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Managed Aquifer Recharge:

an assessment of its role and effectiveness in watershed management

Final report for DFID KAR project R8169, Augmenting Groundwater Resources by Artificial Recharge – AGRAR

BRITISH GEOLOGICAL SURVEY

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Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management

Final report for DFID KAR project R8169, Augmenting Groundwater Resources by Artificial Recharge – AGRAR

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FOREWORD

Watershed development, with a strong focus on groundwater recharge, is being widely promoted across India. Microwatershed management, including the construction of check dams and percolation ponds, currently absorbs over US$500 million per year, channelled mainly from central government sources (Farrington et al., 1999). Most projects take as granted that watershed treatment leads to increased recharge and rising groundwater levels (or slower decline) in the watershed as a whole. These changes, in turn, are assumed to lead to improvements in water supply, drought resilience and, ultimately, more sustainable livelihoods for participating communities. However, the specific impacts of recharge interventions (as opposed to watershed development more generally) are rarely evaluated or documented on a scientific basis. This has raised concerns that Managed Aquifer Recharge (MAR) is being seen too much as a panacea for water supply problems and groundwater overdraft, without the necessary evaluation of its potential in different climatic, agro-ecological, hydrogeological and socio-economic conditions.

This report, an output from the DFID-funded project *Augmenting Groundwater Resources by Aquifer Recharge (AGRAR)*, provides a synthesis of research findings from three locations in India where MAR forms a significant part of watershed development. In each location project partners, working with support from the British Geological Survey (BGS) and the Institute of Social and Environmental Transition (ISET), instrumented and monitored recharge structures and the surrounding microcatchments and carried out livelihoods surveys to evaluate the impact of MAR.

Although the report adds value to current debates around the role of MAR, the study's limitations need to be highlighted. Specifically, detailed monitoring was carried out in only three locations and over two monsoon seasons; the project was too limited in time and scale to assess the long term impacts of MAR across a range of different physical and socio-economic environments. At the same time, the findings provided reasonably good insights into 'what happens' to the water from artificial recharge structures, especially highlighting the variability across different environments in the processes that take place as a result of MAR.

The insights and recommendations of this report are intended to stimulate debate around the policy and practice of MAR in India and elsewhere. The report is therefore aimed at a wide audience, including (a) policy makers involved in the watershed development and water resource management fields; (b) donors and research organisations involved in programme design and technical support; and (c) organisations directly involved in the implementation of MAR activities at field-level, including NGOs.

The AGRAR project is one of a number of India-focussed research projects funded by the UK's Department for International Development (DFID) under the Knowledge and Research (KaR) programme. Taken together, findings from these projects provide important insights into the problems of water resources management and service delivery in rural India.

In addition to the named compilers of this report, the authors would also like to acknowledge the input provided, in the collection and analysis of field data, by many members of staff within the respective organisations (ACWADAM, TNAU-WTC, VIKSAT) as well as those in associated bodies. These include the NGO, GOMUK in the Kolwan Valley study and other university departments in TNAU. Special thanks is also due to Dr M S Rathore of the Institute of Development Studies, Jaipur and Dr A Dixit and M Upadhya of the Nepal Water Conservation Foundation, Kathmandu, Nepal, who contributed greatly to the project at periodic meetings and workshops where progress was discussed and reports drafted. Lastly, thanks are due to colleagues in BGS, CEH and ISET for input to the programme of activities, interpretation of results, peer review as well as design and layout of this publication.

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In order to effectively manage a groundwater resource, and the impacts it has on the economy of the region and the livelihoods of the population, it is important to know the size of the resource, the hydrological relationships to recharge and use (including seasonal and longer-term variability) as well as natural and anthropogenic influences on water quality. For successful application of Managed Aquifer (artificial) Recharge, (MAR) — the focus of this study — there needs to be a source of water, space in an aquifer to store the water and mechanisms to recover the water for beneficial use. These components need to be quantified and put in the overall context of natural recharge and discharge, including abstraction, to assess the impact of MAR in relation to the investment made.

A comprehensive quantification has recently been published in the *Master Plan for Artificial Recharge to Ground Water in India*, (Central Ground Water Board, 2005). It is estimated that an area of 448 760 km^2 — about 14% of total land area of India — is suitable for MAR and that a volume of 36 453 MCM is available for recharge annually. This is equivalent to an average of 80 mm over the entire area and the volume equates to about 18% of the 200 000 MCM of groundwater that is currently utilised annually for irrigation. These figures relate to state-wide estimates so caution should be taken when comparing with the three micro-watershed studies undertaken for the limited period of the AGRAR project, 2002 to 2005. However, the estimates of recharge for the AGRAR sites (that are not limited by storage in the aquifer), were found to be about *one order of magnitude lower* (4 mm to 10 mm) than the CGWB estimates and to represent only about 1% of rainfall.

Other key issues include:

- *The sustainable use of the water (including groundwater) resources.* A balance between input and use is needed, either annually or over a few years, and groundwater forms a major storage reservoir to smooth fluctuations.
- *The impact that MAR has on downstream users, including environmental demands.* Does MAR merely relocate water resources and are the quantities significant in relation to natural recharge?
- *Realisation of communities' expectations.* What do communities expect from MAR interventions and are the benefits distributed equitably, both physically and throughout the social strata?
- *Representatives of research sites.* How far can general principles be applied and to what extent do local geological, hydro-meterological, economic, social and institutional conditions need to be taken into account?

The AGRAR project has addressed these issues through detailed comparative studies at three research sites to quantify the physical effectiveness of MAR and the socio-economic impacts, in order to contribute to the debate on the development of understanding of water resource management.

Conventional wisdom suggests that, in order to address the problem of groundwater overabstraction in India, a mix of regulatory (e.g. licensing) and market (e.g. water and energy pricing) reforms to control groundwater use is required. However, experience indicates these 'traditional' interventions have either proved ineffective, without equivalent focus on *demand management*, or have raised significant

Collection of water for domestic use from a well in the Kolwan Valley basalt aquifer.

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equity questions. Against this background, the development of user-group-based institutions for groundwater management, for the benefit of those most affected by failing groundwater supplies, could, if workable, be an effective option.

Case studies highlight some practical steps that can be taken to manage demand at a local level. In the Kolwan Valley, for example, GOMUKH is supporting investment in organic vegetable production as an alternative to sugar cane through marketing initiatives and help with the provision of inputs. In Satlasana, VIKSAT is promoting low-cost drip irrigation alongside its recharge activities. These are small-scale initiatives, however, and addressing problems of regional overdraft will require more concerted action by government.

A clear message from this report is that MAR is not a substitute for demand management in resolving groundwater over-abstraction. Currently, in some areas, the only effective control on demand appears to be when the groundwater levels have been pumped to depths where resources are small and uneconomic to pump and/or the quality has deteriorated to be unacceptable for irrigation or consumption — the aquifer has been fully exploited. Natural recharge and MAR can make periodic contributions to redress both the quantity and quality issues but not provide a sustainable solution.

In terms of sustainability, findings do not suggest that recharge interventions alone will halt or reverse longer-term problems of groundwater overdraft. For example, in Satlasana or Coimbatore, the scale of regional abstraction far outweighs any additional contribution MAR can make to groundwater availability. In the Kolwan Valley, where groundwater is relatively underdeveloped, recharge activities are unlikely to provide the additional water needed to support further, groundwater-based *Rabi* irrigation. Indeed the dilemma here (and elsewhere) is that recharge interventions may encourage investment in unsustainable farming systems (e.g. sugar cane in the Kolwan Valley) and subsidise investment in a contracting sector (irrigated agriculture in Coimbatore).

The impacts of MAR in relation to commonly stated objectives depend on local conditions. As a result, the ability to assess those conditions and make informed decisions regarding the viability of MAR activities is essential. This should be achieved through the development of a conceptual model including a rudimentary water balance, based on all available information. A conceptual model here simply means an improved understanding of physical processes that govern recharge in different hydrometeorological settings, at different sites.

In addition, the conceptual model will identify significant gaps in knowledge, so decisions can be taken on a staged approach to the site assessment, implementation and operation. The cost benefits of data collection will also need to be assessed in the light of the likely impact of the intervention. There is still a great need to increase the level of knowledge and skills in local implementing organisations in understanding the water balance and assessing the hydrogeological potential and limitations for MAR.

The impacts of man also need to be assessed, including land use, water demand and quantities abstracted. From this information, an initial assessment of key components of any aquifer recharge scheme need to be made and the following basic questions addressed:

(a) Is there a source of water available?

(b) Is there storage space in the aquifer?

(c) How can the water be got into the aquifer? and

(d) Is the intervention going to be effective?

The most appropriate source of water is one that is not used elsewhere or can be more effectively used at a particular site (local or regional scale). Potential sources could include capturing evaporation losses, water that would otherwise contribute to low-quality water bodies (saline or polluted water bodies) or water that arrives in torrential storm events. Where the soil or aquifer lends itself to effective recharge this should be promoted over large areas — field-bunding etc. — to capture rainfall where it lands, reduce runoff and hence the destructive force of flood waters. This is demonstrated in the Satlasana area where permeable sediments overlying the bedrock aquifer facilitate recharge.

If, however, the source water does not run to waste or evaporate then, in all likelihood, it is utilised elsewhere as recharge through stream beds, irrigation water, maintenance of stream flow for ecological and waste dilution purposes, etc. MAR in the area of origin of the water may have many benefits in maintaining water resources, improving quality, improving land management through reduction of soil erosion, etc., but this may be detrimental to downstream users who have traditionally relied on

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the water. The impacts of this relocation of water resources need careful consideration.

In India, activities aimed at augmenting groundwater resources through Managed Aquifer Recharge (MAR) generally form part of a wider set of activities aimed at developing, or rehabilitating watersheds. This is certainly the case for government-funded schemes (the majority) that combine a range of land development or protection, soil moisture conservation, afforestation, pasture development and horticultural activities, as well as explicit water resource conservation or augmentation measures.

Managed aquifer recharge is one element of rural development work in each of the case study sites, forming part of a wider set of watershed development activities (Kolwan Valley, Coimbatore), or undertaken as a discrete activity (Satlasana). In each case, it was assumed that watershed treatment would lead to increased recharge and an improvement in groundwater availability. These changes, in turn, were assumed to support livelihoods threatened by groundwater overdraft and agricultural contraction (in Satlasana and Coimbatore), and entrenched poverty and water scarcity (in the Kolwan Valley). Specific objectives based on local conditions — for example the protection of drinking water supplies, or support for protective irrigation in particular areas/for particular groups — were not considered by the PIAs, or required by programme funders.

Our research suggests these generalised assumptions are flawed. In particular, the 'one size fits all' approach to MAR (and watershed development more generally), based on the notion that MAR will work everywhere, and benefit everyone, is unrealistic. This is not to say that MAR is ineffective. Rather, *the nature, scale and distribution of benefits depends on a set of location specific factors* — both physical and socio-economic — that need to be considered at the outset. The definition of specific MAR objectives, sensitive to local context, should therefore form part of a more flexible, demand-responsive approach to planning and implementation.

One of the key recommendations of the project is for much greater investment in basic scientific research to guide MAR, and watershed development more generally, to allow more flexible and informed decision making at a local level. Along with research into scientific or technical aspects, research on inter-linkages and inter-relations between the institutions and the technical aspects is also critical, especially from the point of view of enhancing the effectiveness of the MAR options and achieving advantages of scale.

Policies have changed considerably in recent years, now emphasising the need for greater community participation and ownership to ensure sustainability. In practice, a spectrum of participation exists, from more interactive (Satlasana: village selection at least) to more passive forms, limited to the provision of labour or information-giving (Coimbatore) — a reflection of (a) programme or project type; and (b) nature and ethos of the PIA.

The community stake in recharge may be less than in other watershed activities because (a) it is not seen as addressing an immediate need; and (b) benefits may be less tangible to the wider community. The incentives for upkeep therefore need to seen in terms of the wider 'incentive' picture.

Drawing on case study and wider watershed experience, several lessons emerge. Firstly, there is a clear need for project promotion and planning phases which would communicate the basic approach, rules and procedures under which communities are eligible to receive support *before* construction begins. This would include responsibilities for the maintenance and upkeep of recharge structures. That said, any approach that assumes, *a priori*, a broad community demand for, and stake in, recharge activities may struggle with whole-community financing when costs and benefits are unevenly distributed or difficult to see. Secondly, there is a strong case for a more detailed consideration of distributional issues at the outset, paying particular attention to which areas and households are likely to benefit in particular physical and social settings.

The AGRAR study has shown how difficult it is to assess the impacts of MAR on livelihoods. There are several reasons. Firstly, longitudinal comparisons are hampered by a lack of baseline data on the 'before' recharge situation. Secondly, with versus without comparisons require a control group with a similar environmental and socio-economic profile to the 'with' group. Thirdly, MAR typically forms one of a number of watershed activities aimed at improving resource productivity, generating employment and supporting livelihoods. Finally, changes in economic conditions, access to infrastructure and other external factors may have as great an impact as the project itself. Attributing changes in livelihood strategies and outcomes to watershed development, and to MAR specifically, is therefore difficult to do with confidence.

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Finally, more attention needs to be paid to the *ex ante* analysis of MAR activities, particularly in relation to costs and benefits, and how these are likely to be distributed between different groups of people, different areas and over time, at the project or programme design stage. Hence our case study evaluations support the view that projects which devote time and resources to consulting and organising local people (e.g. Satlasana) perform better that their technocratic, top-down counterparts (e.g. Coimbatore). Genuine participation combined with sound technical input will perform best of all.

SECTION 1

Managed Aquifer Recharge
– context, objectives and management arrangements

1.1 Why Managed Aquifer Recharge? – definition and use

Managed Aquifer Recharge (MAR) describes *intentional* storage and treatment of water in aquifers. The term 'artificial recharge' has also been used to describe this activity, but adverse connotations of 'artificial' in a society where community participation in water resources management is becoming more prevalent, suggested that it was time for a new name. 'Natural' recharge to aquifers occurs through infiltration of precipitation, either directly to land or through the beds of streams and rivers. Unintentional or incidental recharge due to man's activities also occurs as a result of the effects of land clearing, excess irrigation and leakage from water mains, sewers and storm drains. This water can form a major component of aquifer recharge and should be managed, both from the quantity and quality perspectives, and treated as a resource rather than a disposal problem. MAR has also been called enhanced or augmented recharge, water banking and sustainable underground storage.

MAR is part of the groundwater manager's tools, which may be useful for replenishing and repressurising depleted aquifers, controlling saline intrusion or land subsidence as well as improving water quality through filtration and chemical and biological processes. On its own it is not a cure for over-exploited aquifers, and can merely enhance volumes of groundwater abstracted. However it may play an important role as part of a package of measures to control abstraction and restore the groundwater balance. MAR can also play a central role in water harvesting and reuse.

MAR can be used to address a wide range of water management issues, including:

- storing water in aquifers for future use
- smoothing out supply and demand fluctuations
- as part of an integrated water management strategy
- stabilising or raising groundwater levels where over-exploited
- situations where no suitable surface storage site available
- reducing loss through evaporation and runoff
- impeding storm runoff and soil erosion
- improving water quality and smoothing fluctuations
- maintaining environmental flows in streams and rivers
- managing saline intrusion or land subsidence
- disposal or reuse of waste and storm water.

1.2 What role does Managed Aquifer Recharge play in watershed development programmes and how have approaches evolved?

Activities aimed at augmenting groundwater resources through MAR generally form part of a wider set of activities aimed at developing, or rehabilitating watersheds. This is certainly the case for government-funded schemes (the majority), which combine a range of land development or protection, soil moisture conservation, afforestation, pasture development and horticultural activities, as well as explicit water resource con-servation and augmentation measures. Considered to be a flagship of rural India, watershed development programmes are targeted at treating 63 million hectares over the next 20 – 25 years with an estimated total outlay of Rs 76 000 crores (760 000 million rupees) (GoI, 2000). Presently, microwatershed management in India absorbs over US$500 million per year, channelled mainly from central government sources.

SECTION I

The recently published *Master Plan for Artificial Recharge to Ground Water in India*, (Central Ground Water Board, 2005) has estimated that a total area of 448 760 km^2 (about 14% of the total land area of India) is suitable for artificial recharge and that an annual volume of 36 453 MCM can be recharged (18% of the 200 000 MCM of groundwater that is currently utilised annually). These figures have been estimated in some detail at state level and equate to an average recharge of 80 mm over the entire recharge area. This is planned be achieved by construction of 225 000 structures in rural areas, at an estimated cost of Rs. 198 740 million ($US 4400 M), and harvesting rainwater from 3 700 000 buildings in urban areas at a cost of Rs. 45 860 million ($US 1000 M).

Watershed development projects, in various forms, have been operating in India since before independence. However, the main stimulus to government action occurred in the 1970s and 1980s when long-term field experiments confirmed that introducing physical barriers to soil and water flows, together with revegetation, could generate significant increases in resource productivity. These experiments catalysed the formation of numerous government and a few non-governmental organisation (NGO) projects, schemes and programmes to support microwatershed development.[1] These projects were implemented through a variety of government line departments and to a lesser extent through governmental and donor financed programmes that channelled funds to non-government entities. The microwatershed concept was aimed at 'establishing an enabling environment for the integrated use, regulation and treatment of water and land resources of a watershed-based ecosystem to accomplish resource conservation and biomass production objectives.' (Jensen et al., 1996).

As the above quotation implies, watershed rehabilitation was not originally conceived as a vehicle for rural development. Instead, early watershed development programmes took ecological objectives as their starting point in terms of physical (biomass) targets. These defined the scale and scope of watershed projects, which, in turn, were managed as public works with very limited local participation. In this sense the state led, rather than facilitated, the process of development. Perhaps unsurprisingly, reviews of early projects indicated limited success in meeting environmental and livelihood objectives, with only a small minority of projects (those managed by NGOs and other locally based agencies) demonstrating sustainable outcomes for poor people (GoI, 2000).

This approach changed markedly in the mid 1990s, mirroring wider shifts in water sector policy aimed at promoting a more bottom-up and people-centred planning approach. In particular, there was a shift away from ecological targets to the rehabilitation and development of environmental resources in an integrated manner to generate economic resources within the watershed (James and Robinson, 2001). This included recognition that many land-based activities did not help the landless or the poor, and that management of natural resources needed to be linked with support for sustainable livelihoods.

In terms of strategy, emphasis was placed on participatory approaches that involved local communities in both the planning and implementation of interventions. Many of the changes were catalysed by a progressive set of guidelines (often termed 'the Common Guidelines') for watershed development issued in 1994 by the (then) Ministry of Rural Areas and Employment. The guidelines marked a significant shift in approach in several respects (after James and Robinson, 2001) by:

- encouraging the development of **partnerships** between government and non-government organisations as project implementing agencies (PIAs), including NGOs
- **decentralising** the management of programmes to local government, where possible, and to PIAs. The guidelines specify that, in states where *Panchayati Raj* [2] institutions (PRIs) have been introduced, *Zilla Parishads*

[1] In India, microwatersheds are generally defined as falling in the 500 – 2000 hectare range. A miniwatershed comprises a number of microwatersheds and covers around 5000 hectares. A macrowatershed is equivalent to a river basin, and may encompass many thousands of hectares (Farrington et al., 1999).

[2] *Panchayati Raj* is a system of democratic governance. In 1993 the system was written into the Constitution as the 73rd Amendment. The amendment specifies three tiers of local government: the village (*Gram Panchayat* – often several villages); the block (various local names, including *Taluk*); and the district (*Zilla Parishad*). All tiers should be able to function as 'units of self-government'. The XIth Schedule states that *Gram Panchayats* have a mandate to prepare plans for the management of natural resources within their boundaries.

may have overall responsibility for programme planning and implementation; that PRIs should be part of the Watershed Association; and that members of the *Gram Panchayat* should be part of the Watershed Association. Similar involvement is ascribed to the PRIs in terms of financial provisions, the planning process and technical aspects of projects

- **facilitating the participation** of local people in the design and implementation of watershed rehabilitation activities, including MAR, through especially appointed watershed committees. A watershed committee includes members of the elected village assembly (*Gram Panchayat*), as well as members drawn from a district-level (multidisciplinary) watershed development team
- allowing **local control over the disbursement of central funds** for rehabilitation, through District Rural Development Agencies (*Zilla Parishads*).

One objective of the guidelines is to achieve convergence in approach between the different ministries and departments implementing watershed-based activities. However, this 'single window' strategy may exist more in theory than in practice. Evaluations conducted in the late 1990s suggests they have helped clarify and guide policy, but that they have not been in force long enough to significantly affect implementation on the ground (Farrington, 1999).

More recently (2003), the guidance has been further revised to produce the Hariyali Guidelines. These are intended to reinforce the shift towards community participation through structures of government and make explicit the link between watershed development and drinking water supply. The Hariyali Guidelines specify that community ownership is to be created through a 5% contribution by user groups for common activities, and a 10% contribution for work undertaken on private land. Scheduled Castes and Tribes (SCs/STs) and those below the poverty line need only pay 5% of the costs for both common and private activities. Further, it is stipulated that the selection of watershed areas should prioritise those with larger populations of SCs/STs. Finally, the revised guidelines specify that watershed development committees should have at least 'a one third representation of women and adequate representation of members from SCs/STs (Gupta, 2004).

The various schemes of watershed-based development each have a slightly different focus in terms of areas covered and activities implemented (see James and Robinson, 2001; Gale et al., 2002). The principal schemes are the National Watersheds Development Project for Rainfed Areas (under the Ministry of Agriculture and Cooperation), and the various programmes implemented under the Ministry of Rural Development. The Ministry of Environment and Forests, and the Ministry of Water Resources, also implement watershed-based programmes, leading to major coordination problems. Most continue to focus on dryland, rainfed regions of India, though programmes are increasingly being adopted in moister and forested regions, such was the western ghats and the Himalayas (Joy and Paranjape, 2004). Notwithstanding differences in emphasis and coverage, however, it is clear that watershed development generally is now accepted as a core strategy for rural development.

1.3 What are the general objectives of recharge activities, and how are they defined?

Most recharge interventions form part of a wider set of activities aimed at some combination of increasing productivity of natural resources and, more explicitly, on improving the socio-economic conditions of the resource poor. In general, the assumption is that recharge activities will increase water availability for the community as a whole, including the resource poor, and mitigate groundwater overdraft problems. More specifically, it is assumed that MAR, in combination with other watershed interventions, will contribute to:

- increased productivity of land and water, including irrigation and livestock, and rising incomes
- protection of drinking water supplies in terms of water availability, source sustainability and access
- improved water quality from reductions in salinity and concentrations of elements such as arsenic, fluoride and boron

- reduced vulnerability of watershed populations through creation of a buffer supply for drinking water supply and irrigation use, particularly during droughts

- protection of environmental services, including the maintenance of stream base flows, wetlands and surface vegetation.

These objectives are not new. They first emerged in the 1970s with reports from south India on the impact of overdraft on stream flows and United Nations studies in Rajasthan and Gujarat demonstrating the emergence of overdraft conditions across large areas. As early as the 1970s[3] the GoI was engaged in developing a model bill to support groundwater regulation and management, including groundwater recharge. By the mid-1980s these led to organisations hosting conferences on groundwater recharge and during the 1990s debates over the social and environmental impacts of groundwater overdraft gained increasing prominence, and the potential role of recharge in mitigating or reversing them were highlighted (e.g. Moench, Turnquist et al., 1993; Moench, 1995).

Nonetheless, the translation of objectives into a coordinated set of policies and programmes has proved challenging (Mudrakartha, 1999). Organisations both inside and outside the government have a variety of objectives and separate mandates. The success of these organizations often proves to be self-limiting because of the 'limitedness of the type of stakeholder membership'. A stakeholder approach therefore is essential to ensure a real coordinated collective effort towards an effective institutional mechanism. In Satlasana, the *Gadhwada Sangh* is able to rally people around the water issue. However, due to lack of external regulatory mechanism or a policy instrument, the results are limited (Mudrakartha et al 2005).

Regulatory and wider management interventions, especially those aimed at constraining water demand (such as the groundwater management bill), have often not progressed. Interest in augmenting supply through MAR — a politically more benign alternative — has boomed however, and the number and variety of organisations undertaking recharge activities has increased dramatically (Farrington et al., 1999; Kerr et al., 2002).

1.4 How do the above objectives relate to the stated objectives of recharge in the case-study areas?

The programmes, under which recharge activities were carried out in the case-study areas, and the objectives of each, are summarised in Table 1.1.

A first point to note is that MAR activities are not carried out exclusively under integrated watershed development programmes. In Satlasana, for example, MAR has been implemented as a stand-alone activity during the drought of 1999–2002, with funding from both government and non-government sources. The most pressing and immediate objective of such projects is to create employment and stabilise livelihoods; drought proofing through increasing water availability is a secondary, longer-term goal.

In contrast, recharge activities promoted under the Drought Prone Areas Programme (DPAP) are funded from central sources (channelled through regional and district government), and provide for the development of an entire compact microwatershed, rather than pieces of land scattered in different places. The underlying objective is integrated land and water development based on village or microwatershed plans. Hence in the Kolwan Valley the objective is to 'treat', incrementally, the entire watershed, with the NGO, GOMUKH in this instance, acting as the PIA. Under the DPAP, the creation of rural employment is a secondary objective.

Secondly, the emphasis a project or programme gives to different objectives depends, in part, on the nature and mandate of the PIA. Non-governmental (NGO) approaches to watershed development in India have traditionally focussed on the more

[3] Gujarat has passed a groundwater management act and several other states (Rajasthan, Himachal Pradesh, Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu have also passed or are considering acts (Government of Karnataka, 1987; Government of Tamil Nadu, 1990; Sinha & Sharma, 1987; Government of Rajasthan, 2005; Government of Himachal Pradesh, 2005; Government of Maharashtra, 2005; Government of Andhra Pradesh, 2002). These acts are based on a model bill circulated by the Central Government in 1970 and are now being updated (GOI, 1970, 1991). They all take highly regulatory approaches. See Comman, 2005.

interactive elements of popular participation. Hence in Satlasana, for example, VIKSAT has concentrated on strengthening people's capacity to articulate needs, form groups and act collectively; MAR is one of a number of focus activities for this. This approach contrasts with that of some government departments, and 'transitory' PIAs where large amounts of funding are provided and area-wide adoption is an explicit objective. Hence in Coimbatore, participation was limited to the provision of labour and information-giving, a symptom of both the nature of the programme and, in this case, to the more limited opportunity for the PIA to adopt more interactive, participatory approaches.

Finally, while the emphases and coverage of MAR activities differ, the broad set of objectives is consistent with those described in Section 1.3. All aim to improve the availability of water (to drought-proof rural communities, to increase agricultural productivity, to reduce groundwater depletion), to generate rural employment over the short term (through construction) and longer term (by increasing labour demand in agriculture); and to strengthen rural people's capacity to plan for and undertake joint action.

Table 1.1 Recharge activities, objectives and implementing agencies in the case study areas.

