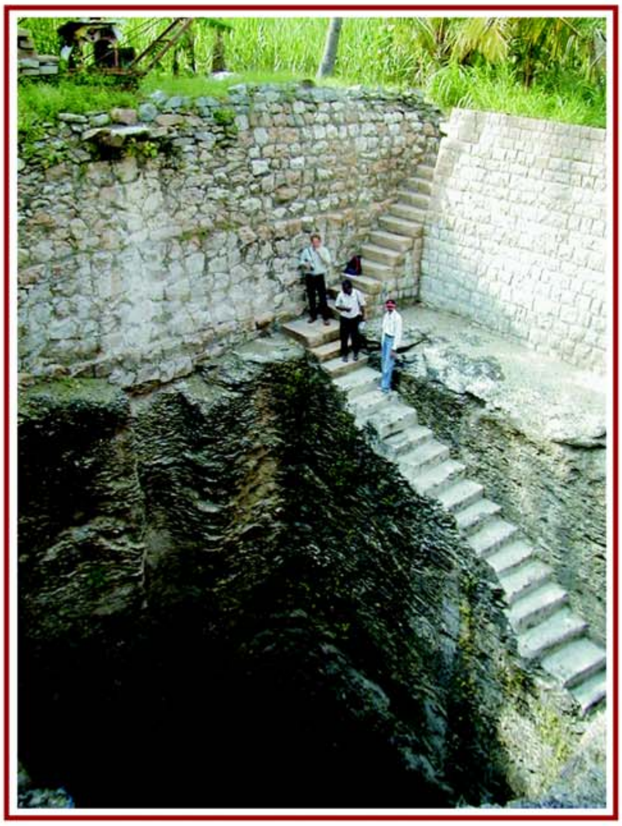
Community Management of Groundwater Resources In Rural India:
Research Report

Background papers on the causes, symptoms and mitigation of groundwater overdraft in India



British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

ADVANCED CENTER FOR WATER RESOURCES DEVELOPMENT AND MANAGEMENT
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Community Management of Groundwater Resources In Rural India:
Research Report

Background papers on the causes, symptoms and mitigation of groundwater overdraft in India

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Front cover: Large diameter dug well in Coimbatore District, Tamil Nadu, India

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SUMMARY

This research report is an output of the project *Community Management of Groundwater Resources in Rural India (Comman)*, funded by the UK's Department for International Development (DFID) under its Knowledge and Research (KaR) programme. The primary aim of the project has been to assess the feasibility of applying local, user-based approaches to groundwater management as a means of mitigating, or avoiding, groundwater overdraft problems in rural areas. Concern over the sustainability of groundwater systems and groundwater-dependent livelihoods has grown in recent years. The project focus on community-level initiatives as a response to such concern is timely given the emphasis now placed, internationally, on the role of communities in natural resource governance.

This *Research Report* report draws together six of the background papers prepared during the project on different aspects of groundwater resources management in India. The report is split into two sections. The first section looks at the problem of groundwater overdraft from different perspectives – physical controls and symptoms, socio-economic impacts, and from the wider context of livelihood transition and groundwater dependency. The second section addresses the management challenge, drawing distinctions between planned (or conventional) management, and self-initiated user-group management.

Groundwater Overdraft: Perspectives and Impacts

In the first paper, Kulkarni provides an overview of the hydrogeological dimensions of groundwater development, looking at the significance of resource threats, and how aquifer characteristics shape - to some extent – the scale, type and magnitude of socio-economic impacts. Several key points emerge, often missed in the general literature on groundwater over-exploitation. Firstly, the problem of groundwater overdraft is not universally experienced across India. There are areas of intense development and limited resources (e.g. Tamil Nadu), but also areas that are relatively underdeveloped (e.g in central India). Intensive development is linked with population density more than resource availability, a point picked up by Mudrakartha and Madhusoodhanan in the second paper. Second, alluvial and hard-rock aquifers have very different characteristcs which condition over-abstraction impacts and responses. Alluvial aquifers are often regional in extent, and intensive use can lower a regional water table, with widespread (interdependent) impacts. In hard-rock areas, on the other hand, problems are often more localised, and relate to drawdown and recovery cycles in wells and limited areas around them, rather than regional aquifers. These contrasting properties have implications for both aquifer recharge activities and local demand-management, a point developed further by Moench, Kulkarni and Macdonald later in the report.

In the second paper, Mudrakartha and Madhusoodhanan explore some of the socio-economic impacts associated with intensive use in the case study areas, focussing primarily on livelihood impacts in Satlasana Taluka, Gujarat. Again, the analysis goes some way beyond well-documented experience – falling water levels, the failure of wells and boreholes - to look at impacts at a local, community-household level. The authors make the point that households have responded in different ways, depending on their ability to cope with cyclical and longer term water scarcity, and their ability to build assets and diversify out of 'bubble economies' based on the intensive use of groundwater in agriculture. They conclude by saying that, while communities alone may not have the means to develop their own micro-constitutions governing resource access and use (a point taken up in later papers), community involvement in resource governance - as in service delivery - is essential.

Moench, in the third paper, takes up the theme of rural transformation in an increasingly inter-connected, inter-dependent, economy. Diversification of household livelihoods and wider rural economies has poverty implications (who wins? who loses?), and affects a community's interest in, and ability to implement, community management. Taking up the last theme, Moench argues that ideas of 'community' are still rooted in a populist vision in which the meeting of local subsistence needs is deemed sufficient motivation for community-level collective action. Moench challenges this view, arguing that any attempt to initiate community based approaches to groundwater management must be founded on a relatively sophisticated understanding of what the community using groundwater actually is, and what the incentives it faces within the wider context of rural diversification might be. Definitions of 'community' that focus on all members within a given village, or even that section engaged in agriculture, are likely to be inadequate.

Groundwater Management: What can be Done?

The section begins with a comprehensive discussion of what the authors term conventional (or planned) management, under which the interpretation of governance is restricted to the state's ability to implement new economic, regulatory and legal reforms – systems of water rights, permitting, tariffs and so on. The authors argue that devising, implementing and then gaining compliance with such reforms in much of rural India is unrealistic, not least because of the numbers of people involved in groundwater pumping. They argue that, rather than looking for management blueprints, we should be looking for context-specific, more opportunistic responses to groundwater problems. This might involve looking beyond sector boundaries and attempting to shape the incentives that drive intensive groundwater use in the first place.

In the final paper, Kai Wegerich provides a comprehensive analysis of the common pool resource (CPR) literature, and explores the challenges of devising and sustaining collective choice arrangements in the groundwater context. The paper argues that the concepts underpinning CPR rules of access and withdrawal are too limited, and too inflexible. Wegerich highlights the powerful role played by leadership and elites – both positive and negative; argues that CPRs can be managed under several different property regimes simultaneously by different actors; and indicates how this 'mesh' of property rights can change over the course of a season, as well as over the longer term. In the groundwater context, he argues that these subtleties make it very difficult to draw up a watertight list of common property design principles that would determine, or define, the success or failure of community management.

Collaboration

The Comman Project is a collaborative project involving Indian and UK research partners. Specifically: the British Geological Survey (BGS); the Overseas Development Institute (ODI); the Institute for Social and Environmental Transition (ISET); the Vikram Sarabhai Centre for Development Interaction (VIKSAT); the Institute of Development Studies Jaipur (IDS); the Water Technology Centre (WTC) of the Tamil Nadu Agricultural University; and the Advanced Centre for Water Resources Development and Management (ACWADAM).

Collaboration has focussed on a series of village case studies, with supporting desk-based reviews. Detailed studies have been undertaken in the Aravilli Hills of Gujarat (led by VIKSAT), the Arwari Basin in Rajasthan (led by IDS) and Coimbatore District, Tamil Nadu (led by WTC). In addition, more limited assessments (referred to in the project as reconnaissance case studies) were carried out at locations where there was evidence of some form of groundwater management by local users.

This report, along with project case studies (Mudrakartha et al (2003), Rathore (2003) Palanisami et al (2003) and Kulkarni et al (2003)), workshop discussions and field site visits, form the basis of the findings presented in the main output from the Comman Project, a guidance document in which the feasibility of community management of groundwater resources as a means to address groundwater overdraft is assessed (COMMAN, 2005).

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GROUNDWATER OVERDRAFT: PERSPECTIVES AND IMPACTS

Groundwater Overdraft: A Physical Perspective

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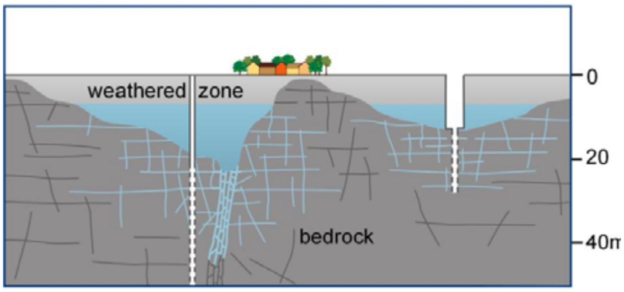
Introduction

Recognition of the need for management of groundwater resources in India is relatively recent. Discussions around this issue gained momentum in the mid-1990s, especially as problems of aquifer depletion, water level decline and groundwater quality were increasingly reported. What had previously been isolated, small-scale problems, developed into ‘regional’, ‘large scale’ issues.

Understanding hydrogeological problems in India is similar to cracking a complex puzzle. The first level in solving the puzzle is to develop a correct understanding of the natural environment in which groundwater occurs and moves. Diverse physical conditions, including complex geological settings, make generalisations rather difficult, even on a local scale. This diversity is significant as, for example, groundwater over-abstraction in alluvial and hard-rock regions (Figure 1), the two dominant geological provinces in India, have very different impacts.



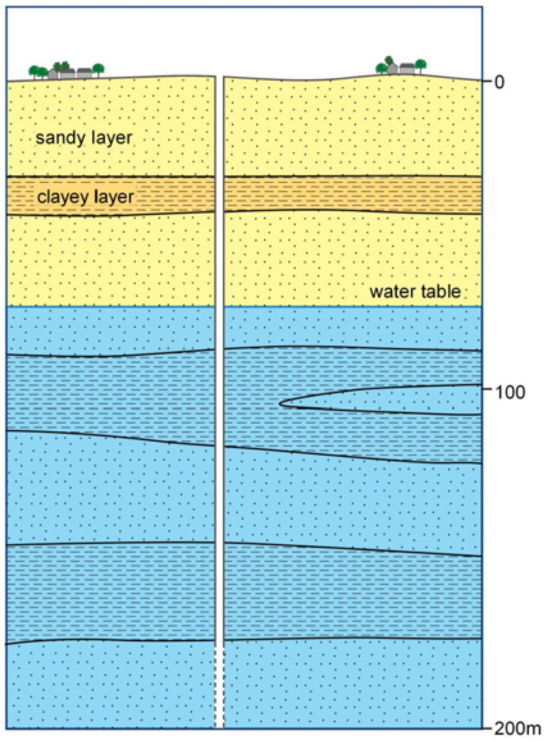


Figure 1 Shallow weathered hard-rock aquifers (e.g. basement - above) and deep alluvial systems (right) the two main hydrogeological settings in India.

Groundwater over-abstraction may be the single largest cause behind changes in rural livelihood patterns across the country. This paper attempts to present the diversity of physical conditions under which groundwater related problems are emerging in India, with the focus of the discussion centering around the effects of groundwater over-abstraction in different hydrogeological regimes.

Groundwater – significance of resource and emerging problems

In India, groundwater has been a source of water for several centuries. The importance of groundwater has conventionally been stated to be two-fold: firstly, as a source of drinking water in most of rural India; and secondly, for the food security of the entire Indian population. Groundwater supplies 80 percent of water for domestic use in rural areas and almost 50 percent of water for urban and industrial uses (World Bank and MWR, 1999). It is estimated further that groundwater supplies more than 50 percent of the irrigated area and that almost two fifths of India's agricultural output is derived from groundwater-irrigated regions. Agricultural productivity is noticeably higher in areas where groundwater is used as the main (and sometimes the exclusive) source of irrigation. However, the importance of India's groundwater resources extends far beyond irrigation and drinking water into other crucial sectors like health and poverty alleviation. Drought prone areas almost entirely depend upon groundwater, where it is often the only source of rural water supply during dry spells. When droughts hit, it is the priority area of drinking water and sanitation that is severely affected. Groundwater also plays a vital role in supporting income-generating activities, such as brick making, and in sustaining the environment.

Groundwater resources have contributed immensely to India's economy (Dhawan, 1988, 1990; Shah, 1993; World Bank, 1998). Constituting the major source of rural water supply, groundwater is now increasingly utilised for urban needs, either as a supplement to bridge shortfalls in established surface water schemes, or as a stand-alone source of supply.

Over recent decades groundwater use in India has increased exponentially with the advent of mechanised pumping and Green Revolution technologies. The rapid increase in groundwater utilisation has had some clear-cut impacts:

1. Water level declines on various scales have led to the deepening of wells, increases in energy requirements for pumping, drastic reduction in drought buffers and reduced flows to streams and rivers.

2. There have been various degrees of depletion in groundwater storage within aquifers. This can be attributed to an increase in the number of wells, an increase in abstraction capabilities for each well and incentives for intensive abstraction for irrigated crops like subsidies for pumping out groundwater. The removal of buffer supplies and the increasingly rapid seasonal depletion in low storage aquifers (Figure 2), like hard-rocks, is in practical terms a more serious concern than the phenomenon of depletion itself (Burke and Moench, 2000).

3. Groundwater quality in some aquifers has deteriorated as a consequence of over-abstraction. Salinity mobilisation, leaching of fertilizers and pesticides used extensively and intensively as a part of agricultural intensification has occurred, along with 'natural' mobilization of elements such as fluoride.

These three problems manifest themselves quite differently in the highly variable hydrogeological regimes in India. This variability can be attributed to a variety of combinations of soil cover and underlying substrates that one finds across various regions in the country. Recharge potential is governed by several factors such as the nature and amount of rainfall, the nature and thickness of soil cover and the underlying sediments or rocks which host groundwater resources. Similarly, the effects of groundwater pumping depend as much on the type of aquifers as the pumped volumes. Groundwater overdraft can affect a group of wells in a village overlying shallow alluvium long before it affects wells in a village that derives water from deeper alluvial aquifers. Similarly, recharge, abstraction and pollution effects have a longer response time in deep alluvial systems than in fractured hard-rock formations. Hence, a background on the broad distribution of hydrogeological conditions across the country is necessary before going into the emergence of problems in various hydrogeological settings.

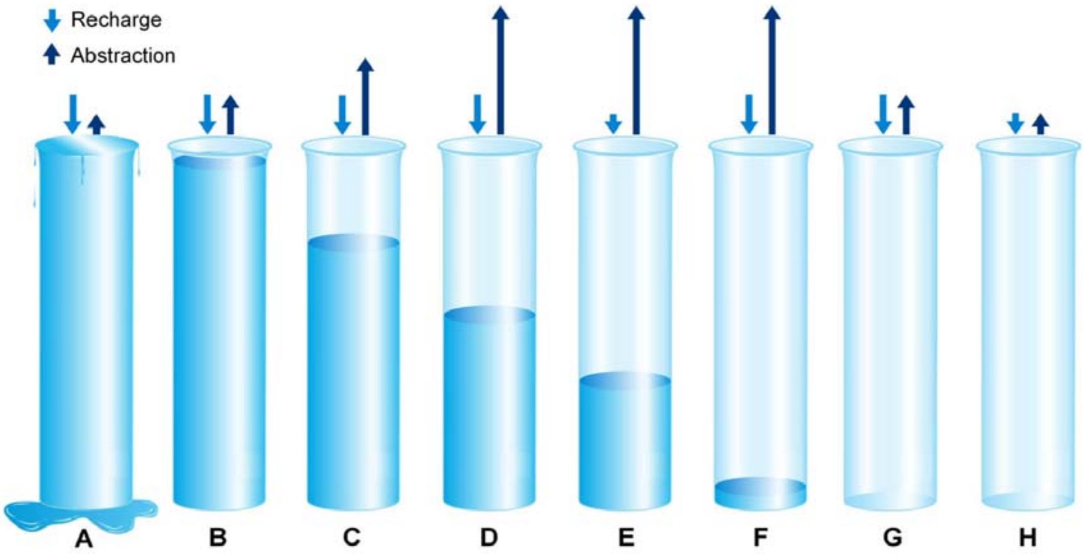


Figure 2 These cylinders illustrate how overabstraction can impact the storage of a shallow aquifer and, in turn, well yields. The water held in the cylinder represents the storage of an aquifer at the end of the dry season. The arrows represent the relative input and output from the aquifer in the form of rainfall recharge and groundwater abstraction, respectively. The change in the storage of the aquifer over time is described below:

A pre-1960s: abstraction minimal, potential recharge greater than abstraction, excess water seen as baseflow to streams

B 1960s/1970s: abstraction increases and is comparable with recharge, baseflow to streams reduces

C,D,E 1980s: abstraction increases further and is now greater than recharge, store of water in the aquifer declines

F 1990s: groundwater stored in aquifer at the end of the dry season minimal

G 1990s/2000s: as little storage in aquifer, abstraction is very much dependent on rainfall in preceding wet season

H in this situation, if there is a drought, with little recharge, potential abstraction is significantly reduced

The hydrogeological provinces of India can be grouped into three major divisions (Figure 3):

1. Hard-rock regimes wherein groundwater is obtained from crystalline or volcanic rocks, most of which cover large parts of the country, particularly in the peninsular region. Nearly 65 percent of the land is covered by such formations.

2. Alluvial regimes of major river basins, mostly in the northern portions of the country. These cover 30 percent of the land area, a majority of which is part of the large Indo-Gangetic plain. Sands, gravels and pebbles interlayered with clay horizons to form a fairly complex and extensive regime of unconsolidated alluvial aquifers.

3. Consolidated sedimentary formations cover about 5 percent of the land area.

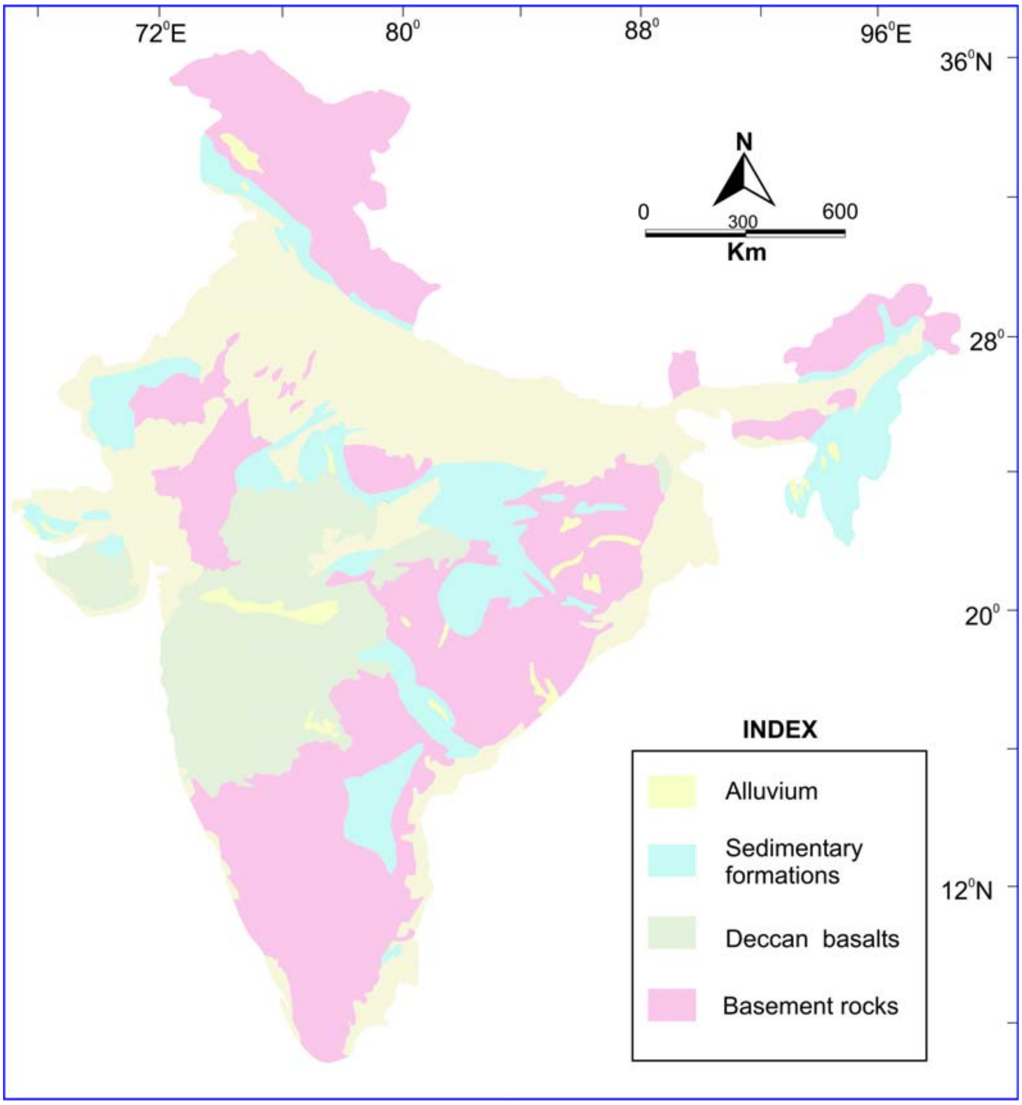


Figure 3 Simplified geological map of India

Hence, hard-rock and alluvial regimes dominate India's hydrogeological domain. Groundwater occurrence in hard-rock areas is restricted by the normally low porosity of the rock. The weathered and fractured zones primarily govern storage and transmission of groundwater in these rocks. Where the physiography of hard-rock areas is rugged and undulating, this restricts recharge to the moderate and poor aquifers below. Alluvial regimes are characterized by gentler landscapes and although there may be variations in porosity and permeability, at medium to large scale, regionally expansive aquifers are not uncommon. Recharge in these areas tends to be greater than that in hard-rock areas. The spatial and temporal dynamics of recharge are quite different for these two regimes.

The magnitude of variation in hydrogeological characteristics between hard-rock and alluvial aquifers is illustrated by the aquifer parameters and well yields given in Table 1. The table highlights the diversity in the storage, transmission and yield characteristics of different hydrogeological settings found in India.

Table 1 Generalised aquifer characteristics, yields and recharge estimates
(after Groundwater Estimation Committee, 1997)

GEOLOGIC FORMATION	**Specific yield as %**	**Transmissivity in m²/day**	**Hydraulic conductivity in m/day**	**Well yield in litres per second**	**Recharge from rainfall as %**
Unconsolidated formations	5 - 18	250 - 4000	10 - 800	40 - 100	8 - 25
Semi-consolidated formations	1 - 8	100 - 2300	0.5 - 70	10 - 50	10 - 14
Igneous and metamorphic rocks (excluding volcanics)	1 - 4	10 - 500	0.1 - 10	1 - 10	1 - 12
Volcanic rocks	1 - 3	25 - 100	0.05 - 15	3 - 6	6 - 14
Carbonate rocks	3 - 7	*Highly variable*		5 - 25	*Not available*

Causes of water level decline

There are several causes behind water level decline (ACWADAM, 2001), although lack of scientific approaches and reliable data make correct diagnoses of water level declines difficult (Figure 4). Macdonald et al. (1995) list three major reasons for declining groundwater levels:

1. The abstraction rate exceeds the capacity of the aquifer to transmit sufficient water to a well, thereby depleting aquifer storage around a well. This is a common phenomenon in highly heterogeneous, hard-rock aquifers.

2. The annual discharge from an aquifer including groundwater abstraction does not exceed the average annual recharge but successive droughts or 'dry' years result in lower than average recharge, producing a short term decline in the water levels in the aquifer. An abnormally high rainfall can subsequently result in water level recovery.

3. The total quantity of water discharged from an aquifer, often groundwater abstraction forming a major proportion of this discharge, exceeds the average annual recharge, producing a long-term decline in the water levels in the aquifer.

It is only long-term data that can indicate whether the groundwater storage has been affected by overexploitation leading to a progressive decline in the water table. However, the key problem here is lack of basic scientific understanding and appropriate data that help diagnose problems of water level decline. Although, the importance of data in this context is being increasingly realised and accepted, there is still plenty of scope for collection, synthesis and access to scientific data to assist the understanding of groundwater problems in highly variable hydrogeological situations.

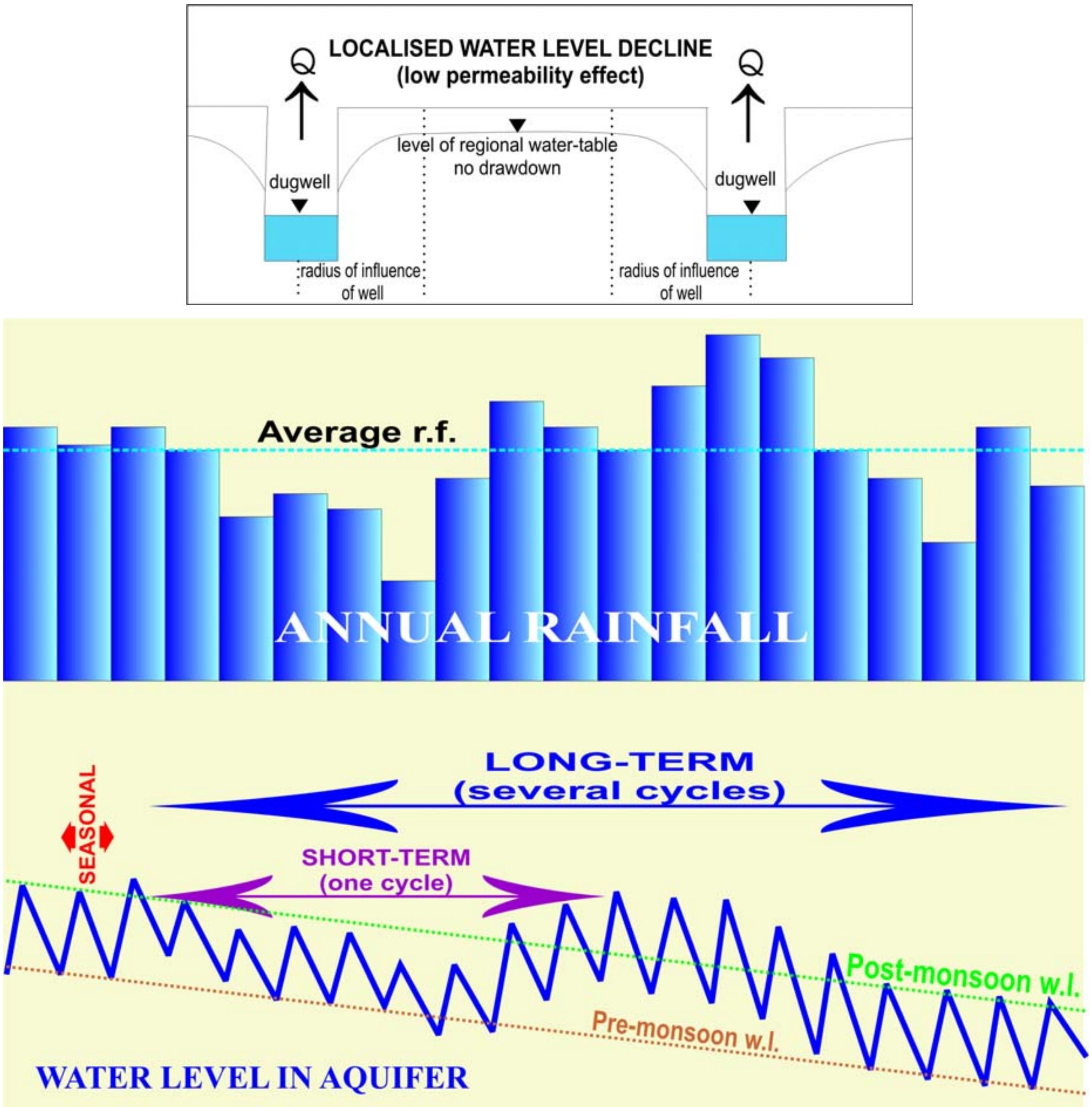


Figure 4 Water level decline in an aquifer is a cumulative effect of seasonal, short and long-term causes

Overdraft in regional alluvial aquifers

Most of central, north, north-east and to some extent, western and coastal areas of India are dominated by thick deposits of alluvium. These alluvial deposits are often not only extensive, covering thousands of square kilometers in area, but attain thicknesses of over a thousand metres in some portions, like the Indo-Gangetic plains. Alluvial deposits are mostly found in the lower reaches of major river valleys and along the coastal areas. These alluvia are essentially composed of clay, sand, gravel and boulders, ferruginous nodules and 'kankar' (calcareous concretions). Some of these sediments possess a high primary porosity.