Site	Project	Stated objectives	Implementing agencies
KOLWAN VALLEY			
	DPAP (1st phase 1998 with ongoing projects in 4 villages)	Addressing water scarcity through an integrated watershed development project, including MAR through check dams on streams	Mainly headed by GOMUKH , although some other institutions have been part of the process of planning; PRI involvement also a part of the process.
SATLASANA			
Mumanvas check dam	SJSY, GoG (2003)	Increase groundwater levels	VIKSAT, *Gadhwada Sangh* and village TGCS
Bhanavas check dam	SDTT (2001)	Drought-proofing and employment generation	VIKSAT, *Gadhwada Sangh* and village TGCS
Bhanavas subsurface check dam	SDTT (2001)	Drought-proofing and employment generation	VIKSAT, *Gadhwada Sangh* and village TGCS
Samrapur check dam & Nedardi percolation tank	OXFAM (2001)	Drought-proofing and employment generation	VIKSAT, *Gadhwada Sangh* and village TGCS
COIMBATORE			
Karnampettai check dam	Rural Landless Employment Guarantee Scheme (1978)	Rural employment generation and improved groundwater storage	Department of Agricultural Engineering, GoTN
Kodangipalayam West pond	Rural Landless Employment Guarantee Scheme (1977)	Rural employment generation and improved groundwater storage	Department of Agricultural Engineering, GoTN
Kodangipalayam East pond	Drought Prone Area Programme (1998)	Drought-proofing	WTC as PIA along with WDT members

Abbreviations: DPAP (Drought Prone Area Programme); SDTT (Sir Dorabji Tata Trust); SJSY (Swaran Jayanti Swarojgar Yojna); TGCS (Tree Growers' Cooperative Societies); GoTN (Government of Tamil Nadu); GoG (Government of Gujarat).

SECTION 1

1.5 How do these objectives align with locally perceived needs in the case study areas?

Although the **Kolwan Valley** receives good rainfall, the valley is used to severe water scarcity during the summer, with river, dug well and spring sources reported as seasonal by both implementing agencies and households surveyed for this study. Nonetheless, MAR was not viewed as a priority either by GOMUKH or by valley communities. The primary objective was to improve the general livelihoods and income earning opportunities of the population as a whole through a variety of watershed development activities and drinking water schemes. Recharge, through drainage line treatment, formed a relatively minor component of this overall strategy aimed at enhancing the water resources base and addressing water scarcity; in GOMUKH's words, 'to make the water walk where it is running, and make it creep where it is walking.' Investment in recharge also reflected the structural features of the DPAP programme: money was available through the *Zilla Parishad* for recharge interventions of this type, in this kind of area, so investment went ahead.

In this sense MAR was not a 'positive' choice made by local communities on the back of dialogue between community members, the NGO and local *Panchayati Raj* institutions. That said, and once funds had been released, some effort was made to canvas the views of different groups on how to ensure wide access to benefits. For example, landless households belonging to the *Dhangars* (livestock herder) tribe were articulated by the community in dialogue with GOMUKH, and have been provided for through access to impounded water behind check dams.

In the **Satlasana** area recharge activities have had a number of objectives, with emphases varying with funding source and programme type. The broad context for intervention, however, has been the long-term decline in the groundwater-based rural economy resulting from groundwater overdraft, exacerbated by recent droughts. Recharge was seen as directly addressing these problems; a mechanism for increasing water availability for *rabi* crops, stabilising agricultural livelihoods and addressing the overall depletion of groundwater levels (see Box 1.1). Landless members of the community expressed interest in MAR activities for four reasons: (a) employment in construction of the structure; (b) increase in agricultural employment opportunities due to increased cropping; (c) their ability to access water for agriculture on rented land; and (d) increased potential of *rabi* crop which is critical to farmers as fodder for dairy cattle. The crop is a secondary, but important, source of income, in particular in drought prone semi-arid Satlasana. It is important to recognise here that significant amounts of land are leased and 70% of this is irrigated.

In **Coimbatore** also, growing water scarcity formed the broad context for action, with symptoms including declining water levels, well abandonment, shifts to less water-intensive/rain-fed crops, distress sales and other coping strategies. Groundwater monitoring records from 1746 observation wells throughout Tamil Nadu indicate, for example, that water levels have dropped by around 3 – 4 m over the last 30 years. In Palladam block, in particular, limited rainfall (the block is in a rain shadow region) combined with overdraft impacts prompted the district administration and the State Department of Agricultural Engineering to take action and prioritise watershed development. In this context, *Panchayat* presidents have been competing to capture funding available from government programmes, and recharge structures provide visible evidence of 'successful' lobbying and inward investment.

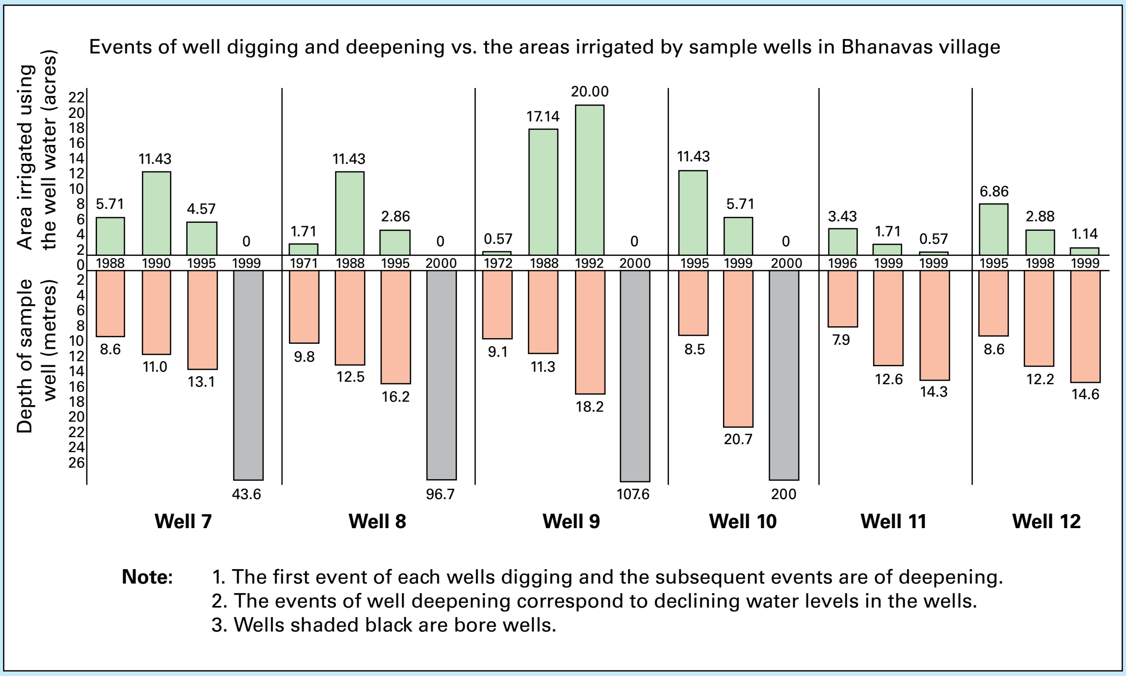
1.6 What was the process of project realisation?

In most situations, realisation of projects occurs for one or more of the following reasons:

- it is part of an on-going government programme in the area (sequential treatment in different watersheds as part of normal programme activities) – e.g. Coimbatore, Kolwan Valley
- it is in response to a specific 'crisis' (drought relief programs) – e.g. Satlasana
- it is due to the presence of an NGO in the region that goes out and seeks funds from various sources and uses whatever opportunities for funding that can be identified – e.g. VIKSAT in Satlasana; GOMUKH in the Kolwan Valley
- it is realised through the initiative of local leaders who identify government programmes and attempt to capture resources from them – e.g. the *Gram Panchayat* in Coimbatore.

Box 1.1 Groundwater development and depletion in Satlasana: the context for MAR.

The history of groundwater development and depletion in Satlasana is highlighted by the experiences of farmers in the AGRAR case study villages of Bhanavas and Samrapur. Farmers here traditionally practiced rain-fed agriculture, but changed to groundwater-irrigated agriculture with the advent of rural electrification, market integration and cheap credit, particularly in the 1980s and 1990s. However, the level of groundwater abstraction required to maintain the boom in irrigated agriculture was not sustainable and, by the mid-1990s, agricultural production was in decline. The figure below shows how wells have been progressively deepened in the case study village of Bhanavas and how in recent years, despite this investment, the area irrigated by wells has declined.



Problems have been exacerbated by the droughts of recent years, especially in the period 1999–2002. Some better-off farmers responded by drilling vertical extension bores at the bottom of dug wells to create borewells up to a depth of 120 m (wells shaded black in the figure above). The majority of small farmers and landless households had to seek alternative or supplementary sources of income, however, and limit expenditure through a variety of coping mechanisms (VIKSAT Case Study Report, 2005; Comman, 2005).

In this context, VIKSAT has promoted a number of village level activities aimed at conserving and enhancing the productivity of natural resources and at building social 'capital'. These include support for more water efficient irrigation technologies, field bunding and the installation of check dams and, in Nedardi village, a percolation pond. The overall objective of recharge interventions, in tandem with improvements in farming practices and land management, is to mitigate groundwater depletion and support (and to some extent drought-proof) the local economy. However, the more immediate and most pressing objectives of recharge construction work carried out during the 1999–2002 drought was employment and income generation, although with a longer term vision of agriculture stability.

SECTION I

Case-study experience in project or programme design and implementation illustrates how all four 'drivers' have catalysed watershed development and MAR.

In the **Kolwan Valley**, GOMUKH's long-term programme is one of river basin management, with the ultimate aim of covering all 16 villages and their habitations. The first phase of the government (DPAP) programme involved selection of three villages, based on their physical location (micro-watersheds) in the river basin. Phasing of the project was dictated by the limited availability of funding under the DPAP programme, with two or three villages selected for each phase. The ongoing process of village selection is iterative in the sense that experiences in initial village sites have informed the selection of other sites and the implementation of the programme more generally. Such experiences have also been used to catalyse interest in surrounding villages.

As implementation proceeds, watershed associations and watershed committees are formed in each project village. The watershed association (*Panlot Sangh*) is a village level group in which every farmer is entitled to become a member. The watershed committee (*Panlot samitee*) is elected by the villagers. The selection of recharge sites is done in consultation with these institutions. In some villages, the proposed beneficiaries are identified or user groups formed, but the process is not always consistent or well informed. Some 10% of total expenditure should be contributed by 'beneficiaries', either as cash or labour (*shramadan*), with the government (through the programme) subsidising the remainder. Since labour is increasingly scarce in the valley (a symptom of its relative economic boom – see Section 4), construction has recently been contracted-out to private companies.

In terms of ongoing maintenance of structures, communities are informed at the outset that they are responsible for upkeep, but incentives are far from clear. In theory, maintenance is 'handed over' to the watershed association and watershed committee, but following construction the activity levels of these groups are low. As a result, maintenance is *ad hoc* or done by GOMUKH. The *Sarpanch* of Chikhalgaon desilted CD3 himself with a tractor rather than calling long-winded community meetings, though this is exceptional. Problems can also arise around issues of ownership and water rights. In the village of Chikhalgaon, for example, check dams were built with the labour and land of Chikhalgaon farmers, but recharge benefits are perceived to have gone to farmers in neighbouring Nandgaon. The problem arises because the streams where check dams are built form boundaries between villages – clearly natural boundaries and zones of influence do not always coincide with administrative boundaries and (village-based) management groups.

In **Satlasana**, VIKSAT has been promoting village-level institutions since 1985, and tree growers' cooperative societies (TGCSs) with a role in water resources management since 1993. TGCSs formed a federation for the protection of land, water and forest (the Gadhwada Jal Jameen, Sanrakshan Sangh) in 1998. The long-term goal of VIKSAT, the Sangh and the TGCSs is to ensure proper management of natural resources on a river-basin level. Thus, the Sangh is also a member of the Sabarmati Stakeholders' Forum promoted by VIKSAT to coordinate management in the Sabarmati river basin.

In terms of recharge activities, VIKSAT has accessed funds from different sources (OXFAM, SDTT and the Gujarat Government) at different times to scale-up interventions to the river-basin level. In this context, the federal Sangh has played a key role in helping to prioritise villages, plan investments and agree cost-sharing arrangements. For example, those most likely to benefit from a given structure are identified and are expected to contribute more to maintenance.

Villagers are now building additional check dams with funds from government schemes. However, because funds from government schemes are staggered and only made available after work has begun, villages utilise loans from financial institutions to hire labour for the initial phase of work. These loans are then repaid when finances arrive from government.

In **Coimbatore**, RLEGP funds were used in 1977 to construct Karanampettai and Kodangipalayam West ponds with aim of creating rural employment, and to improve the recharge of groundwater in the area. Generally, existing common lands (*poramboke* lands) are used for natural resources development initiatives such as the construction of percolation ponds and check dams, though in recent years common lands have been leased for quarrying by the district authorities. This raises some significant poverty issues, as poor people are often disproportionately dependent on common lands for grazing or the collection of firewood and other materials.

The more recent DPAP activities follow the Common Guidelines, with entry point activities (e.g. temple renovation, school building repairs) carried out initially to build rapport with local communities, followed by the establishment of village institutions such as watershed associations and committees. However, a top-down, technocratic approach still prevails, with the DRDA controlling the entire district programme and issuing instructions on the design, planning and implementation of works. Hence the role of local institutions is low, restricted to the initial approach to district authorities for funding. The experience of the WTC in its capacity as a PIA [4] also highlights other problems, including a lack of engagement by the watershed advisory committee in local issues (the committee has to work at the district level alongside other line departments). This forced the WTC to compress planning, design, technical guidance and implementation into a two-year period, and it proved impossible to consult and mobilise villagers, heterogeneous in caste, economic status and land holdings, within the required time.

The experience of the WTC helps explain why user groups formed during the implementation phase disbanded on completion of the project, and why post-project maintenance of structures is still considered, by communities, to be a government responsibility. In addition an overlap between the functions of the local *panchayat* and user groups has led to indecision and inertia. Self help groups, mostly comprising women, have had no role in the watershed programme.

1.7 Some lessons learned

1.7.1 Contrasting approaches to community participation and institution-building

Watershed development policies have changed dramatically in recent years, and now emphasise the need for much greater community participation to ensure sustainability. In practice, the case studies highlight a spectrum of participation from the more interactive (Satlasana – village selection at least) to more passive forms (e.g. Coimbatore), where participation was limited to the provision of labour or information-sharing. This reflects both the nature of the programme, and the nature and ethos of the PIA. The Coimbatore case study illustrates the potential to de-emphasise or short-circuit participatory elements of watershed development under spending and time pressures imposed by a technocratic programme, and the challenges facing a more technically-orientated PIA when it comes to community mobilisation.

The Satlasana and Kolwan Valley case studies illustrate some of the advantages of long-term community-PIA interaction when communities are supported by a 'resident' NGO. In the Satlasana case, recharge work has not been carried out through comprehensive watershed development, but has formed part of a river-basin management initiative supported by VIKSAT. In both the Kolwan Valley and Coimbatore areas, recharge has formed part of a package of measures with relatively little scope for local innovation. One indication of acceptance of (rather than demand for) recharge interventions is the reduction in committee or user group activity following construction, and ongoing problems with the maintenance of structures. In all case studies, recharge was assumed to provide community-wide benefits, and hence structures were generally viewed as community assets, to be financed and managed by the community.

Watershed development work in the Kolwan Valley has raised some issues around cost sharing in situations where costs and benefits are perceived as unevenly distributed. Tensions could be avoided or mitigated if, during the planning phase, specific recharge objectives and beneficiary groups were identified and factored into financing arrangements. This is explored further in Section 4. The wider question about how to reconcile socially defined boundaries like villages with physically-defined catchments is being addressed in Satlasana through a federal decision-making body with village-level representation. The Satlasana case illustrates how decision-making does not have to be embedded in one village-level body; there are advantages in allocating different management responsibilities between different levels.

Both the Coimbatore and (to a lesser extent) the Kolwan Valley case studies highlight the tensions that can arise between formally mandated PRIs operating at administrative scales (now receiving funds directly and with responsibilities in natural resource management), and informal 'user groups' operating

[4] The Water Technology Centre was selected as a PIA out of concern that government departments would not spend DPAP money well.

at village level (village watershed committees) and watershed scales (watershed development associations). These overlapping roles have yet to be resolved in the planning and implementation of watershed development programmes.

1.7.2 Operation and maintenance – whose responsibility?

Project experience highlights common problems with the maintenance and upkeep of recharge structures following construction. Even under the more participatory programmes in Satlasana and the Kolwan Valley, for example, the duties and obligations of different stakeholders — communities, committees and implementing agencies — remain a grey area. In the Kolwan Valley and Coimbatore cases, there is a pronounced drop-off in associational activity following construction. The result is that maintenance is left to motivated individuals and the PIA (Kolwan Valley), or is not done at all (Coimbatore). There appear to be several contributing factors.

- The community stake in recharge may be less than in other watershed activities because (a) it is not seen as addressing an immediate need; and (b) benefits may be less tangible to the wider community. The incentives for upkeep therefore need to seen in terms of the wider incentive picture.
- The key reason is that communities are uncertain about the availability of the water recharged by them for their own use. In other words, lack of understanding and awareness of groundwater hydraulics, both in urban and rural areas, acts as a major impediment to MAR.
- Related to this, questions about whether MAR is a positive choice when projects and programmes specify what is available, rather than allow rural people to define their own priorities. Farmers may be tempted to accept measures they do not view as a priority because construction is labour-intensive, heavily subsidised, and is usually undertaken in the dry season when demand for labour is limited. And village presidents (e.g. in Coimbatore) compete for tied funding.
- While recharge structures tend to be viewed as community assets in programme guidelines, the distribution of costs and benefits can be very uneven, or difficult to identify clearly. Community members may therefore be reluctant to contribute to ongoing operation and maintenance activities that they feel will, or might, benefit others.
- The long legacy of government driven programmes and projects is such that rural people expect the government to take responsibility for the upkeep of structures that are predominantly government funded.

Drawing on case-study and wider watershed experience, several lessons emerge. Firstly, there is a clear need for project promotion and planning phases which would communicate the basic approach, rules and procedures under which communities are eligible to receive support before construction begins. This would include responsibilities for the maintenance and upkeep of recharge structures.

That said, any approach that assumes, *a priori*, a broad community demand for and stake in recharge activities may struggle with whole-community financing when costs and benefits are unevenly distributed or difficult (on the benefit side) to see. Secondly, then, there is a strong case for a more detailed consideration of distributional issues at the outset, paying particular attention to which areas and households are likely to benefit in particular physical and social settings.

SECTION 2

Physical effectiveness of MAR interventions

2.1 What is the availability of water for recharge?

Despite substantial variation in rainfall between case-study sites, in all three case sites significant volumes of water were available for recharge at the local level. 'Availability' here means that it was possible to capture water from surface flows in the basins and use that for recharge at the sites. Availability of water was not evaluated at a basin level or in relation to any existing downstream users. In all cases recharge structures captured water during the monsoon period but were also dry for substantial parts of the year. Variation between the sites illustrates the range of conditions likely to be encountered in many regions.

In Kolwan valley, for example, the structure filled and started overflowing by the 20th June 2004 and continued overflowing to the first week of October. Water remained in the structure until the first week of December, approximately two months following the last overflow. This contrasts substantially with structures at Satlasna, which filled two to three times during the monsoon. In Satlasna water remained in the structures for between two and 20 days. In most cases water only remained in the structures for a few days following any given rainfall event. Finally, in Coimbatore, the structure filled partially during April but didn't overflow, whilst in October the structure filled to overflowing and water remained for three months until the end of January. The fact that overflow occurred indicates that more water was available than was captured in all sites except Coimbatore (where the overflow only lasted for a few minutes) so sufficient water was available at the site level during the monitoring period to undertake recharge activities.

The findings of this study are, by default, snapshots in relation to the availability of water for recharge. Only two wet seasons were monitored and rainfall at none of the sites was 'average'. Understanding the impact of variability of rainfall in relation to the volume of constructed storage in check dams is beyond the scope of this report. However, some of the issues relating to density of structures, multiple agency implementation and downstream impacts are discussed.

2.2 How much water was actually recharged by the structures in comparison to natural recharge?

As with differences in the availability of water between sites and the hydrologic conditions, the volumes recharged differed significantly between areas. The volumes recharged during the 2004–2005 monitoring period in the case study sites are shown in Table 2.1, along with the equivalent in millimetres with respect to the catchment area and the rainfall.

The rainfall during the period monitored was considerably above average at Karnampettai and below average at Satlasana and was slightly above average at Chikhalgaon. Higher, or average rainfall at the first two sites would be expected to result in higher natural as well as higher induced recharge from the recharge structures. It would be expected that the proportion of natural recharge would be higher, unless the recharge from the structure was rejected due to high groundwater levels resulting from the recharge. The structures would be full for longer periods and the surplus water would be available to downstream users.

The rainfall at Chikhalgaon is not significantly different from the average. Predictions of the response in periods with greater or less than average rainfall will be controlled by the low storage capacity of the aquifer, the low groundwater usage and the relatively high annual rainfall. Currently the aquifer would be expected to replenish fully each year, the flow in the stream being maintained for longer periods due to both the additional storage in the structures and that induced into groundwater storage by the structures.

The above results suggest that in all cases the presence of structures significantly increased total

Table 2.1 Summary of recharge at the AGRAR research sites.

	Karnampettai	Satlasana*	Chikhalgaon (CD3)
Catchment area	1.41 km^2	19.5 km^2	0.79 km^2
Rainfall in recharge period. (long-term average)	728 mm** (Average: 527 mm. at Sulur station)	441 mm (693 mm)	1860 mm (Average: 1 660 mm. Karmoli. 12 years)
Volume recharged by structures	14 600 m^3	80 600 m^3	9500 m^3 (effective)
Depth equivalent	10 mm (1.4% of rainfall)	4 mm (0.9% of rainfall)	12 mm (0.6% of rainfall)
Natural recharge as estimated by the project	41 – 47 mm (Sy = 0.8 – 0.9%) c. 6% of rainfall	30 – 120 mm (Sy range 0.5 – 2%) c. 7 – 27% of rainfall	80 – 100 mm c. 5% of rainfall
Natural recharge estimates by CGWB (4 – 8% of rainfall)	29 – 58 mm	18 – 35 mm	150 – 260 mm (Limited by available storage in aquifer)
Increase in recharge due to structures in relation to project estimates (managed/natural)	c. 23%	c. 3 – 13% This does not allow for stream-bed infiltration that would have occurred with no structures	13%

*All structures above Samrapur. ** Rainfall at Sulur. April to December 2004.

recharge in relation to volumes that would have occurred naturally. It is important to recognise, however, that estimates of natural recharge contain significant uncertainty. In addition, even though MAR activities resulted in a large percentage increase in relation to natural recharge, MAR remained a small percentage of total rainfall. However, a large percentage of rainfall will be used to satisfy the demands of the soil moisture deficit, plant growth and evapotranspiration and is hence not available for natural or managed aquifer recharge. To put the figures into context in the catchment area of the Karnampettai recharge pond, 500 mm of water is required to irrigate a crop of vegetables, wheat or potatoes so 15 000 m^3 of water captured enables three hectares to be grown, in a catchment area of about 140 hectares (about 2% of the area).

During periods of lower than average rainfall, recharge structures may not fill to overflowing but greatly benefit the aquifer in the immediate vicinity with recharge of the little water available. The Satlasana case illustrates this point well where the favourable hydrogeological conditions facilitate infiltration. This will deprive downstream users of some of this water but overall will probably induce greater quantities of water to groundwater storage for subsequent use. In average or high rainfall years, the structures are likely to overflow for longer periods, recharge greater quantities (but probably a smaller proportion to natural recharge) and have little impact on downstream users.

The uncertainties in the above arguments stem, in part, from the short time for which data have been collected. Climatic variability is great at the research sites in Coimbatore and Satlasana and a fuller understanding can only be obtained by longer-term monitoring to collect data over a range of drier, average and wetter years. Now that the capital expenditure has been used to establish the research sites, every effort should be made to continue collecting and interpreting data for at least five, and preferably ten years. Continued monitoring at the site in the Kolwan Valley is also justified, not only to determine the impacts of climate variability but also the impacts on the water balance of increased groundwater abstraction.

2.3 What factors influenced how much water was recharged through the main monitoring structures?

Soil conditions and the availability of storage in the aquifer were major factors influencing the amount of both natural and managed aquifer recharge that occurred. In the Kolwan valley for example, groundwater levels are high because of generally high rainfall levels, limited abstraction and low specific yields. As a result, there is limited storage to fill. In contrast, in Satlasana, impermeable conditions in the surrounding uncultivated and eroded hills resulted in high levels of run-off. This combined with permeable conditions in the river bed and substantial space in the aquifer (low groundwater levels due to heavy abstraction) results in a relatively high percentage of recharge through the structure. Finally, in the Karnampettai structure at the Coimbatore research site, fine sediments in the structure resulted in low infiltration rates. Water remained in the structure for several months and relatively low evaporative losses (16%) ensured that over 80% of the stored volume infiltrated. However, the low storage capacity and permeability of the aquifer resulted in the recharge mound being constrained to the immediate vicinity, and downstream, of the structure. Here the groundwater level rose to the stream-bed level.

Natural recharge is generally estimated and presented as percentage of rainfall, often a relatively small percentage. As a result, additional recharge generated through MAR activities can be large, in percentage terms, but quite small with respect to the actual volume of water recharged. In Satlasana, for example, the increase due to MAR activities was estimated at between 3 and 13% of natural recharge but amounted to less than 1% of rainfall or a depth of approximately 4 mm of water across the catchment.

It is important to emphasise, however, that estimates of natural recharge contain very high levels of uncertainty. This is clearly illustrated by the differences between natural recharge estimates produced by the project and those published by the CGWB. It must also be remembered that account should be taken of the other components of the water balance that are available for productive use (soil moisture, surface storage and river flow) and those that are not (environmental demands and evaporation).

2.4 What do generic model results suggest regarding the way groundwater recharged by the structures is distributed in the local aquifer?

Estimates of the amount of water that could be recharged through typical structures were taken from experience at the research sites and other locations. In assessing the significance of these volumes, the point was made that the distribution of the recharge water is important. Here we attempt to address this issue by examining the effect that recharge structures have on the groundwater levels in their vicinity, what happens to these groundwater levels during the following dry season and the implications for users' access to groundwater? The case studies undertaken within the AGRAR project provide field-based evidence to address these questions; these are discussed later. To complement the case studies, computer modelling was also undertaken; the insights from this are presented first.

The model used simulates a simplified version of the recharge structure and underlying geology, within a range of physical settings (Neumann et al., 2004). The assumption made by the model is that the permeability and porosity of the aquifer do not vary and that the structure can be represented by a circle, within which recharge to the aquifer takes place. Although the model ignores the significant complexities that exist in these settings, the results provide valuable insights.

The rise in groundwater levels beneath a recharge structure is determined by the amount of recharge but also by the porosity of aquifer. The smaller the porosity the larger will be the rise in groundwater levels for a set amount of recharge, as less water is required to fill up the spaces in the rock. Recharge beneath the structure will cause a mound to develop; groundwater will flow away from this mound down gradient. The rate at which water flows away from the mound depends on the permeability of the rock. The permeability therefore also determines the shape of the mound. The greater the permeability the lower and wider the mound will be.