Thick, unconsolidated alluvial aquifers can store very large volumes of groundwater in extensive layers of high porosity and permeability. Recharge to thick and extensive aquifers in alluvium can be high. Rainfall infiltration is augmented by infiltration from streams or rivers. Wells tapping alluvial aquifers can yield large volumes of water. The Gangetic basin is filled with unconsolidated alluvial materials estimated to be about 6000 m thick (Rogers et al., 1989). Similarly, the Mehsana alluvial groundwater system in Gujarat extends over an area exceeding 3000 km^2. It is a complex system with an unconfined aquifer underlain by a sequence of several confined layers and catergorised into some six or seven confined aquifers (Mudrakartha et al, 2003). Naturally, with such extensively thick, porous and permeable systems, one would expect enormous quantities of groundwater in aquifer storage. However, despite this, major impacts stemming from large-scale development of groundwater resources in aquifers underlying such regions are apparent.

Aquifers in many alluvial regimes in India, like in the Mehsana region of Gujarat, have been exploited for many centuries. In many areas groundwater overexploitation occurred as a response to changes in cropping (including the introduction of commercial crops and Green Revolution technologies), land reforms, the introduction of mechanised pumping and deep drilling technologies, coupled with pumping subsidies for irrigation. Intensive irrigated agriculture prompted large quantities of groundwater to be pumped from these highly productive aquifers, notwithstanding the magnitude and dynamics of their recharge. Groundwater extraction in the Mehsana aquifer has exceeded recharge since the early 1970s with water levels throughout the Mehsana aquifer continuing to drop over a period of several decades as a response to increased abstraction (United Nations Development Program, 1976;;Moench, 1992).

Shallow alluvial aquifers tapped by traditional large diameter dug wells were the first to be affected by a significant lowering of the water table. In order to chase a declining water table, first boreholes were drilled from the bottom of dug wells and, more recently, independent tubewells were drilled to penetrate into deeper aquifers. Initially the piezometric heads in the deeper aquifers were found to be above the water table in shallow layers but progressively, with increased borewell numbers and depths, and a compounding groundwater draft, these piezometric heads declined by as much as 50 m (Rushton, 1990). In some villages, groundwater levels have dropped by as much as 100 to 115 metres within a span of twenty years (Moench et al., 2003).

Groundwater overdraft in alluvial areas has meant large-scale depletion of extensive and thick aquifers with water level declines occurring over large areas. Depletion of aquifer storage has had many implications including the need to construct deeper wells and greater pumping costs. Drilling for water is very expensive, with deep tube wells costing as much as one million rupees. Groundwater overdraft and deterioration of groundwater quality are almost ubiquitous in many alluvial aquifers. Groundwater salinity continues to be a large scale issue but other chemical and biological water quality problems are emerging.

Water level declines and limited storage in hard-rock areas

Large tracts of India and dominantly peninsular India, are covered by crystalline 'hard-rocks'[1]. It is estimated that these rocks cover nearly 65% of India. Gneisses, schists, granulites and granites are the dominant lithologies of crystalline basement rocks, one form of hard-rock. Crystalline basement rocks are estimated to be exposed over an area of nearly one million km^2 (Athavale, 2003). Apart from these crystallines, a large part of western and central India is covered by volcanic rocks, dominantly basalts, popularly known as the Deccan Traps. The Deccan Trap basalts are exposed over some 1.2×10^6 km^2 and are believed to attain a thickness in the range of 0.36 to 1.3 km (Hooper, 1999; Kaila et al., 1981).

Hard-rocks possess poor primary porosities, and groundwater occurrence is restricted to secondary openings developed through the processes of weathering, exfoliation and fracturing. Generally, groundwater occurrence in basement rocks depends upon the degree and depth of weathering and the nature of the fracture network which can be highly variable, even over distances of metres.

Due to an inherently heterogeneous character, hard-rock aquifers are limited in their extent and thickness and consequently hold relatively limited groundwater storage. This is perhaps the most significant difference between hard-rock aquifers and large alluvial aquifers. The storage in hard-rock aquifers may be assumed to equal two to three years of groundwater recharge, at most. In many areas, this groundwater storage is being depleted as extraction exceeds the average annual recharge. The result is a progressive decline in water levels, an expression of the long-term dewatering of the aquifer. The degree of dewatering depends upon aquifer storage and the relationship between pumping and recharge. In some situations very low permeability may mean dewatering is limited to the zone around a well. Here the aquifer will not be dewatered but well yields will be very limited.

In many hard-rock regions of India, water level declines have occurred rapidly as a response to an ever-increasing demand for water. This increased demand, as in the alluvial areas, is attributable to mechanisation of water lifting devices that went hand-in-hand with high water requirement crops like sugar cane, Green Revolution technologies and power subsidies for irrigation. Moreover, many hard-rock areas in India are also characterised by low and erratic rainfall. In such areas, as the water level in the limited-storage aquifer falls as a consequence of abstraction, drought affected dug wells are deepened first. Progressively, dug wells are converted into dug-cum-bore wells. Later, separate borewells are also drilled to great depths (Figure 5). In areas where recharge to deeper aquifers is actually derived from some leakage from the shallow aquifer, the abstraction from deeper aquifers can result in widespread lowering of the shallow water table (Macdonald et al., 1995).

In many hard-rock aquifers the water in storage at the end of the dry season is very low and severely limits well yields. Irrigation of second (Rabi) and third (summer) season crops is highly dependent on the rainfall of the preceding few years.

Despite aquifer heterogeneity, which was earlier thought to be a limit to regional water level decline in hard-rock aquifers, the problem in many areas is so severe as to have affected aquifers on a fairly regional scale. For example, communities in Maharashtra practising efficient groundwater management are adversely affected due to the regional decline in water levels in the underlying basalt aquifer as a consequence of large-scale groundwater overabstraction in the surrounding areas (Kulkarni et al, 2003).

Linked quality problems

Groundwater quality decline often accompanies the problem of large-scale overexploitation (Adams and MacDonald, 1995). Quality issues that have emerged to the extent of becoming large-scale problems for groundwater resources include increased salinity (coastal and inland) and increased concentrations of nitrate, pesticides, fluoride, iron and arsenic. In most alluvial regimes, water quality problems often compound the existing problem of water availability. Deeper groundwater systems often include saline water zones interspersed with fresh water aquifers. In the Mehsana aquifer system, for instance, groundwater quality is relatively good in the shallow alluvium but deteriorates in the deeper zones and towards the east, where marine sediments dominate the geological sequence (Moench et al., 2003). Overexploitation of this aquifer system has caused saline water to be drawn into the freshwater zones.

Overexploitation is also thought to be a major cause of the increase in concentrations of natural contaminants in groundwater, such as fluoride, as older waters with higher concentrations are drawn in to replace the fresher waters.

Water quality problems that can be attributed to overexploitation of groundwater resources are exacerbated by the impact of pollution. The growth of industrial activities like tanning and dyeing in a rapidly changing rural or peri-urban economy, in particular, has lead to pollution in hard-rock aquifers that are still used as sources of irrigation and water supply (Moench et al., 2003).

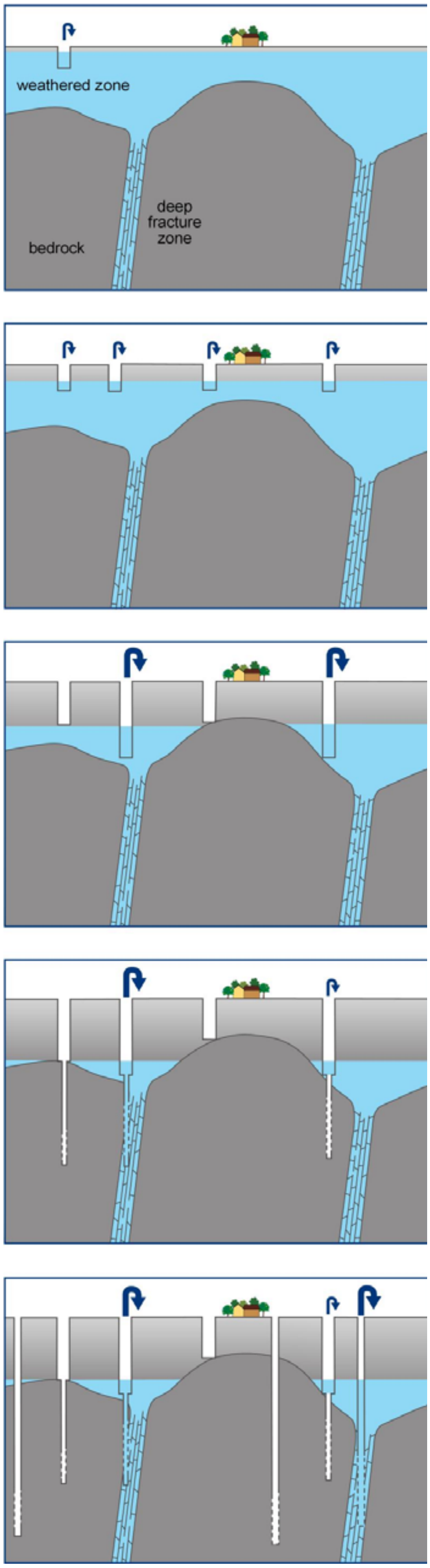
Diversity In Hydrogeological Conditions and the issue of scale

One of the most significant insights from the Comman Project is not just the nature of emerging problems but the diversity in conditions under which the major problems outlined above occur. First and foremost amongst these conditions is the diversity in hydrogeological settings, not only across various areas (representing typical rural settings/regions) but also within individual study sites. This diversity is particularly important in developing appropriate understanding of groundwater systems before prescribing or piloting any management interventions. Dimensions of aquifers or groundwater systems and the livelihoods dependent upon them bring up the issue of scale, not only around the dynamics of the resource, but also in relation to the problems themselves as well as the impacts of solutions to such problems.

Usually aquifers are described with reference to a particular lithology with their hydrogeological properties simplified to a great extent (ACWADAM, 2001) In hard-rock areas, in particular, groundwater occurs within a sequence of two or three types of rocks, each stratigraphically distinct from the other. In such a context, conditions change drastically, even on a local scale, thereby influencing the nature and extent of problems associated with the resource.

Even in a contiguous area, the magnitude of water level decline and the responses to the problem are significantly different. Even two Pani Panchayat schemes from the same watershed in the Deccan basalt face quite diverse sets of problems, primarily due to the high variability in hydrogeological conditions within the basalts. This variability was especially evident in the two Comman Project case study villages in Coimbatore district, Tamil Nadu, both located within a basement hard-rock domain

[1] Hard-rocks is a term used to describe ancient crystalline or volcanic rocks wherein porosity and permeability are normally low and groundwater occurrence is restricted to weathered and fractured layers in the rock.



Pre-1960s: agriculture primarily rainfed with limited groundwater abstraction for irrigation.

1960s/1970s: groundwater developed in push to increase agricultural production

1980s: rates of groundwater abstraction and number of wells increasing. Abstraction significantly greater than rainfall causing storage of aquifer to gradually decline. Where farmers are financially able, wells are deepened, but only as far as the base of the weathered zone.

1980s/1990s: still in groundwater development phase. Storage of the shallow aquifer still declining. Where farmers are financially able, boreholes drilled in base of large-diameter wells (dug-cum-borewells) in hope of intersecting fracture zones in the bedrock, but not always successful. Yields very dependent on recent years' rainfall.

1990s/2000s: farmers, or in some cases, groups of farmers, drill boreholes in search of groundwater, but with limited success. Agricultural production declining.

Figure 5 Hard-rock aquifer scenario to illustrate the impact on groundwater resources of over-abstraction and within a distance of 100 km from each other (Palanisami et al, 2003). This variability can be explained on the basis of diversity in the hydrogeological conditions controlling the accumulation and movement of groundwater in the respective aquifers underlying these two villages. The village of Kattampatti has a more deeply weathered crystalline basement aquifer underlying it. The permeability is relatively high, as is the storage; the aquifer system could be described as regional. The village of Kodangiplayam is also underlain by crystalline basement but the different nature of the parent rock means the weathering is shallower and not laterally well connected. Consequently, the problems around the resource also vary considerably, Kattampatti being still in development mode with water levels declining and Kodangiplayam a case of a self regulating system, with a limited stock of groundwater that fills up and dewaters seasonally. Here the serious impact of overexploitation on agriculture has already been felt. This diversity is also reflected in different coping mechanisms and people's perceptions of possible solutions. It is perhaps this diversity which lies at the root of variable community responses to the concept of 'community based demand management of groundwater'.

Hydrogeological variability also creates a variation in the scale on which groundwater problems manifest themselves. Physical interventions to prevent and mitigate these problems ought to be based upon a correct understanding that takes into consideration variability and scale factors. Artificial recharge measures are a case in point. The uncertainty associated with artificial recharge needs to be addressed on the basis of studies in a variety of environments (Gale et al, 2002; Gale et al, 2003) in order to account for both these factors. In the absence of proper understanding of the variability in hydrogeology and the scale on which groundwater resources behaviour can be mapped in a particular physical regime, the effectiveness of recharge is seldom ascertained.

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Declining Water Levels and Deteriorating Livelihoods

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Introduction

In this paper the impacts of groundwater level decline and aquifer depletion on rural livelihoods are discussed along with the local responses. The paper draws on insights gained from the main case studies of the Comman Project, undertaken in Gujarat, Rajasthan and Tamil Nadu (Mudrakartha et al (2003), Palanisami et al (2003) and Rathore (2003)), focusing principally on the Gujarat case. The case study settings are summarised in Table 1.

Table 1 Summary of the settings for the Comman Project main case studies

Case study location	**Lead partner organisation**	**Case study setting**	**Geology**	**Climate**	**No. households within study villages**	**Specific issues of interest**
Satlasana, Gujarat	VIKSAT	Three remote villages in the foothills of the Aravilli Hills	Fractured and weathered granites	Single monsoon season – average annual rainfall 603 mm	475	Role of village federation in natural resource management, and potential for extension into groundwater management
Coimbatore District, Tamil Nadu	Tamil Nadu Agricultural University	Two villages ~30 km to the east and north-west of the industrial city of Coimbatore	Basement rocks with differing thicknesses of weathering	Bimodal rainfall season - average annual rainfall 702 mm	1850	Growth of the non-farm economy – causes and outcomes
Arwari River Basin, Rajasthan	Institute of Development Studies	Six remote villages, located in the upper, middle and lower reaches of a well-defined river catchment of 1,055 km^2	High relief basement rocks with varying thicknesses of sediment within valley bottoms	Single monsoon season - average annual rainfall ~500 mm	1490	Effectiveness of Village Water Councils and Arwari River Parliament in controlling abstraction

Groundwater dependency of agriculture in India has been increasing over the past three decades. The states of Gujarat, Rajasthan and Tamil Nadu are no exception. Although agriculture and livestock have enhanced the quality of life of farmers and other dependent populations in general, the going has been tough for those in agro-climatically difficult zones. Often farmers attempt to sustain agricultural production and livestock-based income by investing in well structures and related water extraction mechanisms to provide much needed irrigation support. However, there are serious constraints on groundwater supplies posed by geological formations as a result of overabstraction which make people adopt coping strategies, migrate and/or diversify into non-farm based options. Disasters such as droughts hasten the degree and intensity of the adoption of such options, but do not alter underlying trajectories.

It is in this context that the role of community-based organisations could become very important. This paper looks at case studies from Gujarat, Rajasthan and Tamil Nadu to examine the response of such people's institutions struggling to retain their identity in the era of economic liberalisation. The response seems to be varying depending upon a host of factors ranging from caste, economic, social and hydrogeological conditions.

Groundwater and Rural Livelihoods

Over a few decades, groundwater has emerged as the most dependable and accessible water source for drinking, irrigation and industrial use in India. The primary beneficiary has been the agricultural sector. A key feature is that most investment has occurred outside the government sector. The dependency on groundwater for irrigation can be seen from the tremendous increase in water extraction mechanisms (WEM), from less than one million in 1960, to almost 28 million in 2002 (Mukherjee and Shah 2003). This has come mostly from private farmers. Figure 1 shows the increase in electric irrigation pump sets and submersible pumps since the 1970s in Gujarat.

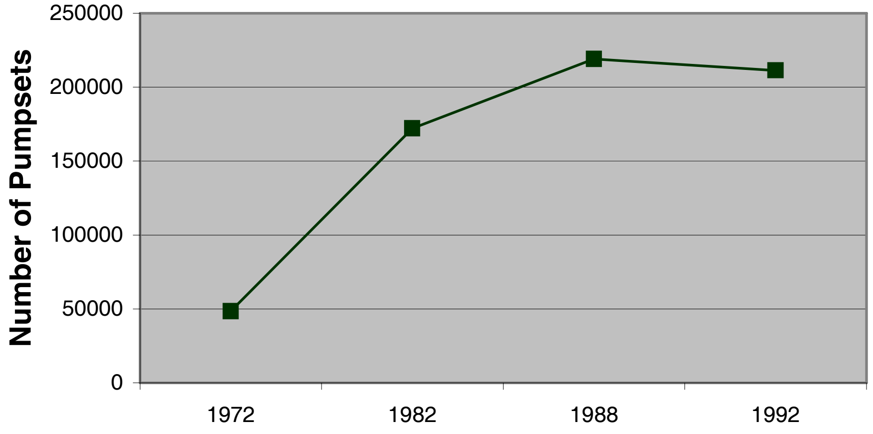
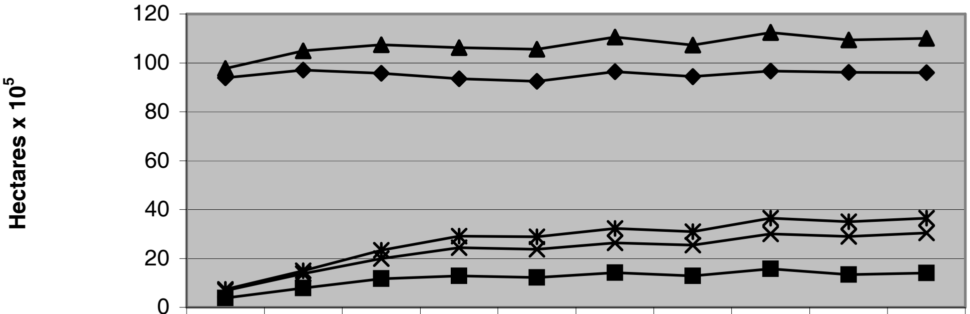


Figure 1 The increase in time of electric pumpsets for irrigation in the state of Gujarat

All these investments have led to an increase in the extent of gross irrigated land. Across India, the ratio of area irrigated by groundwater to the net irrigated area has increased from 46% in 1980-81, to 56% in 1996-97; and the ratio of area irrigated by groundwater to gross irrigated area has increased from 36% to 42% for the same duration (Government of Gujarat, 2000). Within individual states similar trends have emerged depending, *inter alia*, on policies related to agriculture and energy and electricity pricing. In the case of Gujarat, for example, although the area irrigated by groundwater through wells and tubewells as a percentage of net irrigated area is more or less constant at 79%, it has registered a decrease in gross irrigated area from 68% to 65% during the period 1980-81 to 1995-96 as shown in Figure 2. However, in terms of absolute figures, the net area irrigated by groundwater has increased by 50% during the period.



	1960-61	1970-71	1980-81	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97
Net area sown	94	97.1	95.8	93.5	92.5	96.4	94.4	96.7	96.1	96
Area sown more than once	3.7	7.8	11.7	12.8	12.1	14.2	12.9	15.8	13.3	14
Gross area sown	97.7	104.9	107.5	106.3	105.6	110.6	107.3	112.5	109.4	110
Net irrigeted Area Sown	6.8	13.7	20	24.4	23.7	26.4	25.4	30	28.9	30.4
Gross Irrigeted Area	7.3	14.9	23.3	29.1	28.8	32.3	30.9	36.5	35	36.4

Figure 2 Trends in the area under cultivation

The findings of a macro level study by Roy and Shah (2002) highlight an increasing trend of groundwater irrigation in many districts, which the authors conclude indicates greater utilisation of the districts' groundwater resources. However, in the case of low groundwater potential districts, this has led to over-extraction. The study points out that, while it is advantageous to use the resource in areas where there is high potential and low use, it is a matter of concern where there is low potential and high use. Significantly, the study has identified many districts from western and northern India as falling in the low potential and high use category. North Gujarat for instance (which includes Mahesana, Sabarkantha and Banaskantha Districts) has clearly shown such overuse. This is unsustainable in terms of equity and efficiency, and counters the very advantage of groundwater as a "democratic" resource available for people when and where it is needed.

In India, there has always been a tradition of integrated agricultural practice which also provides for meeting fodder requirements from agriculture residues. However, it is found that the market has played an intrusive role in the form of higher, attractive returns for cash crops. This market has reached down to the village and to every farmer, establishing systems of "captive" crops and prices. While this is widespread in water-endowed areas, it was relatively less popular in rain-fed areas.

Data for Gujarat for the period 1980-81 to 1995-96 (Figure 3) highlight significant changes in cropping patterns.

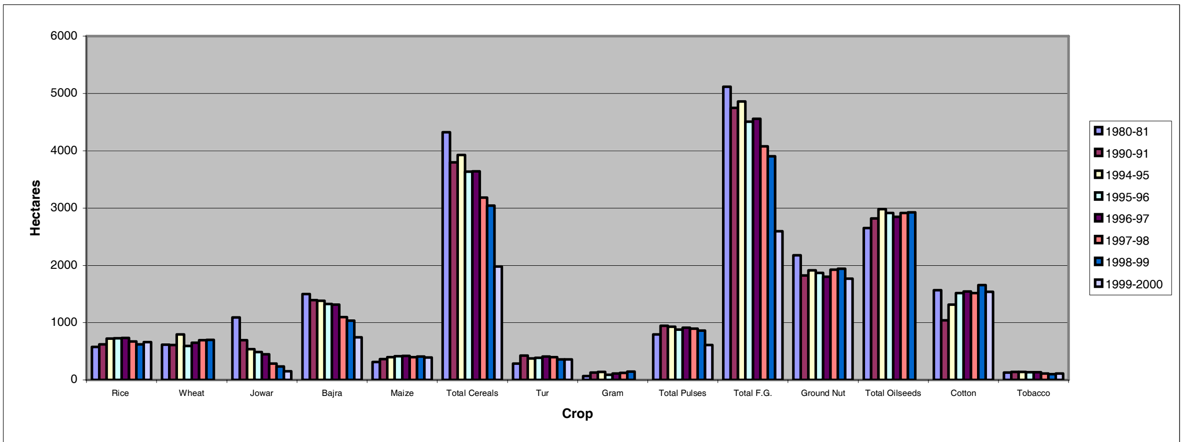


Figure 3 Changing cropping patterns in Gujarat ('000 hectares), 1980/81 – 1999/2000

The total food grains, including cereals, have reduced. Important crops such as jowar, bajra and groundnuts have also reduced. The shift has been in favour of cotton and oilseeds. Interestingly, the level of production of wheat, cultivated as a rabi crop, has remained more or less constant; with wheat also providing fodder for livestock. This is significant as more than two-thirds of Gujarat is drought-prone and has low rainfall conditions. In other words, this indicates that farmers still try to balance, not necessarily successfully, integrated agricultural practices to some extent while pursuing cash cropping at the same time.

Decline of Groundwater Levels and Deepening of Wells

All three case study areas investigated in the Comman Project have experienced groundwater level decline due to the combined pressures of population growth, expansion in agriculture, urbanisation and, in the short term, drought conditions. Other factors include the impounding of surface flows which may lead to the denial of water to downstream areas, as well as reduced recharge to groundwater. Persistent chasing of the receding groundwater levels due to the above conditions leads to adverse long-term effects, especially in hard-rock areas. For example in the Gujarat case study, groundwater occurring in the top weathered zone of around 30-35 metres thickness was almost totally depleted during the drought of the early 2000s.

A common response to recent declines in water levels has been to deepen wells, as had been done during the 1987 drought period. Given that shallow groundwater resources were often exhausted, deepening wells involved the drilling of either an extension bore within a well or a new borewell. The drilling of new borewells demands not only higher capital investment but also increased recurrent costs. The middle income category of farmer may be in the position of risk taking by borrowing money or taking out loans against the mortgage of jewellery or land. Further, they may also sell trees, livestock or other assets to obtain money for investing in wells.

However, as a result of long term depletion of groundwater resources, this course of action was less successful at securing new water supplies in the recent drought than it had been in previous droughts (Figure 4). Data from the Minor Irrigation Census (1996) has shown that the continuous decline of groundwater levels has resulted in a large number of wells and borewells going dry. In Western India, where depletion is highest, many wells and borewells are out of commission. Similar trends are seen in many other parts of the country such as in Tamil Nadu (Roy and Shah 2002).

The following key conclusions can be drawn from Figure 4 based on the hydrogeological conditions of the Gujarat Case study area:

1. The initial deepening has helped tap additional quantities of water from the top aquifer of 30-40 metres thickness in most of the wells. However, subsequent deepening that took place post-2001 (as a response to gradual decline in yields) has failed to produce more water as most wells have struck bedrock. The efforts of some farmers in terms of the excavating of wells with explosives have also failed.

2. However, some wells and surface borewells which encountered productive zones in the bedrock yielded moderate to good quantity of water.

3. Interestingly, the graph shows that the area under groundwater irrigation has shown a steep declining trend since 1996 and has been at an historic low in 2002, implying that the top yielding aquifer has been severely dewatered.

4. The sharp increase in deepening events in the 1999-2003 drought clearly indicates the desperate attempts of many farmers with almost no increase in the area under irrigation. It also indicates the frustration levels the farmers have reached.

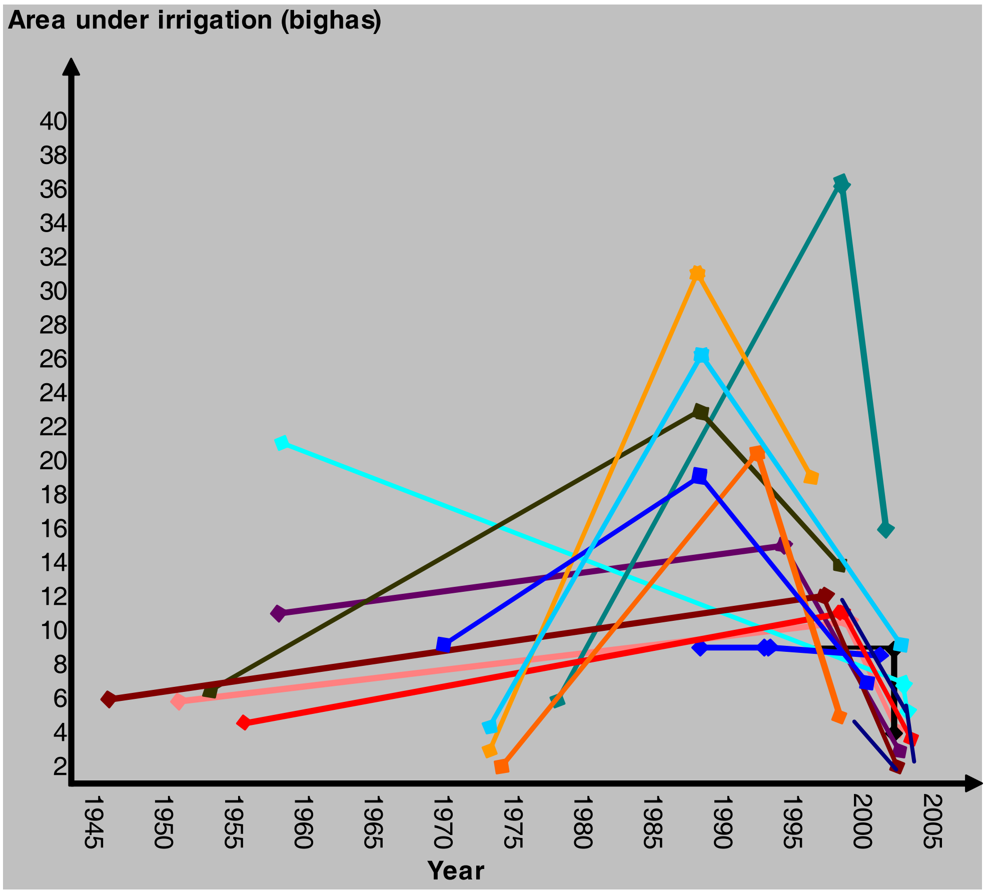


Figure 4 Events of dug well deepening and well irrigation areas in Bhanavas village, Satlasana, Gujarat. *Note: each coloured line shows the history of an individual well, with deepening events marked as spots. A bigha is 0.4 hectares.*

Such a chasing of water levels necessitated higher horsepower pump sets which require more investment as well as higher recurrent costs. In the past decade, for example, the average pump horsepower in the Tamil Nadu case study area has increased from 5 to 10, with the depth of wells increasing from 170 to 250 m. Due to poor yields, the number of hours the wells/dug-cum-bore/borewells are run has reduced from 18-22 hours to an average of around 3-4 hours per day.

The second type of response is seen in the case of Tamil Nadu. When the farmers have realized that there is a need for “storing” water, they have taken to developing farm ponds and surface storage tanks. The number of farmers adopting such techniques over the past decade has almost doubled. While 10% of the farmers have contributed labour for the development of percolation tanks, 25% provided machine power. In some other areas of Tamil Nadu, pumping water from deep borewells and storing in wells is quite common. This is done on a daily basis to “capture” groundwater before the neighbouring farmer wakes up to run his pump set.

The third type of response is seen again in the Tamil Nadu and Gujarat cases where the small and marginal farmers have pooled their financial resources and gone in for joint borewells in a bid to access groundwater for irrigation. This is a strategy to share the high cost of investment which individually these farmers could never afford.

The Impacts of groundwater depletion

Impact on Drinking Water

In the three case study areas, people have been historically dependent upon groundwater for meeting their drinking water needs. Wells constructed by Panchayats exist in all the three case study areas. However, as the three case study areas are prone to severe drought conditions, these wells and borewells often dry up, presenting severe drinking water scarcity especially during May and June – the peak summer months. However, during crisis situations the community, generally stratified along caste lines, responds collectively, ignoring caste differentiation. In the Gujarat study area, for example, the recent 4-year (1999-2003) spell of drought has seen a couple of farmers in each village setting aside the minimal recharge equivalent of 15-30 minutes of pumping twice a day for drinking purposes.

The first three years of the recent drought in north Gujarat as well as in most parts of Rajasthan has caused a severe water crisis, including drinking water scarcity for both humans and animals. Many livestock died due to lack of fodder and water. Drinking water had to be supplied by tankers by the Panchayats for both humans and animals. However, the Gujarat project case study area has now been covered by piped drinking water supply from Dharoi reservoir and there has been no drinking water problem for the past two years.

In the Rajasthan project case study area, although different sides of the well are allocated for different caste groups, all are allowed to take water from the same well during periods of water scarcity. This indicates concern beyond self, as it means the sacrifice of critical irrigation water by certain farmers.

In Naigaon Pani Panchayat village in Maharashtra, one of the Comman Project reconnaissance case studies (Kulkarni et al, 2003), more than 200 people depend upon the community well for their daily drinking water supplies. Here well-use for irrigation was regulated to provide for drinking water needs, especially during the year 2002, a drought year. And yet, even such ‘protected’ sources remain endangered by the effects of regional water level decline.

Impact on Food Consumption

Rural families generally have a tradition of ensuring their food grain requirements are met through raising crops. The decline in water levels, and drying up of almost all wells in both Gujarat and Rajasthan case studies, and more than half in the Tamil Nadu case, has imposed great stress on food security at family level. The effect is not uniform but depends upon adaptive capacity. However, in situations such as the Gujarat and Rajasthan case, the vulnerability of most families is high. The drought conditions in the past few years gradually reduced agriculture to only rain-fed kharif; to the extent that even seeds were being purchased from the market. Thus, the food grain availability and fodder chain was broken, upsetting the food security which existed in some measure. In addition, people were forced to externally source their food grain requirements. However, with the extended spell of drought conditions and reduction of purchasing power, communities resorted to reducing food consumption both in terms of quality and quantity. The findings from the Gujarat case study show that consumption of vegetables, milk, ghee and oil was severely reduced across all families. The option to buy nutritious food is not available for the majority of the families.

Although some of the impacts discussed are related specifically to the drought of 1999-2003, they reflect the longer term trend.

Impact on Social Life

The impact of declining water levels has led to the break up of families, with men often going away to other areas in search of livelihood options. Children and women were thus denied a family life. Often, women and elders were left to fend for themselves. Children were forced to drop out of school and take up some work to earn money for the family. When women migrated to urban areas, they were at risk of harassment. Those women remaining suffer most due to the decline of water levels. In addition to their routine work, they need to fetch drinking water for both the family and the animals.

There were, however, some brighter sides to the water level declines. The kinship relationship has at times become stronger among relatives, as also among friends staying in different parts of the State. Further, co-operation and mutual help among the same caste groups were found to have strengthened. One other impact was that the inter-caste differences blurred as people shared drinking water from the same sources.

Indebtedness and Erosion of Assets

Declining water-levels have also led to gradual erosion of assets, especially in households who are not able to evolve a suitable medium-to-long-term strategy. Loss of assets often begins with sale of cattle, trees, pawning or selling of jewellery and finally mortgaging agriculture land (Mudrakartha et al 2003).

It is not an easy task for male members to mortgage or sell land, or for a woman to allow the pawning or sale of jewellery. It is a traumatic experience as self-esteem and status are compromised. This is often the last option. Often, as an alternative, people take loans at a very high rate of interest, take up sharecropping or work as agriculture labourers.

Responses to the depletion of groundwater resources

Shifting Livelihood Patterns

Increasing stress on the primary agricultural occupation due to water level declines across all three case study areas forced the communities to look for diversified options. The following charts indicate the shift that has taken place in the Gujarat case, using a household example.

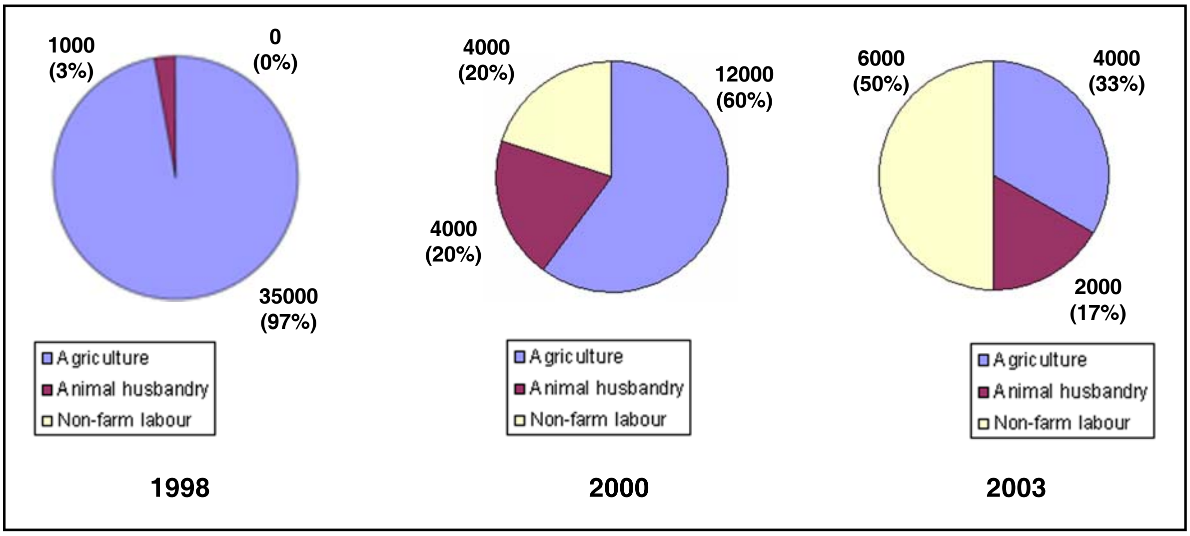


Figure 5 Changes in relative shares of livelihood income sources, Vijesinh household, Bhanavas, Gujarat. *Source: VIKSAT Primary Survey 2003. The size of the circle is proportional to the total annual income*

The following conclusions may be drawn:

1. The proportion of income derived from agriculture, which was the main occupation during 1998, just when the drought had begun in the Gujarat Case study areas, has reduced from 97% to 33% of income in 2003 (summer).

2. The proportion of income derived from animal husbandry, which was a supplemental source of income, has increased from 3% to 17% during the same period.

3. While the income from non-farm activities was minimal in 1998, it increased to 50% as the household turned to labour as an income source.

The relative significance of animal husbandry as an income source is explained further by the following graph, which shows that milk production remained static or slightly increased despite the reduction in agriculture and agriculture based fodder.

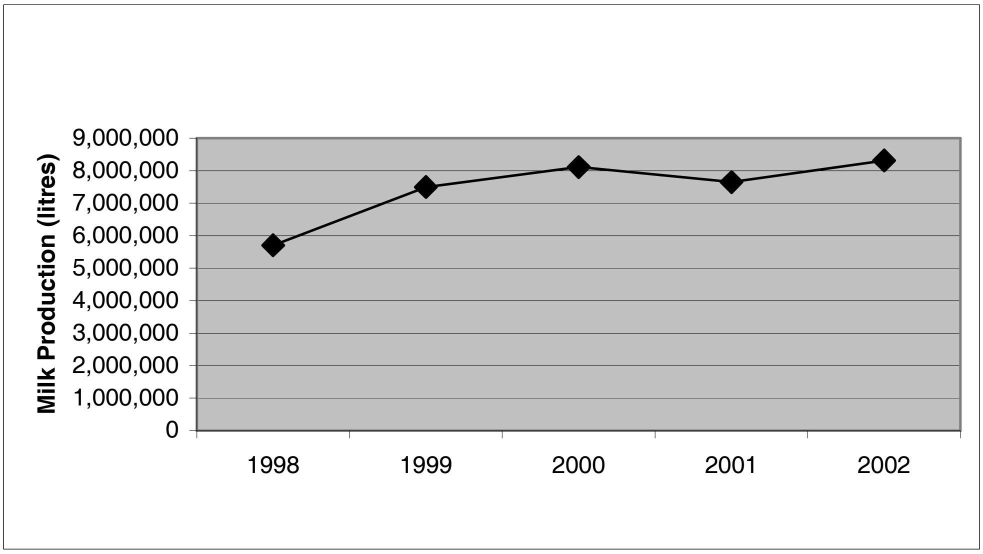


Figure 6 Change in milk production over time in Umri Village, Satlasana, Gujarat. *Source: Dairy Co-operative, Umri, 2003.*

Two factors contributed to this phenomenon:

1. There was a supply of animal food concentrate by the Regional Mahesana Diary. This is also because the Mahesana Dairy is in the process of collection, storage, processing and redistribution of milk to the whole of the district and beyond, not only of milk but also milk products. It is therefore in the interests of the dairy to take care of the small milk producers.

2. Further, government provides subsidized fodder during drought as part of the drought relief programme.

In addition, people fetched fodder from distant places and purchased fodder at high prices. The fodder shortage has led to incidents of cattle mortality in all three study areas. As an alternative to further cattle deaths many people resorted to selling cattle at very low prices to purchase fodder to save the remaining, breeding livestock.

Agriculture Labour and Livelihood Diversification

Communities often manage scarcity of irrigation water availability by adopting crop and livelihood diversification. Crop diversification is not well established except in certain pockets. This is because crop diversification depends upon a host of external factors such as access to quality seeds, timely and adequate rainfall and, above all, market demand. Here, the need for well established market mechanisms to communicate information on market needs, price fluctuations and transport connectivity come into the picture. Knee-jerk response to market signals have seen large numbers of farmers going in for a particular crop based on purely economic considerations, jettisoning diversification, with a desire to capitalise on market demand. Such attempts have also resulted in supply gluts, leading to price crashes and heavy losses.

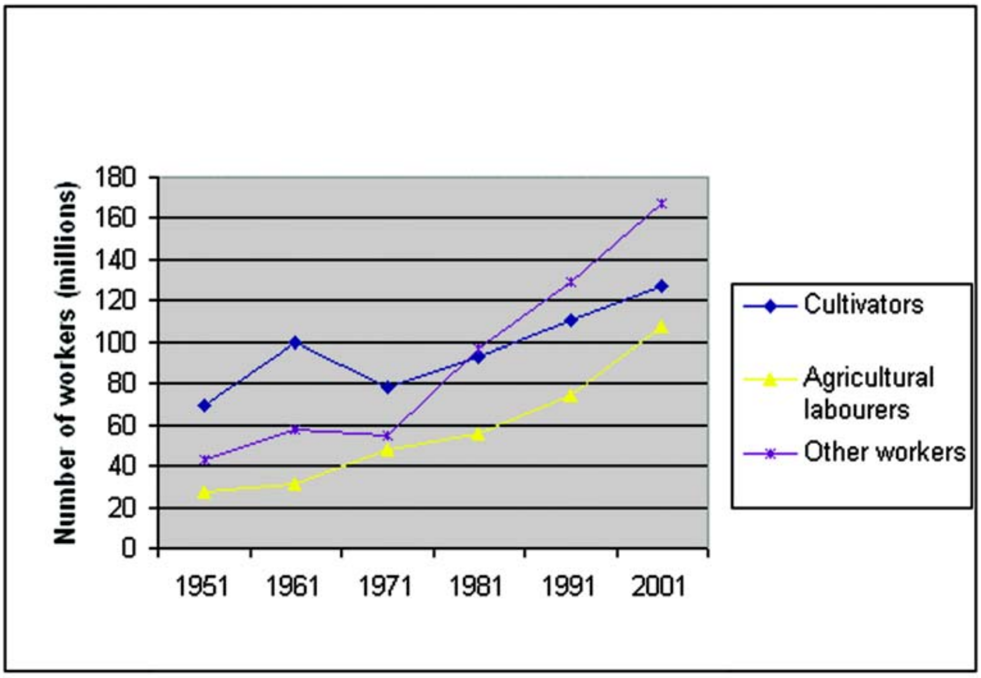


Figure 7 Rural population and agricultural workers in India, 1951 – 2001

During periods of livelihood stress, people tend to migrate and work as agricultural labourers or find non-farm labour. This trend is aggravated during disasters such as droughts and floods. Many farmers who are on subsistence agriculture, migrate to nearby areas to work as agriculture labourers. Landless and some able-bodied members from the farmer families go to urban areas to work as construction labour. The period of such a migration varies from 6 months to one year. This is because, where farmers migrate to other "green" areas, they take up share-cropping, tieing them up for 4-6 months. Those who opt for construction labour get "contracted" on a yearly basis. Thus, the shift is more than temporary. Figure 7, in addition to an overall rising population, shows this substantial economic diversification of the rural population from agricultural to non-agricultural occupations.

The other secondary or supplemental livelihood occupation is animal husbandry. Communities tend to keep cattle, buffaloes and small ruminants as secondary sources of income. However, uncertainties of rainfall and groundwater access affect the sustenance of these animals due to fluctuating fodder and grass availability, both from agriculture residues and the market.

Topsoil from agricultural lands is removed for brick making

Selling Soil: Coping or Livelihood Erosion?

One of the serious impacts of water level depletion on farm-based livelihoods seen in the Gujarat and Tamil Nadu case studies is the selling of topsoil. Finding the going tough, farmers have started selling topsoil, or leasing land to brick kiln owners for a certain period, ostensibly at "lucrative" prices, although farmers lose at least one generation of crop production. In any case, not all farmers have this option as brick manufacture requires hard soil (morrum) which, for example, is available only in certain patches in the Satlasana area.

The loss of topsoil results in a decreased output from cultivation in the following years - a fact of which the farmers are aware. However, this depicts the extreme dejection and helplessness of the farmers and can be compared to the situation where a farmer mortgages or sells his land or wife's jewellery as a last resort.

Diversifying Into Non-Farm Activities

Water scarcity and drought conditions, increased population pressures and the gradual transition of bigger villages into towns/urban centres have led people, in particular from rural areas, to look for livelihood alternatives, including those in the non-farm economy. These opportunities differ from place to place and depend upon a number of factors.

The huge shift of almost 47% to non-farm activities during 1998-2002 in the Gujarat project case study area includes options such as roadside vending, migration to cities to work as construction labour and other unorganised forms of work. Significant among these is the opportunity of diamond polishing which is a highly labour intensive industry.

India earns Rs. 100 billion in foreign exchange through diamond processing and controls 80-90% of the total world diamond polishing market. Almost 800,000 workers throughout India are engaged in the diamond polishing industry. Surat, Mahesana, Bhavnagar and Ahmedabad in Gujarat are some of the key polishing centres where people migrate to in search of employment. Over the decade, a large number of labour-intensive polishing units have sprung up in Satlasana, Visnagar, Mahesana and Palanpur areas. In Satlasana town alone, there are 7 diamond-polishing units employing over 1,100 people. People believe that the diamond polishing industry has helped them tide over the livelihood crisis situation during the recent spell of drought. The industry is, however, highly sensitive to fluctuations in international market demand. There is severe competition from Singapore and China of late and this has hit the industry hard by reducing the profitability and the quantum of work available. Ten to fifteen years ago diamond polishing was more lucrative than government employment and attracted many educated young people. It may be noted that diamond polishing however does not need any formal education except 3-4 months of hands-on training. Recently, due to international fluctuations, 100,000 workers have lost their jobs due to the closure of many polishing units. This indicates the vulnerability of this livelihood option. For many workers, diamond polishing is an alternative source of income since agriculture has collapsed due to depletion of groundwater. At least 50% of those diamond polishing workers indicate a willingness to return to agriculture if the monsoon is good and groundwater levels improve.

In good times, an expert diamond-polishing worker is able to earn about Rs. 300 per day. Normally they earn an average of Rs. 50-75 a day. During times of extreme recession, even this is not guaranteed and many people leave the industry.

In the case of Tamil Nadu, a major non-farm diversification is carried out by medium and large farmers in activities such as the setting up of power looms, quarrying and other non-agriculture businesses. The study indicates that this diversification eludes the small and marginal farmers as well as the landless who migrate to work as agricultural labour, construction labour and in factories in nearby cities and urban centres.

In the case of Rajasthan, besides the traditional occupations such as woodwork, leatherwork and pottery, new activities such as carpet weaving and gem polishing have come into vogue mainly due to urbanization. New avenues also include working in the service sectors such as agro service centres, grocery and vegetable shops, roadside hotels/dhabas and as drivers. Adult females mainly work as domestic workers. Female members are also engaged in carpet making, gem polishing and other traditional occupations.

Even in some areas where Pani Panchayat schemes are in operation, the last four to five years of drought-like conditions have adversely affected agriculture. In the absence of established *in situ* alternatives, residents from many of these villages migrate to nearby cities like Pune and Mumbai as labourers. Some are inclined to migrate as farm labour to neighbouring water-endowed areas where sugar cane is grown. In fact, proximity and easy access to Pune and Mumbai may even constrain the development of alternative *in-situ* livelihood diversification in such areas.

Is Community Management Still Relevant?

Analysis of data from the three case study areas reveals that a majority of people see the community management of groundwater as a potential solution. It is thought there are two major reasons for this. Firstly, the recent drought spell in the case study areas, in particular in Gujarat and Rajasthan, has reinforced and spread wide the awareness of the importance of improving the efficiency of water use and of the structures to increase groundwater recharge; and secondly, the frustration of individuals chasing limited groundwater resources. Many people have become poorer due to indebtedness and erosion of whatever savings and assets. This realisation has led to enhanced debates and discussions in their collective efforts, the Gadhwada Jal Jamin Sanrakshan Sangh in the Gujarat case and the Arwari River Parliament in the Rajasthan case.

People believe that there is a need to enhance recharge to groundwater by having surface water conservation measures. North Gujarat has scope for a large number of surface structures. In the case of Tamil Nadu, the communities themselves have taken up development of surface storage tanks as well as farm ponds in addition to adopting modern irrigation techniques such as sprinklers. Interestingly, in the Gujarat case study in the past 3 years, 150 farmers have adopted sprinklers subsidised by the government. In contrast, up to 2001, farmers' response to such schemes was very poor.

Farmers in the Tamil Nadu case too have responded by altering cropping pattern towards less water consuming crops. For instance, the farmers of Kodangipalayam have over the decade of increasing water scarcity shifted in a major way towards raising rain-fed sorghum, almost abandoning water intensive cotton and bananas. Similarly, the farmers of Kattampatti village have reduced the areas under sugar cane and vegetables by half and moved towards rain-fed sorghum. In both villages, the current area of fallow land has increased from almost nil to 20%.

In the case of Rajasthan, the coming together of people in the form of the Arwari Parliament indicates their strong belief in the need for addressing water issues both at local and at sub-basin level. The Arwari Parliament comprises representatives from Village Water Councils, thus linking the village and the sub-basin. This approach has generated significant social capital, including empowerment of women from all sections of the community. People have contributed 25-80 per cent of the construction cost of community water harvesting structures, and agreed their own rules restricting water-intensive crops.

Another common finding is that almost a quarter of the village communities across all the case study areas are apprehensive of the powerful and the rich who they think have the means, methods and wherewithal to capture the precious groundwater resource. They can drill deeper, install higher capacity pump sets and draw water.

Systematic Efforts for Surface Water Augmentation

In the Gujarat project case study, having understood the need for decentralised supply augmentation by conservation of rainwater, the Gadhwada Sangh and the local farmers association, with the technical and managerial support of VIKSAT, have accessed the Sardar Patel Jal Sanchay Yojana of the Government of Gujarat. There is tremendous scope for construction of large numbers of check dams for drainage line treatment through this programme. To begin with, the Sangh had submitted a plan for 21 check dams for the region out of which six were approved and completed in time before the onset of the 2003 monsoon to capture the excellent monsoon flows. VIKSAT has provided technical and managerial support.

People believe that this approach will help distribute the rainwater into the ground and be available as groundwater for all. They are planning to construct more check dams through this scheme. Combined with the other water harvesting structures constructed during the drought relief programme of 2003 by VIKSAT and the Sangh, a significant harvesting of rainwater has taken place.

In the Tamil Nadu case too, people have increased the number of surface storage tanks and farm ponds by at least 2-3 times their number during the last decade to conserve water to meet the increasing demand. This approach also helped them to manage the erratic and irregular power supply.

The Rajasthan community has been addressing the issue of water scarcity through community construction of johads (ponds/tanks) along drainage lines resulting in significant recharge which has transformed not only into higher returns from agriculture but also built resilience to droughts to a considerable extent.

Society's Understanding of Hydrogeological Controls

In the Gujarat case study area, with VIKSAT's help, people recognise that the underlying aquifer is extensive and regionally connected. People believe that only regional efforts, through a community-based institution such as their Gadhwada Sangh, can lead to proper management of groundwater. Such an approach, it is hoped, will help them control the crops and cropping pattern. The existing indigenous pattern helps them ensure fodder availability for their animals. The rabi crops usually ensure fodder for the summer months. They also feel that approaches to other natural resources, such as forestry, will be strengthened with this approach.

Role of the State

The role of the state is regulated by the policies in vogue and the interpretation of such policies across the state by the implementing machinery. While the Gadhwada Sangh of the Gujarat Case has mobilised state resources for water harvesting structures as well as for Sector Reforms, the Rajasthan case has met with obstacles arising from issues related to policy interpretation, as in the case of construction of check dams across rivers.

Given the present legal scenario, and the complex laws that we have around water, in particular groundwater, it is essential that there is a good understanding between people's institutions and the state. Necessary policy changes need to be made to enable a common pool resource such as groundwater to be properly managed with active involvement of all stakeholders. Without community-based management, or at least community participation in wider resource management strategies, groundwater management cannot meet with success. Here, cues can be taken from Joint Forest Management which has been successfully managed in significant parts of India where an enabling policy environment, as well as management support for user groups from government, has been available (Mudrakartha et al. 2000).

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Groundwater Economies and Beyond: Livelihood Transition in Rural India

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Introduction

This paper examines the changing characteristics of rural areas in India. Rural household strategies, and rural economies with them, are often increasingly diversified. Understanding the drivers and impacts of diversification has major implications for community based management of natural resources, including groundwater. Key questions relate to the changing role of groundwater in rural livelihood activities and whether communities, and user groups within them, have a long term interest in resource conservation.

The Broad Context

India is undergoing a process of peri-urbanization. From what was, as little as twenty years ago, a dominantly rural country much of India has now become urban-linked. The changes are, of course, not all new. Rural and urban India have always been linked by flows of goods and people. Trade and the ever fluid and diversified patterns of migration underlay a rural-urban dynamic of co-dependent livelihood and political systems that helped shape India's being long before its emergence as an independent nation. But now the dynamic is changing in fundamental ways. Where 'rural' areas were once truly 'rural' – distanced by the time required for travel and information flow – now travel to an 'urban' area requires little beyond an hour bus ride and information flow is often instantaneous. Roads, television, radio, phone booths, power grids and most recently the ubiquitous cell phone penetrate through once isolated areas. In addition, many sleepy towns, once dominated by the slow pace of bullock carts, now rumble with trucks and the million voices of a business economy. With much of India's growth concentrated in small towns and cities, urbanization has migrated to the countryside. Rural distances have been shortened as much by the increasing physical proximity of urban areas as they have by the speed of communication and transport. The change is fundamental. Where once an urban job required migration - a fundamental change in the location of life and livelihood - now many individuals commute. Products and production are also no longer 'local.' Milk, that most perishable of rural commodities, is processed and transported nationally. The 'subsistence' rural economy in which commodity flows were circular within an area now rarely exists. The image of fundamental dependence on local resources, never a full description of reality, is now more myth than ever.