Figure 2.1 shows the development of a mound under a recharge structure, as simulated by the model, for typical aquifer scenarios, with different combinations of porosity and permeability. Some scenarios include incorporation of a fracture

SECTION 2

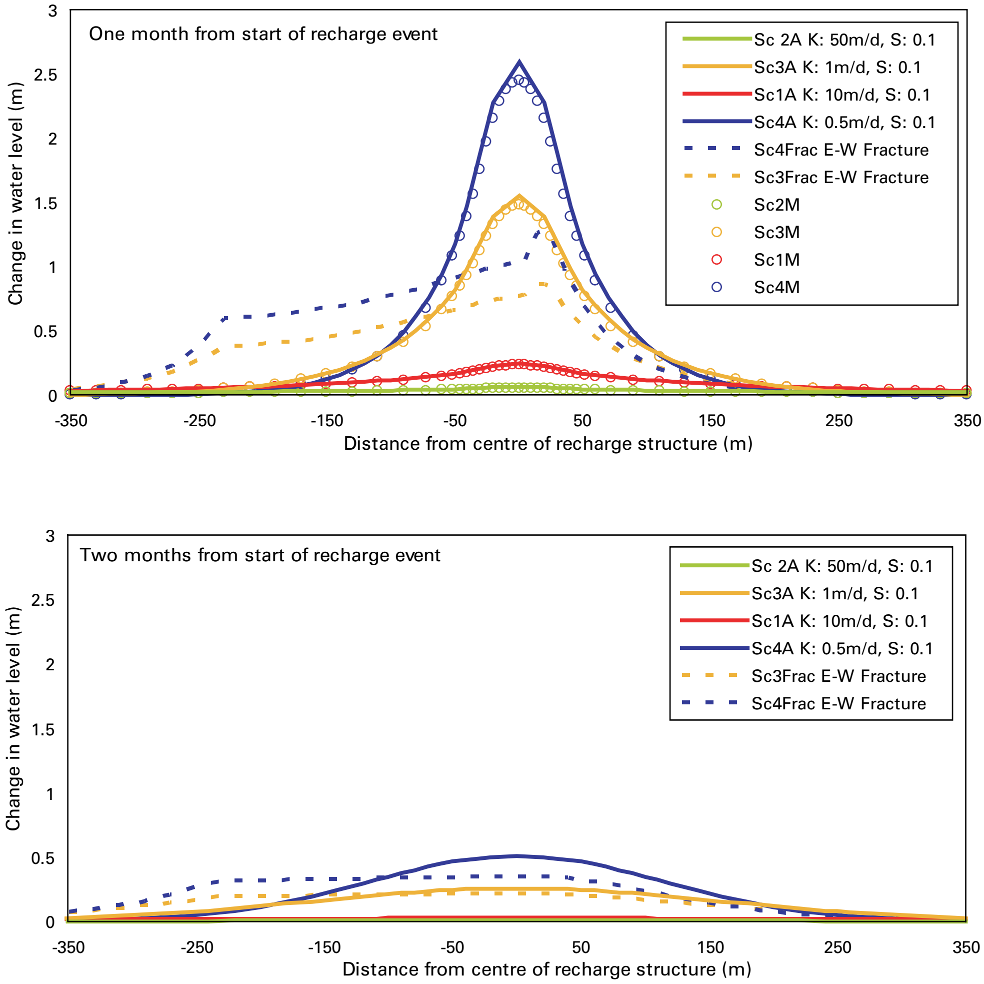


Figure 2.1
Change in water level due to a one month recharge event with distance from the centre of the recharge structure. Levels are shown for one month and two months after the start of the recharge event.

represented by a high permeable zone (K: 50 m/d) that is 15 m wide and extends 230 m to the west from the centre of the recharge structure. Its effect is to channel recharge water instead of spreading it evenly over a large volume of aquifer, as is the case in homogeneous radial flow scenarios. The result, shown in Figure 2.1 is an increase in water levels within this zone to several times the height observed under radial flow conditions in a homogenous aquifer, with elevated levels sustained over longer periods. For a tube well located at 110 m distance to the recharge structure in such a zone, this results in a maximum water level of about twice the height compared to the maximum under homogeneous conditions (Sc4frac). The effect increases with increasing K ratios between aquifer and permeable zone. The above illustrates the general effect of stronger impacts of the added recharge the smaller the receiving aquifer body; i.e. the smaller the aquifer being recharged, the larger the effect.

When recharge stops, the mound both under and adjacent to the structure will start to flatten. The degree to which it flattens is determined by the properties of the aquifer. If a significant mound is maintained during the dry season then that will be an advantage to those farmers with wells in the vicinity of the structure. If alternatively the groundwater recharged from the structure spreads widely across the aquifer, there is the potential to benefit more farmers. However, there will be less water per farmer. Using the typical aquifer scenarios in Figure 2.2, the change in the shape of the recharge mound over the period of a dry season, and therefore the distribution of the water recharged from the structure, was simulated.

This figure shows the shape of the recharge mound for three, four and five months after the end

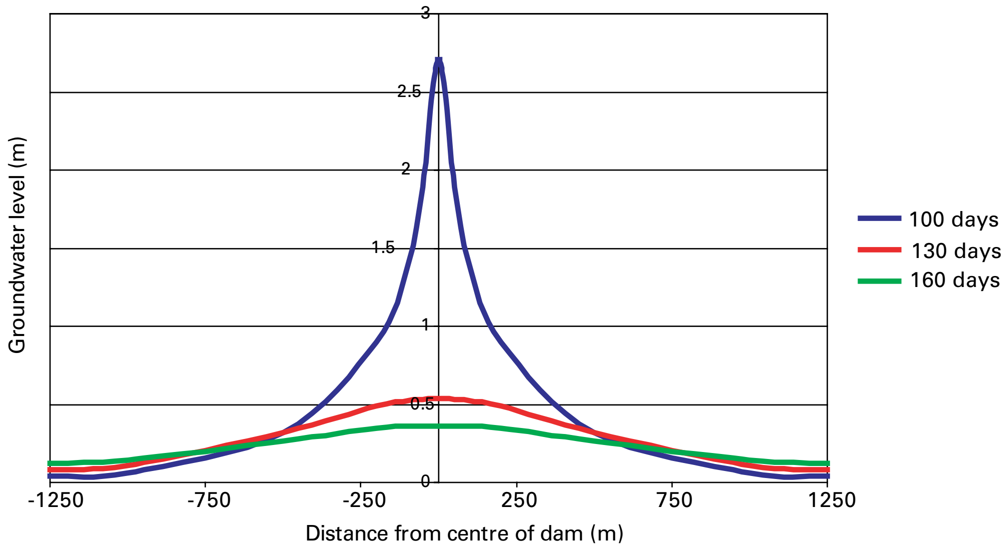


Figure 2.2 Modelled dissipation of recharge mound beneath a recharge structure.

of the wet season, for the typical aquifer scenarios. The mound is virtually indistinguishable after six months from the end of the wet season. For the theoretical situation simulated by the model, therefore, the water from the recharge structure is spread widely across the aquifer. Unless there are physical boundaries to the aquifer, water may move out of the control area of the community the recharge structure was meant to benefit. Where recharge from a structure causes the mount to reach the ground surface, typically along the streamline immediately below the structure (Kolwan valley and Coimbatore research sites) the mound decays through discharge to stream baseflow.

Of course the setting being simulated by the model is a huge simplification of the real world, particularly hard-rock aquifers. Modelling results suggest that the impacts of MAR at a local level will be highly variable. In some cases it may be possible to create ephemeral groundwater mounds that temporarily increase groundwater levels adjacent to structures. This could be a significant benefit to adjacent well owners if it allows the wells to continue in production during portions of the year (presumably immediately following the monsoon) when they would otherwise have gone dry. In addition, where aquifer characteristics limit flow out of an area, recharge could contribute significantly to the ability to maintain production in specific wells. There may, for example, be local zones of relatively deep weathering (perhaps related to zones of enhanced fracturing) which 'trap' significant volumes of water, for the needs of individuals or small groups of users. Both of the above potential benefits depend on the specific nature of the geology in a given area and its relation to the location of specific recharge structures and wells. In the case of a community well, which provides an important drinking water supply, this outcome may be seen as cost-effective. In many other situations, clear benefits to individual wells from MAR will be difficult to identify. Recharge may contribute to the volume of water stored in a large aquifer but, because the mound associated with a given structure dissipates quickly, would not have any noticeable impact on water levels or the functioning of individual wells.

2.5 How do field observations compare with model results?

Having discussed the results of the theoretical approach, how does this compare with direct observations in the case study sites?

- At the **Bhanavas** research site, as the above discussions indicate, substantial recharge occurred during the brief periods of surface flow. Rapid dispersion of the groundwater mound was observed. A mound was evident immediately adjacent to the structure but this dispersed rapidly following recharge events and no sustained change in water levels that could be directly attributed to MAR activities as opposed to natural recharge events occurred. The regional pattern of rise in water levels observed in monitoring wells lagged behind rainfall events and changes in water levels may mask impact associated with specific structures.

- There is limited groundwater storage in the undeveloped aquifer in the **Kolwan Valley**, implying low natural recharge and relatively high run-off. Subsequent to initial natural recharge 'filling' the aquifer, groundwater levels are above the bed level in the recharge structure so groundwater may be contributing water to the recharge structures and baseflow to the stream, along its length. MAR from the structure occurs as short events reflected by rising water levels in one borehole that was monitored immediately adjacent to the structure. During the monsoon, no groundwater mound was observed due to regional rises in the groundwater level. During the dry season, however, build-up of a very local mound was observed as a consequence of the structure. The mound remained evident for a period of six months following the last rain. This was equivalent to four months after the last water infiltrated from the structure. The mound was observable as a one-meter rise over regional water levels and extended only within 30 m of the structure. The slow decay of the mound is attributed to the low hydraulic conductivity of the aquifer (0.25 m/day) in the locale.

- At the **Coimbatore** research site, rapid water level rises of 3–7 m were observed in wells close to the recharge pond. Water levels also rose in wells further away with a peak lagging those adjacent to the pond by several weeks. The proportion of the rise related to natural recharge and that to artificial could not be determined. Increases in water level persisted for up to 90 days in individual monitoring wells and greater impacts were observed downstream of the recharge structure. The rate of percolation varied between events.

2.6 How much variation was present within the monitoring sites?

The above discussion focuses on results from the primary structures that were monitored. In each case-study region, however, several additional structures were also monitored in order to capture regional variation, which turned out to be substantial.

In Kodangipalayam near Karampettai, at the **Coimbatore** site the structures being monitored did not fill in the 2004–2005 season because all the water was captured in upstream structures. During the preceding season (2003–2004), however, these structures filled to depths of 0.7 and 0.9 meters respectively and an infiltration rate of 20 mm/day occurred. Water remained in the ponds for 5–6 months.

In the **Kolwan Valley**, two check dams were monitored downstream from the primary monitoring site. In both cases no recharge occurred because surrounding water levels were higher than the water levels in the structures. As a result, groundwater flowed into the structures even during the dry season rather than vice versa. In the middle structure water remained for a period of 120 days. In relation to the catchment area, between 100 and 120 mm flowed from groundwater into the stream at these structures. Groundwater contributions to the stream thus exceeded the amount recharged in the upstream structure and baseflow to the stream channel downstream of the recharge structure was evident almost until the end of February 2005, far exceeding baseflow cessation in 'non-project' areas (December 2004).

In **Satlasana**, several sites were monitored in detail and more quantitative comparisons between them can be made. The data from the primary and supplementary monitoring sites are compared below. The cumulative figures for the total catchment above the Samrapur check dam are given in the preceding table where the results of the primary sites are compared.

The calculations in Table 2.2 are based on the following factors.

- Some 441 mm of rainfall was recorded in the period studied which is considerably lower than the annual long-term average of 693 mm.

- The natural recharge in the area is estimated from the rise in groundwater level in response to rainfall events, beyond the influence of the recharge structures. From pumping tests the specific yield was estimated to be between 0.5 and 2%. This range reflects the geological variability ranging from fractured bedrock to weathered bedrock of variable thickness. The average rise in groundwater level of 6 m in response to rainfall of 441 mm (484 mm at Nedardi Pond) indicated between 30 and 120 mm of natural recharge; between approximately 7 and 27% of rainfall.
- National guidelines provided by the CGWB recommend a range of 4 to 8% of rainfall. The higher site-specific values may reflect higher infiltration rates associated with the flat-lying coarse alluvial sediments in the area, often accompanied by field bunding to reduce surface flow and soil erosion.

Key implications from the results are:

- The location of the Nedardi Pond causes the apparently anomalous results. The site does not lie on an established drainage line but rather at the base of the steeply sloping bedrock hills, from which sheet run-off occurs. The catchment area is therefore very small (0.13 km^2) and capture of run-off is high. Water is not pumped from the Nedardi pond as it is designed as a recharge structure and it did not fill sufficiently to overflow during the period monitored. However, wells are generally pumped for irrigation during the kharif season in low rainfall years. The soils in the surrounding area have a high clay content originating from sediment washed off the hills. The clayey nature of the soils accumulated in the bed of the pond results in relatively slow infiltration rates (6 – 8 mm/d); not greatly exceeding estimates of open-water evaporation rates. This results in long retention times and high evaporative losses in the months following a rainfall event. However, the estimated percentage recharge is still relatively high, but the quantity is small.
- The relatively low quantity of water (and hence depth equivalent) recharged by the Samrapur check dam relates to the low rainfall and the interception of water by the other structures upstream. Further, the location of the structure over hard rock at shallow depth is likely to limit recharge rates.
- When the total catchment above the Samrapur check dam is compared to the total quantity of water recharged by all the structures, a value of 4 mm depth equivalent is calculated, a figure very comparable with those calculated at the Mumanvas check dam and the Bhanavas check dam, the primary site where monitoring was concentrated.

Table 2.2 Comparison of recharge at the Satlasana research structures.

Satlasana research sites	Mumanvas secondary site	Bhanavas primary site	Nedardi Pond secondary site	Samrapur secondary site
Catchment area	1.75 km^2	11.83 km^2	0.13 km^2	19.5 km^2
Volume recharged by structures	6400 m^3	56 200 m^3	5500* m^3	12 500 m^3
Depth equivalent	3.7 mm	4.8 mm	4.2 mm	0.6 mm
MAR as a percentage of rainfall	<1%	1.1%	8%	0.1%
Increase in recharge due to structures in relation to project ject estimates (managed/natural)	3 – 12%	4 – 16%	35 – 140%	0.5 – 2%

* Based on an estimate of 20% of the 27 600 m^3 of captured rainfall infiltrating, the remainder evaporating.

- The relatively low percentage of total rainfall captured and recharged, less than 1%, is an order of magnitude less than estimates of 25 – 30% sometimes used in water-balance calculations. The figures are also considerably smaller than the estimated natural recharge of between 7 and 27%.

- The quantity of recharge resulting from check dam interventions may however be an underestimate of the true amount. This is because the volumes calculated reflect only that impounded and does not include river-bed infiltration between the check dams and the impact of the two subsurface dams, as well as gully plugs etc. However, if the combined impact of these interventions doubled the quantity recharged, their impact is still small in comparison to 'natural' recharge, especially where enhanced by field bunding.

- Local benefits will be particularly difficult to identify and attribute to particular interventions in areas where conditions are good for recharge. Areas with high permeability and high infiltration rates (i.e. good recharge conditions) may result in groundwater mounds dissipating rapidly. Benefits may be present but they accrue to the region as a whole rather than to specific wells.

2.7 Is the siting of the recharge structure appropriate for the location and what are the impacts downstream?

Detailed measurements at the case study sites enabled the volumes of recharge resulting from the structures to be estimated. The sites were selected to be representative of a range of different hydrogeological, meteorological and socio-economic settings. However, the extrapolation of the results must be tempered by the wide diversity of terrains and environments, not only in India but elsewhere in the world. Additionally, the period of monitoring was short and hence the periods were not 'average' meteorologically. This only goes to emphasise the need for continued monitoring at the sites now that the capital has been invested in both their establishment and support of the development of new skills.

Although the data gathering and monitoring focused on studies at the recharge structure/ micro-watershed scale, some indicators of the downstream impacts were gleaned. This is an issue that needs to be further investigated to determine the extent to which interventions in headwaters of streams have an impact on existing or potential users downstream. Do the interventions merely relocate the availability of water through aquifer storage or is a significant quantity added to the system through the reduction of evaporative losses and discharges to non-potable water bodies?

At the **Kolwan Valley** research site, the groundwater levels in the aquifer are higher than two of the three structures for part of the year. As a result these two structures do not contribute to recharge and the siting is currently inappropriate from a recharge perspective. This could change if groundwater abstraction grows. Whether or not the structures are appropriate thus depends upon projections of trends of groundwater abstraction as well as the long-term objectives that these structures are supposed to serve. The volumes recharged from the structure, where recharge occurred, are much larger than the volume that remains in the form of a distinct groundwater mound that could be tapped by specific beneficiaries. Benefits from the structure, therefore, depend on the assumption that any groundwater recharge is available for use whether or not specific beneficiaries can be identified.

A sequence of three structures has little relevance with respect to MAR. The natural recharge area for the **Chikhalgaon** aquifer is actually further upstream from CD3. Whatever little recharge takes place is through the one structure (upstream), i.e. CD3. Again, in the absence of groundwater abstraction, most of the recharge is lost to baseflow downstream. The two structures downstream (CD2 and CD1) simply collect baseflow from the aquifer and add virtually nothing to groundwater recharge. It is not possible to precisely quantify the increased amount of baseflow contribution to the Walki River, the flow in which is controlled from release from an impoundment upstream. The impacts of MAR are however, beneficial in that baseflow is 'smoothed' through groundwater storage, although only to a minor extent in comparison to the impact of the surface impoundment.

Given the low hydraulic conductivity of the basalt aquifer, most future abstraction is likely to occur along fracture zones. Since such zones are also the primary localities where recharge could occur rapidly, locating structures in areas with direct connection to fracture zones makes more sense than locating them purely on the basis of topography and drainage (on low-conductivity rock). In this situation, it also becomes easier to identify specific beneficiaries from such structures.

The high permeability of the surface sediments at the **Satlasana** research site, combined with the storage in the underlying aquifer as a consequence of long-term water-level decline, have created substantial opportunity for recharge. The storage in the underlying aquifer is within the weathered portion of granitic and gneissic basement overlain by sediments.

Despite its large volume, the **Bhanavas** structure loses most of the water to infiltration over a short period of time (up to 20 days), clearly implying the effectiveness of the structure with respect to recharge to groundwater. Although the **Mumanvas** structure does not store its full capacity of water, it serves as a sediment trap, preventing the sediment load from travelling into the **Bhanavas** structure and others downstream. Given the high permeability of the soils and the presence of substantial storage space within aquifers, the structures appear to be appropriately sited.

The stream flow into and out of the structures at the **Satlasana** research site is not quantified due to the short and intense nature of the storms and hence recharge events. However some qualitative interpretations can be made of the impact of the structures on downstream flow. Sheet flow off the bedrock hills is captured by Nedardi Pond where, due to the low permeability nature of the sediments, a large proportion evaporates. Around the pond, and elsewhere at the base of hills, sheet flow produces severe gully erosion resulting in soil and sediment transport down ephemeral streams. Some of this sediment is captured by the Mumanvas structure, which fills after a single storm event. The Bhanavas structure has a considerably larger catchment area but sedimentation is only a few centimetres each year so large quantities of water are captured, although the check dam does overspill, even during the period monitored which experienced only about two thirds of average annual rainfall. Water flowed briefly over the two subsurface structures and the Samrapur check dam, which lie further downstream. Quantification of the water captured by the various structures amounts to only 1% of rainfall but this does not include the amount infiltrating through the stream bed, which could be considerably larger. The structures add to this significantly but downstream impacts are likely to be small as only a small proportion of recharge and hence available water will result from stream flow.

Rainfall in **Coimbatore**, as in the rest of Tamil Nadu, occurs in two periods during the year. The check dam at Karnampettai is the first structure on the drainage line and effectively captures surface flow resulting in considerable quantities of recharge, and is thus located appropriately. A check dam built subsequently and located a few hundred metres downstream of the Karnampettai check dam received little water even in the higher than average rainfall season. The satellite structures studied did not capture water during the study period as the water was intercepted by other structures further upstream. Only in exceptionally wet periods would there be sufficient flow to fill all structures. This is an area that requires further research to determine the optimum size and density of structures in different hydro-meteorological environments. The issue is further complicated by the number of institutions that construct structures independently with little understanding of the availability of water or the hydrogeology.

Other studies have quantified the redistribution of water at the catchment scale. For example, in the Andhra Pradesh Rural Livelihoods Project (APRLP) (Rama Mohan Rao et al., 2003), data gathered before, during and after the watershed treatment with many rainwater-harvesting techniques has drastically reduced the run-off to village irrigation tanks, thus redistributing the availability of water. This is clearly illustrated to Figure 2.3.

2.8 What impacts does managed recharge have on the quality of groundwater?

The baseline quality of groundwater at the research sites reflects a combination of natural and anthropogenic influences. Imposed on this is the water that is recharged from the various structures as well as from natural recharge. Water chemistry can provide a powerful tool for identifying

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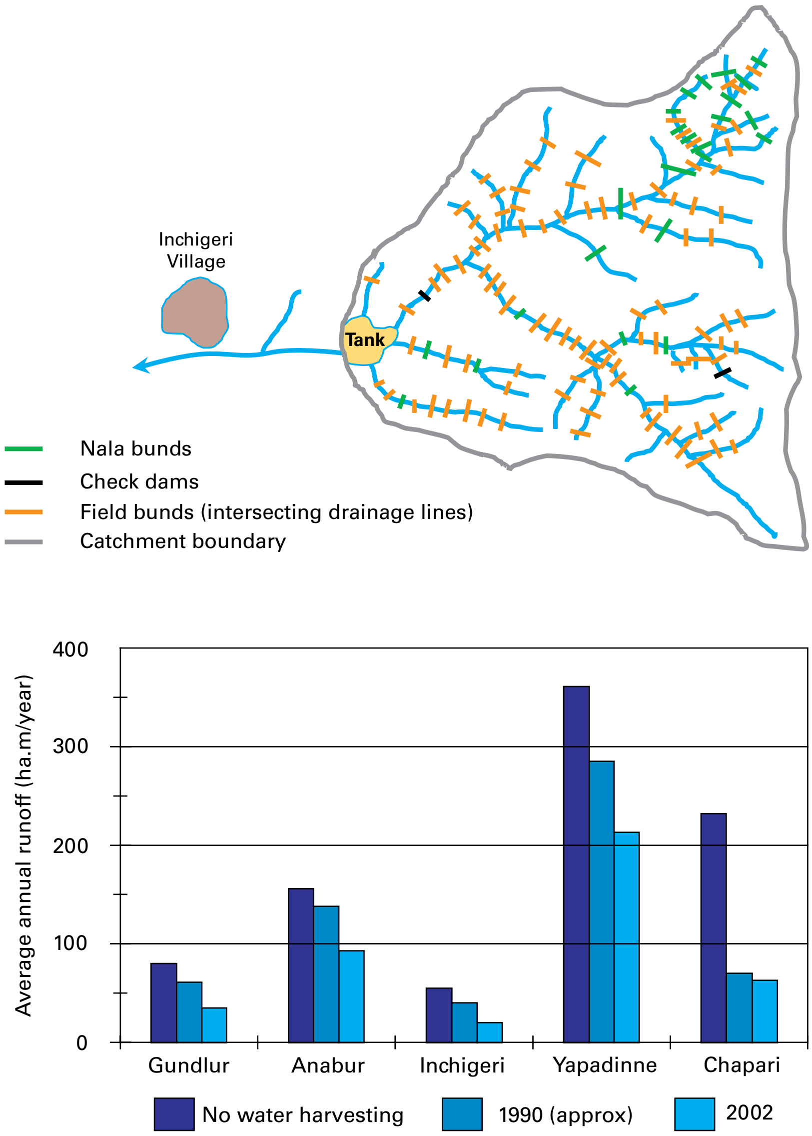

Figure 2.3 Impact of extensive treatment of the Inchigeri watershed on the flow captured in the irrigation tank.

Source:
Rama Mohan Rao et al., 2003.

the extent of recharge from structures designed for that purpose.

The water sources sampled in the Kolwan Valley, near Pune, are all of similar chemical character with bicarbonate (HCO_3) as the dominant anion. Waters are generally fresh and show low mineralisation (median SEC 408 mg/l), which is expected from these very shallow dug wells (down to 15 m depth), tapping the shallow weathered basalt aquifer. The low median chloride concentration of 9.03 mg/l indicates only limited water-rock interaction suggesting short residence times. Magnesium concentrations are however relatively high with a median concentration of 13.8 mg/l, possibly due to high Mg content of the basalt aquifer.

The analyses suggest that the least evolved waters in the Kolwan area are from open water bodies with water chemistry dominated by rainwater and altered by evaporation, but which are only marginally influenced by groundwater. The most mature waters are found in boreholes and dug wells. Cl, Na, Si and especially HCO_3 and Ca are all slightly enhanced in groundwaters compared to sources from open water bodies, distinguishing recharge structure waters to some degree from surrounding borehole waters. Only SO_4 and K concentrations are slightly lower in groundwaters, suggesting some influence of agricultural practices on the water chemistry of open water bodies. However, nitrate concentrations remain low in all sampled sources.

The observations of the major and minor ion chemistry are reflected in the isotopic composition of the samples. The spring water coincides with the meteoric water line for Mumbai (MML) and shows a composition similar to the mean rainfall at Mumbai (GNIP, 2003). However, water from the dam, the river, the recharge structure and groundwater plots on a curve diverging from the MWL towards a relative increase in $\delta^{18}O$, indicating ever-stronger evaporative enrichment. The heaviest waters are the open water bodies, which are slow moving and hence the most modified by evaporation.

The quality of the water is generally good, with major and most minor ions remaining well below the EC permissible concentrations (PCV). Only two samples show nitrite (NO_2–N) concentrations above the PCV of 0.1mg/l, indicating reducing conditions, perhaps due to decaying organic matter in these unprotected open well sources.

In the **Kolwan valley**, water quality data do not indicate impacts of MAR very clearly for two reasons. Firstly, because natural flows are rapid, with an annual flushing/freshening of all waters, including groundwater, there is little separation between samples of artificially recharged water and the background values of groundwater. Secondly, there are subtle variations across samples from shallow aquifers, surface water and deeper groundwater. This variability is an effect of the natural system rather than MAR, again the amount of water being quite small in comparison to volumes in other components of the water balance.

For the **Coimbatore** study area, the Piper diagram (Figure 2.4) reveals very variable water

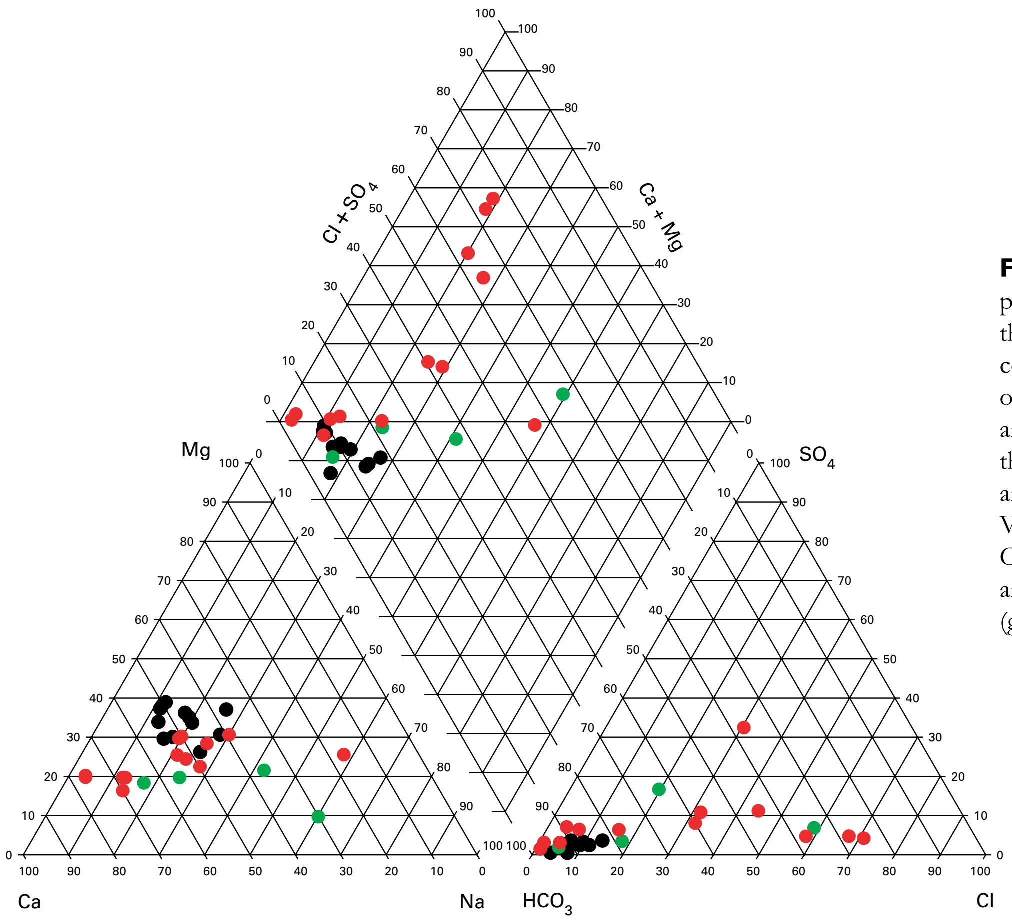

Figure 2.4 Piper plot showing the relative concentrations of major cations and anions in the three research areas in Kolwan Valley (black), Coimbatore (red) and Satlasana (green).

chemistry. Recharge structures and a borehole situated downstream of a recharge structure yield bicarbonate-type water. A water of similar chemistry has been obtained from an open structure with dimensions of about 3 m by 2 m. These waters are of low mineralisation and are of Ca, Mg-HCO_3 type. Groundwater samples from open wells and boreholes are more mineralised (median Cl of 110 mg/l), however wide ranges of water compositions exist from bicarbonate type with high Na, Mg and Ca concentrations to highly mineralised waters, which are of chloride type.

As would be expected, waters from recharge structures in the area are the least mature. Chloride concentrations as low as 1.6 mg/l suggest the water composition to be similar to that of precipitation. Groundwaters are enriched in all major as well as various minor ions, like Sr, F and Si, indicating a degree of water-rock interaction. Some of these mature waters exhibit concentrations above the PCV. Nitrate concentrations exceed the PCV of 11.3 mg/l for NO_3-N in three sources, indicating agricultural pollution and the PCV is exceeded for Ba in one source and Fe in another.

The varied chemistry is mirrored in the isotopic composition of these waters. Recharge structures and a borehole situated just downstream of the recharge dam wall, and an open large dug well, yield waters enriched in the heavy isotopes. They plot on a line of lower gradient than the WML (world meteoric line), indicating evaporative enrichment. Groundwaters are relatively depleted and plot on the WML, with the most depleted waters generally having higher mineralisation. This indicates that within the Coimbatore study area boreholes/open wells draw water from different horizons within the aquifer. The generally rather depleted isotopic composition suggests some groundwaters are old. Data from the Chennai area have $\delta^{18}O$ compositions no more depleted than –4.5 0/00 (Rao et al., 1987), so the Coimbatore deep groundwaters may have elements of Pleistocene age (> 10kaBP).

The water chemistry in the **Satlasana** research site is varied across the four sampled sources. While two dug wells produce Ca-HCO_3 type waters, the recharge structure contains water of Ca, Na-HCO_3 type. Borehole S2 yields more saline water and is of Na-Cl type. The Nedardi pond recharge structure yields the least mature water. Cl concentrations of 7.1 mg/l and HCO_3 concentrations of 39.2 mg/l suggest very limited mineralisation and a water dominated by rainwater, only slightly modified by evaporation as indicated by the isotopic composition. Groundwaters are generally enriched in major and various minor ions, with the highest degree of mineralisation; with chloride concentrations up to 351 mg/l.

Groundwaters in the area exhibit high F concentrations, with all three sampled sources exceeding the PCV of 1.5 mg/l. The highest F concentration contains nearly twice the PCV. The highly mineralised water in one borehole is above the PCV for Na, while another exhibits nitrate concentrations of 15.4 mg/l, which is above the PCV for NO_3-N of 11.3 mg/l.

2.9 Wider lessons learned

This report is written in a context where substantial debate is emerging over groundwater recharge as one of the central components in any solution to India's groundwater problems. There is a perspective that heavy reliance on supply side strategies (including MAR) is likely to be ineffective without equivalent focus on demand management.

The *Master Plan for Artificial Recharge to Ground Water in India*, (Central Ground Water Board, 2005). It is estimated that an area of 448 760 km^2 — about 14% of total land area of India — is suitable for MAR and that a volume of 36 453 MCM is available for recharge annually. This is equivalent to an additional 80 mm over the entire area and the volume equates to about 18% of the 200 000 MCM of groundwater that is currently utilised annually for irrigation. These figures relate to state-wide estimates so caution should be taken when comparing with the three microwatershed studies undertaken for the limited period of the AGRAR project, 2002 to 2005. However, the estimates of recharge for the AGRAR sites (that are not limited by storage in the aquifer), were found to be about one order of magnitude lower (4 mm to 10 mm) than the CGWB estimates and to represent only about 1% of rainfall.

Given the complexity of factors controlling recharge processes and the variability of these factors across the case study areas, it is inappropriate to characterise MAR as a single activity that can be assessed outside of location-specific context. Further, adoption of a holistic rainwater management strategy calls for an appreciation of the water problem in the first place. This involves awareness and understanding of the scientific and social dimensions of the problem and a will to implement a set of strategies including MAR (Mudrakartha, 2004). MAR activities can in some cases substantially increase recharge in relation to natural levels. Where excess water is available within a basin, and aquifer conditions are favourable, MAR clearly can contribute to water availability. At the same time, in many situations aquifer conditions are less than optimal and most water may already be utilised. The degree to which MAR activities can contribute as part of a solution to India's groundwater problems depends, therefore, on the capacity to identify where and under what conditions MAR actually enhances water availability within a given area while not reducing availability for other existing users. Results from the case studies clearly illustrate the location specific nature of MAR opportunities.

The impacts of MAR in relation to commonly stated objectives depend on local conditions. As a result, the ability to assess those conditions and make informed decisions regarding the viability of MAR activities is essential. This should be achieved through the development of a conceptual model based on all available information. A conceptual model here simply means a 'better or improved' understanding of physical processes that govern recharge in different settings or at different sites. The key issue, therefore, is development of capacity at a local level in communities and implementing organisations to develop these conceptual models and identify where MAR activities are likely to generate real benefits.

2.9.1 Availability of water for MAR

Sources of water for MAR include water that is not used elsewhere or can be more effectively used at a particular site (local or regional scale) particularly in relation to abstraction. Potential sources that have little or no impact elsewhere could include capturing evaporation losses, water that would otherwise contribute to low-quality water bodies (saline/ polluted water bodies) or water that arrives in torrential storm events. The latter source of water usually is regarded as a problem as it causes flooding, soil erosion and in urban areas can overload drainage and sewage systems leading to health risks and pollution of surface and groundwater resources. Planning to manage and capture water from more of these extreme events has most potential where other sources are limited or absent. However, consideration must be given to whether this water is already being used elsewhere to meet environmental or human needs. The AGRAR case studies showed that water was locally available but did not address the larger question of whether that water would have been used elsewhere, except at the very local scale of adjacent structures.

Where the soil or aquifer lends itself to effective recharge this should be promoted through capture over large areas (field-bunding etc.) to capture rainfall where it lands, reduce run-off and hence the destructive force of flood waters. This is demonstrated in the Satlasana area where permeable sediments overlying the bedrock aquifer facilitate recharge. In urban areas, progressive expansion of impermeable paving promotes run-off and flooding. Capture of rooftop rainwater harvesting combined with increased use of permeable paving and recharge of road run-off are all positive steps towards making a resource of excess runoff. However, implementation needs to be tempered with the need to manage the quality of the recharge water to ensure that aquifers are not polluted in a wholesale manner, thus affecting existing users.

Other potential sources of water include imported water and the reuse of treated waste water. Imported water would usually take the form of water brought in from another catchment for major irrigation schemes. The potential to store this water in depleted aquifers through spreading, injection or 'leaky' canals need to be considered in order to smooth demand and availability. An established example of this type of scheme is the Central Arizona Project (CAP) aqueduct bringing water from the Colorado River to Arizona (Lluria, 2003). In order to store this water, largely for urban use in the Phoenix Metropolitan area, the Salt River Project uses spreading basins to infiltrate the water into the underlying aquifers. In 1997, 800 MCM were recharged to the aquifer. The balance of the water supply comes mostly from groundwater (which receives intermittent natural recharge) and increasingly municipal and industrial reclaimed water volume. Local run-off, particularly urban and agriculture tail waters, are at present considered unusable because of potential health hazards and are usually delivered to blend with run-off or percolate in detention basins.

2.9.2 Ability to get water into the ground

All AGRAR sites showed that there was an ability to get water into the ground, the variability in local conditions controlling the infiltration rates. At two of the three sites, water stayed in the ground to be abstracted later in the annual cycle through wells. In the Kolwan Valley, natural discharge further down the drainage line accounted for a significant amount of the water recharged. However, in other areas like those underlain by the Mehsana aquifers or in the Kathmandu valley, volumes of natural and managed aquifer recharge may be quite significant. The relatively high porosity of these aquifers means that much greater quantities of water will be required for effects to become apparent to local users in the form of increased yields or raised water levels.

2.9.3 Available storage in the aquifer

If groundwater is not used, a natural balance between recharge and discharge is established for an aquifer. The Kolwan valley site is close to this situation, where groundwater abstraction is limited and groundwater discharges to streams. Water added to such a system simply flows out in the form of increased base flows. If there is a time lag between recharge and discharge, resulting in prolonged base flows, then MAR can be said to make a positive impact on the system despite very little addition of water to the aquifer storage.

In the two other areas, storage has been created by heavy abstraction in excess of natural recharge. In both these areas, the storage available in the aquifer decreases rapidly with depth due to the reducing porosity in different geological formations (20 – 30% in alluvial formation and weathered gneiss to 1 – 2% in the underlying fractured granite). The hydraulic conductivity also decreases with depth imposing limitations on the recovery of this water. In some areas, water quality also deteriorates with depth. Base flows to streams are virtually absent in both areas where groundwater levels in the underlying aquifer remain below the bed levels of stream channels.

2.9.4 Demand for recharged water

Current water use is limited by availability in Satlasana and Coimbatore. Potential demand, however, is orders of magnitude higher than current availability. Any additional water supply created through MAR is likely to be used rapidly. Groundwater overdraft in hard-rock areas that characterise large parts of India is often self-limiting. Once the upper weathered layer is dewatered, abstraction rapidly declines due to falling water levels and/or quality deterioration.

This implies that MAR is unlikely to increase the amounts stored in the aquifer significantly, resulting in recovery of water levels and return of base flow. For water levels to recover and create buffer supplies that are available for use during drought periods, demand would need to be managed. At the Kolwan valley site, the limited demand for groundwater actually helps maintain water levels and baseflow to streams. Use of storage, even in the low porosity basalt aquifer, is currently quite limited. This storage could potentially be used to meet demands for protective irrigation in both the *kharif* and *rabi* seasons.

2.9.5 Technical knowledge

At present most decision-making regarding the implementation of water management activities including the construction of recharge structures, is made on a programmatic basis (State, District, NGO levels) and generally reflects the availability of funds and targets. Relatively little, if any, consideration is given to hydrological, hydrogeological and other factors that influence the effectiveness of MAR.

MAR activities are neither a panacea for water management problems nor ineffective. Their effectiveness depends on whether hydrologic and hydrogeological conditions within a given region, including both natural and human factors, are favourable. As a result, the viability of MAR as a core element in any water management strategy depends on the ability to make informed decisions at the ground level, at a variety of scales.

Capacity to make and implement such decisions will, as a result, be a very significant factor in determining whether or not investments in MAR activities are justified. This implies moving away from a fixed, target-oriented approach of watershed management to a flexible process that is responsive to and reflects ground realities and available scientific knowledge. Even within programmes like WSD, it is still generally unclear as to what purpose any specific structure serves.

SECTION 2

According to our review, some limited practical guidance is available in CGWB publications as well as information, training material and courses provided by NGOs (e.g. CSE *http://www.rainwaterharvesting.org.*) As a supplement to the AGRAR project, VIKSAT produced a CD providing practical guidance on 'Rain Water Harvesting' (*www.viksat.org*). VIKSAT has also produced a 'Training cum Operation Manual' as part of a UNICEF supported project which is widely circulated by UNICEF to all state government and national level departments in India. However, there is still a great need to increase the level of knowledge in local implementing organisations in understanding the water balance and assessing the hydrogeological opportunities for MAR, particularly at the scale at which most programmes are likely to be implemented.

In order to make decisions on the suitability of recharge structures in a specific case; their construction and management, an understanding (or conceptual model) of the physical and socio-economic factors, and their interaction, is needed. The formation of an initial conceptual model can be based on currently available data as well as on information coming out of more specific monitoring networks involving higher levels of expertise and knowledge.

An initial conceptual model can be quickly derived from available information, and should be quantified with estimates in the absence of data. The components of the conceptual model will comprise information on the topography and size of the catchment, the underlying geology and hydrogeology as well as the components of the water balance – rainfall, evaporation and evapotranspiration, and surface run-off (stream flow) and recharge, both natural and managed (artificial). Quantification of the components of the water balance will identify gaps in knowledge that need to be filled with estimates through data collection.

The impacts of man also need to be assessed, including land use, water demand and quantities abstracted. From this information, an initial assessment of key components of any aquifer recharge scheme can be made:

- Is there a source of water available?
- Is there storage space in the aquifer?
- How can the water be got into the aquifer?
- Is the intervention going to be effective?

In addition, the conceptual model will identify significant gaps in knowledge, so decisions can be taken on a staged approach to the site assessment, implementation and operation. The cost-benefits of data collection will also need to be assessed in the light of the likely impact of the intervention.

SECTION 3

Community and livelihood outcomes

The key question we ask in this section is:

How have the changes in groundwater conditions, and the process of recharge design and implementation, affected people's livelihoods in the case-study areas, and what wider lessons can we draw?

Here, the emphasis is not just on physical performance criteria – changes in crop yield, irrigation etc – but on the actual impact of such changes on the lives of different groups of people. We begin by summarising the approach used to assess impacts, and the challenges faced in unravelling complex cause-effect relationships within watershed development projects more generally. We then look at some of the case-study evidence, looking firstly at the relationship between recharge activities and reported changes in groundwater availability, access and use. Finally we focus on livelihood strategies and outcomes, and examine whether (and how) changes here can be attributed to recharge activities. A summary of the research issues, questions and indicators used is provided in Table 3.1.

Table 3.1 Summary of research questions and indicators.

Livelihood component	Key research questions explored and indicators assessed
Water resources	*How have recharge activities affected the water resources asset base of different groups?*
Availability of water: in wells, boreholes and surface sources across seasons, between years	Reported or recorded changes in water levels, water quality, source reliability, pumping hours
Access to water: private and communal sources; access rights	Reported or recorded changes in well and borehole numbers; functioning and non-functioning water sources; changes in ownership of new and existing sources
Use of water: patterns of water use between groups and areas over time	Reported or recorded changes in 'adequacy' of supply for different end uses – domestic and productive uses, farm and non-farm
Livelihood strategies, outcomes	*How have changes above affected people's livelihood strategies and outcomes?*
Crops: production and sources or levels of income	Reported or recorded changes in cropping patterns, intensity, areas, yields, revenue, irrigated vs rainfed production
Livestock: changes in livestock production	Reported or recorded changes in livestock production – cattle rearing, milk production, production systems – and income
Labouring: farm economy, agricultural wage labour	Reported or recorded changes in source, availability, type and pattern of agricultural labour days and income
Labouring: non-farm economy	Reported or recorded changes in source, availability, type and patterns of non-farm labour days and income
Dependence on CPR	Reported or recorded changes in use or dependency on CPRs and access rights
Household welfare	Reported or recorded changes in household assets, housing, standard of living, distress sales, and migration, satisfaction with water sources

Source: based on Gale et al., 2003.

SECTION 3

3.1 What approach was used to assess impacts on livelihoods?

As noted in previous sections, recharge activities typically form one of a number of interventions aimed at developing, or rehabilitating, watersheds. In the case-study areas, for example, recharge activities have been combined with a range of other land development or protection, soil moisture conservation, afforestation and non-land-based measures (self-help groups, support for handicrafts etc) aimed at improving the productivity of natural resources and strengthening livelihoods. The challenge, then, is attempting to isolate or disaggregate the impact of recharge interventions from other watershed activities. As Box 3.1 makes clear, care is always needed in attributing recorded or reported changes in groundwater conditions to impacts on livelihood strategies and outcomes.

Box 3.1 Challenges and limitation of methodology.

While a wide literature exists on watershed development in India and elsewhere, systematic evaluations of impact are rare. Moreover, the comprehensive evaluations that have been carried out (e.g. Kerr, 2002) have focussed on the overall impact of development programmes rather than the contribution of specific activities, such as aquifer recharge. Attempting to identify and evaluate specific cause-effect relationships presents a number of problems:

- **Comparison and benchmarking.** A limitation of the AGRAR study – and one that plagues wider evaluations of watershed development in India – is the lack of baseline data from the study areas. Only in the Kolwan Valley case study was baseline data available on preproject conditions, and these were limited to basic data on village-household size, gender and occupation, with data on groundwater restricted to number of wells in a village and sporadic and seasonally isolated data on water levels.

- **Attribution.** Even in the Kolwan Valley case, the availability of preproject data does not mean that changes recorded, reported or observed since then can be attributed to recharge interventions. In all case study areas, recharge activities comprise one of a number of land and non-land-based watershed interventions, and wider processes of social and economic change may also affect livelihood outcomes.

- **Externalities.** The effects of recharge activities may fall outside the study area selected for analysis. In the current study, an attempt was made to identify zones of recharge influence, through both the technical and livelihoods analysis, without prejudging outcomes. However, the AGRAR project did not look in detail at upstream-downstream interdependencies, and the possible effects of rainfall capture in one part of the basin on another.

- **Timing.** 'When' recharge activities and impacts are studied may influence our understanding of their benefits. For example, while recharge itself may occur quickly, longer-term adjustments to farm (and non-farm) livelihoods may take longer to materialise. With some of the recharge sites, which date back to the 1970s, this is apparently less of a problem. However, for many, maintenance and repair work has only been attended to in the 1990s as part of DPAP watershed development projects. These therefore equate to recently constructed sites and those recently renovated as recharge sites. The timescale for impacts to be felt does, therefore, make before vs. after comparisons, based on recollection of a prerecharge situation (rather than baseline data), rather more challenging.

Box 3.1 continued

To address these problems, research teams adopted a mix of methods and approaches aimed at measuring and describing change, and testing cause-effect relationships. In the Satlasana and Coimbatore case studies, for example, comparisons were made between the situation (for sample households) before and after watershed development, and before and after recharge interventions; and by comparing the experiences of households 'with' recharge against those 'without'. In all case studies, a mix of agreed quantitative and qualitative methods were used to measure change and seek the views of different household groups on processes and outcomes. These are described more fully in the AGRAR project's Guidelines for Fieldwork report (Gale et al., 2003), and in the individual case study reports. Key highlights include:

- **Kolwan Valley:** sample survey of 279 households, representing 45% of the total population of the five surveyed villages. Of the five villages, three (Chikhalgaon, Bhalgudi and Hadashi) were included under GOMUKH's watershed development programme, while two (Nandgaon and Nanegaon) were not.
- **Satlasana:** sample survey of 31 households from five villages, located at varying distances (5 – 500 m) away from recharge structures. Includes one 'control' sample from village with no recharge structures.
- **Coimbatore:** sample survey of 60 households from two village hamlets, one with recharge structures (Karanampettai) and one without (Sangothipalagam). Sample in Karanampettai split into those (12 households) near structure and those (28 households) further away.

3.2 What do survey results tell us about changes in water resource conditions?

In all of the case-study areas, some sample households reported positive impacts on water resource conditions following project interventions. However, the scale and nature of impacts varies across the three sites, and links to recharge interventions are far from clear-cut.

Although the Kolwan Valley receives good rainfall, the valley as a whole used to face severe water scarcity during the summer months, with river, dug well and spring sources reported as seasonal by both implementing agencies working in the basin and households surveyed for the current study. Since watershed development programmes were first introduced in 1997 – 98 however, water scarcity has eased considerably, though groundwater remains relatively undeveloped. What has changed, and why?

The first point to note is that there has been no rapid development of groundwater in the Kolwan Valley generally, or in the specific villages and micro-watersheds where recharge activities have taken place. Compared with the Satlasana and Coimbatore study areas, groundwater remains relatively under-developed, with less than 100 wells in the valley as a whole, and 32 (mainly private) wells across the five study villages. In addition, GOMUKH has identified 140 springs in upper catchment areas, some 10% of which have been developed or protected as part of GOMUKH's watershed development activities. These groundwater sources are used mainly for domestic water supply, with some limited irrigation. Nonetheless, well and borehole numbers are slowly increasing, with some wealthier land owners now investing in well deepening in areas immediately adjacent to, or downstream of, recharge structures (see Box 3.2). Of the 10 – 15 boreholes drilled in the valley during the last 8 – 10 years, however, about 10 are concentrated in villages like Nanegaon and Nandgaon where recharge structures have not yet been built.

Box 3.2 A water point history: Maruti Phale's well.

The well CH2 belongs to Mr Maruti Phale. It is located in the Chikhalgaon watershed, on the western flank where lands are registered under Nandgaon village. He owns around six acres of land in Nandgaon. He narrates that the well was shallow and narrow till six years ago. It used to irrigate one acre of land then. Mr Phale used to pump it for about three hours just after the rainy season, one and a half hours between January and March. In April and May, he used the well only for drinking water. The well was subsequently deepened and properly constructed after the check dams in Chikhalgaon were constructed. He spent around Rs. 90 000/- for excavation and construction of the well. Presently, he pumps water from the well for three hours from November onwards till March. In April and May, he pumps it for one hour per day for irrigation. He now grows rice and vegetables on his land throughout the year.

The well was deepened as a consequence of improved incomes. Drawing a direct link with recharge activities is more difficult. However, it is clear that the construction of the check dam provided the impetus to begin work on the well on the assumption that the well would benefit from the intervention.

In terms of groundwater levels and source reliability, the picture is mixed. The few primary data that are available from GOMUKH's own monitoring wells suggest that water levels have risen since recharge work began. This is supported by farmers' own views canvassed during the survey, with 70% of respondents in the three programme villages reporting a rise in the water table and associated increases in irrigation and livestock (more fodder), compared with around 30% across all five (with and without) villages. Although spring conditions in the upper catchment were not a focus of the AGRAR study, these are also reported as 'rejuvenated' and, at least in some cases, perennial. However, the link with recharge activities is again ambiguous since many of the 'rejuvenated' springs have also been developed and equipped with storage tanks.

The absence of major groundwater development around recharge structures in the Kolwan Valley would suggest that groundwater that is recharged provides baseflow into the River Walki. This hypothesis is supported by reported changes in river flows over the last 8 – 10 years. In particular, the river is now reported as 'near perennial' by both the PIA and sample households, and surface irrigation lifts along its banks, and in some cases 3 km distant, have certainly increased. However, a clear link with recharge activities is again difficult to draw, as river flows have also been affected by the construction of tanks and dams in upstream areas, designed to regulate river flows across seasons.

In contrast to the situation in the Kolwan Valley, groundwater development in the Satlasana and Coimbatore areas is such that overdraft is now a serious problem. In both areas, water levels have been falling for several decades with the rapid expansion and intensification of irrigated agriculture. The key question here, then, is whether recharge activities promoted under government and donor programmes have reversed, or mitigated, problems.

Looking again at groundwater levels and reliability, recharge structures appear to have had a positive influence on groundwater availability, though within much more localised, structure-specific areas. In both areas, drinking water supplies are now provided through major piped (surface) water schemes. In both areas, however, groundwater sources are still used for other domestic uses, such as bathing and washing, though links with recharge interventions were not explored. In terms of water for irrigation, farm households with private wells in the vicinity of recharge structures (within 500 m or less) reported an improvement in groundwater availability for irrigation, though evidence in the round is not always clear-cut. Indicators are described below.

- *Groundwater monitoring levels and farmer views on groundwater availability* (though data and perceptions do not always match). Around the Bhanavas check dam in Satlasana, for example, monitoring data highlight a relatively short pulse of groundwater recharge detected to a distance of around 240 m downstream of the structure, and dissipated towards the end of December. However, the survey of farm households highlighted impacts to around 500 m in both upstream and downstream areas, including influences on agricultural production felt into the winter (November – February) and summer months (March – June) in some cases. In Coimbatore, monitoring results indicated enhanced recharge to a distance of around 400 m below Karnampettai check dam, roughly consistent with livelihood influences discussed below, with enhanced recharge maintained over the year.

- *Incidences of well failure and patterns of groundwater development in Coimbatore*. Within the immediate area around the Karnampettai check dam, for example, no wells have failed or been abandoned (in contrast to the surrounding area), and while investment in new wells and/or well deepening has stopped in all sample groups, well density (spacing) and pumping hours remain positively correlated with distance to structures.
- *Pumping data from irrigation wells* (also difficult to interpret). Within the area around Karnampettai check dam, for example, daily pumping hours are higher than those in the surrounding area. This was interpreted as indicating greater groundwater availability, but could also reflect differences in well ownership or electricity supply across relatively small household samples. In Satlasana, on the other hand, pumping hours decreased across all sample groups, including the control groups. This could highlight the effects of a good monsoon in the 'after recharge' sample compared with the 'before recharge' drought. It could also indicate that recharge interventions have reduced, but not stopped, the long term problem of declining groundwater levels or it may simply indicate a deterioration in the reliability of electricity supply.

3.3 How have recharge activities affected people's livelihoods?

3.3.1 Domestic water supply

In terms of assured drinking water supplies, all three case study areas have benefited from the introduction of piped schemes, significantly reducing the burden of water collection on women, and dry season water shortages. In the Satlasana and Coimbatore case-study areas, these provide water from distant surface sources, unrelated to watershed development works. In the Kolwan Valley, groundwater-based reticulated systems have been introduced as part of the watershed development programme, but in isolation from recharge activities further upstream. Spring development and protection in the upper catchment has provided those without ready access to downstream systems with improved domestic supply but, again, benefits are unrelated to recharge activities. In both the Kolwan Valley and Satlasana cases, however, the development of women user groups (WUGs) to manage systems and organise operation and maintenance has contributed broadly to community organisation and empowerment efforts, including those around watershed development and recharge.