What does this have to do with community-based groundwater management? Management of any resource requires investment of time, energy and other inputs. It only occurs where 'users' - that social grouping that through the values it directly or indirectly receives has incentives to maintain the resource in a given condition - make the required investment. As India changes to a peri-urban society, the nature of communities and the interdependence between livelihood and natural resource systems is changing. In the idealized (perhaps mythical) rural economy, village communities draw their primary sustenance from the use and management of local forest, water and land resources. Such resources are fundamental to their existence. While commodity flows *do* cross community borders, the cycle of a local agricultural economy is circular and depends directly on the condition of local resources. Each year's crops, the livelihood base of the community, depend on the local alchemy of land and water. Disrupt the resource base and the community's livelihood ceases to exist. The community *depends* on water and has a direct incentive to manage the resource base to ensure its own survival. This myth, never a full description of reality, faces fundamental challenges in a peri-urban world. With increases in transport, communications and access to a diversified national economy, communities are defined less and less by place and more by networks of occupation and association that often cut across broad geographic regions. Livelihood systems are also diversifying. In consequence, both the existence of village 'communities,' and their direct dependence on local land and water resources are declining. As the idealized image of rural communities diverges ever further from reality, concepts of community based groundwater management must address fundamental questions regarding the nature of community and where such communities may have an incentive to manage local natural resources.

The purpose of this paper is to locate questions regarding community-based management of groundwater resources within the larger dynamic process of change that is reshaping the nature of rural life in India. Our objective is to paint a broad picture and, within that, identify those factors we believe work both for and against attempts to initiate community based groundwater management. In addition, within the changing nature of community, we hope to identify the groups most likely to benefit from successful groundwater management initiatives.

The Peri-Urbanization of India

The external view of India is often stereotyped by images of mega-cities embedded in a slow moving traditional hinterland of small villages where life proceeds at the pace of bullock carts. This image is increasingly distant from reality. Indian's aren't migrating in huge numbers to urban areas and leaving rural areas depopulated. Data from the 2001 Census of India, for example, classify slightly over 72% of the population as living in rural areas and only show 7% as living in large urban cities of populations over one million. Rural population has declined from 74% in 1991 and 77% in 1981 – but there has been no huge shift into urban areas.[2] Changes are more subtle. Rather than migrating to urban areas, urban characteristics are gradually spreading out and reshaping India's once-'rural' areas.

Traditional images of a rural hinterland dotted by small villages are no longer true. Villages are growing in size and becoming small towns capable of supporting a diversified economic base. In rural India there are approximately 981864 habitations (villages) of various sizes. Approximately one-third of these have a population of less than 200 (15% with a population of less than 100) while only 16.4% have populations exceeding 1000. Villages exceeding 1000 population, however, account for nearly 55% of the total population while the one third with populations of less than 200 account for only 5.6% of the population. Most 'rural' inhabitants now live in relatively large villages. The change has been gradual but consistent as Figure 1 below indicates.

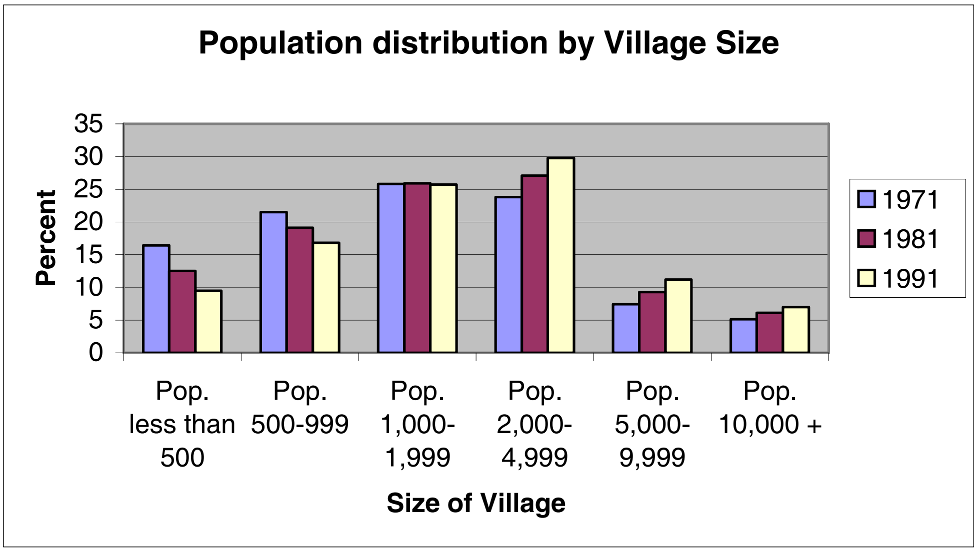

Figure 1 Population distribution in rural villages of India
Source: Census of India, 1971, 1981, 1991

[2] Census of India, 2001, 1991, 1981

Figure 1 clearly indicates an on-going decline in the percentage of the population residing in small villages (those with less than 1000 population) accompanied by stable or increasing populations in villages having populations of 1000 or more. Even the absolute number of small villages has declined significantly in the smallest (population less than 500) size bracket. This has important implications for the structure of rural livelihoods. Villages with larger populations are much more likely to support a diversified base of services and other non-farm activities than would be the case with small villages. Similar patterns are present where 'urban' populations are concerned. As Figure 2 indicates, the percentage of population residing in small towns (Classes VI,V and IV – i.e. those with less than 20,000 inhabitants) has been declining while the percentage of population in larger towns has been increasing.

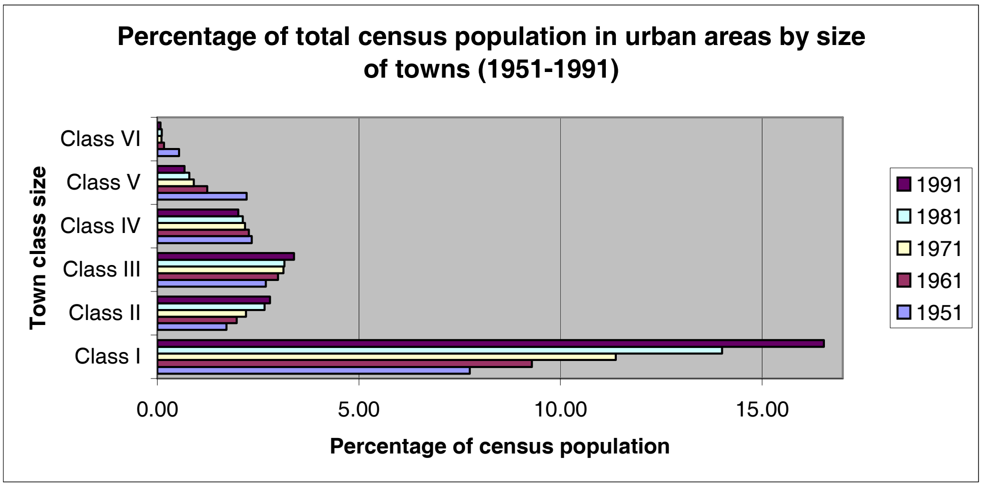

Figure 2 Change in town sizes

Source: Census of India, 1951-1991. Note: Class 1 = population of >100,000, Class II = population of 50,000-99,999; Class III = population of 20,000-49,999; Class IV = population of 10,000-19,999, Class V = population of 5,000-9,999 and Class VI = population of less than 5000.

Increasing concentration of the population in larger villages has been accompanied by other structural changes in basic infrastructure such as electricity, telecommunications and roads. As Figures 3-5 clearly document, access to infrastructure has increased dramatically. The number of public call offices (a critical indicator of telephone access in rural areas where most people can't afford private phones), has increased from near zero to almost 350,000 – and most of these are linked to the national network. Similarly, electrification has increased dramatically and is now leveling off as most villages are, at least nominally, connected to the national grid. This is also the case with paved roads.

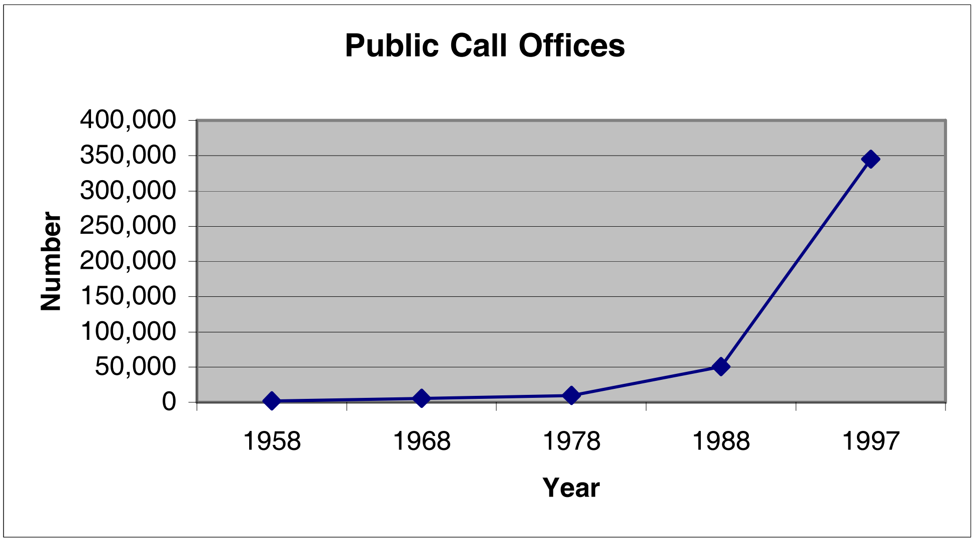

Figure 3 Public call offices

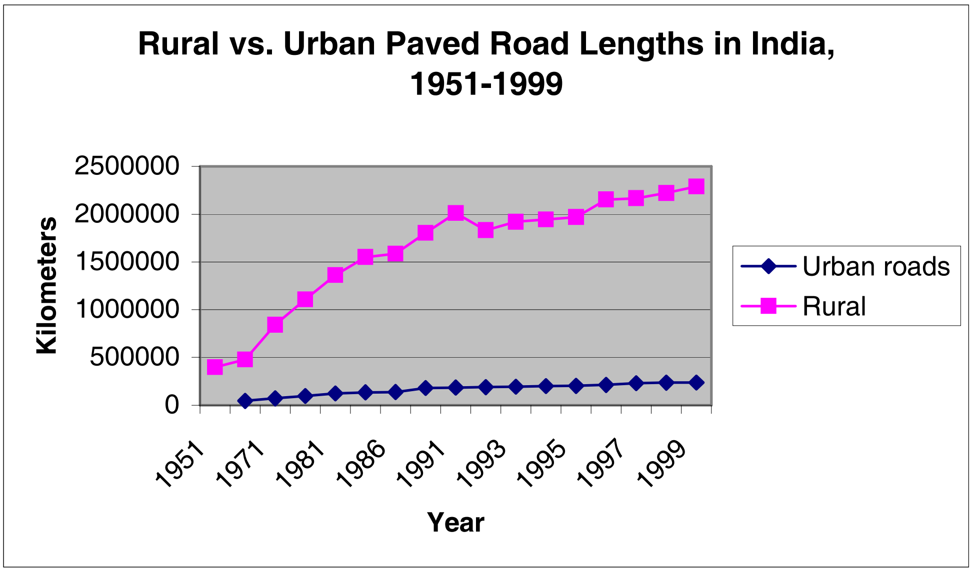

Figure 4 Road network

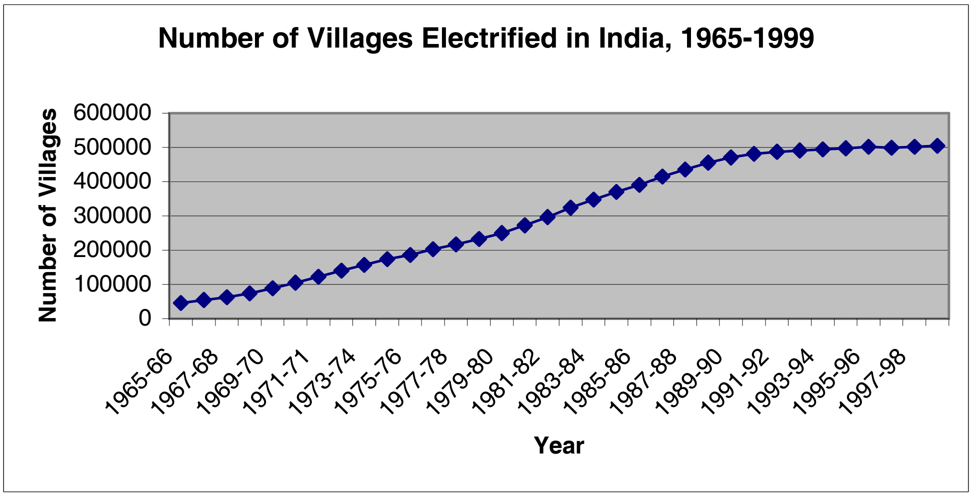

Figure 5 Village electrification

While the data underlying the above figures need to be interpreted with care (electrification, for example, indicates connection to the grid, not the availability of power when users may need it), they do indicate a basic change in 'rural' infrastructure.

Twenty years ago travel times between villages and towns or urban areas were often determined by the pace of a bullock cart travelling on unpaved roads. Under the best of conditions such travel took substantial time while during the monsoon season many villages were effectively cut off. Now, the presence of all-weather roads has enabled the extension of public and private bus or local taxi service far into once isolated areas. In many regions the distance an individual farmer or worker could travel within a day to sell produce or search for a job has expanded from a few to many tens (or hundreds) of kilometres. Complementing the ability to travel, individuals are now able to communicate with others in distant locations to find out about a wide variety of factors (from jobs to market conditions) that influence their livelihood options and choices. Finally, with power and access to transport many non-farm activities that could not earlier have been undertaken in rural areas are now often possible.

Rural areas are, in effect, much more closely connected to urbanized towns and livelihood options than ever before. Large towns and small cities are more numerous and, as a result, much less physically distant from 'rural' areas while at the same time the radius of contact for individuals living in rural areas has expanded. Many rural areas are, from this perspective, peri-urban.

Changing Livelihood Systems

Changes in rural infrastructure and demographics have fundamental implications for livelihoods. Data from the Census of India and National Sample Survey indicate that migration has declined. As Mahindra Dev points out, however: "both Census and NSS ignore or severely underestimate short duration (circular) migrants and commuting labour. The National Commission on Rural Labour (NCRL) estimates more than 10 mission circular migrants in the rural areas alone" (Dev 2002). Commuting is a major source of livelihoods in all sites studied by the Comman Project and micro studies in other areas indicate that this is both a common feature and a major factor contributing to labour mobility (Dev 2002). As Dev, citing Srivastava, (1998) states: "in the source areas, increased labour mobility has contributed to breaking down the isolated nature of rural labour markets and greater integration between rural and urban labour markets. The overall impact of labour outmigration in the recent period has been to put an upward pressure on wages and accelerate changes in production relations." (Srivsastava 1998; Dev 2002). The depth and extent of changes in production relations may have been limited by the low educational levels of much of the rural workforce (Dev 2002) but structural changes are clearly occurring.

Economic data for rural India show substantial diversification from agricultural to non-agricultural activities (See Figure 6). As can be seen, the number of 'other workers' has increased substantially and now exceeds both cultivators and agricultural labourers.

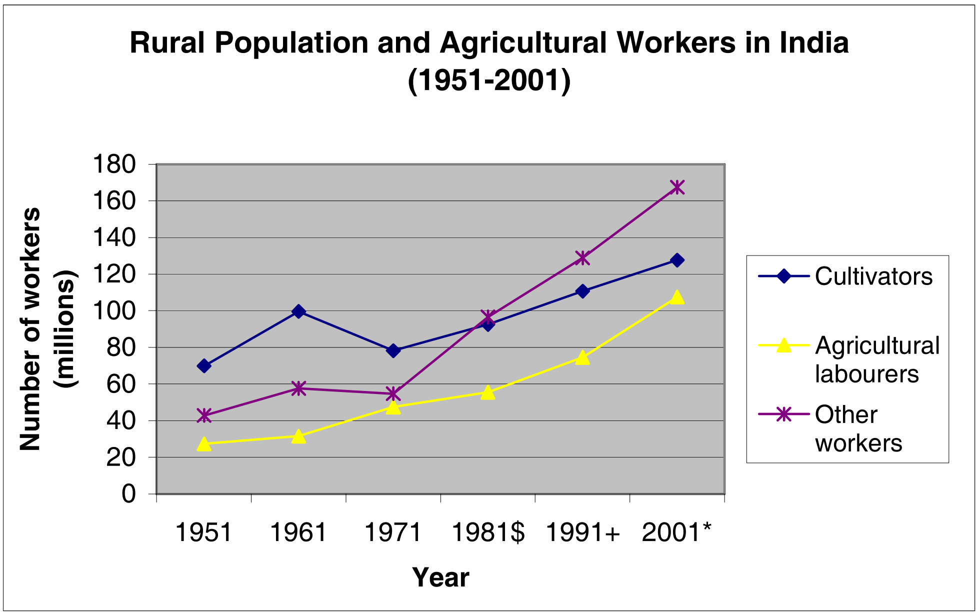

Figure 6 Rural livelihoods

Source: Census of India (1951-2001)

The above patterns conform with trends in India and many other parts of the world as well. As Daniel Start indicates: "Recent surveys suggest that non-farm sources account for 40-45% of average rural household income in sub-Saharan Africa and Latin America and 30-40% in South Asia, with the majority of this coming from local rural sources rather than urban migration" (Start 2001).

The causes of the above shift are subject to substantial debate and a variety of push and pull factors are probably important. Operational land holdings in agriculture have, for example, been declining steadily. The number of 'marginal' holdings (less than 1 ha) has increased dramatically over recent decades and the total area under large (>10 ha) and medium (4-10 ha) has declined as has the total agricultural area within larger holding size classes (see Figures 7 and 8). As a result, many farmers probably find themselves with insufficient land for cultivation. In addition, factors such as declining access to groundwater in areas affected by depletion, drought and general degradation of the natural resource base represent substantial 'push' factors.

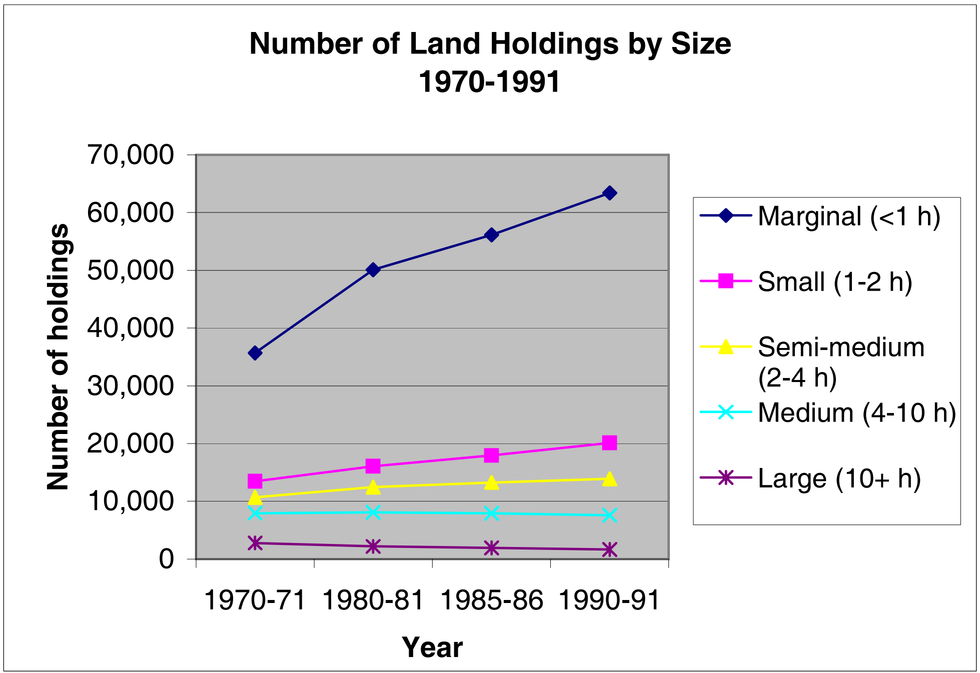

Figure 7 Landholdings by size class

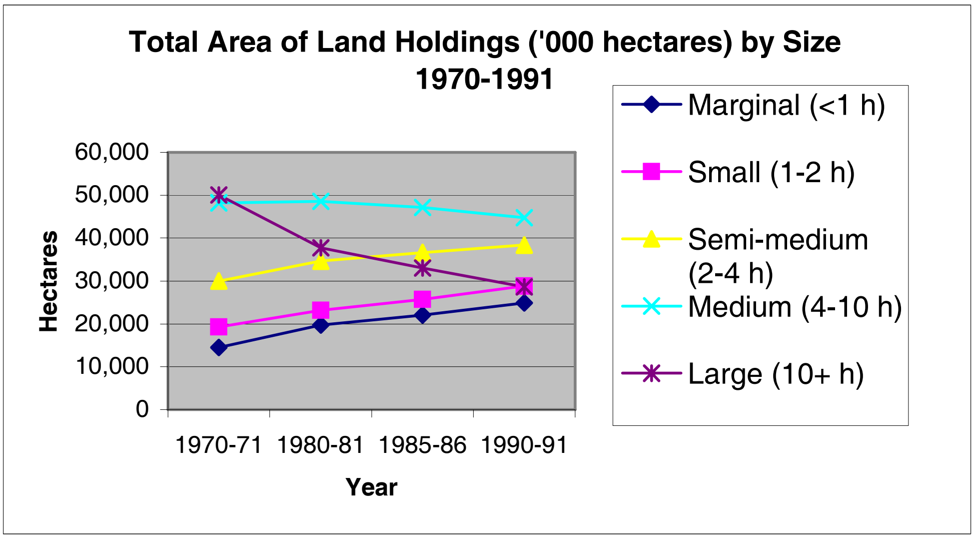

Figure 8 Total area under different landholding size classes

The above push factors are not, however, the only considerations at play. In most rural areas, non-agricultural wages are higher than wages in the agricultural sector (Sundaram, 2001; Dev, 2002). Among other things, key results from Sundaram's analysis indicated "widespread gains in labour productivity getting translated into equally widespread and significant growth in average wage earnings per worker and per capita" along with "a reduction in the share and size of the workforce in agriculture" (Sundaram 2001). Casual wage labourers in agriculture received, on average, 25.48 Rs/day while casual workers in rural areas received 30.89 Rs/day on public works projects and 37.49 Rs/day in non agricultural activities. Urban casual workers receive slightly more – on average 39.75 Rs/day.[3] Of all occupations, casual labour in the agricultural sector is the worst paid of all occupations. In addition to

[3] Wage rates for 1999-2000 normalized to 1993-94 prices.

wage differentials, other 'pull' factors are probably also important. These range from income diversification and reduction of exposure to the risks associated with agriculture to increases status and access to services such as schools for educating children that are often associated with employment in the non-farm economy.

Many of the 'advantages' of engagement in the non-farm economy are now accessible to individuals living in 'rural' areas; particularly the larger villages and towns along with smaller city areas. "Rural" India is becoming peri-urban; penetrated by urban forms of communication, transport and power systems. As Start citing Bryceson (2000) comments: "Straddling both rural and urban economic domains, rural people increasingly depend on urban labour markets, urban remittances, urban trade and urban social networks" (Start 2001). Rural household economies are also increasingly diversified. As Deb et al found in a survey of Aurepalle village in Andhra Pradesh: "In 1975, households were recorded in the survey as drawing on at most three sources of income. The majority of the farmers had one (37%) or two (55%) sources. By 2001, the number of income sources increased to five and no households except those in the non-farm category had only once source of income. The majority of the farmers (59%) had between two and four sources of income. 16% of the households had five sources" (Deb, Rao et al. 2002). Similar patterns were found in another village surveyed by Deb. Overall, the process of peri-urbanization appears to combine increased interaction between rural and urban areas, growth in 'rural' towns and villages, growth of the rural non-farm economy and, even within the farm economy, diversification of livelihood systems beyond agriculture.

The Changing Nature of Community

As India becomes increasingly 'peri-urban' and livelihood systems change, the nature of communities is changing as well.

Historically the diverse groups living within rural villages often depended on the same single agricultural system for livelihoods and survival. Their livelihoods were interdependent. In addition, most people had strong place-based identities. Society wasn't as mobile or fluid and migration, while always technically possible, often wasn't a realistic option families could chose in response to livelihood or community constraints. As a result, villages were in the most generalized sense 'communities.' There were shared interests and needs that cut across the boundaries of family, caste and religion. People, whatever their divisions, needed to interact and to maintain institutions, such as the traditional Panchayat, to moderate their interactions within the geographic boundaries of villages and local areas. Overall, village communities often really were 'communities' and represented common groupings bound together by more than chance location.

In today's world, it is unclear how often villages remain as true place-based communities. Many of the ties binding diverse groups within villages are now much weaker. Non-agricultural livelihood systems, for example, often depend on networks of contacts and relationships that extend far beyond (and may not include) others within a given village location. Furthermore, as the national economy diversifies and rural areas become increasingly peri-urban, it is far more possible for individuals or groups to 'opt out' of communities by migration or less drastically by ceasing to maintain or observe the traditional institutions of community. The Panchayat's writ is eroded – village elders can often do little if individuals within a village ignore their dictates or if, more subtly, the village as a whole gradually ceases to care.

This process is also occurring at the caste and family level. Almost two decades ago, roads and the increased access to markets they enabled were identified as a primary factor underlying the breakup of joint families in the Garhwal Himalaya (Moench 1988). As market access increased, nuclear family units were less and less dependent on larger joint family groupings for economic survival. Historically, key livelihood activities (in this case milk sale and access to grasslands) required long-distance seasonal migration while others (maintaining subsistence crops) were village based. Both activities were essential for survival but individual nuclear family units lacked sufficient labour to maintain both livestock and agriculture. Access to roads changed this by enabling families to sell milk and new market crops while remaining based within the village. As the requirement for seasonal migration decreased so did the economic interdependence within joint family groups and, over a period of less than two decades, most joint families within the village ceased to function as single economic units. This type of process is common. As roads, markets and communications increasingly penetrate through rural areas, dependency relationships within families and caste groupings change. In some cases, interdependence may increase (commercial agriculture often, for example, requires capital injections obtained through urban jobs) while in other cases it decreases. In a general sense, however, the web of interdependency relationships is likely to be less and less bounded by location. Instead, people depend on networks of relationships within occupations or other identity groups that are not place based.

One way to explore changes in community is through the density of interactions. In a traditional village, individuals needed to interact with others in the village frequently to meet multiple needs. Ties would often have included kinship, the daily activities of farm operation, numerous shared household tasks, the maintenance of joint (village) infrastructure, and larger economic integration. Development often nibbles away at the density of interactions within a village grouping. A water tap in the house reduces your need to communicate and get along with other women in your neighbourhood. The presence of a local bus service reduces your dependency on others in your village for agricultural labour. Access to large markets reduces the mutual dependency between individual producers and individual traders. The presence of a rice mill reduces the hours women traditionally had to share pounding and husking grain. A sense of 'community' is often created through numerous shared tasks and regular interaction within a small defined group. Development processes reduce the number of tasks and the frequency of interaction required within narrowly defined village groups. In a peri-urban village, while you may still know your neighbours, you do not need to interact with them on a daily basis to meet multiple basic needs. The density of interactive ties has declined.