In all case-study areas, households continue to rely on other groundwater sources to meet non-drinking water uses. In Karnampettai hamlet in Kodangipalayam village (Coimbatore), a hand-pump for domestic uses has been installed below the check-dam to provide a reliable source of domestic (non-drinking) water. However, this was done on a separate programme: in none of the case-study areas was protection and/or provision of domestic supplies an explicit objective of any programme.

3.3.2 Agriculture and farming systems

In the Kolwan Valley, links between recharge activities and agricultural change are difficult to draw with certainty. This is because (a) groundwater recharge from the check dam (CD3) discharges to stream baseflow quickly, with only limited potential for impacts on individual wells; and (b) groundwater development in the valley is still limited, albeit increasing. There have been significant agricultural changes since watershed work began.

- *There has been an increase in the cultivated area* (as wasteland is brought into production) and an increase in the proportion of irrigated land, principally from surface water 'lifts'. The benefits of (surface water) irrigation are distributed reasonably equitably amongst land-owning households as the valley bottom, where most lift irrigation is concentrated, contains both large and small land holdings. In this area most households own land; there are very few landless labourers.

- *Significant increases in Kharif irrigation have taken place* (supplementary – during poor monsoons) *and irrigated Rabi cultivation has taken place*, including wheat and, increasingly, cash crops such as vegetables and sugarcane (see Box 3.3). In 1998, for example, only 1% of the farmers in the valley reported growing irrigated *Rabi* crops. In the current survey, this figure had increased to around 12%. This figure may underestimate the extent of actual irrigation, as farmers are reluctant to report unauthorised lifts from the river, which have no formal approval from the irrigation department. The growth of water-intensive sugarcane has concerned GOMUKH, who are now actively promoting organic vegetable production as a less water-intensive alternative. These changes cannot be attributed directly to recharge activities carried out under the watershed development programme. Most irrigation water is drawn from the River Walki, not groundwater. However, groundwater recharge has contributed additional (lagged) baseflows to the river, supporting river flow throughout the year and therefore an increase in *Rabi* cultivation. The precise contribution of additional groundwater recharge to water availability and reliability, compared with the effects of staggered tank releases in upstream areas, is unknown.

- *Increasing irrigation from wells and boreholes has been observed*, though with no clear links to recharge activities. In the villages of Nandgaon and Nanegaon, for example, farmers have drilled boreholes independently to irrigate orchids and vegetables resulting in rising incomes. Latterly, GOMUKH has started work in these two villages, which are currently under watershed development projects. The only clear relationship between recharge structures and farm livelihoods occurs through lifts from water impounded behind some structures; farmers with nearby land use this water for irrigation. These are both formal and informal arrangements. Where one village owns a structure but another owns some of the surrounding land, this can lead to inter-village conflicts over water rights (see Section 1.6).

- *There have been increases in livestock*, with most farmers now owning at least one bullock or buffalo, and associated increases in milk production, now marketed through cooperatives. Across the five (with and without) study villages, for example, there has been a 22% increase in milk production since the 1998 baseline. These changes are linked with the increasing availability of water from the river, springs and wells, and with the increasing availability of green fodder during the summer.

In the Satlasana and Coimbatore case studies, links between recharge activities and agriculture appear to be more localised. In both areas, sample surveys comparing control groups beyond project areas with those within, and comparisons over time (before and after), highlighted changes in cropping patters and irrigation intensity. However, both areas are experiencing quite rapid economic changes, and cause - effect relationships again require close scrutiny. Specific changes are highlighted in the surveys.

- In **Satlasana**, increases in cropping intensity and crop yields, including an extension of groundwater irrigation to limited *Rabi* crops (e.g. vegetables, mustard) and, for the few borewell and borehole owners, there is support for both *Kharif, Rabi* and limited summer (irrigated pasture) crops (see Box 3.4). As noted above, however, groundwater monitoring suggests that recharge impacts do not extend this far into the dry season. In terms of irrigated area, moreover, the only sample

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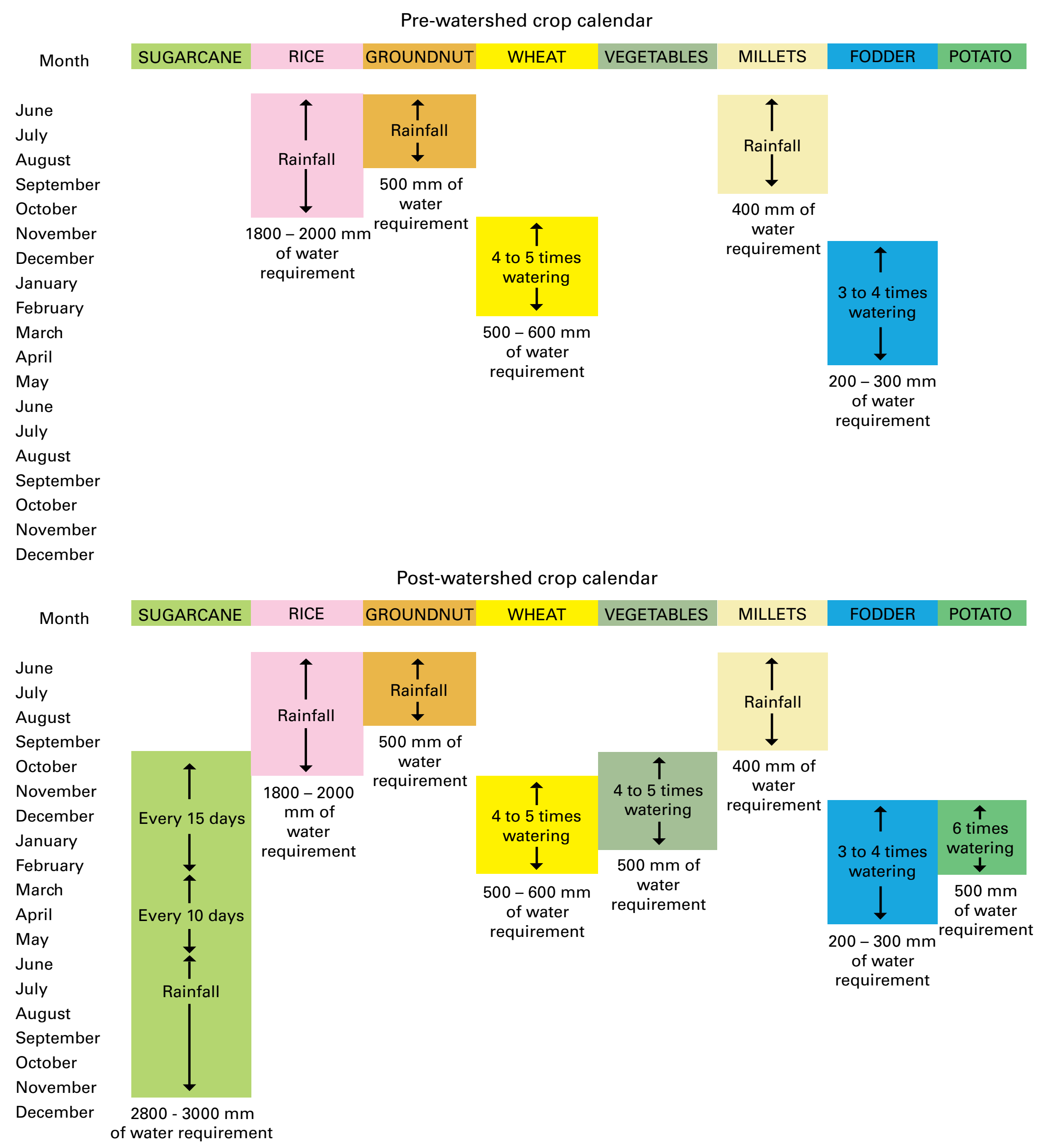
Box 3.3 Agricultural changes in the Kolwan Valley.

The crop calendars below illustrate the pre and post-watershed programme situation in the Kolwan Valley, based on a comparison between a baseline survey conducted in 1998 by GOMUKH and the AGRAR survey conducted in 2004. A number of changes are apparent. Firstly, while there has been little change in the *Kharif* crop (rice still dominates), there has been an increase in supplementary *Kharif* irrigation. In addition, more irrigated cash crops are grown in the *Rabi* season, principally sugarcane and vegetables. These crops now dominate *Rabi* season production, with the proportion of irrigated wheat falling significantly in most areas.



groups reporting an increase in the proportion of (groundwater) irrigated cultivatable land were in the downstream areas of Bhanavas check dam and the subsurface check dam in Vajapur. In other village households, including those close to the Nedardi percolation pond and other recharge structures, the irrigated area decreased.

- In **Coimbatore**, and to a lesser extent Satlasana, the localised impacts of recharge are dwarfed by wider, structural changes in the rural economy. Within agriculture, for example, there has been a significant shift to less water intensive crops across the Coimbatore sample groups, together with an increase in fallow agriculture and reductions in irrigated area. In the Kodangipalayam watershed as a whole, for example, the proportion of cultivable land that is irrigated with groundwater has shrunk from approximately 67% to 41% over the last 10 years. At the same time, water intensive crops, prevalent 20 years ago, such as rice, banana, coconut and turmeric, have been replaced by annual fodder crops such as maize and sorghum. In addition, trees are cultivated that help reduce risk by providing fruit and many other products including mulch, fuel, construction materials etc. That said, it is significant that the pockets of more water intensive crops remaining (mainly turmeric and banana) are found in the zones immediately downstream of recharge structures, where irrigation intensity and irrigated area are still greater than in the remainder of the watershed.
- There are increases in the leasing of land as larger landholders diversify into the rural non-farm economy (RNFE) and reduce their economic dependence on agriculture. In case-study villages in Coimbatore, for example, land is leased out at roughly Rs 8 000/year/acre, mainly to lower caste, landless migrants from Dindigul District specialising in vegetable production. Hence in both the Satlasana and Coimbatore cases, where most rural households do not own land (in contrast to the Kolwan Valley), wider changes in the rural economy, unrelated to watershed treatment, are allowing 'new' households to farm land and access groundwater.
- As in the Kolwan Valley, there is an increase in the number of households rearing livestock for milk production. In Coimbatore, this is linked with the shift to less water intensive farming systems and the planting of drought-resistant sorghum and rain-fed fodder maize. In Satlasana, the growth of animal husbandry as the major secondary occupation is also a response to water scarcity and the need to generate quick cash returns. Here, however, there is also strong institutional support from a network of dairy cooperatives (known as District Milk Societies). The Satlasana study highlighted slightly higher cattle holdings and milk production in treated areas compared with the control, with links between higher crop production in these areas and the availability of fodder (e.g. straw fodder from groundnut and Bajra during the *Kharif*; wheat straw during the *Rabi* season).

Box 3.4 Groundwater recharge and agricultural change in Satlasana.

Survey results in Satlasana highlighted agricultural changes over time and between areas. Comparisons were made between the situation (for sample households) before and after construction of recharge structures, and between farm households in areas with and without (the control group) recharge structures. Neither analysis is perfect: the before versus after comparison is between a drought year (2002) and a good monsoon year (2003); the with versus without comparison is based on a control group of only three households. Putting both together, however, some tentative conclusions can be drawn.

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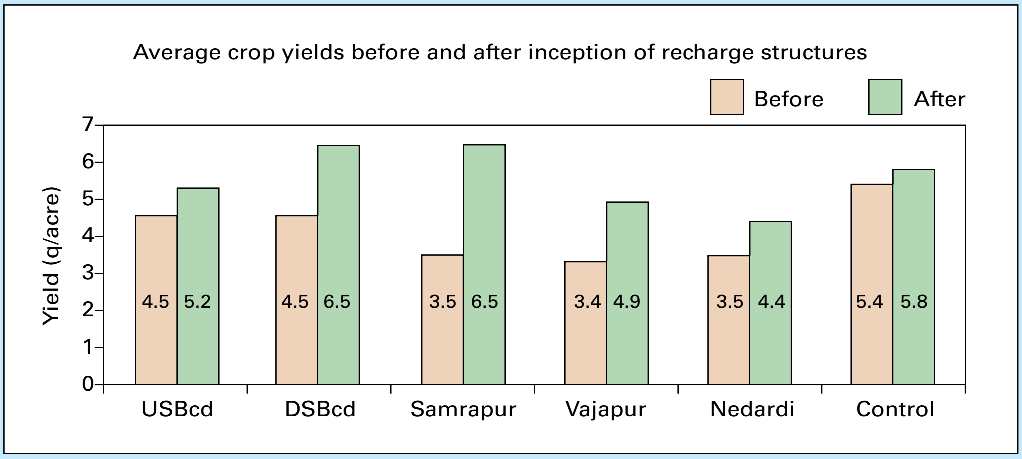
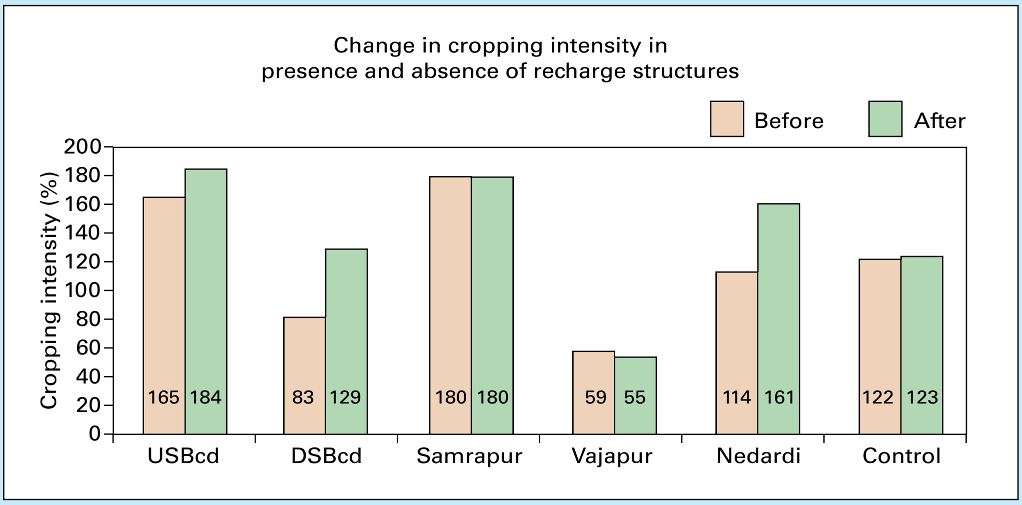
Box 3.4 continued

The most significant increases in cropping intensity reported by sample households occurred in the downstream area of Bhanavas check dam (5 – 500 m downstream of the structure), and below Nedardi pond (91 – 366 m downstream). In these areas, cropping intensity increased by 46% and 47%, respectively, following completion of the structures, compared with very little change in the control group. Crop yields followed a similar pattern, with increases of up to 3 quintals/acre reported by all respondents except in the area above the Bhanavas check dam.

Cotton, groundnut, castor and minor millet (*bajra*) are the most common *Kharif* crops receiving supplementary irrigation from dug wells. Wheat, mustard and vegetables are the most common *Rabi* crops irrigated with water from borewells and, in a good year, by some dug well owners. Well ownership is skewed heavily towards a few wealthier farmers. Across the five villages surveyed, comprising 605 households, 70 farm households (12%) own wells. Of these, only 15 (roughly 2%) own borewells. However, some land is leased by wealthier farmers to marginal farmers and landless households.



Note: USBcd refers to farm households surveyed in the upstream area of Bhanavas check dam between 122 m and 500 m away from the structure. DSBcd refers to farm households surveyed in the downstream area of Bhanavas check dam, between 5 and 500 m away from the structure.



3.3.3 Income, employment and equity

A wide range of factors influences livelihood strategies and outcomes in the case-study areas. These include watershed development and drought-proofing programmes funded by the government, and the recharge components within them. They also include wider processes of socio-economic change occurring independently of such programmes, related to improving market access, labour mobility, diversification of livelihood opportunities for some, and the growth of the RNFE. Attributing changes in livelihood outcomes to recharge interventions, specifically, is therefore more difficult than fleshing out links with, for example, crop production and irrigation patterns.

In the **Kolwan Valley**, links between recharge activities and livelihood outcomes are particularly difficult to draw with confidence. As noted previously, groundwater recharge here is not retained within localised 'mounds', but dissipates quickly. In this context, what do survey results tells us about livelihood changes and what, if anything, can we say about their causes?

Firstly, while agriculture remains the primary occupation of most households, the proportion of income derived from agriculture (own farm and farm labour), and the proportion of households for whom agriculture is the main occupation, has declined over recent years. At the time of GOMUKH's baseline survey in the valley in 1996, for example, around 80% of respondents cited agriculture as their principal occupation; by the time of the current survey (2004), this figure had fallen to approximately 60%. Over the same period, the importance of other income sources and occupations – principally business and services – has increased, reflecting in part the movement of labour (both seasonal and permanent) to nearby towns and cities. In the current survey, for example, virtually all households reported that one or more (male) members of the household worked in cities, particularly Pune and Mumbai, increasing in-valley dependence on remittance income. One potential downside is the increasing burden of agricultural labour that falls on women; the percentage of female cultivators has increased by over 50% since the 1991 (Government of India) census. The sale of land, mainly to city dwellers in Pune, is another recent phenomenon. However, there are no clear links between any of these trends and watershed development, or recharge. Indeed migration and land sale is most prevalent in the villages of Bhalgudi and Hadashi, respectively, both part of the watershed development programme.

Secondly, income levels have increased significantly in all five villages surveyed. Since the 1991 census, for example, average annual income has increased by around Rs 5000 – Rs 7000, and by Rs 3000 since GOMUKH's 1998 baseline survey. Average income for sampled households in the five villages is now around Rs 34 000, well above the official poverty line of Rs 12 000. Prior to the watershed programme, around 40% of households were below the poverty line, compared with less than 10% now. Again, links with recharge activities are difficult to draw. By far the highest household incomes were recorded in the village of Nandgaon, where sugar cane cultivation is widespread, but this village was, at the time of the survey, not part of the watershed programme.

Thirdly, the effect of rising disposable incomes can be seen in the asset status of households and their expenditure priorities. The first priority across social groups is house improvement, and the number of *pucca* (well built) houses has increased significantly throughout the valley, as has access to sanitation facilities. Purchase of livestock is another priority, occurring in all survey villages, in response to improved fodder availability and the presence of milk cooperatives.

In the Satlasana and particularly in the Coimbatore area, similar economic shifts are occurring (see Box 3.5). In both areas, however, survey results highlighted localised, agriculture-related livelihood impacts that could be more readily attributed to recharge interventions, albeit with some caveats. In Coimbatore, though, these are dwarfed by shifts within agriculture, and between agriculture and other sectors that are occurring independently of watershed programmes.

In **Satlasana**, the agricultural changes described earlier translate into rising income levels for those households, within the influence of structures, with land and access to groundwater. In all sample groups, for example, income from agriculture increased – in the case of Bhanavas and Nedardi by double – following recharge activities, compared with insignificant change in the control group. At the same time, income from animal husbandry also increased in most locations, in part due to the availability of irrigated fodder. It is surprising however that impacts were felt in the area upstream of the Bhanavas check

Box 3.5 The impact of MAR on the rural poor.

A key concern is whether MAR activities improve the livelihoods of poorer groups, or whether it is the better-off, with greater command over existing land and water resources, who benefit disproportionately. A number of issues emerge from the case-study experience.

Firstly, the interests and priorities of poorer groups were not explicitly canvassed in either the Kolwan Valley or Coimbatore cases. In the Satlasana case, the village-level institutions supported by VIKSAT provided a useful forum for discussing needs and prioritising villages for MAR interventions. These institutions have reportedly helped ensure that the voices of poorer households – the landless and marginal farmers - are heard and factored into decisions. In none of the case study areas, however, was any explicit attempt made to assess distributional and equity issues prior to project implementation.

Secondly, any direct benefits to the poor from MAR will depend on whether they can (a) access any 'additional' water generated through recharge; and/or (b) increase labour days and income through employment in, for example, check dam construction.

In terms of the former, benefits are difficult to gainsay. In each area, drinking water supplies were assured prior to, or as a component of, watershed development work through separate drinking water schemes, though some households continue to use (private) groundwater wells and boreholes to supplement scheme supply. In terms of productive water use, the direct benefits of agricultural intensification or extension accrue, not surprisingly, to those with land and access to groundwater in the vicinity of the structures. These tend to be better-off households, though there are interesting exceptions. In both the Coimbatore and Satlasana case studies, for example, some wealthier farmers now lease land to agricultural labourers while they diversify into the non-farm economy. And in Satlasana and the Kolwan Valley, herders have benefited through access to stored water behind some of the structures. In both cases, at least some of the benefits of recharge activities are being captured by poorer groups, though benefit-sharing was not planned for or brokered by the PIAs.

As far as employment creation is concerned, structures in all three locations were built using local, hired labour. In the Kolwan Valley, the watershed programme as a whole has been instrumental in generating 2.1 *lakh* (210 000) days of employment. However, the growing scarcity of labour has recently led the PIA to subcontract construction of a check dam to an outside firm. In the Satlasana case, employment generation was an explicit objective of the drought-relief projects implemented between 1999 – 2002. A key issue in all areas, and more generally, is whether employment gains are sustained beyond the initial construction phase, for example in maintenance or, indirectly (see below), through an increase in agricultural labour days.

Thirdly, indirect benefits to the poor from MAR are likely to depend on whether agricultural intensification/extensification in the vicinity of recharge structures generates employment opportunities for those households dependent on farm labour. A key issue here is whether any increase in the demand for labour is met from family sources or from hired labour. The case study picture is difficult to interpret as a range of other factors, unrelated to recharge interventions, have influenced the rural economy and agricultural employment. In the Kolwan Valley where labour is scarce and landless households relatively few in number (around 10% of the total), employment gains from agricultural growth appear to have been met from farm-family sources and sharecropping for poorer, marginal farmers. In Coimbatore a similar pattern emerges, though here local labour is increasingly skewed towards the non-farm economy where higher, more reliable income is available. In Satlasana there is a clearer link between MAR and agricultural intensification, though reported growth in work availability within project villages (around 5%) is modest.

Box 3.5 continued

Other studies highlight important intra-household dimensions to agricultural intensification. For example Turton, (2000) observes that while increases in agricultural productivity are generally considered 'a good thing', men usually appropriate on-farm gains, while the increased drudgery is disproportionately borne by women. Intra-household issues were not examined in detail on the current study, though in all cases women were reported as the main cultivators, with men involved more in non-agricultural activities and migration. In the Kolwan Valley, the percentage of female cultivators recorded in the survey was around 50% higher than that recorded in the 1991 census. VIKSAT note that in project villages in Satlasana, where animal husbandry is a major secondary occupation, the increased availability of (irrigated) fodder benefits women especially, since they no longer have to collect fodder from forest lands further away.

dam where monitoring data indicate that groundwater conditions are unaffected by the recharge structure.

In the **Coimbatore** area, survey results suggest that recharge intervention may have lessened, but not reversed, long-term trends in agriculture away from groundwater-intensive irrigation, and shifts from agriculture to other livelihood options, at least in small areas. For example, all of the farm households surveyed, including those identified as 'realised beneficiaries' within zones of recharge influence, reported shifts to less water intensive crops (such as sorghum) and livestock rearing, a reduction in the proportion of irrigated land and irrigation intensity, and/or growing dependence on the RNFE as a source of income and labour. However, these shifts were generally less pronounced within the recharge zones. Within this sample group, income levels, and the proportion of household income derived from agriculture, was higher than for other groups, including the control. In addition, the number of own farm and off-farm agricultural labour days was also greater.

In terms of equity and the distribution of benefits, there are significant differences between case studies. In the **Kolwan Valley**, where land is less scarce and landless labourers are a minority group, rising income levels and labour demands are reported to have benefited most households. For example, both small and large landowners are located close to the river, where perennial flows (positively influenced by recharge) have supported lift irrigation and livestock watering. A few smaller farmers also purchase water from those with lifts, but the extent of this is not known. Farmers were often reluctant to discuss their involvement in informal water transactions, probably because they were not authorised by the irrigation department. Landless households belonging to the Dhangars (livestock herder) tribe have also negotiated access to water stored behind check dams for watering livestock

In both Satlasana and Coimbatore, agricultural benefits appear to be skewed more sharply towards those relatively few households with existing commands over land and water. In Satlasana, for example, only 70 (12%) of farm households own wells out of a total of 605 households in the survey villages, and only a proportion of these are located within the influence areas of recharge structures. In the village of Karanampettai, Coimbatore, only 17% of households own land, and over 90% of these are small and medium-sized landholders with limited, and shared, access to groundwater infrastructure. In these circumstances, a key question is whether any increases in agricultural productivity generate labour gains for marginal farmers and the landless beyond zones of influence, and without direct access to groundwater (See Box 3.5). In Coimbatore, landless migrants have moved in to villages such as Karanampettai to farm leased land, but this appears to be a response to wealthier residents leaving agriculture for higher returns in the RNFE, rather than to perceived gains from recharge interventions. In Satlasana too, larger land holders are also reported to be leasing irrigated land to landless families, but there are no data on this. However, the study concludes by indicating that landless households have not benefited significantly from recharge interventions beyond short-term employment in the construction of check dams.

SECTION 4

What are the wider lessons for recharge interventions?

Summarising the comparative analysis in Chapter 3 and on insights from Chapters 1 and 2 of this report, what lessons can be drawn for the way in which recharge interventions are planned and implemented?

4.1 The objectives of MAR

Managed aquifer recharge is one element of rural development work in each of the case study sites, forming part of a wider set of watershed development activities (Kolwan Valley, Coimbatore), or undertaken as a discrete activity (Satlasana). In each case, it was assumed that watershed treatment would lead to increased recharge and an improvement in groundwater availability. These changes, in turn, were assumed to support livelihoods threatened in Satlasana and Coimbatore by groundwater overdraft and agricultural contraction, and in the Kolwan Valley by entrenched poverty and water scarcity. Specific objectives based on local conditions – for example the protection of drinking water supplies, or support for protective irrigation in particular areas or for particular groups, were not considered by the PIAs, or required by programme funders.

Our research suggests these generalised assumptions are flawed. In particular, the 'one size fits all' approach to MAR (and watershed development more generally), based on the notion that MAR will work everywhere, and benefit everyone, is unrealistic. This is not to say that MAR is ineffective. Rather, the nature, scale and distribution of benefits depends on a set of location specific factors, both physical and socio-economic, that need to be considered at the outset. The definition of specific MAR objectives, sensitive to local context, should therefore form part of a more flexible, demand-responsive approach to planning and implementation.

4.2 Demand, planning and participation

Investment in groundwater recharge could not be described as a positive choice on the part of some of the communities surveyed for the AGRAR project. In the Kolwan Valley and Coimbatore areas, for example, recharge was one element of watershed programmes that were essentially predesigned. Certainly with DPAP programmes in the Coimbatore area, for example, community participation and consultation – now enshrined in watershed guidelines – was restricted to the provision of labour and information-giving. In the Kolwan Valley, where there is a resident and respected NGO, the quality of community participation was higher. Even here, however, recharge was part of a watershed 'package', with little scope for innovation and flexibility. One indication of acceptance of, rather than demand for, recharge is the pronounced drop-off in associational activity following construction in both areas, and ongoing problems with operation and maintenance.