Community continues to exist but it becomes less and less defined according to traditional patterns of location. The office, trade group, market, school, temple and water tap become the paramount spaces of interaction for people rather than the village or housing cluster. As a result, as peri-urbanization proceeds, villages may increasingly become place-based agglomerations of people that lack the density of cross-cutting relationships and sets of identities required to create community. The degree to which this is true will, of course, vary greatly between locations. It is, however, a central issue determining the logic underlying 'community' based approaches to natural resource management. Rather than identifying the village as the 'community' with an incentive to manage resources, those concerned with resource management need to identify communities of interest. The question of 'which community' is central to any notion of 'community' management.

Implications for Community Based Groundwater Management

Those advocating community-based approaches to natural resource management have tended to equate villages with communities. In watershed and joint forest management, for example, NGO and government programs generally require all members of a given village to sign-on and become members of a management group. The approach assumes that all those living within a village have a strong shared interest in local forest and watershed condition and, as a result, need to be involved in management processes. Inclusion of *all* village members is particularly emphasized in order to ensure that economically and socially marginalized groups – the groups who are often most dependent on forest and watershed resources – are not excluded from the management process. In contrast to forestry and watershed programs, participatory irrigation management initiatives dealing with surface systems generally emphasize user groups rather than villages. The hierarchical structure of surface irrigation systems where main canals, distributaries and minors each provide water to very clearly specified plots of land enables clear identification of individual users. Those who aren't within the command of a system do not get water and do not have a stake in irrigation management.

In the groundwater case, well owners are in some ways the equivalent of individuals within the command of surface irrigation systems. They are the ones with the greatest direct, current stake in groundwater conditions and, therefore, the individuals with the greatest potential incentive to invest in groundwater management. Other individuals do, however, have a potential stake in groundwater resource condition. In some cases this is direct (i.e. those dependent on community wells for drinking water supply) and in other cases it is indirect (landowners who may wish to construct wells of their own at some time).

All this implies that any attempt to initiate 'community' based approaches to groundwater management must be founded on a relatively sophisticated understanding of what the community using groundwater actually is and what the incentives it faces within the larger dynamic of peri-urban transition might be. Definitions of 'community' that focus on all of the members within a given village or even that section engaged in agriculture are likely to be inadequate. Instead, in order to identify whether or not a potentially viable basis for community management exists, a series of key questions must be addressed including:

1. Who actually uses groundwater and has control over existing wells?
2. Do such users represent a distinct economic, cultural or other sub-group, i.e. a distinct 'community,' within the area where management may be needed; and
3. Given the larger economic context and process of demographic change, does the 'community' of groundwater users have;
    a. Any incentive to manage groundwater (what benefits might they receive)?
    b. An existing or potential social basis that would enable the users to change groundwater use in order to achieve common benefits?

Conclusions

India is undergoing a process of social and demographic change in rural areas that has fundamental implications for groundwater and other natural resource management options. As the non-farm economy grows and extends into previously agricultural 'rural' areas, the structure of livelihoods is changing and with it the incentives to manage natural resources on a sustainable basis. In addition, the nature of the community involved in groundwater use is probably changing. All this implies a need to move away of concepts that focus on villages as the 'natural' unit of community for management and, instead, develop a process to identify whether or not communities of users exist that have both the incentive and practical capacity (in terms of community structure) to undertake management.

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THE MANAGEMENT CHALLENGE: WHAT CAN BE DONE?

Conventional Management: Attractions and Limitations

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Introduction

This paper scopes the significant challenges involved in the management of groundwater resources by rural Indian communities. It uses conventional, internationally dominant groundwater management theory as a means to 'unpack' groundwater management into various components and then examines the technical, socio-economic and institutional issues associated with each. The paper begins by describing in brief the important role groundwater plays in rural livelihoods, how the overexploitation problem has developed and the impacts and responses. It goes on to outline groundwater management theory before examining the technical, socio-economic and institutional issues. It concludes by summarising research questions, which will be addressed by the project.

The main objectives of this paper are as follows:

- to examine the applicability within the rural India context of internationally dominant/ recognized groundwater management theories and to highlight the major constraints and challenges this context presents; and
- where possible, focusing on technical aspects, to identify appropriate measures that could be employed to allow conventional theories to be put into practice.

What is Conventional Groundwater Management?

Conventional approaches to groundwater management combine scientific, technical and (typically hierarchically structured) institutional components to achieve socially defined management objectives. Most conventional approaches take the hydrologic system as a starting point. Although this is not always achieved in practice, they focus on basic hydrologic units – aquifers or surface river basins – as the most logical or 'natural' physical management units. At the foundation, conventional management thinking is structured around mass balance concepts, i.e. the balance between water and other mass flows in-to and out-of hydrological units, and how those flows alter conditions, such as groundwater levels, the stock of water available, flow directions or pressure gradients, and the quality of water, within units. Conceptually, conventional management institutions are designed to enable a relatively narrow set of managers with a high level of technical expertise to manipulate flows into and out of any given management unit to achieve whatever hydrological conditions are required to attain desired social objectives.

Although the objectives of management could be defined in a very wide variety of ways, conventional approaches to groundwater management do not focus on the full range of social objectives that are theoretically possible. Instead, they are 'water focused' and generally emphasize:

1. sustainability of the groundwater resource base (which in most cases is effectively defined as the 'sustained yield' or balance between inflows and outflows from aquifers);

2. maintenance of water quality; and

3. allocation of available water supplies to broad use categories (agriculture, domestic, industrial and environmental) along with, in many cases, the maintenance of water rights systems.

Although it can be structured in ways that are conceptually clear, in practice, "sustainability" is a highly abstract and often unclear objective. Notions of sustainability are, however, the starting point on which the groundwater monitoring programmes of many countries, including India's, are founded. India's monitoring programme, for example, is designed to produce estimates of recharge and extraction for local hydrological units across the country. In areas where recharge is estimated to exceed extraction by a large margin, the government encourages groundwater development, sometimes providing subsidies. In areas where extraction approaches or exceeds recharge estimates, subsidies are closed and the drilling of new wells is discouraged. The conceptual objective is two fold: first, to encourage utilization of groundwater resources; and second to ensure that such utilization does not deplete the stock of groundwater in storage and thereby leaves subsequent periods (years or generations) with the same levels of overall water availability.

Even at a conceptual level, the above definition of sustainability soon breaks down. Precipitation levels are inherently variable and one of groundwater's most important uses is as a drought buffer. As a result, it makes sense to draw groundwater storage down during droughts and allow it to replenish during normal years. But what is a 'normal' year? Periods of record for precipitation data are often short and may not reflect long-term averages. Furthermore, given the prospect of climatic change, substantial uncertainty exists regarding whether or not historical data are of much utility in predicting future precipitation levels. Add to this changing land use patterns (which often affect recharge), other human interventions in the surface hydrological system and technical uncertainty regarding the nature of a given aquifer or regional hydrological system dynamics and it becomes conceptually difficult to determine how much groundwater really could be extracted on an indefinite or 'sustainable' basis without changing the stock in storage. If one adds changes in water quality potentially induced by groundwater utilization then the clarity of sustainability concepts becomes even further muddled. Finally, social goals often focus on livelihoods and the sustainability of economic or environmental systems – neither of which may be inherently related to the stock or quality of groundwater in storage.

Given the limitations of sustained yield concepts, in practice, management to attain sustainability and other objectives generally comes down to maintenance of groundwater levels within a relatively narrow range. In specific, management generally attempts to maintain water levels within a range where pumping costs for irrigation or other uses are low but the water table is sufficiently below ground level to avoid water logging or salinisation problems. Management attempts also generally focus on maintaining groundwater storage as a buffer against drought and avoiding long-term water level declines even when such declines have few immediate economic implications. Groundwater management also often focuses on water quality concerns. In practice, however, most initiatives emphasize a relatively narrow range of specific concerns such as the avoidance or mitigation of saline intrusion in coastal areas or attempts to control point-source pollution problems. They rarely attempt to address long-term, non-point source changes in water quality. Since the Comman project's primary objective focuses on the management of groundwater supply availability, the discussion from this point onward will not emphasize water quality and pollution. It is, however, important to recognize that water quality is central to conventional concepts of sustainability.

Where water availability is concerned, because conventional approaches to groundwater management are founded on hydrological mass balance concepts and take notions of sustainability within hydrological units as a starting point, they rely on a common set of capabilities, discussed below.

Basic scientific and monitoring capacity

Conventional approaches assume that aquifers or hydrological units can be clearly defined and that, within units, the scientific capacity exists to document, monitor and quantitatively model key hydrological parameters such as:

1. aquifer characteristics (geological structure, the hydrological conductivity of units, infiltration rates, and so on) that are required to determine aquifer behaviour;

2. inflow to aquifers from rainfall, stream flows and other sources;

3. natural outflow from aquifers to streams, evapotranspiration, and subsurface flow to other aquifers;

4. induced outflow from aquifers via wells (including the ability to locate all wells within an aquifer and the ability to monitor extraction from them); and

5. groundwater storage within aquifers.

In general, conventional approaches assume that sufficient baseline data and information on regional hydrogeology exist or can be collected *to predict*, at least in a general manner, the impact of management interventions on hydrological conditions. They also assume that human and institutional resources are available to *collect, maintain and analyze* hydrological and water use data on an on-going basis. Finally, they assume that the human and institutional resources are available and can be deployed to develop and *implement* management activities.

Technical capacity to change the supply and/or demand for water

Because conventional approaches focus on the mass balance of water within aquifers, they implicitly focus on technical options for changing inflow or outflow from aquifers as the primary points of leverage for management. Where inflow is concerned, most attempts to manage aquifers focus directly on technologies to increase recharge. Such technologies include small dams for water harvesting and recharge, infiltration galleries, injection wells and watershed management (specifically, attempts to manipulate vegetative cover and soil conditions in ways that optimize recharge). Where outflow is concerned, most conventional approaches emphasize interventions that *directly* affect the ability to extract water from aquifers. Technical interventions of this type include well spacing and limitations on well depths or pump capacities. Conventional approaches also often emphasize technologies for increasing the efficiency of water use. In the case of irrigation, this includes promotion of drip, surge irrigation or sprinklers and in the case of urban water use it often focuses on changes in household appliances such as toilets and washing machines.

A key point to note in the above description is that conventional approaches tend to focus on technological interventions that change either the ability to extract water from an aquifer or the amount of water required to meet existing uses – *without* changing the uses themselves. In other words, conventional approaches to groundwater management take the basic structure of water demand as fixed. They focus, for example, on irrigation efficiency but generally do not question whether or not agriculture as a form of livelihood is appropriate in a region. In some cases, management does attempt to change the structure of demand via, for example, regulating the types of crops grown to reduce water demand. Attempts to promote an ethic of water conservation are also common. Groundwater management initiatives do not, however, generally extend to address the livelihood systems from which the structure of water demand emerges. These are generally taken as 'givens,' part of the context in which groundwater management must occur but not, in themselves, a central part of the groundwater management equation. As a result, most conventional approaches focus on the technical capacity to manipulate flows into and out-of aquifers but, with the exception of questions such as whether or not adoption of key technologies is economically viable, do not address the evolving social context in which technological interventions must fit.

Institutional capacity

Marshalling the assumed basic scientific and technical capacities to actually implement management in any region requires the presence of management organizations. As a result, conventional approaches to groundwater management require the existence or ability to create an organization that can plan and implement management within individual hydrological units. The need for an organization also implies the presence of a legal framework for such organizations (whether government, non-government or community) and structures that give such organizations the legal authority and capacity to act. Such authority generally includes some form of regulatory capacity (the authority, for example, to require registration of wells, regulate well spacing or require water users to adopt efficient water use technologies). It also includes the authority to construct any physical infrastructure (such as recharge ponds) required for management. Most importantly, however, conventional approaches assume that organizations have the political, financial and human capacities to take effective action to meet management objectives. They assume, for example, that passage of a law or promulgation of regulations at a national level is not blocked by political considerations or organizational limitations and actually translates downward into tangible changes such as well registration, enforcement of drilling depths, adoption of efficient irrigation technologies and so on that occur at the level of individuals and communities.

In addition, conventional approaches assume that stable financing mechanisms can be created to sustain the activities of management organizations. In some cases this is via direct support as a governmental agency and in other cases, as in the Western U.S.A., agencies are allocated a limited taxation authority. Whatever the mechanism, management entities require a sustainable financial basis in order to develop the capacity to act. Finally, management organizations are assumed to have the capacity to implement: to take socially or politically defined management objectives and translate them into action at the field level. In sum, the institutional capacities assumed in conventional management approaches include:

1. Legal frameworks enabling the creation of management organizations.

2. Capacity within management organizations to develop or access the scientific and technical inputs required for management.

3. Authority and capacity (manpower, political will, social legitimacy, etc) for such organizations to control and regulate aspects of water use or extraction.

4. Authority and capacity of such organizations to construct physical infrastructure for management.

5. Mechanisms for the sustainable financing of management organizations and their activities.

6. The existence of implementation capacity once objectives have been socially or politically defined.

Can conventional approaches to groundwater management be implemented?

In evaluating whether or not conventional approaches to groundwater management are likely to succeed in any given area, the core capacities outlined above can serve as guidelines. Answers are, in effect, required for a fairly limited array of questions under each heading including:

Scientific and Monitoring

Are available scientific and groundwater monitoring capabilities sufficient to:

1. *Identify* hydrological units;

2. *Document* major hydrological parameters within individual units including: recharge, extraction, natural outflows, etc..,

3. *Monitor* on an *on-going basis* changes in parameters (including water use);

4. *Plan* management programmes; and

5. *Predict* the impact of management interventions on groundwater storage, water levels, and so on?

Technical Capabilities

Are technical avenues available to directly manipulate *both* the supply and demand for water? Are technical interventions available, for example, to:

- *Harvest additional water?* Is most of the precipitation available within a basin already captured or does some flow to locations (the ocean or low-quality water bodies)? Do infiltration rates limit the amount of water that can be recharged to aquifers even if it is captured? If water is recharged, does it remain within an area or simply increase groundwater discharge in other areas?

- *Reduce net groundwater extraction?* Would the adoption of, for example, drip irrigation systems actually reduce the net amount of water extracted from an aquifer – or does 'inefficient' water use at the field level contribute to groundwater recharge? If surplus irrigation water simply returns to an aquifer then irrigation efficiency improvements at the field level may just reduce recharge and contribute little to reducing the net extraction from an aquifer. This point has been the subject of major debates at an international level (Moore and Seckler 1985; Seckler 1996; Seckler, Amarasinghe et al. 1998). Evaluating the likely impact of technological interventions on the demand-side depends heavily on location specific conditions and must be evaluated on a case by case basis.

Institutional Capabilities

Do institutions exist or can they be created that would have the ability to implement management activities affecting both the demand and supply of water? More specifically:

1. Can management organizations be created that have an ability to directly influence supply and extraction at the level of hydrological units?

2. Do mechanisms exist for financing the activities of such organizations on a long-term basis?

3. Do organizations have the capacity and authority to build infrastructure or undertake other activities to enhance the supply of water within aquifers (can they, for example, build check dams and recharge structures)?

4. Do organizations have the social and political clout to regulate or otherwise directly influence water extraction and use sufficiently to bring supply and demand into balance?

If positive answers do not exist to any of the above questions, then conventional approaches to groundwater management can, at best, serve as partial solutions. Although listed last, the institutional questions are probably the most important. Unless an institution capable of functioning at an aquifer or hydrological unit scale exists, then assembling the required scientific, technical, planning and wider regulatory or social influence capacities will be next to impossible. In other words, the question of *who will actually do the management* is of fundamental importance to the viability of conventional management approaches.

Mapping conventional approaches onto the technical context

Basic technical requirements for conventional management

Conventional approaches to groundwater management require certain basic inputs including, as previously discussed, a solid scientific understanding of groundwater systems, hydrological data, trained people, and access to key technologies.

Scientific understanding of groundwater systems

Despite large scale efforts on the part of Government and non-government organizations, a proper scientific understanding of groundwater systems in India is far from achieved. Many entities (individual or institutional) working in the water sector and related fields have various degrees of awareness, knowledge and understanding regarding groundwater resources. The situation is illustrated well by the current 'movement' for watershed development and management. Many watershed projects claim they have led to significant improvements in groundwater conditions, specifically increase in recharge and rise in groundwater levels in the area of intervention. Actual impacts are, however, rarely if ever evaluated or documented on a scientific basis. Instead, most projects take as granted that watershed treatment leads to increased recharge. In many situations, however, this may well not be the case. Internationally, research has clearly indicated that the impact of changes in vegetative cover on groundwater depends heavily on site specific conditions, - on a conceptual level, the balance between changes in infiltration related to soil characteristics and changes in evapotranspiration related to water use by vegetation. In Australia, tree clearing has caused groundwater levels to rise due to decreases in evapotranspiration (Burke and Moench 2000).

The situation in watershed projects is illustrative of fundamental gaps in hydrological understanding at a project level. This is especially true for hard-rock regions where, even standardisation of terminology for geological and hydrogeological units is lacking in hydrogeological descriptions given by various individuals and workers (Kulkarni et al, 2000). The current situation reflects the slow pace of change in the scientific understanding of hard-rock systems. As one of the authors wrote nearly a decade ago:

"At present, the monitoring systems and analytical procedures used in hard-rock regions do not differ greatly from those developed for and used in alluvial aquifers. This may well be inappropriate (Narasimhan 1990). Water table conditions in hard-rock regions can show tremendous variation between individual wells even within a single village. Furthermore, unlike alluvial aquifers, changes in storage in the vadose (unsaturated) zone may be the primary factor determining actual water availability in hard-rock areas (Narasimhan 1990). Even for the saturated zone, estimating changes in storage requires accurate assessments of specific yields from pumping tests. Most analytical methods for interpreting pumping tests were initially devised for bore wells in alluvial aquifers with relatively simple geometric configurations. They do not apply to the large diameter wells and complex, heterogeneous, hydrological conditions typical of the hard-rock aquifers extending throughout most of peninsular India (Moench 1996). As Narasimhan states: "indiscriminate fitting of hydraulic test data to available mathematical solutions will but yield pseudo hydraulic parameters that are physically meaningless" (Narasimhan 1990), p. 362). Overall: "a sound rational basis does not exist yet for quantifying resource availability and utilization." ((Narasimhan 1990), p. 354)"

It is important to recognize that gaps in hydrological understanding are not confined to India but plague conventional approaches to groundwater management even in the most technically sophisticated countries. Experts in hard-rock, fracture flow modelling are often the first to admit that quantitative solutions for groundwater evaluation do not exist in most anisotropic media. The situation often is not much better in supposedly 'simple' alluvial basins. In the San Luis Valley of Colorado in the United States, for example, hydrologists have been unable to resolve a 30% gap in water balance estimates (between what they know flows into the valley and what flows out) despite three decades of intensive monitoring, consulting analyses and research.[4] The gap probably has to do either with deep groundwater flow patterns or with evapotranspiration from native vegetation and wetlands (which is only now being estimated). Similarly, in California, hydrological experts working at the state level classify the Central Valley (globally among the most intensively studied aquifer systems) into over 20 separate aquifers while the USGS treats it as a single interlinked aquifer system. Even there, fundamental scientific debates over how the hydrological system really works remain unresolved.

Overall, the presence of substantial gaps in the scientific understanding of regional hydrological systems is a major challenge facing the implementation of conventional approaches to groundwater management in India. It should, however, be recognized as a global challenge rather than one confined to the India context.

[4] ISET research program interviews, 1999

Hydrogeological data

In order to develop a technical understanding of hydrological systems, sound data are one of the most important requirements. In India, as in many other countries, the hydrological database essential for conventional management is weak. Where groundwater is concerned, the primary data collected for characterizing groundwater systems include:

1. Basic geological information along with a very limited set of pumping test data to characterize the hydrological characteristics of formations;

2. Water level data from networks of monitoring wells. The Central Ground Water Board operates a low-density national network of monitoring wells. In addition, each state has a, generally somewhat more dense, network of monitoring wells;

3. Basic water quality data (typically Electrical Conductivity);

4. Some basic data on crop water use and cropped areas;

5. Estimates of well numbers and pump utilization; and

6. Associated hydrometerological data on rainfall, humidity, etc.

Problems within this basic data set have been widely discussed elsewhere (Moench 1992; Moench 1994; World Bank 1998). Periods of record are short and the accuracy of much data is open to question. In addition, some of the data on, for example, pump numbers and extraction rates are based on indirect measures (such as the number of loans issued for well construction) and probably do not reflect ground realities. Equally importantly, even if all data were fully reliable, the types of data collected are often insufficient for characterizing the hydrological system. Bi-annual water level data from monitoring wells, for example, does not capture the seasonal dynamics that often dominate groundwater availability in hard-rock areas. Similarly, daily rainfall data do not capture the intensity-duration characteristics of precipitation events that are central to determining how much recharge might occur. Finally, key data for accurate estimation of water balances, such as evapotranspiration by native vegetation, are not collected at all.

An even more challenging problem for conventional management has to do with data scale. Many hydrological systems in hard-rock areas are dominated by localized flow systems. Data are, however, often only available on a regional scale making them irrelevant for any specific project or localized hydrological unit.

Data problems are widely recognized. One positive development in this direction is the Hydrology Project. Set up with the help of funding from World Bank, Government of Netherlands and Indian Implementing Agencies (key Central and State Agencies), a Hydrological Information System has been put in place in seven peninsular states of India. The system promises a lot but issues relating to scaling up and down of available data and credibility in extrapolation of data still need to be tested and resolved.

Access to key technologies and information

Sound groundwater management initiatives require access to tools like basic monitoring instrumentation like sounders, pumping equipment, chemical sampling and access to laboratories dealing with various analyses. Over and above this, technologies like GIS and Remote Sensing, although available in India, are often out of reach for projects dealing in groundwater management. Two important reasons for this are lack of funding and limited expertise available to apply the technology in groundwater management initiatives. As a result, in many situations, often only basic equipment (such as that for resistivity surveys) is available making generation of detailed hydrological information impossible.

Secondly, information such as that available through the Hydrology Project or with Central and State groundwater agencies is difficult to access for small organizations involved even in genuine and significant groundwater management efforts. The reasons for lack of such access is mostly because smaller organizations are often not aware of such information or the process of accessing this information for such organizations is still unclear although many organizations and educational institutions are coming forward with demands for hydrological and hydrogeological information, especially from the Hydrology Project Network[5].

Addressing the Fit between Technical Requirements and Available Capacity

As the above sections indicate, the technical requirements for conventional approaches to groundwater management often do not match well with field-level conditions. Data from monitoring networks are often unavailable or of questionable quality. Individuals with the required training and perspectives may not be present and the technologies required may be unavailable.

How could the above technical gaps be addressed? Part of the solution, as argued in more detail later in this paper, may lie in redefining concepts of groundwater management – i.e. moving beyond conventional concepts. Part may also lie in innovative approaches to meeting the basic technical requirements needed for conventional management. We focus sequentially on this second aspect here. Before going on, however, it is important to emphasize that at least some of the 'technical' issues are rooted in institutional limitations. As long as groundwater management is defined as a technical activity to be undertaken and financed by state organizations the 'demand' for approaches to resolving complex interdisciplinary problems will be limited. Access to equipment and human resource availability are, for example, dominantly institutional issues. If the creation of local organizations can be enabled and if these have independent sources of financing then demand for technologies and trained human resources will increase. At present, local groups for groundwater management do not exist. As a result, the demand for technologies and human resources is largely limited to that created by state organizations, a very small pool.

Scientific Understanding

It is far from clear how gaps in basic scientific understanding of regional hydrological systems can be resolved over large areas within the short to medium term. Deployment of substantial additional governmental resources for this purpose is, in most states, unlikely given available budgets and manpower. Furthermore, as documented in the San Luis Valley case mentioned above, even additional basic scientific research, while important, would probably not be sufficient to resolve many gaps in the mass-balance estimates within regional hydrological systems. An additional limitation may be the nature of the mass-balance 'sustained-yield' approach in the hard-rock systems that underlie sixty

[5] Hydrology Data Users Group Meeting, 2003

percent of India. Since storage in hard-rock systems is low and confined to the upper weathered zone, the sustained-yield concept may have little utility. Instead it may be more appropriate to view wells in hard-rock areas as 'cisterns' where depletion and recharge occur over short periods of time. From this perspective the management question would have more to do with efficient use of water captured within the wells than management of the aquifer *per se*. A key point to recognize here is that technical limitations facing groundwater management are as much a product of how management objectives are defined (i.e. conventionally in relation to sustained yield) as they are related to anything inherent in the hydrological system and the nature of scientific knowledge.

One avenue for rapidly increasing the scientific understanding of local aquifer systems that has been discussed – but not evaluated in detail – might be to harvest the knowledge of local users. Such users are often (though far from always) aware of many local features that influence groundwater availability and dynamics in their local areas. Harvesting this information and evaluating its accuracy could be a useful avenue for increasing basic understanding of hydrological systems at the local to regional scale.

Hydrological Data

Scale issues are probably the most fundamental challenge to meeting the data requirements required for characterizing regional hydrological systems. Many other issues, such as the lack of data on evapotranspiration by native vegetation could be addressed through focused research programmes.

Scale issues cannot be resolved simply by increasing the density of state and central government groundwater monitoring networks. In many areas, data are needed at a micro-watershed scale. Even doubling or tripling monitoring network density would not provide the information required. Furthermore, attempting to drastically increase monitoring network density would be highly inefficient because it would result in substantial costs for data collection in many areas where such data are not required.

One potential avenue for resolving scale issues could be to develop and implement systems for generating high quality monitoring data through local communities in areas where groundwater management is emerging as a critical issue. Such initiatives would complement data generated through existing state-operated monitoring networks. Two elements would be key with respect to this approach. First, it would be important to focus on a limited number of 'strategic' aquifers where data collection can be concentrated. The second element would be to develop and test community-based groundwater monitoring procedures and to create incentives for communities to develop and maintain monitoring systems over the long-term. If this type of data collection can be done in conjunction with data collected through state organizations and if access to formal data sets in the Hydrology Project can be increased, it may be possible to generate adequate data in key locations for conventional approaches to management.

Human Resources and Technology Access

As with questions of scale and monitoring, part of any solution to the technology and human resource issues raised above would be to concentrate available capacity on the management of 'strategic' aquifers. This is, in effect, what is already being done by national and state organizations when they focus on the management of aquifers in locations such as Delhi.

On a more basic level, however, human resource and technology requirements are, at least in part, a product of how problems are defined. By defining groundwater management objectives in terms of aquifer sustained yields (the conventional approach as, for example represented by methodologies adopted by the Central Ground Water Board (Ground Water Resource Estimation Committee 1997)), the technology and human resource requirements for management are very high. If instead, as in the California example noted above, simple key indicators of groundwater conditions – such as water levels and water level trends – are used, then the dependence on high level technical expertise and access to high technology equipment can be reduced.

It is important to recognize that this has implications for the basic nature of engineering education. Part of the human resource problem is not a lack of people but limitations in how they have been trained. Since hydrologists are generally trained using concepts such as sustained-yield, they do not tend to think in terms of using simple empirical indicators of aquifer conditions as reference points that can be monitored and understood by non-experts. This is where changes in education could help create an effective interface or framework for dialogue between users and those involved in technical assessments of groundwater resource conditions.

Scale issues

While discussing earlier in this chapter if conventional groundwater management can be implemented, the question was raised as to whether it is possible for users to ring-fence the water that they conserve for future use. The answer is heavily dependent on the local physical setting. The hypothesis is that by enhancing water recharging during the monsoon season or by reducing abstraction during the crop growing season(s), an increased stock of groundwater (a 'mound') can be created beneath the land of the user group that can be accessed at a later time, perhaps to grow an additional crop in the summer season or as a buffer for subsequent years in case rains fail. Is it the case that this stock will remain in the control of a geographically well-defined user group or will it simply flow away. There are a number of ways that water can flow away: it can move off down the natural regional groundwater gradient; the 'mound' can flatten under its own gradient; or it can be pumped away by those outside of the user group. Analysis of the parameters that control the movement of groundwater in these circumstances have helped to assess the effectiveness of the user group groundwater management approach.

In Kulkarni's paper in this report, the main hydrogeological environments of India were listed as: alluvial systems, both deep regional and local shallow aquifers; and shallow weathered hard-rock aquifers of basaltic, igneous or metamorphic origin. These aquifers have vastly different aquifer parameters. In simplistic terms there are two parameters that control the degree to which water can move away from the control of the user group, the transmissivity (T - permeabilty of the aquifer times its saturated thickness) and the storage (S - where the aquifer is unconfined, this is referred to as the specific yield, the proportion of water in the saturated rock that will drain under gravity). As the transmissivity increases the groundwater will move away more easily, as the storage increases the greater the amount of water that needs to flow away to change the water-level. These two parameters combine in a single term called the diffusivity (T/S). The lower the diffusivity the more chance that conserved water will stay beneath the user group controlled area. Table 1 shows, for the major hydrogeological environments, the ranges of diffusivities used in the modelling exercise (see below). However, as has been stated elsewhere in this section, the data upon which these estimates have been made are limited and the storage coefficients are prone to great uncertainty.

Table 1 Major hydrogeological environments in India: ranges of diffusivities used for modelling

Hydrogeological environments	Diffusivity (m^2/d)
Shallow alluvial	12,500 - 25,000
Deep alluvial	50,000 - 150,000
Basalt: amygdaloidal at outcrop	2,000 - 20,000
Basalt: compact at outcrop	2,000 - 4,000
Shallow basement	2,500 - 20,000
Deep basement	10,000 - 100,000

Aquifer systems, particularly hard-rock aquifers, can be extremely heterogeneous. However, before assessing the importance of these local complexities, we can gain some insight into the potential of the user group groundwater management approach by simulating simplified, uniform approximations of these settings. To do this we have used a simple computer model (Macdonald et al 1998). The model allows abstraction within a central zone, occupied by the user group, to be reduced compared with that outside (those not in the user group). The model requires the recharge to the aquifer to be specified as well as the distance to the edge of the outer boundary of the aquifer. The scenario modelled assumes that the annual abstraction outside of the protection zone equals the annual recharge (both expressed in height of water). This approximates what occurs currently in many heavily exploited, low storage aquifers in India, where aquifers are effectively empty at the end of the dry season and the level of irrigation is dependent on the previous wet season rainfall. The pattern of recharge and abstraction input to the model is shown in Table 2.

Table 2 Pattern of recharge and abstraction input to the model.

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	monsoon season/Rabi crop						Kharif crop				summer	
Recharge	✓	✓	✓	✓	-	-	-	-	-	-	-	-
Abstraction	-	-	-	-	-	-	✓	✓	✓	✓	-	-

The model shows how in theory a mound could develop in time under the user group, were it to reduce its abstraction. The simluated water-level distributions show that significant water-level increases occur beyond the boundaries of the user group zone. The response of those just outside of the user group to the increase in groundwater levels as a result of the actions of the user group is likely to be an increase in pumping.

Ignoring this increased pumping from outside, we can use the model to calculate the volume of water leaving the user group area. If a significant proportion of the water that is not abstracted by the user group then leaves the user group control, the validity of the management approach needs to be questioned. Better economic return may be had from abstracting the groundwater when you can rather than trying to save water.

In Figure 3, the proportion of the water conserved by the user group (through reduced abstraction) that leaves the user group area is shown for typical aquifer settings, for a period of five years. The total volumes of conserved water lost over the five years is greater than 90% in all cases. This proportion will reduce as the diffusivity decreases, however, it is only when the user group radius becomes a significant percentage of the overall aquifer (>80%) that the proportion of conserved water remaining within the user group area after five years falls below 20%.

The conclusion is that only when the user group size is of a similar scale to that of the aquifer system is there the potential for the user group approach of reducing abstraction to establish a significant long-term buffer[6]. Given the social and institutional challenges in bringing together disparate groups with their own agendas to accept common goals, as has already been discussed in this report, the potential for the user group approach is only likely to be economically viable in geological environments where there are small bounded pockets of aquifers.

In the case of large regional aquifers such as in Mehsana District in Gujarat, the potential to bring many and varied users together would appear to be very difficult. However, even in the weathered hard-rock aquifers of Maharashtra, formed from the Deccan Basalts, conditions may not be appropriate, as suggested by the modelling. Problems are being experienced in the Pani Panchayat villages where groundwater is the source of irrigation. This is due to the increase in abstraction of groundwater in surrounding villages where groundwater is still in a development stage (Kulkarni et al, 2003).

Clearly there will be greater potential in weathered hard-rock aquifers but the Comman case study in Coimbatore District in Tamil Nadu (Palanisami et al, 2003) illustrates the difficulties in assessing the scale of these aquifers. The two villages being studied are both underlain by metamorphic Precambrian basement rocks. However, due to different mineralogy, grain size and structure, the weathered shallow layer is quite different. In one of the villages the weathering is limited, the shallow aquifer is typically 10 m deep; in the other, weathering is greater, the shallow aquifer typically 35 m in depth. In the former case the aquifer is very patchy with outcrops seen in many locations; in the latter case the aquifer extends laterally for up to tens of kilometres and could be described as regional. The analysis above would suggest that there is only potential for the user group approach in the former case[7]. The problem that arises is obtaining the data or involving those with sufficient technical capabilities (as discussed elsewhere in this paper) to be able to recognise where it would be reasonable to attempt a user group approach should the socio-economic conditions be appropriate. These two villages are only a few kms apart.

The success that can be achieved, however, is illustrated by the activities of the NGO, Tarun Bharat Sangh (TBS), in the Arwari Basin. TBS have been able to mobilise the local community to undertake water conservation measures at a basin scale. As the boundaries of the communities involved matches the boundary of the shallow alluvial aquifer from which they obtain their irrigation water, there is no interference from those outside the villages involved. Even so, measures are still restricted to supply augmentation through artificial recharge structures and demand management is limited.

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6 This makes the assumption there is sufficient storage in the system i.e. that the enhanced recharge and reduced abstraction do not simply result in increased discharge as baseflow to rivers

7 In fact, although the impact of overexploitation has already been seen in the former village, in the latter farms are still within a period of groundwater development and therefore it is unlikely that the social conditions presently exist to bring in measures to address falling groundwater levels.

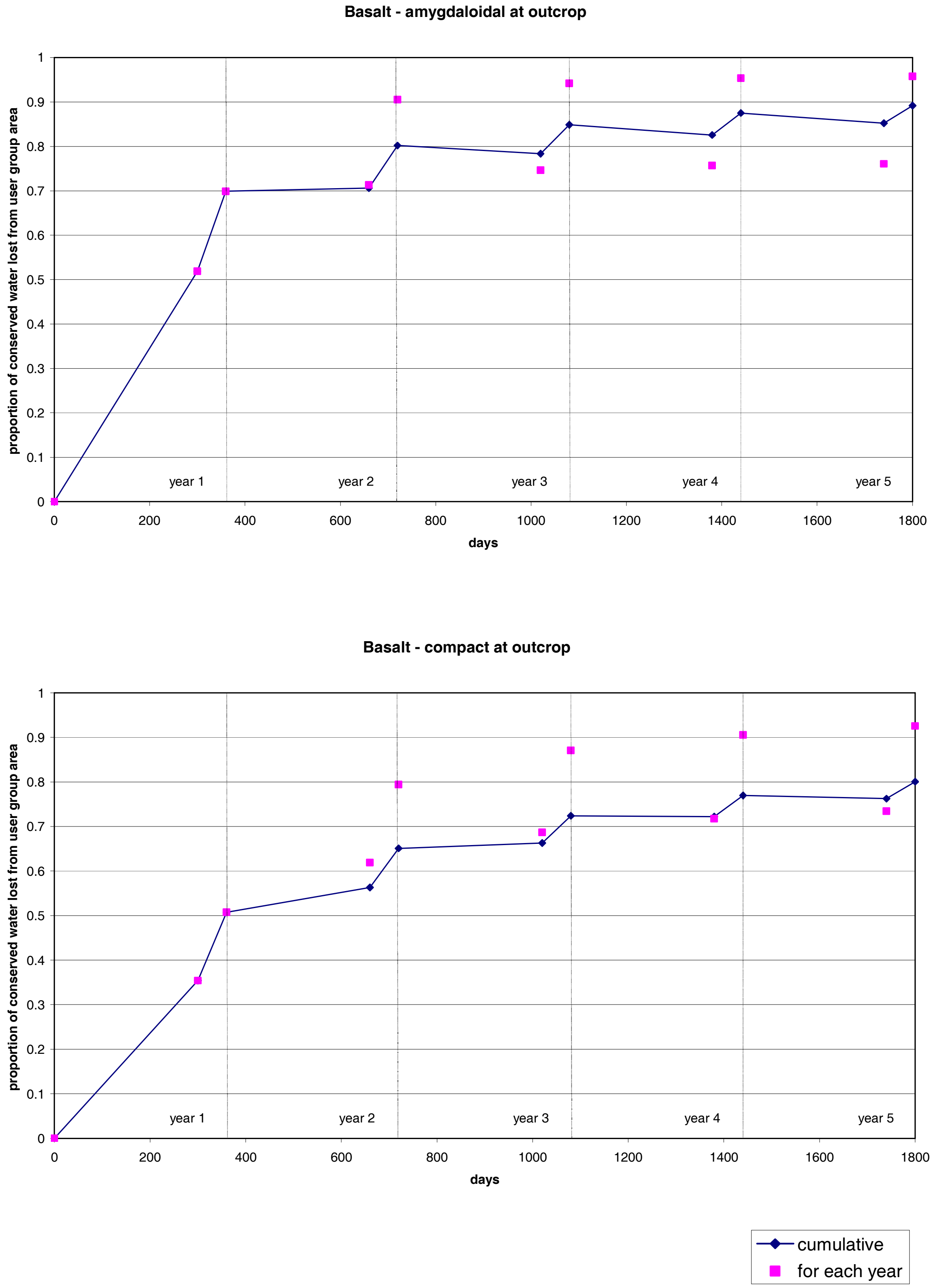
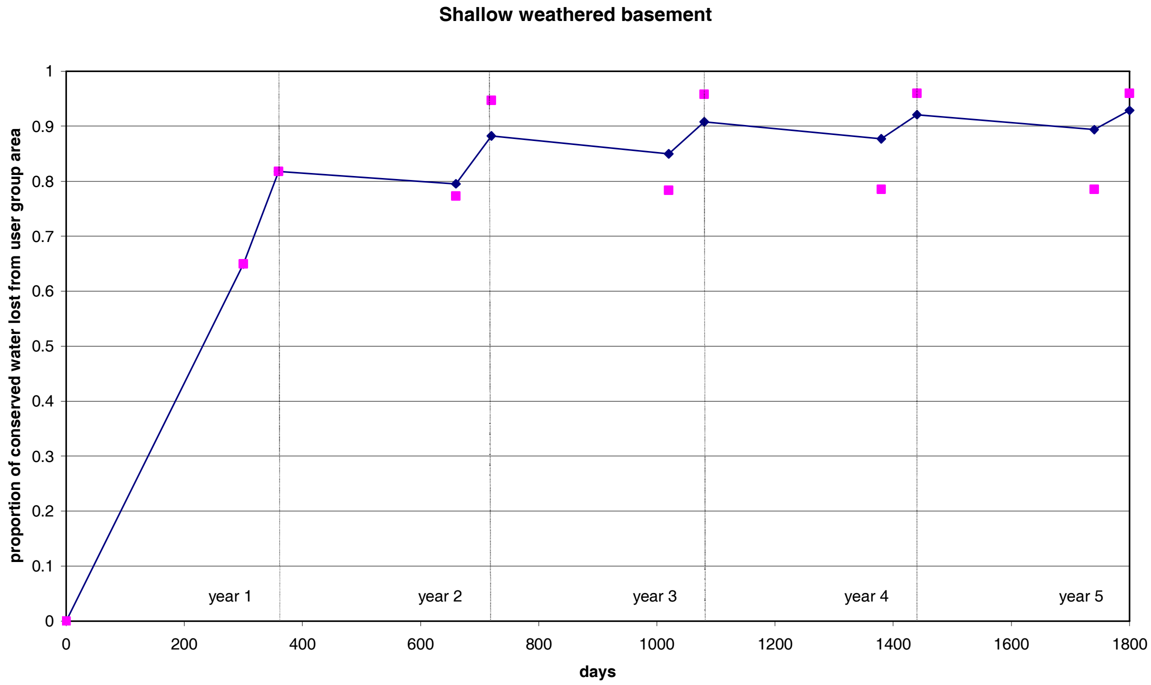


Figure 3a Proportion of water conserved by the user group (through reduced abstraction) leaving the user group area for typical aquifer settings, for a period of five years



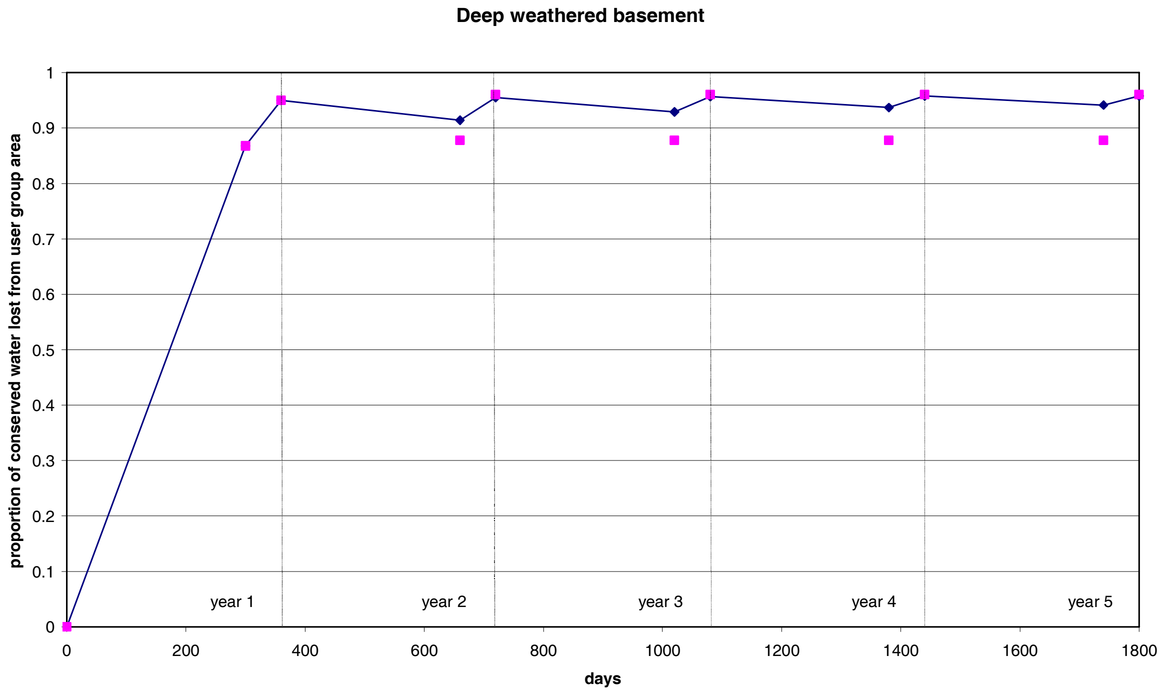


Figure 3b Proportion of water conserved by the user group (through reduced abstraction) leaving the user group area for typical aquifer settings, for a period of five years

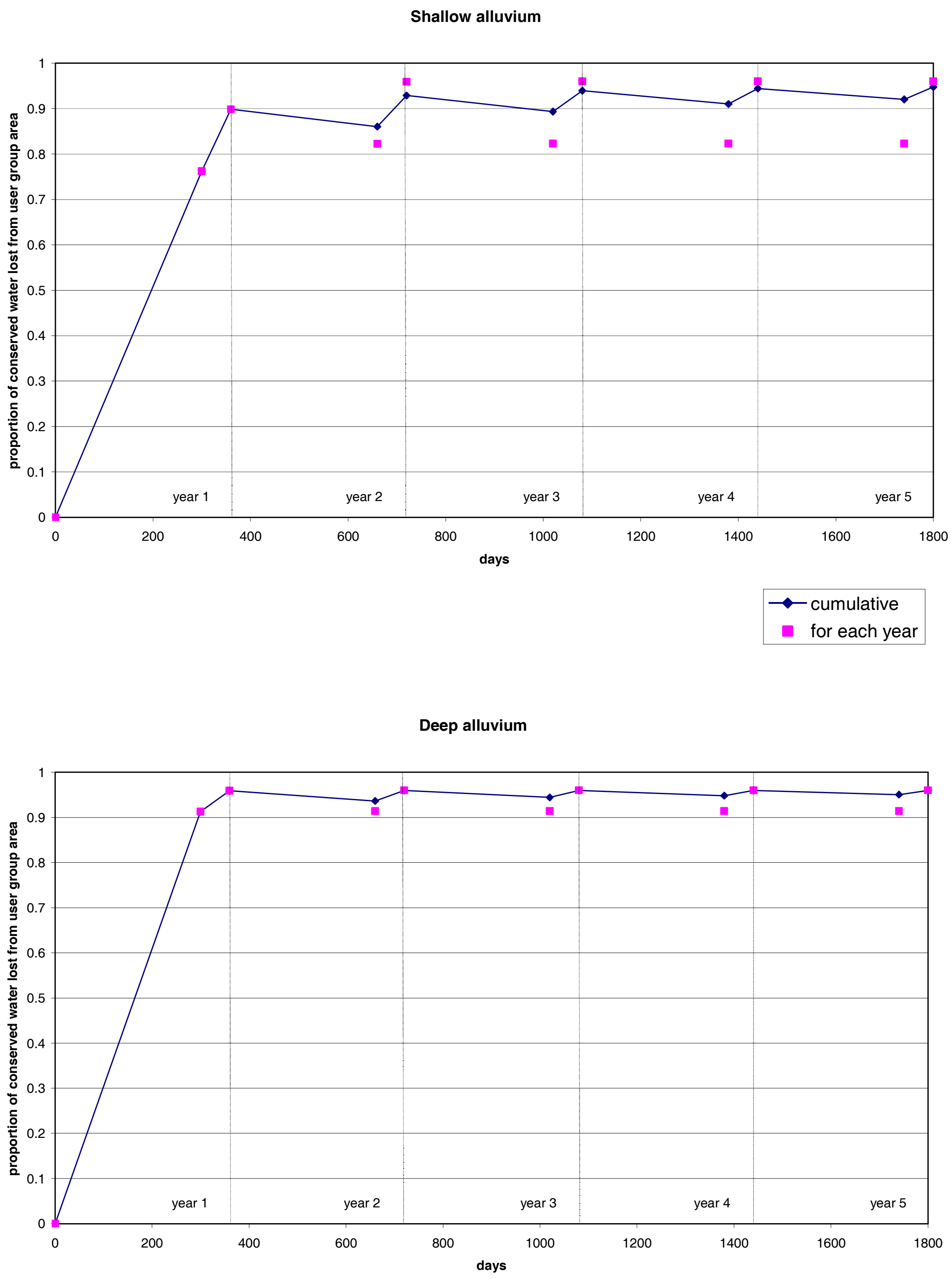


Figure 3c Proportion of water conserved by the user group (through reduced abstraction) leaving the user group area for typical aquifer settings, for a period of five years

Mapping Conventional Approaches onto the Social and Institutional Context

As highlighted above in the section on the institutional capabilities, institutional rather than technical issues are probably the most fundamental challenges facing the development of effective approaches to groundwater management. The question of *who* will actually do the management is of fundamental importance and remains to be answered. As previously emphasized the most important question is: *Do institutions exist or can they be created that would have the ability to implement management activities affecting both the demand and supply of water?* To reiterate:

1. Can management organizations be created that have an ability to directly influence supply and extraction at the level of hydrologic units?

2. Do mechanisms exist for financing the activities of such organizations on a long-term basis?

3. Do organizations have the capacity and authority to build infrastructure or undertake other activities to enhance the supply of water within aquifers (can they, for example, build check dams and recharge structures)?

4. Do organizations have the social and political clout to regulate or otherwise directly influence water extraction and use sufficiently to bring supply and demand into balance?

The above issues are absolutely central in the Indian context. Let us take each of the issues sequentially.

Creation of Management Organizations

As substantial literature over the past decade documents, organizations capable of functioning at the intermediate geographic scale required for aquifer management are not common in India (Moench 1994; Moench 1996). Most water resource management by communities occurs at the village level. Most other water resource management is implemented by the state. Even in hard-rock areas where groundwater flow regimes can be relatively localized, hydrologically interconnected zones often extend under multiple villages. In alluvial aquifers, such as the Meshana basin in Gujarat, the area overlying a single aquifer may contain thousands of villages. As a result, the question of whether or not management organizations can be created at the level of aquifers is a significant one.

Two major alternatives exist for forming management organizations at the level of aquifers or hydrological units: (1) governmental; and (2) representational or community-based. These are discussed below.

Governmental

Formation of governmental organizations for groundwater management can, given sufficient political will, clearly be implemented in high priority locations. This has already been done in Delhi under the auspices of the newly formed Central Ground Water Authority. This authority has the ability to notify areas for management based upon criteria such as the emergence of clear overdraft concerns. Once an area has been notified, the Authority has the formal power to regulate activities such as well drilling and to mandate registration of all wells.

Whether or not notification of areas for intensive management through groundwater management authorities will prove viable away from major urban centres or other particularly high priority locations is an open question. Many of the activities required for conventional approaches to groundwater management are regulatory and involve restrictions on wells or water uses. Such interventions are bound to be politically unpopular, a point of particular importance. More than sixty percent of India's population depends on agriculture and rural voters are central to the political stability of governments at the state and central levels. Since relations between rural residents and the state bureaucracy are often characterized by mistrust and conflict, politicians may be extremely reluctant to create new regulatory organizations unless a very high level of demand exists from those subject to regulation. As a result, *it seems highly unlikely that governmental organizations will have to be formed for groundwater management in many of the rural areas where overdraft problems are now emerging.* High priority areas where those demanding regulation (such as urban users served by municipal supply systems) are different from and politically dominate those directly using the resource (i.e. rural farmers) appear much more viable.

Representative or community-based

A substantial literature has developed over the past two decades that documents the conditions common to successful management of common pool resources (see for example BOSTID 1986; Ostrom 1990; Ostrom 1993; Bromley 1998) such as groundwater. Some of the most important factors that emerge regularly in this literature include:

1. a high level of broadly felt need for management;
2. clear systems of rights or rules-in-use governing access and resource utilization;
3. clear boundaries on the resource and the user group;
4. mechanisms to control free riders (including ways to restrict access for non-members or those not holding resource use rights)
5. clear systems for monitoring resource condition and use including documentation of the benefits from management
6. relative economic and cultural homogeneity among group members
7. a proportional equivalence between the costs and benefits from management
8. effective mechanisms for enforcement
9. small primary management group size often accompanied by the nesting of institutions where some management functions need to occur at regional or system rather than local scales.

This last point follows from Mancur Olson's frequently quoted passage in *The Logic of Collective Action* in which he notes that: "unless the number of individuals is quite small, or unless there is coercion or some other special device to make individuals act in their common interest, *rational, self-interested individuals will not act to achieve there common or group interests."* (Olson 1965).

Taken together all of the factors discussed above point toward fundamental social organizational challenges facing the development of community-based approaches to groundwater management under the conditions currently prevailing in India.

In many parts of India, users have little incentive to invest in managing the resource base. As Palanisami et al documented in the research undertaken in Tamil Nadu as part of this project (Palanisami et al, 2003), economic systems are in many areas changing rapidly and individuals, although they may fully recognize the impacts declining water levels are likely to have on agriculture, may not view these as primary threats to their livelihoods. As a result, a 'broadly felt need for management' may not exist. Where rights and 'rules in use' are concerned, existing rights systems are rules of capture that effectively allocate all power to individual landowners. As a result, they create strong disincentives for collective management. The issue of resource and user-group boundaries is also important. In both hard-rock and alluvial areas, identifying hydrological system boundaries for management purposes can be technically complex. Unless these can be identified, however, both the physical system and the boundaries of the user group that need to be involved will remain unclear. Mechanisms to control free riders are also problematic. Wells are generally owned by individuals and located on private lands. Even within individual villages developing mechanisms to ensure that individuals cooperate with management initiatives is likely to be complex. Monitoring of resource use and condition does not appear particularly problematic but documenting the benefits from management could be. In many locations, particularly in large aquifer systems, reductions in extraction or increases in recharge may not result in rapid or even observable changes in water levels. As a result, it may be difficult to convince individual users that management is having much benefit.

The above list goes on and questions could be raised in relation to each bullet point. It is important to recognize, however, that among all of the above points, scale is perhaps the most central challenge that must be addressed in order to enable the development of any representative or community-based organization for groundwater management. Challenges in creating a 'broadly felt need for management' or related to boundary definition, enforcement, free rider control, homogeneity, and so on are all likely to increase with the geographic scale of management and the number of individuals that need to be involved. As a result, community-based or representative management approaches appear to have the greatest chance of success in areas where hydrological systems are highly localized, as discussed earlier in this paper.

Overall there appears to be a major institutional gap where effective forms of organization have yet to be identified. The creation of management organizations by the state appears to be most likely in high priority areas where political support for management can be generated. Community-based approaches appear most likely to work in areas where groundwater flow systems are highly localized and therefore technically possible to manage at a local village level. In many regions, neither of these criteria apply.

Financing

Aside from organizational questions *per se*, issues related to the financing of groundwater management organizations and their activities should not be underestimated. At present most states in India are running budget deficits and there is tremendous pressure to reduce the size of the bureaucracy. As a result, the creation and staffing of new governmental management organizations finds little support from those in charge of state budgets. Obtaining governmental financing for local management organizations faces similar problems. While donor financing could be obtained for pilot initiatives, at present alternative models for financing groundwater management activities on a long-term basis do not exist. In locations such as the western U.S., water districts (which are generally governed through user-elected boards of directors) have quasi-governmental powers of taxation and use these as their main source of revenue. While theoretically possible, such mechanisms are not common in India. As a result, how management organizations might be financed remains an open question.

Capacity and Authority to Implement

Where state capacity and authority to implement physical management activities, such as the construction of recharge structures, is concerned, groundwater organizations would face few challenges in the initial creation of such infrastructure. Numerous governmental programmes already involve the construction of dams across rural India. Two major limitations are, however, important to recognize:

The state has faced far more problems *maintaining* infrastructure than initially constructing it. Water harvesting and groundwater recharge structures require regular maintenance if they are to remain operational. From tanks and village ponds to major surface irrigation systems, the maintenance of water related infrastructure is very weak in much of India. As a result, major questions exist whether or not governmental entities would actually have the capacity to maintain infrastructure for groundwater management if it were constructed;

Much groundwater management, particularly interventions designed to influence the demand side, depends on actions at the level of individuals. Choice of irrigation technologies, number of pumping hours, crops grown and so on are all major factors influencing groundwater demand. While governmental entities have the capacity to build large-scale infrastructure, they tend to be very weak in their capacity to influence actions at the level of individuals.