Both the Kolwan Valley and Satlasana communities have benefited from long-term partnerships with resident NGOs, able to access funds and draw on a range of social development and technical expertise. In Satlasana, VIKSAT has played a key role in building community awareness of and interest in natural resource management, and in supporting democratic forums at village and intervillage (federal) level, with different roles and decision-making responsibilities. The emphasis on federal decision-making is significant, as it provides a forum for (a) discussing the needs of different villages, and prioritising villages for 'scarce' programme funds (e.g. for drought relief); (b) reconciling upstream-downstream conflicts that might arise through MAR; and (c) connecting people with the government bureaucracy, and giving them a stronger voice and lobby. This provides a good illustration of how physical and administrative boundaries can be reconciled through decision-making bodies at different levels, and also how, in this case, representative bodies (such as the federal *Sangh*), can work alongside, rather than in competition with, democratic *Panchayati Raj* institutions (Mudrakartha and Madhusoodhanan, 2005).

Clearly the benefits of long-term NGO engagement with watershed communities cannot be replicated everywhere. A major challenge is how to marry the benefits of a 'thick and deep' NGO-type approach, with the coverage demands of government programmes. Allowing PIAs much greater flexibility in the design and implementation of watershed programmes, and the recharge activities within them, could bring progress. This, in turn, would require a change of approach within district agencies (*Zilla Parishads*) charged with the oversight and monitoring of programmes: although the Common Guidelines provide for flexibility at a local level, they are still interpreted as rules, with narrow technologies and inflexible implementation procedures, at district level (e.g. Coimbatore). For PIAs such as GOMUKH and WTC, the challenge would then be to match watershed interventions more closely to ground realities, both physical and socio-economic, rather than with prescribed targets specifying how many structures, of what type, should be constructed in any given area.

Drawing on these observations, we would argue that (a) participation needs to extend beyond labour contributions and information sharing; and (b) that technical decisions should be informed by an understanding of local geohydrological conditions. Key issues that need to be addressed by PIAs (given flexibility from district government) therefore revolve around the following issues.

- The *physical appropriateness/efficacy of MAR in an area:* in view of the topographic, climatic and geological conditions in a watershed, will check dams and other structures make any significant difference to groundwater recharge, or would structures merely act as evaporation ponds, or redistribute water around a 'closed' watershed? Case study findings suggest that recharge activities are currently implemented without an adequate understanding of physical controls, but that a basic dataset for more informed decision-making could be gathered at little extra cost, and applied by a field technician.

- The *contribution MAR could make to groundwater-dependent uses.* A key question here is what a 'significant' difference means in terms existing or intended water uses. Case study findings highlight large variations in the additional recharge that structures generate, over and above the water (rainfall, streamflow) that would have recharged naturally. In all areas, however, the volumes involved are minor in relation to catchment irrigation demand and the amounts recharged are about one order of magnitude lower than estimates at a national level. As noted in Chapter 2, for example, a large recharge structure such as that in Karanampettai provides around 15 000 m^3 of additional recharge. This may be significant in drinking water terms, but is only sufficient to irrigate a crop such as wheat or groundnut (with roughly 500 mm of water requirement) over an area of three hectares. This in a watershed of some 140 hectares.

- The *siting and design of recharge structures:* if additional groundwater recharge is feasible, what type of structures, located in which portions of the watershed, are likely to be most effective? Case study findings suggest these decisions could also be better informed with basic hydrogeological knowledge so that impacts could be predicted and planned for. Little account of the water availability or hydrogeological context and water balance are taken into account by the many agencies implementing schemes. Siting and design decisions also need to be sensitive to locally defined objectives canvassed, rather then pre-judged, by the project. This requires discussion around livelihood strategies and livelihood priorities, and how different wealth groups, or household types, might stand to gain or lose from recharge. Although drinking water supply and watershed development programmes are treated as distinct, there may be a strong case for targeting recharge at the protection of communal drinking water and livestock supplies, for example. Or ensuring that landless households are allowed to water their livestock from stored water, or are granted fishing rights. Tailoring recharge activities in this way would help ensure that benefits are distributed more equitably.

- The *needs and interests of different groups:* a project that devotes time and resources to consulting different groups about their priorities, and involving people in objective-setting, is more likely to meet poverty and environmental goals. So, what are the priorities of different groups (particularly landless labourers and herders, small or marginal farmers), and how might they stand to benefit (or lose) from recharge activities? Case studies (see Annex) suggest that recharge structures are viewed as community assets (at least by funders and implementers) that will benefit all members of the community. In reality benefits are skewed towards those with land and existing access to groundwater; poorer people have benefited (e.g. through rent of irrigated land; short-term employment), but not as a consequence of recharge interventions per se, or a 'pro-poor' bias in planning.

- *Arrangements for ongoing management and benefit-sharing:* case study experience indicates that benefit sharing between groups is largely accidental rather than planned for, and that ongoing maintenance of structures remains a problem. These two issues are linked, as any approach that assumes broad community stake in recharge may struggle with whole community financing in circumstances where costs and benefits are perceived to be unevenly distributed. There is also the question of demand noted earlier. Do communities and households actually want recharge and, if so, is demand based on realistic expectations, and an understanding of obligations, conveyed by the PIA?

Following on from the last question in particular, there is an argument for greater decentralisation, such that local institutions are given more freedom to plan their own development with untied funding. Naive? Such an approach is currently being piloted in Madhya Pradesh, where untied funds from DFID and the state government are being released to *Gram Sabbas* with district supervision and capacity-building, to plan and implement their own livelihood-improving investments.

4.3 Impacts and sustainability

The AGRAR study has shown how difficult it is to assess the impacts of MAR on livelihoods. There are several reasons. Firstly, longitudinal comparisons are hampered by a lack of baseline data on the 'before' recharge situation. Secondly, with vs. without comparisons require a control group with a similar environmental and socio-economic profile to the 'with' group. Thirdly, MAR typically forms one of a number of watershed activities aimed at improving resource productivity, generating employment and supporting livelihoods. Finally, changes in economic conditions, access to infrastructure and other external factors may have as great an impact in influencing the outcome that a project seeks to achieve as the project itself. Attributing changes in livelihood strategies and outcomes to watershed development, and to MAR specifically, is therefore difficult to do with confidence.

That said, any project seeking to improve the livelihoods of the rural poor should conduct basic water and livelihoods audits to inform the objectives and design of its activities. In other words, it should avoid the temptation to make easy assumptions about benefits as our own, imperfect, *ex post* evaluations of MAR indicate that the picture is mixed. In the Kolwan Valley, for example, recharge interventions have had no direct impact on the livelihoods of nearby farmers except through use of impounded water, negotiated independently of the project. Instead, there is a more diffuse and difficult to attribute impact at the watershed scale, resulting primarily from the return of perennial flows to the river, but complicated by economic shifts and market integration. In the Satlasana and Coimbatore cases, it appears that recharge activities have helped mitigate, but not reverse, the problems of growing long-term water scarcity in small, structure-specific areas. In all cases, the additional recharge generated by structures, in relation to irrigation demand, is minor.

In terms of benefits and beneficiaries, the case studies also raise significant questions about equity. Presently, the primary stakeholders in MAR are those with existing land holdings and access to groundwater close to recharge structures. Hence in Satlasana and Coimbatore, agricultural benefits were skewed towards land owners (a minority group) with private wells (a smaller minority). Poorer households — the landless and near landless — can benefit indirectly through trickle-down effects (e.g. through increased labour days in agriculture), though our case studies provide no solid evidence for this. The poor may also benefit directly through construction of recharge infrastructure; indeed employment generation is sometimes the primary objective of 'recharge' projects in the first place. A key issue then is whether benefits can be sustained through longer-term trickle-down. Again, case studies provide no solid evidence for this. Interestingly, both the Satlasana and Coimbatore studies did highlight land-leasing by larger land owners, allowing some landless households (including migrants) to rent irrigated land. However, this appears to be a response to wealthier residents exiting agriculture for higher returns in the RNFE, rather than to gains from recharge.

In terms of sustainability, findings do not suggest that recharge interventions alone will halt or reverse longer-term problems of groundwater overdraft in Satlasana or Coimbatore. In these areas, the scale of regional abstraction far outweighs any additional contribution MAR can make to groundwater availability. In the Kolwan Valley, where groundwater is relatively under-developed, recharge activities are unlikely to provide the additional water needed to support further, groundwater-based *Rabi* irrigation. Indeed the dilemma here, and elsewhere, is that recharge interventions may encourage investment in unsustainable farming systems (e.g. sugar cane in the Kolwan Valley) and subsidise investment in a contracting sector such as irrigated agriculture in Coimbatore.

A clear message from this report is that MAR is not a substitute for demand management. Case studies highlight some practical steps that can be taken to manage demand at a local level. In the Kolwan Valley, for example, GOMUKH is supporting investment in organic vegetable production as an alternative to sugar cane through marketing initiatives and help with the provision of inputs. In Satlasana, VIKSAT is promoting low-cost drip irrigation alongside its recharge activities. Small border irrigation introduced many years ago has now become common practice in Satlasana among the farmers. This helps in water conservation by avoiding an excessive saturation zone caused by flood irrigation. These are, however, small-scale initiatives and addressing problems of regional overdraft will require much more concerted action by government.

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Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management

Final report for DFID KAR project R8169, Augmenting Groundwater Resources by Artificial Recharge – AGRAR

ANNEX
Summary of AGRAR case studies

1 Introduction

The findings presented in the main document are based on the experience gained through undertaking three case studies in India. These case studies set out to assess the physical controls on the effectiveness of artificial recharge structures, the impact the structures have on groundwater resources and the yields from the wells and boreholes that tap these resources. Ultimately they assessed the livelihoods of those communities which they were designed to benefit. The three case studies were located in the Kodangipalayam watershed in Coimbatore District, Tamil Nadu; in the Kolwan Valley, west of Pune, Maharashtra; and in Satlasana Taluka, north Gujarat.

In this Annex, the generic approach undertaken in the case studies is presented (Section 2) and summaries are given of the three case studies (Sections 3 – 5). In each case-study summary, the setting is described, specific aspects of the methodology used are set out and the main results in terms of the impact on groundwater resources and on livelihoods are presented. The key findings in each case are listed at the end of each section.

2 Approach

It was recognised from the start of the AGRAR project that establishing a one-to-one relationship between livelihoods and artificial recharge activities would be problematic. This difficulty stemmed from the highly complex environment of 'push and pull' factors that seemed to dictate livelihoods on a regional scale as compared to the 'local' scale on which artificial recharge was implemented, coupled with complex hydrogeological factors. The main challenges, in light of the complex external environment and the scale effect were:

- spatial scale factors, attributing causality (how to separate-out the impacts of groundwater recharge from other watershed-project activities, and more so, from wider socio-economic changes)
- time scale factors, wherein some impacts may be only be realised over the long term
- upstream versus downstream interdependencies.

Broadly, it was thought that these challenges could be overcome through an approach that attempted to analyse the situation of water-related aspects in

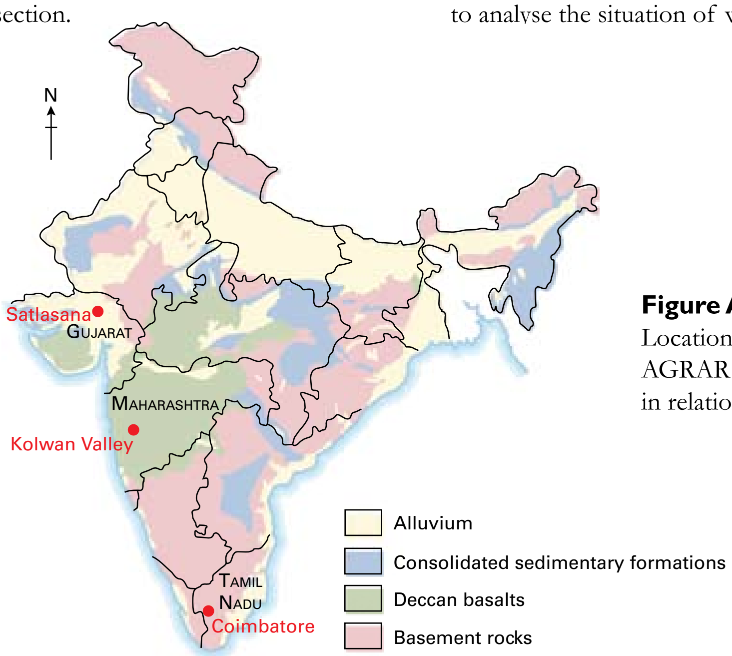


Figure A1.1
Locations of the three AGRAR research sites in relation to geology.

ANNEX – Section 2

people's livelihoods by asking about the situation before and after watershed development, and before and after recharge activities. Additionally, comparison was made between the experiences in villages; households 'with' recharge against those 'without', outside the project area.

In addition, a physically based field study was undertaken to allow estimates to be made of the volumes of water recharging as a result of a small number of representative structures. The distribution of this water in the aquifer over time was monitored, allowing the potential increases in well yields and baseflow to streams down gradient to be estimated.

By comparing the results of the socio-economic and physical elements, it was hoped that the impact of the recharge structures on the livelihoods of local communities could be examined. In addition, issues associated with the setting-up and maintenance of the schemes were also explored, assessing the role of institutions, both internal and external to the local communities.

Both studies looked at existing contextual data ranging from district scale down to village and individual structure scale. The physically based study involved a series of baseline surveys plus the monitoring of flows and water levels over time. The baseline surveys included: the mapping of the geology and its hydrogeologically important features; topographical surveys to delineate the catchments of the structures; and mapping in detail the contours of the structures themselves. The components that were monitored over time included: rainfall and other climate data, to allow evaporation from the free-standing water in the recharge structure to be quantified; groundwater levels in existing wells and boreholes drilled for the project in the vicinity of the structure; water-levels in the structure itself; surface flows into and out of the structure; sediment flow into the structure and how this changed its storage volume; pumping tests to estimate the hydraulic properties of the aquifer; and the chemistry of local drinking wells, to assess whether these have benefited from the structure. In addition to the main sites, a number of satellite sites were studied to help assess how representative the results were. The monitoring in all the case-study areas was undertaken over the period June 2003 to March 2005; this covered two dry seasons and the intervening two wet seasons. However, all data were only available for one wet season (2004) and two dry seasons (2004 and 2005).

The socio-economic study was based on a series of household surveys conducted within the main villages and other satellite habitations, as well as informal interviews. The methodology adopted is described in more detail in a previous AGRAR project report (Gale et al., 2003). The main objective was to develop an understanding of how managed aquifer recharge (MAR) – carried out as a separate activity or as part of a watershed development programme – affected people's livelihoods in the case-study areas. This involved, firstly, looking at the relationship between recharge and groundwater availability, access and use. Secondly, it involved looking at livelihood strategies and outcomes, trying to unravel the effects of recharge from wider processes of socio-economic change. This annex focuses mainly on livelihood changes.

The downstream side of the Bhanavas check dam.

3 Summary of the Kodangipalayam case study

3.1 Overview

Kodangipalayam watershed is located within Coimbatore District in the west of the state of Tamil Nadu. It is bordered to the west by Kerala and the mountains of the Western Ghats (Figure A3.1). As is the case across much of Tamil Nadu, agriculture is the main rural livelihood in this region, however, other livelihoods are having a growing role in the rural economy. In Coimbatore District, the textile industry provides a major income for both those employed in the industrial centres and for those employed in the many weaving sheds that have been established in the villages themselves (Photo A3.1).

The area under investigation centres on the Kodangipalayam microwatershed, to the north-east of the city of Coimbatore (Figure A3.1). The AGRAR project has looked at the impact on groundwater availability of a number of recharge structures in this watershed. This has included detailed monitoring of one structure to estimate the volumes of additional recharge it has allowed and to assess the effect on the local groundwater levels and well yields. The project has also looked at any benefits that changing groundwater availability has had on the livelihoods of local villagers, particularly given the diversification of livelihoods that is occurring and the declining reliance on agriculture as the principal source of income (see Comman, 2005).

The study has been led by the Water Technology Centre (WTC) of the Tamil Nadu Agricultural University, which is based in Coimbatore city. WTC was the implementing agency for a watershed scheme in Kodangipalayam, one of 15 that it undertook in watersheds across the district between 1995 and 2000, funded by the Drought Prone Areas Programme. However, the recharge structures under investigation in this case study were constructed by the Government of Tamil Nadu in the 1970s.

Figure A3.1 Location of the research site in the Coimbatore District, Tamil Nadu state.

3.2 Kodangipalayam watershed

Kodangipalayam watershed consists of two microwatershed with a total area of 5.0 km^2. It includes the villages of Kodangipalayam, Sangothipalayam, Karanampettai, Perumagoundampalayam, Rasagoundampalayam,

Photo A3.1 Power looms in village provide an alternative source of employment and income.

ANNEX – Section 3

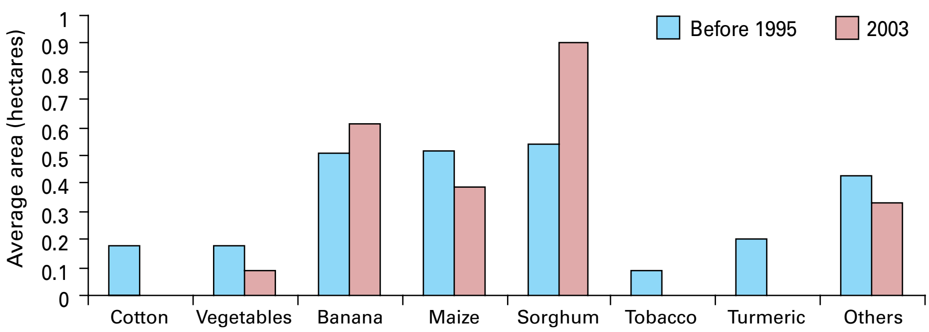
Chinnakodangipalayam and Periyakodangipalayam. The population of the watershed is approximately 5700, with around 500 households. Rainfall in this region of India occurs in two seasons as a result of the south-west monsoon (June to September) and the north-east monsoon (October to December). The regional average total annual rainfall is 650 mm, measured at Sulur (7 km from Kodangipalayam). The area is underlain by shallow weathered crystalline hard-rocks (charnockites, migmatites and banded gneisses) which have relatively low groundwater storage capacity. In the 1980s and 1990s, the boom in groundwater-based agriculture saw significant increases in pumping from wells and boreholes to the point where it is thought very little groundwater remained in storage in the bedrock aquifer at the end of the cropping season. The limited storage of the aquifer constrained the degree to which groundwater could be developed. The lack of any buffer in the groundwater system has meant that when the rains are low and insufficient for full recovery of groundwater levels, the availability of groundwater for irrigation in subsequent years has been severely affected. This has increased the level of risk involved in agriculture.

The livelihood strategies within the region are shifting in response to this lack of reliability in groundwater supplies but also, independently, as new opportunities develop in the non-farm economy. Many wealthy households have specialised in textile manufacture as congested urban centres out-source production. Poorer households — the landless and marginal farmers — also appear to have benefited, with new labouring opportunities in the power-loom sheds (Photo A3.1) providing a way of increasing household labour days and incomes and spreading risk. At the same time, the proportion of income derived from agriculture has declined. Poorer groups have shifted from cultivating water-intensive crops such as turmeric, tobacco and vegetables, to less water-intensive crops such as fodder sorghum (banana being the exception), and have increased rain-fed agriculture and the area of land left fallow (Figure A3.2). However, although there is a decline in agriculture, it still forms a key income source in the case-study area (see also Box 3.5 of this report).

Watershed schemes were seen as a means to address the groundwater availability issue. A number of watershed schemes have been undertaken in Kodangipalayam watershed. The Karanampettai recharge structure, the main investigation site for this study, was constructed in 1978 by the Department of Agricultural Engineering under the Rural Landless Employment Guarantee Programme. The Kodangipalayam west pond, the satellite recharge structure for the AGRAR case study, was also constructed in 1977 under the same programme. The Kodangipalayam east pond, again a satellite recharge structure for the study, was constructed in 1998 under the Drought Prone Area Programme (DPAP) implemented in the Coimbatore District from 1995 to 2000. Other watershed treatment activities such as field bunds, summer ploughing, percolation and farm ponds, major and minor check dams were constructed in the study area as part of the watershed development programme.

Under the DPAP, the WTC has acted as the project implementing agency (PIA). Despite the national emphasis on community participation and implementation flexibility, however, watershed development at district level has proceeded in a technocratic, top-down fashion, with a strong emphasis on infrastructure targets. Moreover, the

Figure A3.2
Changes in cropping patterns from before 1995 compared to 2003.



strengths of the WTC do not lie in community mobilisation and institution building. For these reasons, communities have played a very limited role in project design and implementation, and ongoing maintenance of structures is not considered by the communities as their responsibility.

In recent years a connection has been made to a piped public water supply network with water sourced from reservoirs in the Western Ghats. However, groundwater still forms a component of domestic water supply, particularly as the piped network is not totally reliable.

3.3 The study

The study in the Kodangipalayam watershed centred on the impact of a recharge structure near the village of Karanampettai (Photo A3.2).

Using existing topographical maps the catchment of the Karanampettai structure was defined, an area of 1.41 km^2. Detailed topographical surveys were undertaken to map the shape of the structure so that water levels in the structure could be related to the volumes stored. The capacity of the Karanampettai structure when the water level is coincident with the top of the dam wall is 10 200 m^3.

The monitoring infrastructure put in place around the Karanampettai structure is shown in Figure A3.3. In total nine boreholes were drilled for monitoring groundwater levels here. Groundwater levels in the piezometers and in existing dug wells were monitored on a weekly basis. The water level in the recharge structure was monitored using a gauging post.

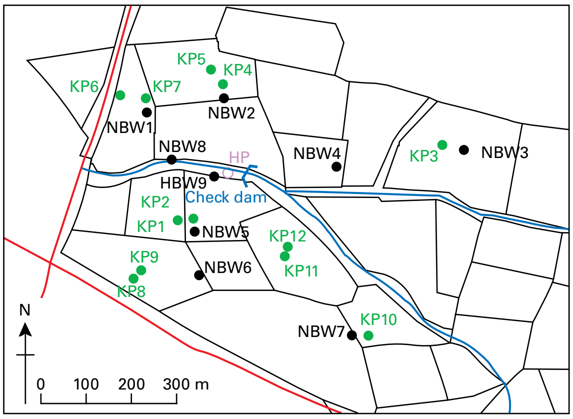


Figure A3.3 Location of monitoring wells (KP1 etc.) and borewells (NBW 1 etc.) in relation to the check dam in the Karanampettai micro-watershed. The hand-pump (HP) is located just downstream of the check dam.

An automatic weather station and other rain gauges were used to monitor climatic parameters. Calculations of evaporation were compared with those measured from a pan evaporimeter.

It was not possible to estimate the stream flow into the structure but estimates could be made of the flow over the dam wall using the water levels measured by the automatic digital recorder in the structure and an empirical formula.

The volume of sediment deposited in the structure was estimated by conducting a grid survey within the water-spread area of the recharge structure before and after the monsoon. Infiltration tests were carried out to assess the impact of the fine sediment deposited in the structure. Pumping tests were undertaken on the existing dug wells to help estimate the hydraulic parameters of the weathered hard-rock.

Hydrogeological surveys of the whole Kodangipalayam watershed area showed a significantly different groundwater system in the west of the watershed compared to that in the east. In the west the parent rock (gneiss) is more easily weathered and as a result it has been possible to dig wells deeper (typically 15 to 30 m); well yields are also greater. In the east, the less easily weathered parent rock (charnockite) means a lower groundwater potential (wells typically 10 to 20 m deep).

The socio-economic study was based on a sample survey of 60 households from two village hamlets, one with recharge structures (Karanampettai) and one without (Sangothipalagam). The sample in Karanampettai (the 'with' group) was further divided between 12 households located in the immediate

Photo A3.2 Automatic water level recording device in Karanampettai recharge structure when nearly full.

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downstream area of the structure (within 500 m), and those further away (beyond 500 m). In addition, comparisons were made between the 'before' and 'after' situations for the Karanampettai sample group, based on reported changes in levels and sources of household income. The survey was based on a structured questionnaire, supported by more open-ended interviews with households in each group.

3.4 Impact of recharge structures on water resources

There was a problem with the rain gauge located within the study catchment and therefore the rainfall used is that at the Sulur meteorological station, approximately 7 km away. The rainfall across the two monsoon seasons of 2004 was 753 mm here, about 40% higher than the long term average annual rainfall of 527 mm. Figure A3.4 shows the bimodal pattern of the rainfall.

The main structure under investigation, in Karanampettai village, did not fill during the first monsoon season in 2004. The maximum volume stored was 5 350 m^3, around half of its capacity of 10 200 m^3. In the period between the south-west and north-east monsoons, sediment that had been deposited in the structure was removed. The structure did fill during the second monsoon season. It was estimated that it overflowed for a period of 15 minutes, calculated to be approximately 4 000 m^3. It is estimated that overall the Karanampettai structure captured 80% of the run-off within its catchment.

A water balance on the Karanampettai structure enabled estimates to be made of the proportion of the water stored that infiltrated to the underlying aquifer. The water balance took into account the amount of water that evaporated from the open water, which fluctuated closely around a value of 4 mm/day. A comparison of the change of water level in the structure with the topographic survey allowed the change in storage in the structure to be estimated. The water level variation for the period of the 2004/05 hydrological year is shown in Figure A3.4. The impact of the removal of sediment between the main rainfall seasons can be seen as the rate of decline in the water level increases significantly. During the first monsoon season, the rate of decline reduced from 23 mm/day to 12 mm/day; attributed to the lower permeability silt layer in the centre of the pond. With this silt removed, the infiltration rate increased to 30 mm/day during the second monsoon season, with no reduction in rate as the pond emptied. Combining the change in storage with the open water evaporation and taking into account other components of the water balance gives infiltration volumes for the first and second monsoon seasons of about 4 500 m^3 and 10 100 m^3, respectively. If the assumption is made that the unsaturated zone storage at the end of 2004 and 2005 dry seasons are the same, the infiltration can be equated to the aquifer recharge over that period.

The efficiency of the structure can be assessed by comparing the proportion of the stored water that infiltrated with that which evaporated. Of the water that was stored in the structure during the south-west monsoon season, approximately 17% evaporated while 83% infiltrated; during the north-east monsoon season, 13% of the water evaporated while 87% infiltrated.

In this location there are particular difficulties in estimating natural groundwater recharge as cropping is ongoing for much of the year. The estimate of natural recharge was made based on a combination of groundwater level fluctuation in an area away from

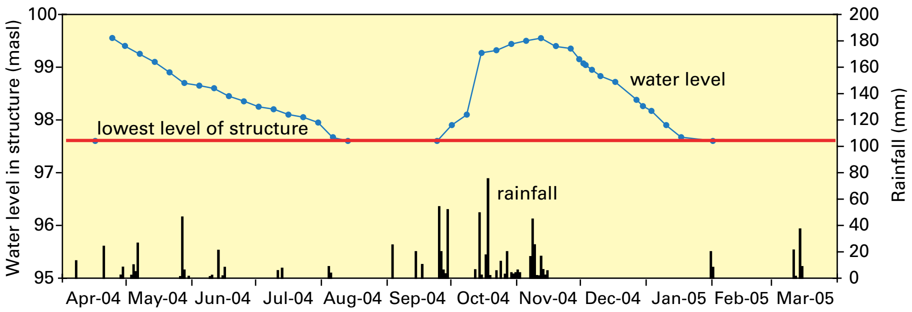

Figure A3.4
Water level in the Karanampettai recharge structure in response to rainfall; April 2004 to March 2005.

the influence of any recharge structure and specific yield calculated from pumping tests. The natural groundwater recharge was estimated to be around 6% of the rainfall, the structure providing an additional 23% of recharge on top of the natural groundwater recharge.