In contrast to the above, community-based organizations are likely to face a different set of issues with regard to groundwater management implementation. As a starting point, community-based organizations generally lack formal authority to undertake activities associated with groundwater management. Even the construction of water harvesting structures has proved contentious in some areas.[8] More intrusive actions – such as attempting to regulate crop choice or well construction – currently lack any legal foundation. While such actions can be taken on the basis of community consensus, community-based organizations currently have no formal authority to control any aspect of groundwater resource use by individuals. As a result, neither the authority nor the capacity to influence groundwater demand by any mechanism other than consensus through community-based organizations currently exists.

Overall, social capacity to influence the supply aspects of groundwater management, while far from sufficient, currently exists in both state and community-based organizations. Authority and capacity to influence groundwater use are, however, equally important for conventional management initiatives. This points toward larger questions of regulation.

Social and Political Capacity to Regulate

Conventional approaches to groundwater management rely heavily on the ability to regulate groundwater demand. This can be achieved either directly – through the establishment of legal or administrative controls over use or indirectly through, for example, economic mechanisms. Both approaches have been widely discussed in India in relation to groundwater legislation and power supply and pricing policies.

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[8] This has, for example, been the case with some of the sites where water harvesting structures have been constructed by Tarun Bharat Sangh in Rajasthan. Other smaller examples abound.

Direct Regulation

Proposals for groundwater regulation by the state have been present in India since the mid-1970s. Despite the powers such proposals would give to existing government departments concerned with groundwater, resistance from the public and analysts has been substantial. In the context of surface irrigation management, regulation has proved problematic. As Vaidynathan stated over a decade ago, often "system managers ... have no *effective* power to enforce the rules or the penalties for violating those rules" (Vaidyanathan, 1991, p. 19). Furthermore, as B.D. Dhawan commented on groundwater regulations when they were passed in Gujarat in the 1980s: "there is little hope for effective implementation of such laws which are inherently difficult to enforce in the Indian conditions of small land holdings, inadequate administrative set-up in the countryside, and eroded state of ethics." ((Dhawan 1989), p.9).

The above comments by analysts do not just reflect the perspectives of those outside the state. Resistance to the creation of government regulatory organizations has been substantial even within the state and central groundwater bureaucracies where power would be conferred. As many individuals in such organizations have pointed out to the authors over the last decade, existing state and central groundwater organizations were set up to develop the resource base, not directly manage it. The Central Ground Water Board-Central Ground Water Authority has a small scientific staff in Delhi and a limited number of regional offices within states. State groundwater departments or their equivalents generally have a construction wing specialized in groundwater drilling and a small staff of hydrologists whose task has been to evaluate and monitor the resource base. The groundwater bureaucracy has little if any physical presence even at the district to say nothing of block, village or ultimate farm level where groundwater use actually occurs. Simply surveying the number of operational wells would be a mammoth task for the current bureaucracy to implement on its own. Actually monitoring groundwater use on the millions of wells scattered among India's fragmented landholdings appears far beyond its capacity from the perspective of individuals within the bureaucracy.

Given sufficient political support, the bureaucracy is fully capable of concentrating its resources and regulating groundwater use within limited, very high priority, areas. This is, for example, currently being attempted in New Delhi and some of the aquifers near Chennai. In these areas, residents are now required to register wells and obtain permits before new wells can be drilled or existing ones deepened. Regulations restricting pumping from private wells or governing other aspects of groundwater use have not, as far as we are aware, been initiated. As a result, the verdict is not yet in regarding the viability of regulation even in high priority areas. Similar state regulatory initiatives across broad areas in Gujarat, Rajasthan or other states where groundwater resource extraction is high appear unrealistic to most individuals encountered within the bureaucracy.

Where community-based organizations are concerned, at present no legal authority exists that would formally enable regulation of wells or water use. A few informal initiatives have, however, been attempted. In Alwar District, for example, groups at some of the sites where management has been initiated through Tarun Bharat Sangh have agreed to limit water intensive crops. They have not, however, attempted to limit actual pumping from wells, well spacing or other aspects of groundwater use.

For both community and state regulatory approaches, sanction capacity may be one of the most fundamental flaws in conventional approaches to groundwater management. Sanction capacity tends to exist (or be possible to create) in areas where everyone agrees management is absolutely essential

- such as the primary aquifer serving a capital city. It rarely exists in other locations (too many wells, too many opinions on needs, strong differential power relationships, etc).

The table below, adapted from Macdonald et al (1995), indicates the wide array of potentially effective points for regulatory intervention along with our estimates of their enforceability through state or community level institutions.

Table 3 Options for controlling groundwater abstraction (after Macdonald et al, 1995).

Control		**Physically possible**		**Potentially effective**	**Rural acceptance**		**Enforceable**	**Comments**
		Existing	**New**		**Existing**	**New**		
Well design	Depth	Y	Y	Y	N	Y	Y - state, select areas D - remote rural areas D - community	Protect shallow and deep aquifers
	Diameter	N	Y	not beyond a critical limit	NA	Y	D (dug wells)	Viability to be assessed
Pump	Type	Y	Y	Y	N	Y	Y - state, select areas through manufacturers D - community	
	No. per well	Y	Y	Y	N	D	D	Multi-ownership difficulties
	Intake position	D	Y	Y	D	D	D	
Well abstraction	Duration	D	Y	Y	N	D	D	Control through electrical supply, pump type and co-operative user groups
	Rate	D	Y	Y	N	D	D	
Location in relation to public supply well		D	Y	?only when aquifer details known	N	Y	Y - both state and community	Example – broad based protection zones not necessarily effective
Markets		D	Y	Y	D	Y	D - most markets in India are informal and involve arrangements between individual users. Regulation would be very sensitive	Very delicate issue, would need to be handled with care, since markets are generally more entrenched in regional and deep seated aquifer systems.

Y=yes; N=no; D=doubtful; NA=not applicable; ?=needs further research

Overall, as a result, the question of institutional capacities is absolutely central to the viability of conventional management approaches. Who will actually ‘implement’ the management is a major question. The need for interventions to control groundwater demand is widely recognized – but the ability to actually regulate use either through governmental or community-based organizations has not been widely tested. Furthermore, even without testing, the viability of directly regulating well characteristics, extraction and groundwater use appears questionable.

Indirect Regulation through Power Pricing

In addition to direct regulation, linkages between power pricing policies and overdevelopment of groundwater have been widely discussed for over a decade (Arora & Kumar, 1993; Ebrahim & Mohanty, 1993; Malik, 1993; Nagaraj & Chandrakanth, 1993). While it is beyond the scope of this paper to summarize the extensive debates that have occurred over power pricing, they are of direct relevance for conventional approaches to groundwater management and, as a result, important to note here.

Power for irrigation pumping is, in most states, provided on the basis of a low, flat-rate fee based on pump horsepower. This tariff structure has been recognized for a long time as providing strong incentives for inefficient water use and contributes to overdevelopment (Moench, 1991). As a result, shifting electricity prices to a consumption based structure and removing (or at least reducing) the current level of subsidy has been advocated by many groups, including the World Bank, as an essential first step toward addressing groundwater overdevelopment problems (World Bank 1998; World Bank Study Team 2001).

The first and probably most important point to note is that while power price reform has been widely advocated for over a decade, actual reforms have proved politically difficult to implement. Many state governments have debated price reform and have made more or less progress depending on their ability to manage the political opposition it generates. In this context, while pricing reform may occur, it is unlikely to be tailored to potential opportunities for indirect regulation of groundwater extraction. Furthermore, despite the clear incentives subsidies create for groundwater extraction, it is far from clear that indirect regulation via changes in power pricing would move groundwater use towards more sustainable levels. Analyses undertaken at various points over the last decade indicate that the returns from groundwater irrigation are often sufficiently high that changes in power pricing would have a limited impact on the overall amount of groundwater extracted (Moench 1995; Kumar and Singh 2001). In addition, it is difficult to tailor power pricing policies to meet groundwater management needs in specific areas. Areas suffering from groundwater overdraft often exist within a short distance of canal command areas where groundwater levels have been rising and water logging is a concern. Power pricing policies designed to reduce extraction in overdraft areas would, as a result, exacerbate water logging concerns in other areas. Finally, power pricing policies affect all agricultural power use, not just groundwater pumping. As a result, attempting to manipulate power prices to induce changes in groundwater demand would have widespread implications for other types of agricultural activities.

Overall the situation with power pricing indicates that major limitations exist for indirect regulation of groundwater extraction through economic mechanisms. A wide variety of factors influence the economics of groundwater extraction. It is difficult to tailor these to meet the specific needs emerging in any given management area.

Objectives of groundwater management

The above sections identify what appear to the authors to be inherent limitations in conventional management approaches and the 'sustained yield' concepts on which they are founded. As a result, it is essential, while not rejecting the importance of conventional approaches, to move beyond them. The starting point for this must be the objectives from which management approaches grow.

International literature searches as well as some of the attempts at groundwater management in rural India suggest a possible range of objectives beyond sustained yield that could provide a foundation for innovative approaches. The specific objectives that emerge focus on issues such as poverty alleviation, social stability and security, and economic transition (Burke and Moench 2000; Shah, Alam et al. 2000; Abderrahman 2001; Moench 2002). Taken together, however, *they point away from the resource base and toward the quality, resilience and adaptability of the livelihoods currently based on groundwater use*. The question is not, for example, whether or not sufficient groundwater is available to indefinitely maintain low income agricultural livelihoods but whether or not groundwater development can serve as a mechanism to help populations transition out of high vulnerability livelihoods and into lower vulnerability livelihoods. Agricultural intensification that draws down available groundwater stocks can, over a generation or so, enable education, capital accumulation and the movement of entire populations from subsistence livelihoods to diversified economic systems in which agriculture may only represent a small component. This, according to some authors, was the specific objective of groundwater development programmes in Saudi Arabia. The following section, drawn from a recent paper by Moench (2002), briefly summarizes the Saudi example.

"Between 1975 and 2000 Saudi Arabia used about 19% of the non-renewable groundwater stored in the upper 300 meters below ground level to develop settled agricultural populations in many rural areas. Although the primary crop was wheat, the national objectives behind this had little to do with food production *per se*. Instead, the primary stated objectives were to settle nomadic groups, to build stable populations in areas that would otherwise be relatively unpopulated desert, and to limit rural-urban migration.

Saudi Arabia shares borders with eight other countries. Many of these border regions are located in unpopulated desert areas where traditional populations have always been nomadic and difficult for a central authority to monitor or control. As a result, the development of settled agricultural populations in sensitive border regions was seen as a key tool for stabilization of such areas. It would reduce the number of nomads and by implication "put people on the ground" in locations where disputes might arise with neighbouring countries. In addition, Saudi Arabia faced major social challenges as it transited from a rural to urban society. Before 1974 the rural population in Saudi Arabia exceeded 50% and roughly 30% of the rural population was nomadic. As oil revenues grew, large numbers of jobs and other opportunities were created. The urban opportunities caused intensive migration of rural inhabitants to urban areas (the urban population increased to approximately 70% of the total by the mid 1990s) which "disrupted the social system and created a vacuum in rural areas."(Abderrahman 2001).

To limit urban migration and stabilize rural populations, Saudi Arabia drilled more than 100,000 wells, provided a 40% subsidy for farm equipment and put in place a price support policy for wheat between 1980 and 2000 that ranged from $0.57 to $0.97/kg. From Abderrahman's perspective:

"This agricultural development was an essential tool for social balance between urban and rural areas. The intensive agricultural developments resulted in the creation of stable farming communities in rural areas….These prosperous communities helped in supplying the country with educated healthy generations of young men…They also helped in filling the deserted areas and in giving the support to security and defence authorities in remote areas…Other benefits were gained also such as minimization of movement of inhabitants from rural to urban areas."(Abderrahman, 2001).

The situation in Saudi Arabia has strong, though probably unintentional, parallels in India. In some of the Comman Project field sites in Tamil Nadu, agriculture was the dominant livelihood two decades ago. Since then a wide variety of factors have allowed the expansion of non-agricultural livelihoods. Much of this expansion was enabled by external inputs such as extension of the power grid, road construction and communications improvements. The ability of local populations to utilize these inputs may well, however, have been increased by the social capital they had initially created through groundwater-based agricultural intensification. Groundwater development several decades ago may have enabled them to educate children and make other investments that are now coming to fruition in conjunction with other social infrastructure changes.

While the situation in Tamil Nadu is suggestive – but poorly documented – the link between groundwater use and social transition in other parts of India is clear. Groundwater development has played a major role in poverty alleviation across broad sections of the country (Shah, Alam et al. 2000; Moench 2001). In some areas, such as Gujarat, the capital accumulated during three to four decades of intensive groundwater based agriculture appears to be a significant factor enabling livelihood and economic diversification. As Tushaar Shah has documented, the groundwater economy is now, in some locations, declining. This is not, however, leading to widespread impoverishment. While some populations are 'left behind' many transition successfully to other livelihood systems.

The point here is that *de facto* groundwater management practices which are, from a conventional perspective, unsustainable may contribute to long-term improvements in livelihoods. If one moves beyond a groundwater focused perspective, the core issues have less to do with groundwater conditions *per se* than with issues such as equity, the problems facing populations that are poorly situated to move beyond groundwater dependence and the environmental costs associated with decades of intensive groundwater use. As a result, a wider perspective on groundwater management would emphasize larger questions of livelihood and economic transition, social equity and environmental impacts rather than simply the sustained yield of a given aquifer. From this perspective, the objective of 'groundwater management' might have little to do with direct control overextraction or recharge and much more to do with how different policies influence social transitions based on use of the resource along with the environmental impacts such use has.

Between this extremely broad livelihoods and social-transition perspective and the conventional focus on sustained yield exist a wide variety of management concepts that directly link aspects of water use with social, economic and environmental objectives. These include:

1. efficiency of groundwater use, focused on obtaining a high 'crop per drop' ratio. In practice this could well mean use of technologies like drip and sprinkler irrigation, addressing the issue of distribution of groundwater, especially for irrigation.

2. equity of groundwater use wherein the concept of common property can be used within a community.

3. ensuring an agricultural production that is not only reliable but can be increased to a maximum / optimum / satisfactory level.

4. providing a buffer of groundwater resources for drought years bearing in mind that groundwater resources constitute the best option for reserving supplies during drought periods.

5. prioritising uses of the groundwater resource, e.g. drinking, livestock, irrigation and industrial and implementing interventions that enable allocation of available resources to specific uses.

6. maintaining the environmental role of groundwater resources, e.g. maintaining baseflows, wetlands etc.

Further exploration of conceptual issues surrounding the objectives and applicability of groundwater management concepts would serve little purpose until they are grounded in the India context. As a result, the next section of the paper focuses on the specific context in which groundwater management debates are occurring in India. Before shifting, however, it is important to recognize that the concepts and objectives bulleted above do not, at present, represent or aggregate into any internally consistent management philosophy. They do, however, point toward key social values that go beyond sustained yield and begin to provide a practical link between groundwater *per se* and wider perspectives on livelihoods and environmental sustainability.

Summary: Fundamental and Situational Challenges to Conventional Groundwater Management

The above two sections mapping conventional approaches to groundwater management onto the technical, social and institutional context in India highlight a wide array of challenges. While some of these challenges are situational and could be changed through appropriate policies or other interventions, others are fundamental.

Scientific Challenges

It is important to recognize that, whatever policy or other changes are made, fundamental gaps in hydrogeological data and scientific understanding will remain. Short periods of record for hydrological data cannot be rectified until the decades required to collect additional data have passed. On an even more basic level, given climatic variability and change, the unknown relevance of historical data as a tool for predicting future conditions represents a fundamental constraint on our ability to manage resources in a sustainable manner. In addition, many gaps in the ability of science to quantify flows through hard-rock aquifer systems or accurately estimate key elements of the mass balance equation determining water availability will remain weak. As a result, the ability to define, for example, volumetric water rights in a way that directly relates to aquifer conditions faces fundamental scientific limitations. Such limitations are compounded by the situational context, including the highly politicised nature of agricultural and power policies, surrounding groundwater data collection India.

The above analysis suggests the importance of moving away from reliance on estimates, such as the extraction-recharge figures produced by the Central Ground Water Board, as the basis for initiating groundwater management. In this context, approaches to groundwater management need to focus on simple, direct, empirical measures of groundwater conditions such as water level trends. Such empirical measures are directly observable and relate to the availability of water users actually experience at the field level. Higher level mass-balance concepts are useful tools for organizing understanding of how aquifers work and can be important for determining which empirical indicators to use – but they provide little quantitative guidance for management at the local level. It also suggests that groundwater management is most likely to be effective in areas, which are hydrogeologically relatively straightforward. Complex aquifer systems with difficult to evaluate flow systems are likely to be far more difficult to manage than more hydrologically straightforward areas.

Overall, reliance on direct empirical measures and focusing management on hydrologically straightforward areas may be central to the ability to implement conventional groundwater management concepts.

Institutional Challenges

While many institutional challenges facing groundwater management in India are situational and have to do with immediate political or economic considerations, it is important to recognize that fundamental blockages may exist. Scale and forms of human organization may represent one such fundamental challenge.

If many of the elements documented as important to the management of common pool resource represent 'fundamental' characteristics of human organization, then it may be impossible to create conditions conducive to community-based approaches at the scale groundwater management is needed in many areas. This pessimistic view suggests that because of scale, the number of individuals involved, free rider and enforcement problems, and scientific difficulties in defining resource boundaries, community-based organizations are only likely to be effective at local levels. Above such local levels, some form of quasi-state or less participatory organization will be essential in order to implement conventional forms of groundwater management.

Statal forms of organization also face major, we would argue fundamental, challenges in implementing conventional groundwater management. India is a democracy. Within democracies, the political position of politicians is threatened if they undertake unpopular regulatory moves that have immediate negative impacts on the livelihoods of their constituents. Demand side management of groundwater, which is essential in many areas if extraction is to be brought into balance with recharge, will in most cases have a negative impact on farmer livelihoods, at least over the short-term. This 'fundamental' dynamic is a key factor underlying the lack of "political will" groundwater experts often complain about in relation to groundwater management. State organizations have fundamental reasons for supporting supply-side approaches and equally fundamental reasons for avoiding demand side management in most areas.

Developing criteria that would assist communities, government entities, NGOs and others to recognize when conventional approaches to groundwater management are likely to be blocked by fundamental institutional or scientific challenges is important. At least two sets of opportunities are clear:

1. areas where hydrological systems relatively match community scales and individuals have a strong incentive to contribute to management represent an opening for community-based approaches;

2. strategic aquifers where management by the state would be supported by politically influential populations.

Beyond such areas it is important to recognize that conventional groundwater management interventions are likely to be partial. Politically popular interventions (such as the construction of recharge structures) are likely to prove viable while other interventions (typically those involving regulation or other initiatives to change demand) are unlikely. This all leaves large areas where conventional groundwater management approaches may well not prove capable of addressing emerging overdraft problems. As a result it is important to revisit the foundations on which conventional approaches to groundwater management are based. Redefinition of groundwater management may assist society in identifying avenues for meeting core objectives even when conventional management approaches prove difficult to implement.

Expanding the Definition of Groundwater Management

Conventional perspectives on groundwater management focus on water availability and quality, with ‘needs’ and ‘uses’ taken as given. There is little attempt to disaggregate water demand and identify the fundamental services society requires – and then explore whether or not these could be met with less water. Take the case of agriculture. In most cases, conventional approaches to demand as part of groundwater management focus on irrigation service. The groundwater management perspective emphasizes water supply in relation to crop water needs. It then identifies ways to improve the efficiency of water supply in relation to those needs (i.e. via drip) with the assumption that this will reduce the demand for groundwater. Occasionally, this perspective is pulled up one further level to address crop choice (lower water intensity crops) and the impact that might have on water demand. In general, however, the core objectives society is attempting to achieve through agriculture are not identified as part of the groundwater management equation. These core objectives: livelihoods, food production and food security are not directly considered in conventional approaches to groundwater management. We believe they are of fundamental importance to an expanded perspective.

What core social objectives are threatened by groundwater overdraft? From the perspectives of individuals, policy makers and politicians, groundwater dependent livelihoods are probably one of the most important closely followed by environmental conditions, regional economic systems and other secondary considerations. If one focuses on these core values rather than groundwater conditions *per se* it may be possible to identify a host of areas where interventions could mitigate the impact of groundwater overdraft (and possibly reduce overdraft levels) even where the ability to directly manage the resource base is limited.

Take a livelihoods perspective. In many areas such as Gujarat, intensive groundwater-based agricultural livelihoods have only been central feature of regional economies for three to four decades. From an historical perspective, such livelihoods are transitory. Prior to groundwater development, livelihoods were based on animal husbandry and low-intensity rainfed agriculture. Now, four decades after groundwater development initiated a transition away from these historical patterns, livelihoods are shifting again. In many areas, communications and transport have improved dramatically and the educational level of populations has improved. As a result, many rural residents have already diversified into a wide array of non-farm activities. In the Tamil Nadu case study area, twenty years ago agriculture was the mainstay of the economy, now although it remains a significant source of income, it is no longer dominant. Families have diversified into the wage labour market, small business and a host of other activities. This diversification may have been accelerated by decreased access to groundwater as water levels fell – but it was enabled and driven by a host of factors outside the agricultural economy.

The above dynamics are, as Shah and Alam (2000) suggests, probably common throughout much of India. They suggest that livelihood focused interventions may have as much, if not more, ability to mitigate the impact of emerging groundwater problems than conventional forms of groundwater management. By identifying the problem, not as a water issue, but as a livelihood issue, all sorts of solutions – groundwater management as well as non-groundwater solutions, may become evident. One 'solution' to groundwater overdraft, for example, may be to encourage regional economic transition out of agriculture and into lower water intensity forms of livelihood. Since this is already happening in many areas, unlike attempts to form 'community groundwater management organizations' it matches with the incentives individuals already face. In addition, if regions shift to low water intensity forms of livelihood, it may pull demand off groundwater resources and allow aquifers to recover.

The difference in approaches is important to note. In contrast to conventional notions of demand management, for example, emphasizing the development of non-farm livelihoods does not involve any attempt to directly regulate or control groundwater extraction and use. Instead it focuses on enabling people to make livelihood shifts they are often attempting to, in any case, on their own. From this perspective, financial self-help groups, micro-credit, education, improvements in communications and transport, etc could all be seen as components of any response to emerging groundwater problems. Furthermore, by recognizing the potential implications these different types of intervention may have for mitigating groundwater problems, alternative institutional arrangements may be possible to identify.

While many limitations may exist with respect to the direct management of groundwater resources through community-based strategies, these limitations may not apply to the wider points of leverage just identified. It may, for example, be far more realistic for communities to develop common banking arrangements or support the construction of transport networks than for them to attempt to regulate groundwater extraction.

Overall, expanding identification of the problem away from groundwater *per se* to livelihoods and other social values has clear potential as an avenue for mitigating emerging groundwater problems.

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Community Based Management: A Review of the Issues

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Introduction

The purpose of the paper is to evaluate the literature on Common Pool Resources (CPRs) and to pinpoint parameters which influence the potential for sustainable resource management by rural communities.

The paper is structured into two parts. It starts with a discussion of the conceptual framework of Ostrom's characteristics of CPRs and Bromley's distinction between different property management regimes. It continues with a brief debate on the rules-approach to CPR management. The second part of the paper focuses on a selection of key parameters for sustainable resource use. It is concluded that even though parameters influencing CPRs can be determined, their interaction and interdependence remain vague.

A theoretical framework of CPRs

Classification of goods

Ostrom (1990) identifies four different types or classes of goods:

- Private goods - single use; restricted to people who pay
- Toll goods/club goods - joint use; restricted to people who pay
- Common pool goods - single use; not restricted
- Public goods - joint use; not restricted

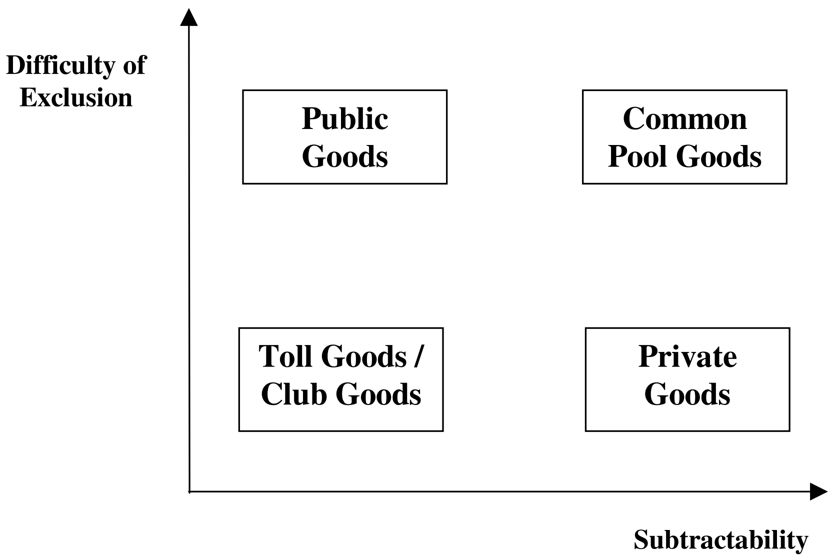

Figure 1. A general classification of goods. Based on Ostrom (1990)

Ostrom argues that private goods are characterised by relative ease of exclusion in an economic and legal sense and are subtractable, i.e. after purchase private goods are not available to others. Public goods are the opposite of private goods. The good can be consumed by more than one person, and in relative terms, the benefits do not get reduced by additional users. Toll goods share with private goods the relative ease of exclusion and with public goods the relative lack of subtractability. CPRs share with private goods the subtractability of resource units, and with public goods, the difficulty of exclusion (Ostrom et al 1994, p.7). However, these definitions are relative, goods can belong to different groups at the same time, hence it depends on the level of analysis to distinguish between the goods. A commodity can be a private good for a group, such as private property for a household with different users all utilising the resource.

According to the above classification CPRs can be defined as “a class of resources for which exclusion is difficult and joint use involves subtractability” (Berkes 1989, p.7). This definition is similar to Ostrom’s and Feeny’s and highlights the essential dynamic of the CPR problem. Nearly ten years later Williams defines common pool resources as “natural or man-made resources used simultaneously or sequentially by members of a community or a group of communities” (Williams 1998, p.1). Williams’ definition does not address issues of excludability and subtractability, hence, he does not distinguish between public goods and CPRs or club goods and CPRs. However, his definition is important because it shows that different groups can utilise the same resource, and that the resource use does not necessarily reduce the benefits for other users in all cases. Hence a combination of the two definitions would be appropriate, which incorporates the multi-dimensions of CPR use.

Problems of CPRs

As mentioned above CPRs have two defining characteristics:

- the difficulty of excluding individuals from benefiting from a good; and
- the subtractability of the benefits consumed by one individual from those available to others (Ostrom et al, 1994, p. 6).