Water levels in the monitoring boreholes drilled in the vicinity of the main structure (Figure A3.3) show that the distribution of the recharge from the structure occurs over a limited area. Water levels in all boreholes, independent of the distance from the structure, respond in a similar way subsequent to major rainfall events. It is only in the boreholes directly downstream of the recharge structure that a significantly greater rate of rise in groundwater levels is noted. In the case of NBW9, located 64 m downstream of the dam wall, this rise continues for 48 days until the groundwater level is similar to that of the base of the structure. In the case of NBW8, located 165 m downstream of the dam wall, this rise continues for 65 days until the groundwater level reaches the level of the streambed, becoming base-flow to the stream. The enhanced groundwater levels downstream of the recharge structure appear to persist throughout the year. The chemistry of water samples taken from a number of wells and boreholes across the watershed indicate a complex hydrogeology. However, those in the vicinity of the recharge structures do have less mature waters.

The effectiveness of the Karanampettai recharge structure in holding up run-off and increasing infiltration has been indicated above. All of the stream-flow into the structure during the south-west monsoon was captured and around 70% of

Photo A3.3 The Kodangipalayam West recharge structure received little water during the period monitored due to capture upstream.

the north-east monsoon; that is around 80% of the overall stream-flow during 2004. This highlights the potential impact on downstream users of the construction of recharge structures upstream. The problems that can occur are illustrated well in the Kodangipalayam West satellite site (Photo A3.3). This structure is downstream of six smaller structures constructed subsequently. This has seen the inflow to Kodangipalayam West dramatically reduce. Indeed over the period of the project, when rainfall was significantly higher than average, the inflow to the large structure was negligible.

3.5 Impact of recharge structures on livelihoods

In terms of domestic water supply, most needs in the area are now met through the Pillur (surface) water scheme, operated by the Tamil Nadu Water Supply and Drainage Board. This provides community standposts and also individual household connections. As noted previously, however, households continue to rely on groundwater sources to meet non-drinking water uses, or to provide domestic water when the government scheme fails. Little information is available on this from the Coimbatore study. However, we know that in Karnampettai hamlet in Kodangipalayam village, a hand-pump for domestic uses has been installed below the check dam to provide a reliable source of domestic (non-drinking) water. This was completed on a separate programme. In none of the case-study areas was protection and/or provision of domestic water supply an explicit objective of any programme.

In terms of agricultural impacts, links between recharge activities and production/income appear to be very localised, and dwarfed by wider, structural changes in the rural economy (see Box 3.5). Within agriculture, for example, there has been a significant shift to less water intensive crops across the Coimbatore sample groups, together with an increase in fallow and reductions in irrigated area. In Kodangipalayam watershed as a whole, the proportion of cultivatable land that is irrigated with groundwater has shrunk from roughly 67% to 41% over the last 10 years. At the same time, water intensive crops, prevalent 20 years ago, such as rice, coconut and turmeric, have been replaced by annual fodder crops such as sorghum. That said, it is significant that the pockets of more water-intensive crops remaining

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(mainly turmeric and banana) are found in the zones immediately downstream of recharge structures, where irrigation intensity and irrigated areas area are also higher. Within this sample group, income levels, and the proportion of household income derived from agriculture, is higher than for other groups, including the control. In addition, the number of own-farm and off-farm agricultural labour days was also greater (Table A3.1).

In terms of equity, agricultural benefits appear to be skewed towards those (relatively few) households with existing commands over land and water. In the village of Karanampettai, for example, only 17% of households own land, and over 90% of these are small and medium-sized landholders with limited, and shared, access to groundwater infrastructure. In these circumstances, a key question is whether any increases in agricultural productivity generate labour gains for marginal farmers and the landless beyond zones of influence, and without direct access to groundwater. In Coimbatore, landless migrants have moved in to villages such as Karanampettai to farm leased land, but this appears to be a response to wealthier residents leaving agriculture for higher returns in the rural non-farm economy, rather than to perceived gains from recharge interventions.

3.6 Key insights from the study

Key insights from the case study are summarised in the following points.

- Watershed development activities in the district have been undertaken in a top-down, technocratic manner, with an emphasis on coverage and infrastructure targets. There has been little scope for local flexibility, innovation and community participation in decision-making.

- Results from the investigation indicate that the main recharge structure is relatively efficient at capturing run-off and enhancing recharge. Although the impacts of this recharge persist throughout the year, the raised groundwater levels appear to be limited to an area immediately downstream of the structure where they rise to the stream bed, thus filling the available storage capacity.

- Findings from the socio-economic study indicate that recharge interventions may have lessened, but not reversed, long-term trends in agriculture away from groundwater-intensive irrigation, and shifts from agriculture to other livelihood options, at least in small downstream areas.

- Within these areas, pockets of more water-intensive cropping exist, and land-owning households derive more of their income and employment from agriculture. These benefits are skewed towards the few households with existing land holdings and access to water, though the leasing of land to landless incomers may spread benefits to some extent.

Table A3.1 Income and employment patterns among selected farmers (income in Rs/year).

	Before recharge (N=40)		After recharge			
			All beneficiaries (N=40)		Realised beneficiaries (N=12)	
	Days	Income	Days	Income	Days	Income
Own-farm	147 (45%)	15 716 (47%)	160 (46%)	21 369 (48%)	182 (49%)	28 723 (59%)
Off-farm	65 (20%)	5200 (16%)	65 (19%)	8100 (18%)	90 (24%)	10 000 (20%)
Wage	116 (35%)	12 500 (37%)	120 (35%)	15 000 (34%)	98 (26%)	10 200 (21%)
Total	328	33 416	345	44 469	370	48 923

Note: 'Off-farm' refers to labour on other people's land; 'Wage' refers to non-agricultural employment. Those households located immediately downstream of the recharge structure derive more of their income from working their own land, and are relatively less dependent on off-farm labour and wage labour.

4 Summary of the Satlasana case study

4.1 Overview

Satlasana Taluka is located in the foothills of the Aravalli Hills in the north of Gujarat State (Figure A4.1). Agriculture is the primary livelihood of most households in the region. The region suffered a prolonged drought between 1999 and 2002 and, in response to the reduced availability of water there was a move towards non-agricultural livelihoods, which for many involved migration, both temporary and permanent. However, agriculture remains the primary income source and a heightened awareness of the need to conserve and enhance groundwater resources has resulted in the construction and reinstatement of a number of recharge structures. Two of these structures, a recharge pond and a check dam, are the main focus of the investigation for the AGRAR project.

The study has been led by the non-governmental organisation Vikram Sarabhai Centre for Development Interaction (VIKSAT) based in Ahmedabad and with a field office in Satlasana. VIKSAT has been promoting natural resources management in the area since 1992.

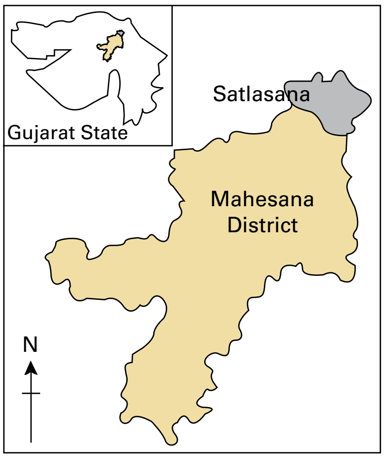

Figure A4.1 Location of the research site in the Satlasana Taluka, Gujarat state.

4.2 Satlasana Taluka

The AGRAR study has centred on recharge structures located in four villages in Satlasana Taluka. The Aravalli Hills which surround the villages form a well-defined catchment of approximately 20 km^2 (Figure A4.2). The area is semi-arid; the average annual rainfall is around 650 mm, with rainfall occurring from late June until the end of September. There are typically 30 to 35 days of rainfall in a year.

The main aquifer in the catchment is formed by shallow weathered and fractured granitic rocks. These are overlain in the upper regions of the valley floor by thick layers of sediment (15 – 20 m) weathered from the hillsides. The main part of the valley floor is moderately undulating. The Dhamani River flows out of the catchment, heading south-east to eventually join up with the Sabarmati River, the main river of Gujarat. Drinking water in the area is provided by a piped network from the Dharoi reservoir in the Aravalli Hills. This is a recent development, recognising the extreme hardship that was suffered as a result of the recent drought, and also the high fluoride concentrations that have been found in some drinking

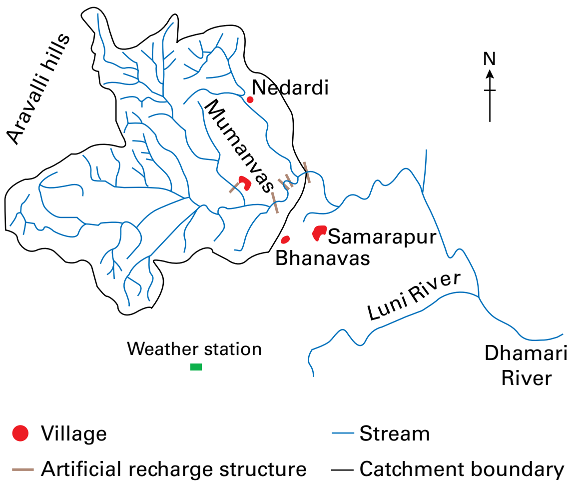

Figure A4.2 Location of the check dams in the Satlasana research watershed.

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water wells. High levels of fluoride were confirmed by the analysis of groundwaters undertaken as part of the AGRAR project.

Groundwater is the primary source of irrigation water. Development of groundwater resources accelerated in the 1980s with increasing numbers and depths of dug wells. The 1990s saw the introduction of drilling rigs (Photo A4.1) and electrified pumps. There are a total of 85 private wells and boreholes being monitored within the area. As in other case study areas, the increase in pumping from wells and boreholes eventually meant little groundwater remained in storage at the end of the cropping season, and there was no buffer to fall back on for drinking water or irrigation supplies in poor rainfall years.

The population of the four villages with recharge structures is 4 243, with a total of 605 households. During the 1990s the population increased by around 20%. Agriculture has been the traditional livelihood. Groundnut, castor and millets are the most popular *Kharif* crops (rain-fed); wheat, mustard and tobacco, the most popular *Rabi* crops (first irrigated crop during the dry season). The drought of 1999 – 2002 saw a temporary move away from water-reliant agriculture. Animal husbandry and labouring were the most common alternative livelihoods. The latter included: agricultural labouring in local districts where canal irrigation water was available; diamond polishing in the local town; and migration further afield to urban centres to find work, such as in housing and road construction. Although there has been a move back into agriculture since 2003 when the drought came to an end, the lack of reliability in water for irrigation is likely to see many move permanently away from this form of livelihood. To improve water security, VIKSAT has been working with the community to introduce methods to conserve and enhance groundwater resources and use water more effectively, such as drip irrigation. They have also been promoting alternative livelihoods through micro-enterprise activities such as the production of detergent powder, spice powders and handicrafts.

Photo A4.1 Drilling monitoring boreholes in the Satlasana research watershed.

4.3 The study

The generic approach being undertaken in the AGRAR project is set out in Section 2 of this Annex. Here some of the site-specific aspects are presented.

The focus of the AGRAR project has been on two recharge structures located in the villages of Bhanavas and Nedardi; structures in Mumanvas and Samrapur villages, also in Satlasana Taluka, have also been monitored but not in as great detail (Figure A4.3). The Bhanavas (Photo A4.2) and Samrapur check dams were constructed in 2001 by VIKSAT under the Drought Prone Areas Programme supported by OXFAM and the Sir Dorabji Tata Trust, Mumbai. Mumanvas check dam was constructed by VIKSAT under the Government of India Swaran Jayanti Swarojgar Yojna scheme in 2003.

Mumanvas check dam is the furthest upstream. In the two years it has been operational, Mumanvas has filled completely each year with sediment brought in by rainfall run-off, having been excavated during the intervening dry season. It would seem that it acts to some degree as a sediment trap for the Bhanavas Dam, although the catchment of Mumanvas is only a small proportion of the overall catchment for Bhanavas. The sediment load into Bhanavas is small relative to its volume; the significance of this is discussed later. The structure at Nedardi village is a percolation pond (Photo A4.2). The pond was constructed in the mid 1990s by the Gujarat State Government and is located at the foot of a hill. Detailed topographical surveys were undertaken on each of the structures

Photo A4.2 Sampling the water in the Nedardi Pond.

mentioned to allow water-levels within to be equated with storage volumes. The capacity of each is shown in Table A4.1.

Piezometers were drilled in the vicinity of each of the recharge structures, five at distances from the Bhanavas check dam: BP1 (8 m), BP2 (65 m), BP3 (90 m), BP4 (240 m), BP5 (600 m); four at distances from the Mumanvas check dam: MP1 (30 m), MP2 (82 m), MP3 (154 m), MP4 (450 m) and two at distances from the Nedardi Pond: NP1 (20 m), NP2 (96 m). In addition, 85 private dugwells, borewells and dug-cum-borewells were monitored during the period of the study both for water level but also type and extent of crops being irrigated. Other aspects of the monitoring network included a digital water level recorder located in a stilling well in the Bhanavas Dam, an automatic weather station and an evaporation pan. Geological logs from the drilling, a hydrogeological survey and borehole pumping tests helped a conceptual model to be developed for the area.

Table A4.1 Capacity of recharge structures measured to the top of the spillway

Mumanvas Check Dam	6400
Bhanavas Check Dam	21 800
Samrapur Check Dam	12 500
Nedardi Percolation Tank	27 650

The socio-economic study was based on a sample survey of 31 households from five different villages, with households located at varying distances (5 – 500 m) away from recharge structures. The five villages were Bhanavas, Samrapur, Nedardi, Mumanvas and Vajapur. The latter provided a control group, as it has not received watershed assistance. The survey was based on a semi-structured questionnaire, supported by more open-ended interviews with households.

4.4 Impact of recharge structures on water resources

In 2004, the rainfall in the study area was 441 mm, around two-thirds of the average of 693 mm, measured between 1989 and 2004. The majority of the rains occurred in two periods, in mid June and the first half of August, at the beginning and the end of the normal period of the wet season. The rains resulted in three periods of inflow to the recharge structures being monitored (Figure A4.3 and 4.4). The Nedardi pond has a relatively small catchment area of 0.13 km^2. It did not overflow at any time, the greatest volume of storage being 11 200 m^3, approximately 40% of the capacity. The Bhanavas check dam overflowed on two occasions, for 11 minutes and 5 hours and 50 minutes respectively. The volume of water stored in the dam was 56 800 m^3 over the whole of the wet season.

The rate of decline in the water level in the Nedardi pond and that in the Bhanavas check dam are significantly different. This is not surprising as the check dam is located in a drainage channel lined with coarse sediment, whereas the pond is constructed at the base of a large outcrop in an area with clayey soils. Figure A4.3 shows the water-level plot for the Bhanavas check dam. The rate of water-level decline after the first filling of the check dam is approximately 225 mm/day. This is significantly greater than in any of the recharge structures being monitored in the

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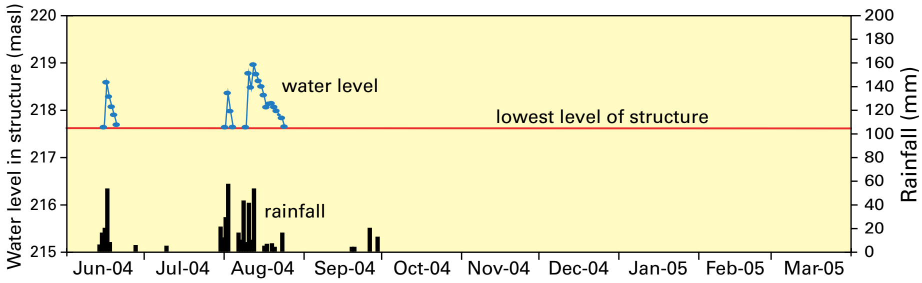

Figure A4.3 Water level in the Bhanavas recharge structure in response to rainfall; June 2004 to March 2005.

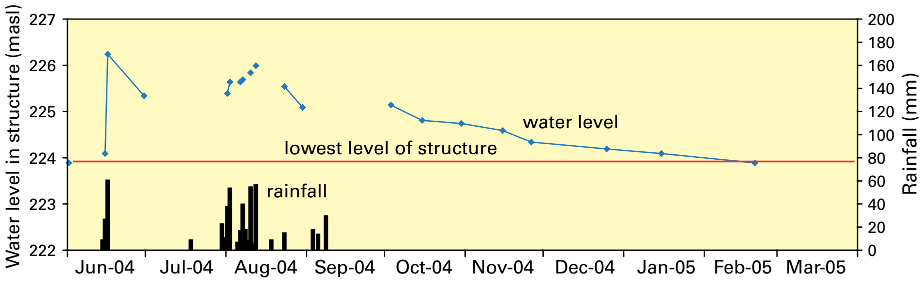

Figure A4.4 Water level in the Nedardi Pond in response to rainfall; June 2004 to March 2005.

other case studies. Potential evaporation during this period is estimated to be 5 mm/day. The rate of water level decline for the latter period of the last filling is in comparison 78 mm/day, still significantly greater that the potential evaporation, which was about 3 mm/day during this period.

The Nedardi Pond filled as a result of the first period of rainfall in June 2004, reaching its maximum water level for the year a few days after the rains began. The water level was topped up by subsequent rains and did not dry out until January 2005 (Figure A4.4). The rate of water level decline averaged about 7 mm/day during the dry season, ranging from 13 mm/day from September to November and declining to about 4 mm/day in subsequent months. These rates of water level decline indicate that a large proportion of the water is evaporating.

The water balances undertaken on the Bhanavas check dam, allowed the volume of water infiltrating into the subsurface to be calculated. Assuming the unsaturated zone storage at the end of the 2004 and 2005 dry seasons are comparable, this is equivalent to the groundwater recharge. The estimate of recharge over the whole of the wet season is 56 200 m^3. This compares with an estimate for the volume of recharge from the Nedardi Pond of 5500 m^3.

Monitoring in piezometers adjacent to the Bhanavas check dam indicates the impact the recharge structure is having on local groundwater levels and helps to assess how this additional water is distributed in the ground in space and in time (Figure A4.5). The first major rainfall period caused a maximum rise of around 9.9 m in groundwater levels in the nearest piezometer (BP1), 8 m down-gradient of the dam wall, in the period of seven days. This compares with a maximum of 2.1 m in 24 days in a piezometer 90 m away (BP3) and a maximum of 1.5 m in 26 days in a piezometer 240 m away (BP4, see Figure A4.5). These groundwater-level variations can be compared with a piezometer which is located at a significant distance from all recharge structures and from a river bed (MP4, Figure A4.5); the piezometer is situated higher in the catchment than the dams under observation. A comparison between BP4 and MP4 suggests that much of the variation in the groundwater level in BP4 could be due to natural groundwater recharge, suggesting that the recharge structure at this distance and in this direction may have a minor impact on groundwater levels. In addition, given that the groundwater levels in BP1, BP3 and BP4 fall at the same rate from around the beginning of December, it would appear any groundwater mound associated with

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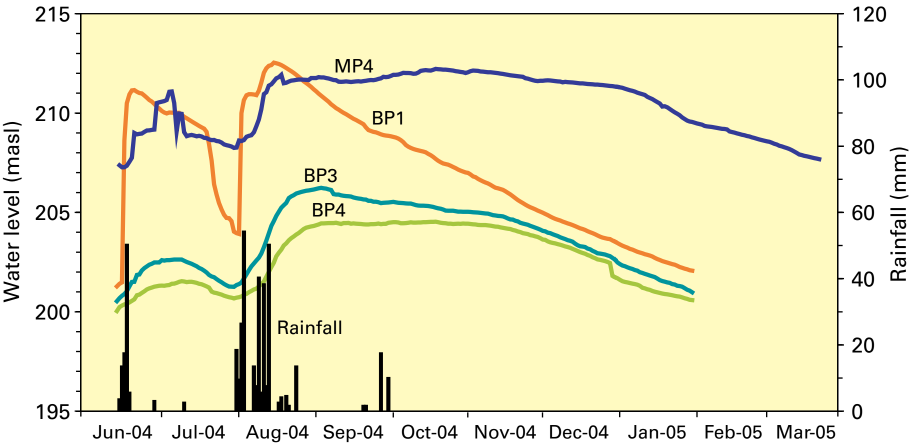

Figure A4.5 Water levels in monitoring piezometers around the Bhanavas check dam in response to rainfall; June 2004 to March 2005.

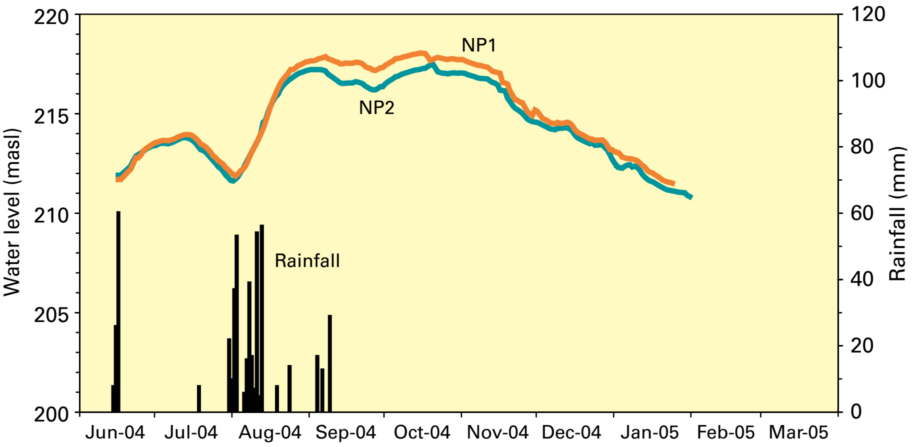

Figure A4.6 Water levels in monitoring piezometers around the Nedardi Pond in response to rainfall; June 2004 to March 2005.

the recharge structure has dissipated by this time.

It is less easy to interpret the impact on groundwater levels in the vicinity of the Nedardi Pond (NP1 and NP2) compared with natural groundwater recharge, as the pattern of groundwater fluctuation does not follow that of the control piezometer, MP4. A comparison of the piezometers (Figure A4.6) in NP1 and NP2 does, however, show that the two groundwater levels become coincident by mid-November 2004, suggesting that by this time there is little localised impact of the pond on groundwater levels. The decline in the water level in the pond in the dry season from December 2004 onwards is similar to the rate of evaporation.

So what does this indicate about the effectiveness of the recharge structures? The additional water that the recharge structures are contributing to the aquifer dissipates quickly and would appear to have little sustained local benefit. The measure of the effectiveness of the recharge structures is therefore how this additional recharge compares with the natural groundwater recharge across the whole of the study area (Photo A4.3). The natural recharge was calculated based on estimates of the storativity of the aquifer (0.5 to 2%) and the rise in groundwater level in response to recharge events. This gives a distributed recharge over the catchment of 45 to 180 mm, which is equivalent to 10 to 40 times the recharge contributed by the Bhanavas check dam. Additional factors that need to be taken into account when assessing the impact of the structures are, firstly, given the permeable nature of the river-bed sediments, a proportion of the water that flowed past the Bhanavas check dam prior to its construction would have recharged through the river bed anyway and, secondly, recharge will be occurring in the river bed between recharge structures. Quantification of these contributions has not been made.

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Photo A4.3 The flat, bunded fields and permeable soil facilitates recharge over wide areas and reduces erosion of soil around the Bhanavas check dam.

4.5 Impact of recharge structures on livelihoods

In terms of agricultural impacts, links between recharge activities and production income are again localised, though groundwater monitoring data and farmer perceptions do not always match. Around the Bhanavas check dam, for example, monitoring data highlight a relatively short pulse of groundwater recharge detected to a distance of around 240 m downstream of the structure, and dissipated towards the end of December (see above). However, the survey of farm households highlighted impacts to around 500 m in both upstream and downstream areas, including influences on agricultural production felt into the winter (November – February) and summer months (March – June) in some cases.

Overall, the survey highlighted increases in cropping intensity and crop yields, including an extension of groundwater irrigation to limited *Rabi* crops (e.g. vegetables, mustard). In terms of irrigated area, however, the only sample groups reporting an increase in the proportion of (groundwater) irrigated cultivatable land were in the downstream area of Bhanavas check dam and Vajapur sub-surface check dam. In other village households, including those close to the Nedardi percolation pond and other recharge structures, the irrigated area decreased (Table A4.2).

Table A4.2 Changes in irrigated areas resulting from recharge interventions.

Location	Cultivated area (acres)	Percent irrigated area		
		Before recharge interventions		After recharge interventions
		Normal	Drought	
USBed	10.48	98.0	46.9	84.4
DSBed	12.40	67.8	28.8	81.6
Samrapur	6.49	82.4	65.9	82.4
Vajapur	23.37	80.5	17.1	87.8
Nedardi	10.70	74.6	16.0	65.3
Control	6.28	100.0	18.2	77.4
Total	69.72	83.9	32.2	79.8

Other agricultural impacts identified included slightly higher cattle holdings and milk production in treated areas compared with the control group, with links drawn between higher crop production in these areas and the availability of fodder (e.g. straw fodder from groundnut and Bajra during the *Kkarif*; and wheat straw during the *Rabi* season).

These changes translate into rising income levels for those households, within the influence of structures and with land and access to groundwater. In all sample groups, for example, income from agriculture increased — in the case of Bhanavas and Nedardi by double — following recharge activities, compared with insignificant change in the control group (Figure A4.7). At the same time, income from animal husbandry also increased in most locations. It should be noted, however, that the drought conditions before the construction of the recharge structures compared with relatively good rains subsequent may have led to a misconception about the effectiveness of the structures.

In terms of equity, benefits are skewed towards those with existing land holdings and groundwater access. For example, only 70 (12%) of farm households own wells out of a total of 605 households in the survey villages, and only a proportion of these are located within the influence areas of recharge structures. In these circumstances, a key question is whether any increases in agricultural productivity generate labour gains for marginal farmers and the landless beyond zones of influence, and without direct access to groundwater (See Box 3.7). In the case-study villages, larger land holders are reported to be leasing irrigated land to landless families, but there is no data on this. However, the study concludes by indicating that landless households have not benefited significantly from recharge interventions beyond short-term employment in the construction of check dams. Employment generation was one of the primary objectives of recharge.

4.6 Key insights from the study

Key insights from the Satlasana case study are summarised in the following points.