Oakerson reasons that the exclusion principle “refers to the ability of sellers to exclude potential buyers from goods and services unless they pay a stipulate price.” (Oakerson 1992, p.44). In the debate on CPRs, the concept has been broadened to include non-market means of excluding potential users from accessing a good. Williams reasons that “difficulty of exclusion - arises from several factors including the cost of parcelling or fencing the resource and the cost of designing and enforcing property rights to control access to the resource.” (Williams 1998, p.1). The difficulty of excludability is connected to the ‘free-rider’ problem. Gibbs & Bromley argue “if individuals fail to contribute to the management of a collective good when they expect that others will, they are behaving as free riders” (Gibbs & Bromley 1989, p.25). It is possible to distinguish between different free-rider situations, such as appropriation by non-members, additional appropriation by members and the costs of provision by members. (In addition, second-order free-riding is possible, this implies that individuals avoid monitoring of others or the enforcement of rules by rule-breakers. Individuals can fail to contribute to the monitoring and enforcing of CPR use rules, but assume that others will.)

Each user is capable of subtracting from the benefits that others derive from a CPR. In other words, “The resource units (e.g. bundles of firewood or fodder) that one user extracts from a common pool resource are not available to others.” (Williams 1998, p.1-2). However, it could be argued that subtractability is not in itself a problem, or by itself the cause of externalities. After all, private goods are subtractable but the consumption or use are not necessarily problematic. Hence, substractability only becomes a problem when the resource is limited and no alternatives to the resource are available. Subtractability creates externalities for different users and can therefore lead to rivalries between different users. Oakerson argues that subtractability can apply to some resources in two ways. Firstly subtraction from a flow of benefits; what one appropriates is unavailable to others. Second, cumulative use by many individuals will eventually subtract from the total yield of the commons over time. The latter type of subtractability reduces the capacity of a resource to generate benefits (Oakerson 1992, p.44). Because of this characteristic it is argued that CPRs are potentially subject to over-exploitation, depletion or degradation. However, not all users utilise the CPR similarly therefore not all uses have to be subtractable to all users in the same way. It could be argued that the concept of subtractability is problematic where it just focuses on the use of a resource for one activity and assumes potential costs and benefits are equal for all users.

Ostrom distinguishes between two types of CPR problems: appropriation and provision. While the appropriation problem of a CPR is related to the "subtractability of the benefits consumed by one individual from those available to others." (Ostrom et al 1994, p.6). "Provision problems, are related to creating a resource, maintaining or improving the production capabilities of the resource, or avoiding the destruction of the resource. [...] In provision problems, the resource facility or resource stock of the CPR is problematic" (Ostrom et al 1994, p.9). Hence, provision problems are related to the operation and maintenance (O&M) of the resource and its delivery system, in the case of groundwater this could imply land management (that increases run-off, reducing the potential for groundwater recharge), recharge tanks and common pump-systems. The task of provision is to ensure the resource and its distribution system is sustainable over time and to guarantee efficient and reliable service delivery.

According to Ostrom "solving provision problems depends on achieving adequate solutions to appropriation problems" (Ostrom 1990, p. 49-50). She argues that provision problems are intractable, unless appropriation problems are resolved. However, "the nature of the appropriation problem is affected by how well the provision problem is solved" (Ostrom et al 1994, p.15). Examples from irrigation systems indicate that even if the appropriation problem is resolved, it is still possible to free ride in terms of provision. Hence the provision of a CPR faces the difficulty of excluding individuals from benefiting from provision improvements. In the case of groundwater and recharge tanks, individuals who are not contributing to the O&M of the tanks are still able to utilise groundwater. Any improvements in recharge will affect all users, including those who chose not to contribute.

Because of the link between provision and appropriation of groundwater as a CPR, it might be feasible to connect tank or pump management organisations with groundwater management. This would imply that tank irrigation associations or surface water associations could extend their role to manage groundwater abstraction by members of the associations.

CPR rights and management

In addition to the distinction between subtractability and excludability and appropriation and provision, it is possible to distinguish according to the rights to the resource (property). Bromley & Cernea (1989) distinguish according to the management system, identifying four different property regimes:

- Public property: ownership and control over use rests in the hands of the state. Individuals and groups may be able to make use of the resources, but only at the forbearance of the state.

- Private and corporate property: sanction ability to legally and socially exclude others.

- Common property: “private” property for the group, group decision regarding exclusion (club goods and toll goods would fall into this category).
- Open access: “no property rights have been recognised”, as “everybody’s access is nobody’s property.”

The difference between common pool and open access resources is that in the latter case the number of users, or the resource utilisation, is not limited. The utilisation of the resource is neither managed nor controlled and therefore open to all and prone to over-consumption. Hence, the difference between the two is management of the resource. This is similar to the groundwater case in South Asia where until now groundwater utilisation has been developed without institutions or organisations to manage the resource.

However, evidence from cases indicates that the distinction between different CPR management systems is not as clear-cut as the theory assumes. Very often the boundaries are blurred and two management systems operate simultaneously. Williams states that “a few CPRs can be easily classified under one property-right system.” (Williams 1998, p.3). For example, state property, which is administered through specialised government agencies. Here various codes and legislative edicts prescribe rights for different users and penalties for infractions. However, even clear property right systems are dependent on the ability of monitoring and enforcement. Without these abilities clear property regimes are invalid.

In addition, for many CPRs a clear classification is not possible. Williams reasons that “a given resource may produce flows (for a definition see below) that are subject to two different property regimes seasonally or over the long term.” (Williams 1998, p.3). He argues that “fields that are cultivated by individual households often revert to communal use after grain harvest or when they are left in fallow so that crop residues and natural vegetation on these fields can be freely grazed by the entire village herd or collected by those households who need them.” (Williams 1998, p.3).

Because of the multi-functionality of CPRs it is possible for different uses of the same resource to be managed according to different property regimes. For example a tank for rainwater harvest could be used under private property for fishing, open access for basic needs and collectively for irrigation and groundwater recharge. Hence, one would have to consider inter-group relations in the utilisation of CPRs.

Furthermore, Williams points out “communities that possess primary use rights often allocate rights of access to subsidiary groups.” (Williams 1998, p.3). He states “groups holding secondary or tertiary rights may be other ethnic groups engaged in a different occupation, women or the poorest members of the community.” (Williams 1998, p.3). The access rights to the CPR between these groups would have to be renegotiated according to the availability of the resource and according to the priority of different uses, for example, water for domestic, livestock or irrigation use. The primary use-group may shift, which could lead to conflicts or renegotiation of access rights. Hence, the heterogeneity of users and the multiple functions of CPRs make Bromley’s distinction between property rights regimes blurry. The debate suggests that CPR management regimes have to be flexible and dynamic.

CPR management: institutional rules hierarchy

Steenbergen & Shah argue that "informal rules and norms even without a formal or informal organisation can effectively control groundwater exploitation" (Steenbergen & Shah in press, p.8). They argue that "compliance or non-compliance is visible and does not need a special organisation to enforce it. Any person can through open contempt or intimidation withhold another person from breaking the moral code." (Steenbergen & Shah in press, p.9). However, they do not state how these informal rules and norms come into existence, or how they change over time. Furthermore, they seem to suggest that these rules reflect a general "moral" code, which is uncontested or generally accepted from all members of the community equally.

In addition, it is questionable whether such a system can deal adequately with a CPR which has multiple functions and a fluctuating resource flow. A rule-based system focusing on operational rules only would seem to be less adaptable to deal with changes, such as market, technology, politics and environment. Furthermore, Steenbergen & Shah's focus on operational rules does not take into consideration that operational rules are embedded in a hierarchy of rules. Hence higher-level rules influence, define and sanction operational rules when larger changes occur.

As indicated above, the focus on already existing operational rules seems to ignore that these rules are based on power asymmetries. Mosse, analysing tank irrigation systems in India, argues that these systems did not come into being as isolated autonomous village systems, but they were part of a political process in which rival chiefs extended and maintained domains of control (Mosse 1997, p.477). Hence, old operational rules might reflect the interest of old stakeholders and their control over resources. Along this line is the reasoning of Baland & Platteau, who argue "weaker categories of users are frequently excluded by dominant groups" (Baland & Platteau 1999, p.785). In addition, Mosse states that rules describe "publicly accepted norms of official codes. Often, these rules 'encode' the interests of some people better than others" (Mosse 1997, p.481).

Hence operational rules are embedded in a larger frame of rules. Ostrom (1990) and Ostrom et al (1994) suggest a rule hierarchy:

- *Operational rules* directly affect the day-to day decisions made by appropriators concerning when, where and how to withdraw resource units; who should monitor the actions of others and how; what information must be exchanged or withheld; and what rewards or sanctions will be assigned to different combinations of actions and outcomes.

- *Collective choice rules* indirectly affect operational choices. These are the rules that are used by appropriators, their officials or external authorities in making policies – the operational rules – about how a common pool resource could be managed.

- *Constitutional choice rules* affect operational activities and results by determining who is eligible and by defining the specific rules to be used in crafting the set of collective-choice rules, that in turn affect the operational rules.

In terms of groundwater management, the operational rules determine the rights for the individual users to abstract groundwater and the collective-choice rules determining when, where and what kind of pumps could be used for abstraction.

Because of the multiple functions of a CPR, operational rules need to take into account the relationships among uses and the time when each user group is dependent on the resource. Oakerson argues that "limits may be imposed on both duration and type of use, as well as on the amount of the resource flow that can be appropriated during a time period." (Oakerson 1992, p.46). Williamson states "Adaptation to increased resource pressure requires innovative institutional arrangements and policies to reconcile the different resource-use priorities of heterogeneous users and to prevent resource degradation." (Williams 1998, p.2). This would imply that simple operational rules may not be flexible enough. Bromley & Cernea reason that it is necessary to establish an organisation with legal empowerment, which can take action and can formulate working rules incorporating the demands of the different user groups (Bromley & Cernea 1989, p.55). Feitelson & Haddad agree and state that in case of crisis, such organisations need increasingly flexible structures to adapt and respond to change and also the ability to monitor and verify agreements, and therefore reduce the potential for future disagreements (Feitelson & Haddad 1998, p.7). However, flexibility is not only needed in crisis situations. CPR organisations are subject to continuous changes in the socio-economic and political context in which they operate and this dynamic in turn influences the bargaining situation of user groups.

CPR system, flow and scale

The CPR literature distinguishes between the 'resource system' and 'resource flow'. It is argued that the resource system is the base, which has to be kept at a particular level to guarantee a certain resource flow. In case of a renewable resource, the resource flow should not exceed the average replenishment rate of the resource. However, especially with groundwater, the *rate of replenishment* varies according to the groundwater system. Exceeding the rate might lead to depletion or degradation of the resource system. Hence, it is important to *identify the resource system and the resource flow* for any CPR. Keeping the system at a sustainable rate can safeguard future resource flow utilisation.

The size of a CPR, and how this compares with the user-community, has great relevance to the approach taken to its management. This scale issue affects the appropriateness of management and control mechanisms which could be enforced. Hence, it is important to determine the boundaries of the resource, such as the replenishment area and the area in which the resource is utilised. Shah mentions a study of groundwater irrigation in the northern Anuradhapura district of Sri Lanka, which showed "that for every acre of groundwater irrigation area, 34 and 37 acres of recharge area are needed for sustainability in upland and lowland areas, respectively (Premanath & Liyanapatabendi 1994 in Shah et al. 2000, p.9). *However, because of the multiple functions of a CPR, the scale of management is dependent on the form of utilisation*. It could be argued that certain forms of utilisation do not exceed resource flow and therefore no management is needed. An example could be the extraction of groundwater for drinking water in rural areas, here the rate of utilisation might be even below the rate of replenishment.

The Comman Project is assessing whether it might be possible to manage groundwater on a local scale. Local management is only possible when the resource in question can be effectively 'closed off' (closed off on the one hand to uncontrolled outside users and in addition to outside influences, which could endanger the resource system) thereby ensuring that local users are in control of the quantity and quality of groundwater. In such a case the groundwater conserved is largely accessible to the user group alone. This would imply that the boundaries of the resource coincide with the boundaries of the user group. It is important to note that this may be difficult to achieve.

Possible Parameters for collective action: an overview and discussion

Introduction

In the (mainly irrigation) literature on CPRs, a number of different parameters have been identified which determine collective action. This section provides an overview of the range of parameters and some more detailed discussion around key issues. The analysis is structured under five sub-headings (see Table 1):

(1) Awareness of/interest in the resource within the community;

(2) Incentives and ability for cooperation;

(3) Distribution of benefits and costs of resource use and protection;

(4) Potential for enforcement;

(5) Asymmetries of power and influence of individuals and of communities based on access to the six capitals

Different parameters are identified under each. Those identified as key are discussed in the following sections. While they all have an important influence on collective action over the resource, not all of the parameters have a positive influence, and many are interconnected. In the first section 'visibility of the resource and degradation' and 'existence of alternatives' are identified as parameters, while the first could have a positive influence on collective action the second parameter is negative. Furthermore, in the same section the parameter 'importance of the resource conservation to people's livelihood' is connected to 'visibility of the resource and degradation', arguably if the resource is not important for people's livelihoods, then the likelihood of collective action is less. All of the parameters are relative, the 'scarcity of resource' might be different for different user groups, hence this parameter could interact with 'wealth endowment' and 'number of conflicting uses' of the second section. Some of the parameters in the second section are discussed later illustrating their interconnectedness.

The last section of the table 'asymmetries of power and influence of individuals and of communities based on access to the six capitals' introduces the concept of different capital assets[9]. The concept of the six capitals is important because in understanding the livelihood strategies of individuals or communities and the implications for collective action on CPRs.

Possible Parameters: Discussion

Number of resource users

Since Olson, the group size has been seen as a crucial determinant for collective action. Olson argued "unless the number of individuals in a group is quite small ..., rational, self-interested individuals will not act to achieve their common or group interests" (Olson 1965, p. 2). In a study on third-party monitoring Agrawal analysed small, medium and large sized villages in India. He concludes that

[9] Capital assets are the resources upon which livelihoods are built. DFID identifies five categories: human, social, natural, physical and financial capital (DFID, 2000). A sixth asset – political capital – has also been identified as important by some authors (e.g. Nicol, 2000)

“Medium-sized groups will be best placed to provide collective action.” (Agrawal & Goyal 2001, p.88). Agrawal categorises groups as small, when they have 30 or fewer members, and large with more than 100 members. However, the membership varied only between 10 and 175 households (Agrawal 2001, p.80). He argues that small and large groups may not be able to protect resources effectively, the reason for the first is that they might be unable to raise sufficient funds to undertake monitoring and the latter because of the limits on effective monitoring (Agrawal & Goyal 2001, p.90). However, other authors come to different conclusions. Marwell & Oliver claim, “a significant body of empirical research ...finds that the size of a group is positively correlated to its level of collective action” (Marwell & Oliver 1993, p. 38). Agrawal reasons that “Lumpiness of a collective good implies that there are either large set-up costs or a minimum viable scale.” This leads him to propose that small groups are likely to be at a relative disadvantage in providing such collective goods (Agrawal & Goyal 2001, p.65). The proposition only includes the size of the group not its financial or political resources, however, the group size cannot be seen in isolation from other parameters.

Wealth endowment

Baland & Platteau claim that “There is abundant evidence to support the hypothesis that the costs of initiating collective action are largely borne by the economic elite.” (Baland & Platteau 1999, p.780). They argue that for example the rural co-operatives in the Netherlands were often created by groups of influential, better-off farmers. According to them, these farmers could bear the cost of initiating collective action. In addition Wade argues that the effectiveness of a local irrigation council “depends on its councillors all having a substantial private interest in seeing that it works, and that interest is greater the larger a person’s landholding” (Wade 1987, p. 230). Furthermore, big landowners claims on CPRs “are sufficiently large for some of them to be motivated to pay a major share of the organisational costs” (Wade 1988, p. 190). Baland & Platteau argue that on the other hand poorer farm owners do not initiate collective action. Reasoning that each of them internalises too small a share of the benefits resulting from well-managed CPRs.

Table 1 Possible parameters for collective action over CPRs

(adapted and modified - sources Edig in press; Laube & Kirchhoff in press; Baumann & Sinha 2001)

Awareness of/ interest in resource within the community	
• Scarcity of resource • Visibility of resource and degradation	• Importance of the resource conservation to people's livelihood • Existence of alternatives
Incentives and ability for cooperation *(italicised parameters discussed in following sections)*	
• *Number of resource users* • Number of conflicting uses • Distribution of benefits and costs • *Wealth endowment* • Rate of time preference • Social capital • *Leadership*	• *Social heterogeneity* • *De jure and de facto rights* • Past experience with collective action • Past experience with outsiders • *Exit opportunities and time horizon* • *Emblematic events* • *Technological heterogeneity*
Distribution of benefits and costs of resource use and protection	
• Level of investment require to make resource productive • Exit opportunities • Income inequality	• Inequality in land holding • Allocation rules chosen • Prices
Potential for enforcement	
• Size of resource • Clarity of definition of boundaries • De jure and de facto rights • Legal backing from higher-level agencies	• Potential to exclude others • Community acceptance of executive body • Monitoring capacity
Asymmetries of power and influence of individuals and communities based on access to six capitals	
• Natural • Physical • Human	• Social • Financial • Political

However, the wealth endowment has not only positive effects. Mosse argues that some individuals have the capital to "deviate from the rule without attracting public notice or sanction" (Mosse 1997, p.481). He argues that the poor, lower caste or women farmers do not have this possibility. Baland & Platteau make a similar observation. "Wealthier users can not only refrain from participating in resource-preserving collective actions, but they may also attempt to under-mine such actions in order to further their own private interests." (Baland & Platteau 1999, p.782). Shanmugaratnam links participation of the wealthy with exit opportunities and political capital, arguing, “Absentee herd owners favour open access rangelands so that their herds can graze anywhere. They may even use their political influence to prevent pastoral associations receiving legally defensible land rights.” (Shanmugaratnam et al, 1992, p. 20).

Exit opportunities and time horizon

Baland & Platteau argue that the access to economic opportunities external to the resource system changes the time horizon of the CPR users. However, the effect of ‘exit opportunities’ varies according to the initial situation of the CPR users. They reason that some users “enjoy better access to the CPR because they possess a relatively large amount of the production factors required to exploit it” (Baland & Platteau 1999, p.774). Here the production factors could be defined as the six capital assets – human, social, natural, physical, financial and political - that households combine to make a living.

According to Baland & Platteau “wealthy users can shift to the alternative occupation, therefore have an incentive to overexploit and deplete the CPR. On the contrary, users deprived of such outside opportunities attach a higher value to the future state of the resource” (Baland & Platteau 1999, p.775). Often the poor have uncertain prospects of exit opportunities, therefore “they are more keen to preserve the local CPR as a hedge against the risk of unemployment” (Baland & Platteau 1999, p.775). However, Ellis argues against their reasoning. He states that “poor migrants from remote areas are less likely to re-invest urban earnings in agriculture, while better-off migrants from nearby or high potential areas are more likely to do so” (Ellis 1999). Again it is questionable whether one can use exit opportunities alone to determine collective action on CPRs. Steenberg & Shah argue that investment in water resource development in India took place, because of migrant workers earnings in the Gulf States (Steenbergen & Shah in press, p.3). However, water resource development does not imply water management and contribution to the upkeep of CPRs. In a different paper on African small-holder irrigation he argues that the income of migrants is not necessarily reinvested in small-holdings (Shah 2000).

Leadership

According to collective action literature, it seems that “commons work best when a recognised and legitimate leadership can regulate use” of the CPR (Ensminger & Knight 1997, p.8). Blower & Leroy confirm this view in their analysis of community collective action against “locally unwanted land users”. Here, the role of the local elite determines the success of local initiatives (Blower & Leroy 1994, p.207). Mosse argues that “leaders with wide-ranging influence are able to act as ‘water brokers’, arranging the purchase of water and its delivery or sale to villagers en route.” (Mosse 1997, p.479). While in Mosse’s example, kin and caste links are determining leadership, Wade argues that big landowners can initiate collective action and take the leadership (Wade 1987, p. 230). However, as already argued above, wealthier users might also undermine collective action. This could also be the case for old leaders. Exit opportunities can increase the bargaining power of middle-income farmers, which might lead to an increase in political capital of these groups. Hence, old and new leaders might be in competition over power and leadership does not necessarily lead to collective action over CPRs.

Blau & Scott (1969), analysing CPR management structures, use the term mutual-benefit organisations. According to them these organisations have problems maintaining democratic processes. Apathy of the members is common as well as the development of oligarchic control through active minorities.

They argue that sometimes within mutual-benefit organisations the democratic controls are sacrificed for the accomplishments of objectives. In addition, studies indicate "persons of higher socio-economic status tend to belong to more associations and to participate more actively in them than persons of lower status" (Blau & Scott 1969, p.105). The combination of the two factors shows that even though a democratic organisation for CPR management is set up, it does not imply that the original system continues.

Social heterogeneity

Baland & Patteau analyse social heterogeneity and its effects on collective action. They argue that "poor stakeholders might have shorter time horizon and therefore have to choose strategies which yield more immediate results, and disregard longer-term considerations in resource conservation." (Baland & Platteau 1999, p.774). They reason that depending on the level of wealth, poorer users may not participate because collective action violates their survival constraint. This would imply that the better off farmers would have the main burden of contribution. Furthermore, it implies that the poor would infringe the management rules of the community to a larger extent then the rich. However, Robbins (2000) analysing corruption in forest management in India, shows that the local elite has easier access to CPRs. Robbins argues that the higher caste elites occupy important positions in government, policing and forestry. The social capital of the local elite reduces access costs to the forest resources. Lower cast elite which do not have connections to position holders have to pay higher 'entrance fees' in the form of preliminary bribes, the higher entrance excludes poorer households as well.

Heckathorn argues that "heterogeneity not only introduces actors with higher than average valuation of the public good, it also introduces actors for whom the value of the public good is small or even negative." (Heckathorn 1993, p.342). He distinguishes between three different systems of collective action: voluntary systems; compliant control based systems (compliant control mandates cooperation and oppositional control is blocked); and balanced systems (actors can exercise both compliant control and oppositional control) (Heckathorn 1993, p.340). He argues that in the compliant control system, cooperation begins earlier than in a voluntary system and reaches higher limits. According to him "production does not decline even if the cost of participation far exceeds the value of the public good." (Heckathorn 1993, p.340). Hence, individuals have no choice other than complying. He reasons that "heterogeneity has the most dramatic effect on the compliant-control system because it introduces actors who value the public good highly. These enthusiasts are motivated to control voluntarily and to exercise compliant control so that others contribute as well." (Heckathorn 1993, p.342). However, Robbins (2000) case study shows that heterogeneity does not always lead to optimal outcomes in terms of collective action on CPRs. If the poor users place high value on the goods, it does not imply that they have the power to secure compliance from the rich and powerful.

Baland & Platteau argue that "maximum inequality leads to an outcome that is remarkably close to the social optimum" reasoning that wealthier users, because they usually have more incentives to 'co-operate', tend to contribute more to collective action (Baland & Platteau 1999, p.777). However, this seems to be based on the assumption that the wealthier users have a high interest in the resource. Robbins' example shows that not all products of the CPR are protected equally, he argues "corruption does not act on the local ecology in a generalised pattern, destroying all species equally or at the same rate. Instead, certain species are targeted while others are not" (Robbins 2000, p.437). Baland & Platteau add that the impact of inequality "is highly sensitive to the characteristics of the technology" in use (Baland & Platteau 1999, p.779).

Technological heterogeneity

Baland & Platteau argue that the "characteristics of the technology used under common property crucially affects the way inequality bears upon collective action" (Baland & Platteau 1999, p.775). They analyse the behaviour of rich and poor fishers and their use of technology (the size of the net meshes). In their theoretical examples they come to the conclusion that the wealthier fisher can increase his benefits by using larger net meshes. In case of egalitarian distribution a fisher changing from small to large meshes would be worse off (Baland & Platteau 1999, p.777-80). Hence, according to them poor fishers would try to manipulate the status quo situation by using a different technology, which allows them to increase their short-term benefits. Under their reasoning the wealthier user would not have additional benefits from using a different technology, the user can choose a long-term strategy and therefore does not overuse the resource in the short-term.

It is questionable whether the fishery case could be compared to the groundwater case because access to different technology in combination with financial capital and natural capital might already restrict other users from utilising the resource. Hence, a public good can become a de facto private good, because of the technology in use. For example the case of groundwater in Yemen, rich farmers with large landholdings and access to capital can pump large quantities of groundwater, while farmers with smaller land holdings and less resources do not have the means to access groundwater resources. The situation is further complicated where there is competition among different types of uses, for example:

- Irrigation versus basic needs
- Irrigation versus animal husbandry
- Poor farmers versus rich farmers (food crop versus cash crop).

De jure and de facto rights

In India, the de facto right to groundwater (states) implies, that groundwater belongs to all those who have land overlying it (Kumar 2000; Shah et al 2000). Kumar (2000) states that according to this right a landowner can abstract any amount of water. Shah argues that the "de facto rights of key and wealthy users, may restrict collective action" (Shah et al 2000, p.9). Implementing more equitable de jure rights faces the problem that "new rules cannot vary dramatically from the existing repertoire of rules in use or they will exist only on paper" (Ostrom 1992, p.314). This is further confirmed by Robbins (2000), who argues that formal rule changes, which are introduced in a top down approach, might push former rules into informal arrangements.

The consideration of de facto rights challenges the assumption that a high level of heterogeneity enables collective action. If collective action benefits the users with the de facto rights then they would favour it, however if the de facto rights holders are not benefiting from collective action then they will not support it. One could reason that a shift of rules is dependent on the bargaining power of the group benefiting mostly from the de facto rights.

Emblematic events

Collective action over CPR management is also dependent upon influences which are outside the sphere of influence of the community. Ensminger & Knight analysing competition over land from outsiders, reason that outsiders can create a common threat for all the members of the group. Therefore outsiders can shift the bargaining power of the local group members. A settlement of resource distribution might be reached which does not reflect the real power relationships if the group could be viewed in isolation. Ensminger & Knight reason "when the alternative is a worst-case scenario for all parties, even the powerful may be forced to accept less personally optimal outcomes." (Ensminger & Knight 1997, p.14).

The impact of natural events is comparable to that of outside influence. Steenbergen & Shah indicate that "the three successive drought years that Gujarat faced during 1985–87 bought water issues to their cyclical peak in the public mind." (Steenbergen & Shah in press, p.7). Hence, natural and non-natural events might have an emblematic effect and trigger windows of opportunity for collective action on CPRs. However, not every emblematic event leads to a shift, hence emblematic events is again only one parameter which interacts with other parameters.

Conclusion

This brief review of the literature on CPRs indicates that the conceptual framework of institutional rules on common property management is very restricted. Already the terms in use such as 'collective choice rules' imply a relatively homogeneous user group, with broadly similar interests in the resource and equal power relations. However, the evaluation of parameters for collective action indicates that powerful actors and leadership have a strong impact on rule making. In addition, while the theory suggests that property rights are easily distinguishable, evidence suggests that a given CPR can be managed under different property rights simultaneously. It seems that the conceptual framework of CPRs lacks sufficient flexibility to explain multiple functioning CPRs.

Even though it is possible to determine parameters influencing CPRs, their interaction in a dynamic environment remains poorly understood. More research is needed to analyse the impact of outside dynamics such as markets and technological change on the various groups managing CPRs at the local level. Furthermore, the interaction between the influence of elites, *de facto* versus *de jure* rights and the influence of top-down changes on resource management need more research attention. The various parameters identified are interconnected, to describe them in isolation does not reflect this dynamic and might lead to misinformed policies resulting into a new 'tragedy of the commons'.

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