- In contrast to watershed development activities in the other case-study areas, the development of recharge structures in Satlasana has occurred as a stand-alone activity. The main short-term objective was employment generation; other benefits (principally the

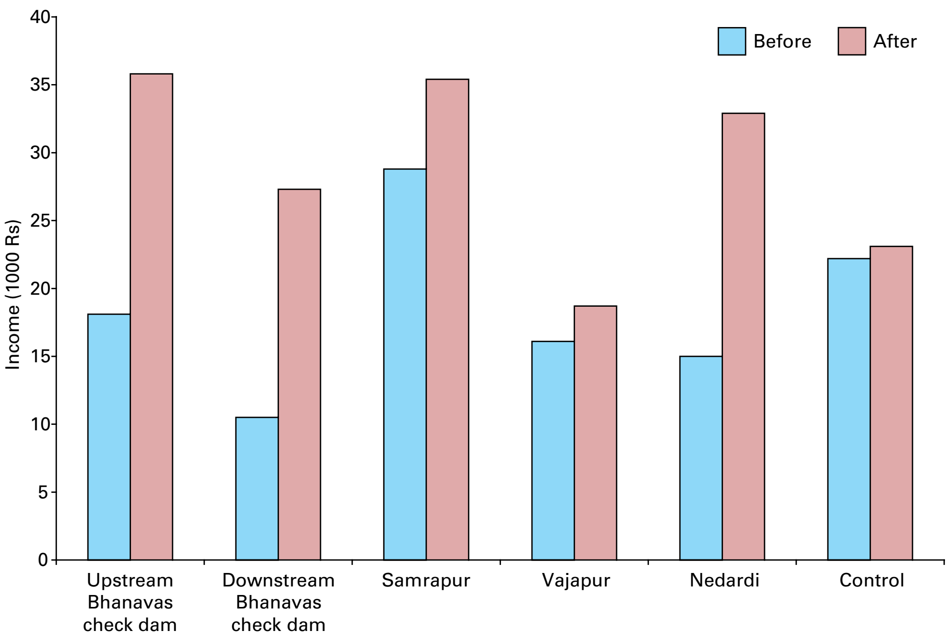

Figure A4.7
Location-related changes in agricultural income (Rs thousand/year) across sample groups.

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stabilisation of agriculture) were assumed to follow.

- The two main recharge structures under investigation have differing degrees of effectiveness in terms of the recharging the water captured. However, even with the Bhanavas Dam, which was highly effective in recharging the water stored, the benefit to groundwater resources appears to be limited to adding a few percent to the volume of natural recharge occurring in the surrounding bunded fields.

- VIKSAT has played a key role in supporting community initiative and institution building. One outcome has been a more participatory approach to the planning and implementation of recharge activities, and the establishment of a federal-level people's institution (the *Sangh*) capable of prioritising investments and mitigating upstream-downstream externalities.

- Results from the socio-economic study highlight limited and localised impacts on agricultural livelihoods, with benefits (production, income, employment) skewed towards the better-off. As in Coimbatore, these effects are unlikely to reverse wider and longer-term trends towards less water-dependent farming systems, and shifts between the farm and non-farm economies, resulting from growing water scarcity and economic transformation.

5 Summary of the Kolwan Valley case study

5.1 Overview

The Kolwan Valley sits in the foothills of the Western Ghats of Maharashtra. The Walki River drains the valley, which is well defined by the steep basaltic hills that surround it. The valley, with an area of 80 km^2, is the home to around 15 000 people, still reliant on agriculture as their main source of income. Government-funded watershed improvements have been ongoing in the valley over the past decade. The level of activity in this area has risen significantly in recent years since the NGO, GOMUKH, became involved in 1998. GOMUKH has introduced watershed activities into 10 of the 16 villages in the valley, including the construction of a number of recharge structures.

The AGRAR project has looked at the impact of a selection of these recharge structures in three of the valley's villages. This has included detailed monitoring of three structures in one valley to estimate the volumes of additional recharge they have allowed and to assess the effect on local groundwater levels and well yields. The project has also looked at the benefits any change in groundwater availability has had on the livelihoods of the local villagers and on those in the valley as a whole.

The study has been led by the Advanced Center for Water Resources Development and Management (ACWADAM), an NGO based in Pune, the nearest city. The study has been undertaken in collaboration with GOMUKH and with the local communities.

5.2 The Kolwan Valley

The Kolwan Valley is located in Mulshi Taluka, in Pune District, which is in the west of Maharashtra State (Figure A5.1). The majority of the state has a semi-arid climate, however, Kolwan is located on the eastern slopes of the Western Ghats, the mountain range that runs from north to south

Figure A5.1 Location of the research site in the Pune District, Maharashtra state.

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along the western edge of peninsular India. As a result, rainfall is significantly greater here, 1 800 mm on average per annum, although highly variable. The rain occurs mainly during a single monsoon season, generally from June to October.

The Kolwan Valley is surrounded by basaltic hills; at their maximum height, 1100 metres above sea level (masl), lying significantly higher than the valley floor, which at its lowest point is 570 masl (Photo A5.1). These basalts are part of the Deccan Traps that cover a very large area of India (in excess of 500 000 km^2), including most of Maharashtra. The Walki River that drains Kolwan Valley flows into the Mula River and, eventually, into the Bhima River.

Rain-fed agriculture is the main livelihood of the communities living in the Kolwan Valley, though irrigation (predominantly surface water) has increased substantially over the last decade (see Section A5.5). Other livelihoods include livestock rearing, forestry, service in the farm and non-farm industry and labour (again farm and non-farm types). Figure A5.2 shows how the proportions of household occupations are distributed between the four broad categories of agriculture, business, service industries and labouring. It also shows how the proportions have changed over the period from 1996 to 2004. Although still dominant, the proportion involved in agriculture has reduced: those working in the service industry have increased significantly in number. The reason for the increase in the service industry and business is partly due to the improved communication and transportation links to nearby cities such as Pune and Mumbai, and also improved access to education in nearby towns and cities. Virtually all households have at least one member working temporarily or permanently away from home. Although agriculture has reduced proportionally as an occupation, the cropped area has not fallen significantly. Paddy is the most common crop grown in the area during the *Kharif* (wet) season, taking over from sorghum (*jowar*). Wheat is the main *Rabi* season crop, however, in recent years the growing of vegetables and sugar cane, both of which are irrigated crops, has increased substantially.

The availability of drinking water is not a major problem in the valley. All the villages have at least one water supply scheme. Drinking water is most commonly sourced from the Walki River, pumped up through piped networks to the villages, which are generally located on the middle slopes of the valley, away from the flood-prone valley bottom. Some treatment (mainly chlorination) of the water is undertaken but not all sources and not all the

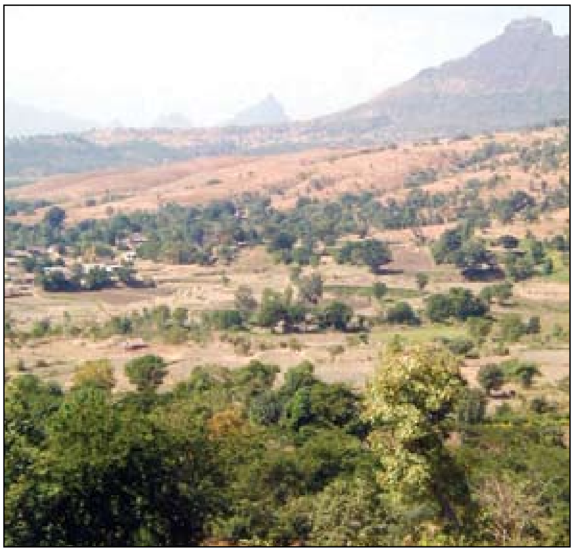

Photo A5.1 Topography and vegetation in the basalt scenery of the Kolwan valley.

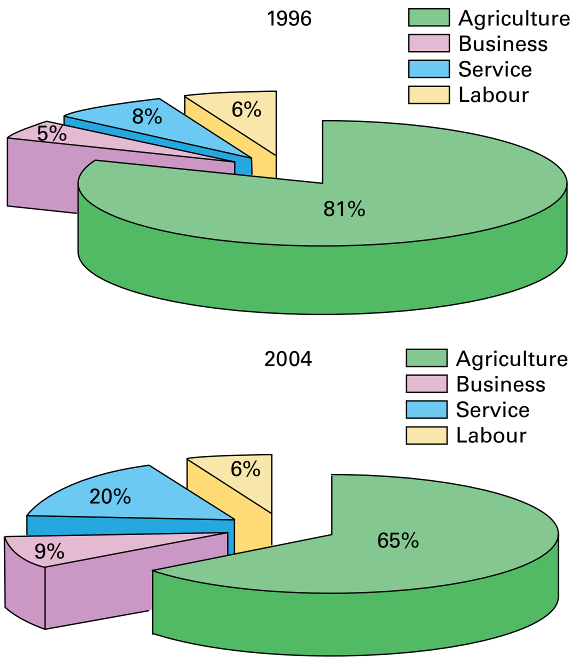

Figure A5.2 Comparison of household occupations in the Kolwan Valley, 1996 and 2004.

time. No major health problems associated with contaminated water have been reported. River water is supplemented by spring water and groundwater from wells (Photo A5.2). The majority of irrigation water is lifted from the river.

Many developmental organisations are working in the Kolwan valley. Watershed development work has been carried out by a number of NGOs such as GOMUKH, Gramshakti and Gangotree, in addition to government-run programmes taken up through the *Gram Panchayats*. Such work has included the construction of spring-tanks, bunding, water-impounding structures, forestation and contour trenches. There are 28 check dams or weirs within the Kolwan Valley. The government constructed ten of these and GOMUKH were responsible for the remainder.

At the beginning of their work in the valley in 1998, GOMUKH, in consultation with local communities, identified a number of critical issues they felt they needed to address through their watershed development work. These included: scarcity of water for irrigation, despite an annual normal precipitation of 1 580 mm; heavy reliance on rain-fed agriculture, forcing household members to migrate for employment during poor rainfall years; and degradation of land as a result of soil erosion due to high run-off from the heavy rains, requiring high investment in the repair of land.

Photo A5.2 Large diameter well used for irrigation water supply, Kolwan Valley.

5.3 The study

The main study area within the Kolwan Valley was the village of Chikhalgaon and a series of recharge structures along a drainage line to the west. The approach undertaken within the study is outlined in Section 2 of this Annex. All aspects of this generic approach were addressed in the Kolwan Valley study. Figure A5.3 shows the location of the

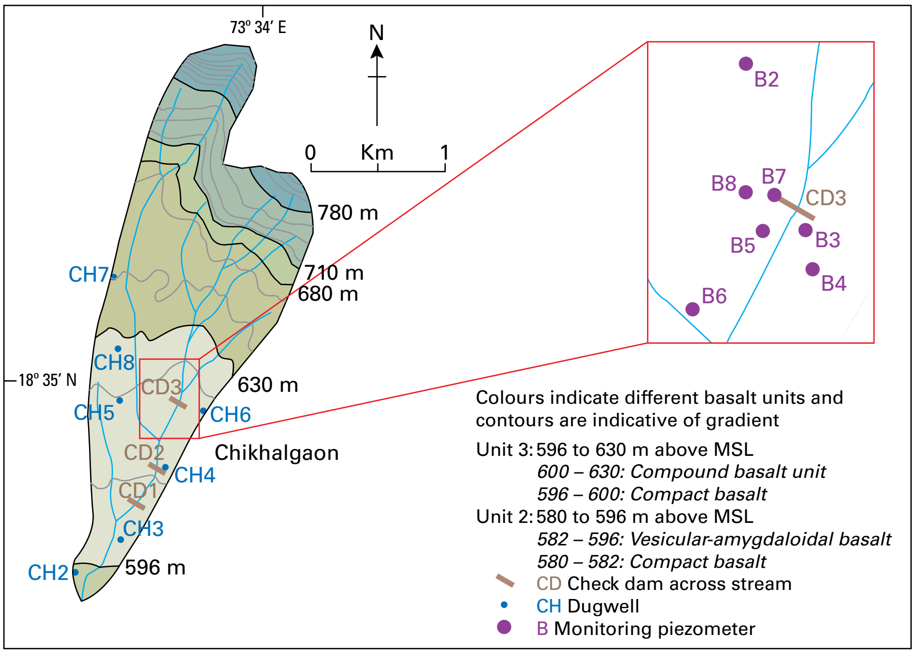

Figure A5.3 Location of monitoring dugwells (CH2 etc.) and borewells (B2 etc.) in relation to check dams (CD1, 2 and 3) and geology in the Chikhalgaon micro-watershed.

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main study area with the location of the structures monitored. In total nine boreholes were drilled for monitoring groundwater levels (Figure A5.3). Flumes for measuring flows into the structure were constructed upstream of CD3. A stilling well was constructed at a low point in CD3 and an automatic digital water-level recorder installed (Photo A5.3).

The size of the catchments of the three check dams associated with Chikhalgaon village, defined using the topographical survey, are: 1.72 km^2 for CD1; 1.60 km^2 for CD2; and 0.79 km^2 for CD3. Detailed topographical surveys also allowed the volume of the structures to be estimated.

Geological mapping of the Kolwan Valley (Figure A5.3) shows it to have a series of eight basalt units (lava flows resulting from separate periods of volcanic activity), seven of which are mapped within the Chikhalgaon watershed. Each unit has a compact, less weathered lower section and a fractured/jointed, more weathered upper section; the latter having the capacity to store more groundwater, being more permeable and therefore a much better aquifer (Figure A5.4). The check dams at Chikhalgaon are all located on the upper section of one of the basalt units.

Photo A5.3 Water level monitoring equipment in CD3, flowing at full capacity.

The socio-economic study used a series of household surveys within Chikhalgaon and the other satellite villages as well as informal interviews with some villagers. A sample of 279 households was covered during the survey, representing some 45% of the total population in the five villages. The sample was determined to provide proper representation of all the landholding categories and caste groups.

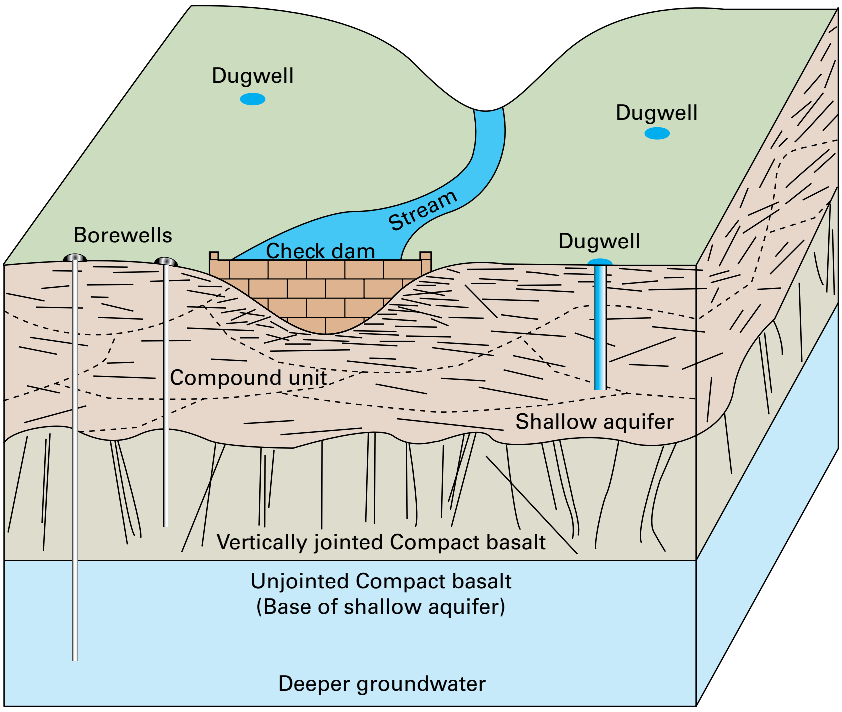

Figure A5.4 Schematic block diagram of hydrogeology of basalt units in relation to check dams, dugwells and monitoring borewells.

5.4 Impact of recharge structures on water resources

The proportion of rainfall that forms run-off is very high. Based on estimates of run-off and other data, including groundwater level fluctuations, the natural recharge to the basaltic aquifer (the vast majority of which occurs where the upper section of the basaltic units is at outcrop) was estimated as 105 mm for the 2004/05 season. This is limited by the capacity of the aquifer to accept recharge; at the end of the dry season in 2004, groundwater levels in the aquifer were typically two to three metres below ground.

The volume of inflow to CD3 was estimated to be 2 320 000 m^3. There was flow in the stream that drains into CD3 for nearly the whole of the period of the wet season, and flow over the dam wall out of CD3 (2 025 000 m^3) for most of that time as well (Figure A5.5). The difference between the inflow and outflow is about 13% of the inflow. However, the calculation of a water balance for the dam is very difficult as neither of these flows can be estimated with great confidence. Further complication is added as the water table in the vicinity of CD3, although initially below the base of the dam, rose up above the base and indeed above the water level in the dam for some periods of the wet season. Therefore, rather than recharging the aquifer, at times groundwater was flowing into the structure. The response of the water level in CD3 is shown in Figure A5.5. The rate of decline of the water level in the dam increases significantly from around the middle of December because the surface area of the standing water in the dam is much smaller below 616 masl and because it is thought the dam is being drained by a large fracture.

There is greater confidence in the value of infiltration during the dry season as there were no flows into the structure. Water level data for observation boreholes near CD3 and the specific yield of the aquifer (estimates based on pumping test data) were used to estimate recharge during the wet season. These estimates compared reasonably well with those from the water balance, giving a higher degree of confidence.

Based on a water balance for the check dam, the total infiltration over the wet and dry season for 2004/05 for CD3 is 26 000 m^3. If divided by the area of the catchment for CD3, the infiltration is 33 mm, which is a significant proportion of the estimate of natural recharge (105 mm).

Monitoring in the vicinity of CD3 showed that the structure does have some impact on groundwater levels. However, the rise in levels that can be attributed to the structure would appear to be negligible a couple of weeks into the dry season. Recharge to the aquifer would appear to move quickly through the shallow aquifer system. Indeed it is thought that much of it exits the aquifer short distances downstream as baseflow to the stream. This explains why the water balance indicates relatively high volumes of recharge compared with the capacity of the aquifer to store it. These conclusions are backed up by the water chemistry which indicates that natural groundwaters must pass through the system very quickly and shows no correlation between quality and distance from the sampling point to the recharge structure.

The results from the Chikhalgaon area are broadly representative of those from the other areas in the Kolwan Valley that were monitored. It would appear that the local benefit of the recharge structures to well yields during periods when irrigation is required,

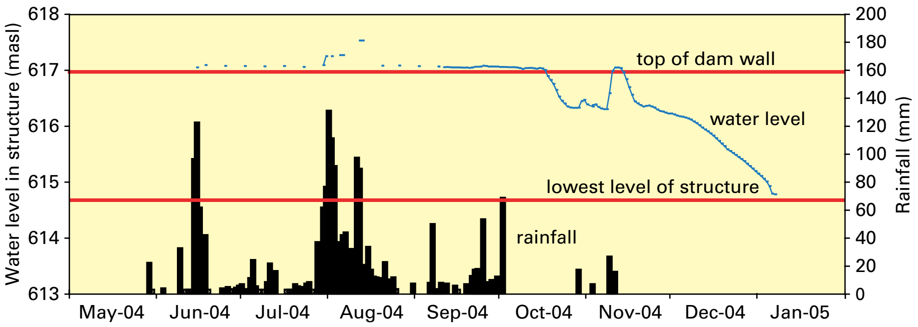

Figure A5.5 Water level in the check dam CD3 in the Chikhalgaon micro-watershed in response to rainfall; May 2004 to January 2005.

i.e. the *Rabi* and summer cropping seasons, is limited. To assess the benefits of the watershed approach, including recharge structures, one needs to look at the valley scale rather than individual structure scale. Here, although the data on which conclusions are made are largely anecdotal, it would appear that the main stream and river flows have benefited from watershed activities in that flows are less flashy and sustained for longer periods of the year. This implies that watershed activities slow down water movement through the catchment and result in more groundwater recharge, which although not significant on a local scale, is resulting in greater levels of baseflow. Given that the infrastructure exists to use the Walki River as a source of drinking and irrigation water for all the communities in the valley, this is a positive outcome. Moreover, these artificial recharge measures are likely to become more effective if, as trends suggest, abstraction of groundwater increases.

5.5 Impact of recharge on livelihoods

In terms of domestic water supply, groundwater based reticulated systems have been introduced as part of the watershed development programme, but in isolation from recharge activities further upstream. Spring development and protection in the upper catchment has provided those without ready access to downstream systems with improved domestic supply but, again, benefits are unrelated to recharge activities. However, the development of water-users' groups to manage systems and organise operation and maintenance (as in Satlasana) has contributed broadly to community organisation and empowerment efforts, including those around watershed development and recharge.

Links between recharge activities and agricultural change are difficult to draw with certainty. This is because (a) groundwater recharge from the check dam (CD3) discharges to stream baseflow quickly, with only limited potential for impacts on individual wells; and (b) groundwater development in the valley is still limited, albeit increasing. There have been significant agricultural changes since watershed work began, however.

Firstly, there has been an increase in the cultivated area (as wasteland is brought into production) and an increase in the proportion of irrigated land, principally from surface water 'lifts'. Related to this, there have also been significant increases in *Kharif* irrigation (supplementary – during poor monsoons) and irrigated *Rabi* cultivation, including wheat and, increasingly, cash crops such as vegetables and sugar cane (see Box 3.3). In 1998, for example, only 1% of the farmers in the valley reported growing irrigated *Rabi* crops. In the current survey, this figure had increased to around 12%. This figure may under-estimate the extent of actual irrigation, as farmers are reluctant to report unauthorised lifts from the river, which have no formal approval from the irrigation department.

Secondly, irrigation from wells and boreholes is increasing, though with no clear links to recharge activities. In the villages of Nandgaon and Nanegaon, for example, farmers have drilled boreholes independently to irrigate orchids and vegetables resulting in rising incomes. Latterly, GOMUKH has started work in these two villages, which are currently under watershed development projects. The only clear relationship between recharge structures and farm livelihoods occurs through lifts from water impounded behind some structures; farmers with nearby land use this water for irrigation. These are both formal and informal arrangements. Where one village owns a structure but another owns some of the surrounding land, this can lead to inter-village conflicts over water rights.

Thirdly, livestock numbers have increased, with most farmers now owning at least one bullock or buffalo, and associated increases in milk production, now marketed through cooperatives. Across the five ('with' and 'without') study villages, for example, there has been a 22% increase in milk production since the 1998 baseline. These changes are linked with the increasing availability of water from the river, springs and wells, and with the increasing availability of green fodder during the summer.

It follows that links between recharge activities and livelihood outcomes are even more difficult to draw with confidence. As noted previously, while agriculture remains the primary occupation of most households, the proportion of income derived from agriculture (own farm and farm labour), and the proportion of households for whom agriculture is the main occupation, has declined over recent years. At the time of GOMUKH's baseline survey in the valley in 1996, for example, around 80% of respondents cited agriculture as their principal occupation; by the time of the current survey (2004), this figure had fallen to approximately 60%. Over the same period, the importance of other income sources and occupations – principally business and services – has increased, reflecting in part the movement of labour (both seasonal and permanent) to nearby towns and cities. One potential downside is the increasing burden of agricultural labour that falls on women; the percentage of female cultivators has increased by over 50% since the 1991 (Government of India) census. The sale of land, mainly to city dwellers in Pune, is another recent phenomenon. However, there are no clear links between any of these trends and watershed development, or recharge. Indeed migration and land sale is most prevalent in the villages of Bhalgudi and Hadashi, respectively, both part of the watershed development programme.

Income levels have increased significantly in all five villages surveyed. Since the 1991 census, for example, average annual income has increased by around Rs 5000 to Rs 7000, and by Rs 3000 since GOMUKH's 1998 baseline survey. Average income for sampled households in the five villages is now around Rs 34 000, well above the official poverty line of Rs 12 000. Prior to the watershed programme, around 40% of households were below the poverty line, compared with less than 10% now. Again, links with recharge activities are difficult to draw. By far the highest household incomes were recorded in the village of Nandgaon, where sugar cane cultivation is widespread, but this village was (at the time of the survey) not part of the watershed programme (Figure A5.6).

The effect of rising disposable incomes is evident in the asset status of households and their expenditure priorities. The first priority across social groups is house improvement, and the number of well-built houses has increased significantly throughout the valley, as has access to sanitation. Purchase of livestock is another priority, occurring in all survey villages, in response to improved fodder availability and the presence of milk cooperatives.

Looking at distributional changes in the valley, where land is less scarce (than in other case study areas) and landless labourers are a minority group, rising income levels and labour demands are reported to have benefited most households. For example, both small and large landowners are located close to the river, where perennial flows (positively influenced by recharge) have supported lift irrigation and livestock watering. A few smaller farmers also purchase water from those with lifts, but the extent of this is not known. Farmers are often reluctant to discuss their

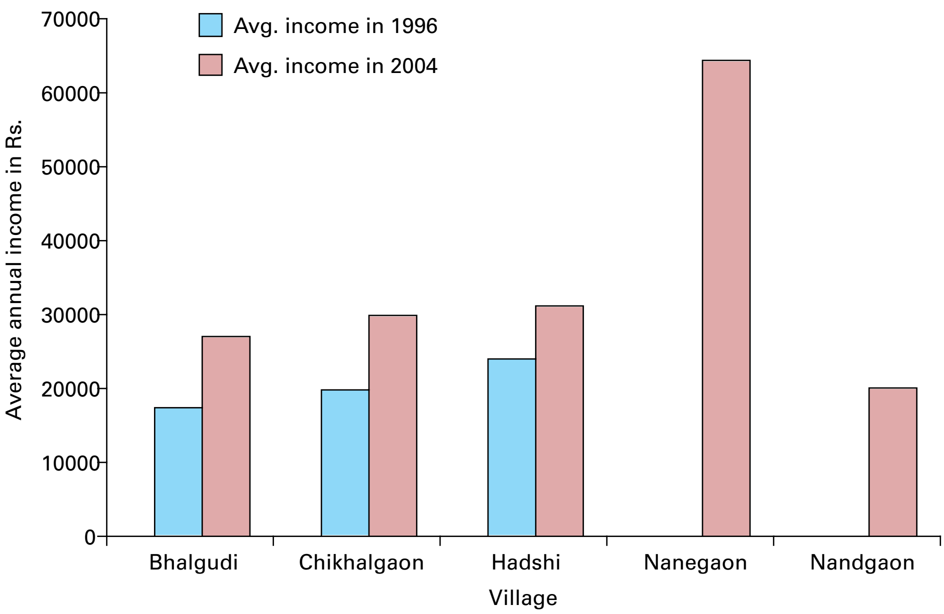

Figure A5.6 Comparison of average annual household income in the villages in the study area, 1996 to 2004.

Note: no baseline figures are available for the villages of Nandgaon and Nanegaon where, at the time of the survey, recharge structures had not been developed. However, incomes are reported to have risen sharply.

involvement in informal water transactions, probably because they are not authorised by the irrigation department. Landless households belonging to the *Dhangars* (livestock herder) tribe have also negotiated access to water stored behind check dams for watering livestock.

5.6 Key insights from the study

The main conclusions from the Kolwan Valley study are summarised in the following points.

- Communities living in the Kolwan Valley have benefited substantially from the long-term engagement of GOMUKH in watershed development. However, recharge is one element of watershed development – it was accepted as part of the overall package, not demanded by communities to meet specific water-related objectives.

- GOMUKH has played a key role in supporting local self-help groups and community initiatives. However, a lack of positive demand for recharge activities and limited input of communities into objective setting, planning and implementation has created a 'grey area' with respect to ownership and ongoing maintenance.

- Given the geology of the area, recharge structures have not created significant groundwater mounds around or downstream of structures. Instead, additional recharge is dissipated quickly, with benefits best assessed at valley rather than structure scale. A range of evidence suggests that recharge activities, as part of the watershed treatment package, have increased baseflows to streams and the River Walki.

- Groundwater development in the Kolwan Valley is limited, but increasing. Identifying direct links between recharge activities, groundwater development, enhanced baseflow to the river and livelihood impacts is extremely difficult. However, the greater reliability of the river has undoubtedly contributed to (greater) irrigation, agricultural (including livestock) production, and the income and asset status of farm households.

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