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Augmenting Groundwater Resources by Artificial Recharge. AGRAR Guidelines for Field Work

Groundwater Systems and Water Quality Programme Programme

Commissioned Report CR/03/167N

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/03/167N

Augmenting Groundwater Resources by Artificial Recharge. AGRAR Guidelines for Field Work

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British Geological Survey

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1 Introduction

The purpose of this report is to provide guidelines for the AGRAR project partners for carrying-out investigations at the three case study sites in India. The scopes of the hydrological and socio-economic assessments were described in the project Inception Report (CR/03/028). This document provides more detailed guidance on how those assessments may be undertaken. The report has two main chapters dealing separately with the hydrological and socio-economic aspects.

This technical part of the document is intended to provide broader guidance on the field methodologies to be used by giving more comprehensive information on the range of potential methods. It is not intended to be used to the exclusion of textbooks and standard guidelines and methodologies that are routinely used. Where issues are not addressed in sufficient detail, clarification this should be sought from the literature, government departments, equipment manufacturers or other experts. It should therefore be regarded very much as a *working document* and feedback can be incorporated into the report during the life of the project.

However, in order to ensure comparability across the three study sites in India, several technical parameters, determined and methodologies, used need to be common to all sites, namely:

- detailed geological description;
- groundwater contour map and seasonal fluctuations measured using electric dippers (this implies accurate levelling in of all monitoring points relative to the geodetic datum);
- develop a conceptual model of the hydrogeology;
- install an automatic weather station, to enable calculation of evaporation, accompanied by a standard evaporation pan;
- install an automatic water level recorder in the main recharge structure to accurately record fluctuations;
- develop a stage/volume relationship for the main recharge structure;
- survey and monitor the water quality in the recharge structure and the aquifer to determine background potability and changes resulting from induced recharge;
- monitor the water quality in the recharge structure and the aquifer to determine scale of recharge (chloride and isotopic methods):
- Undertake socio-economic surveys using the checklist developed in Pune as a focus, but drawing on tools and methodologies described elsewhere in AGRAR project documents.

In terms of the socio-economic evaluation, Chapter 3 provides further guidance on the objectives, approach and presentation of the evaluation. The Chapter draws on, and develops, ideas presented in the AGRAR review and inception reports, and those discussed at the methodology meeting in Pune (May 2003). At this meeting, it was agreed that the focus of the socio-economic evaluation should be an examination of the role water plays in supporting livelihoods at each of the case study sites, rather than a narrow examination of site-specific recharge effects. Findings can then be combined with technical results to assess how changes in groundwater availability affect the livelihoods of different wealth groups, and over what spatial scales, side-stepping some of the methodological hurdles associated with the ‘with vs. without’, and ‘before vs. after’ benchmarking of recharge effects.

The need for mixed methods, both quantitative and qualitative, is emphasised. The use of sample surveys based on questionnaires, and more exploratory, open-ended and participatory techniques, is suggested. A good deal of quantitative/semi-quantitative information on the economic, livelihood and resource characteristics of the study areas is already available from the ComMan investigations. It is therefore important that this is built on and that the partners pay particular attention to capturing, and presenting, the more qualitative ‘stories’ from each of the sites.

Echoing the point made above for the technical guidance, this is a working note. Feedback and further notes on guidance can therefore be added to the document as case study preparation proceeds.

2 Components of the hydrological assessment of recharge structures

The aim of the hydrological assessment is to undertake a systematic evaluation of the effectiveness of small-scale artificial recharge structures to the three different Indian field sites in terms of recharging the aquifer. The assessment will involve catchment-wide surveys and monitoring to relate potential additional recharge resulting from the recharge structure to the water budget in the catchment. The surveys and monitoring on a recharge structure scale will help quantify the water balance for the recharge structure itself. Limited surveys and monitoring at a number of satellite recharge structures will help to assess the representativeness of the results from the main recharge structure under investigation.

The field programme for the hydrological component of the case study work was outlined in the AGRAR Project Inception Report (Gale et al., 2002). This is repeated in **Table 2.1** below. Guidance on the activities required to carry out the hydrological aspects of the field programme is set out in this chapter. The chapter is organised on an activity basis; some sections may be applicable to both the scale of the recharge structure and its catchment.

Table 2.1 Fieldwork programme for the hydrological assessments at the AGRAR case study sites, as outlined in the AGRAR Project Inception Report (Gale et al., 2002)

Surveying and monitoring within the catchment of the recharge structure

i. Topographic survey to identify the catchment of the recharge structure.
ii. Survey of land-use within the catchment, including type and timing of crops, and surface drainage patterns.
iii. Installation and daily monitoring of a network of rainfall gauges to quantify rainfall and its spatial variability.
iv. Monitoring of daily climate data from an automatic weather station located at the recharge structure site to allow evapotranspiration from the catchment to be approximated.
v. Monitoring of surface water flow from the catchment, measured at the recharge structure outlet.

Surveying and monitoring in the vicinity of the recharge structure

i. Hydrogeological survey to assess the groundwater flow system. This may involve limited geophysics, dedicated borehole drilling and/or borehole tests to estimate aquifer parameters.
ii. Development and monitoring of a network of groundwater level observation points in the vicinity of the recharge structure, including suitable existing wells and newly drilled piezometers. This network will monitor groundwater levels upstream, downstream and lateral to the structure (and at different depths) to help assess background fluctuation in the water table, existence of perched water tables, the groundwater gradient, the additional recharge from the structure and how this recharge dissipates during the dry season.
iii. Monitoring of groundwater abstraction from wells and boreholes in the vicinity of the recharge structure.
iv. Collection of surface and groundwater samples for isotopic and chloride analysis to help assess the zone of influence of the recharge structure and evaporation rates.
v. Detailed topographic survey of the recharge structure to enable the volume of water being stored to be calculated from the standing water level.
vi. Installation of a water-level recorder at the lowest point in the recharge structure and subsequent monitoring of water level. In addition, a gauging post will be installed as a back-up for monitoring.

vii. Monitoring seasonal changes in the volume of the recharge structure due to: the ingress of sediment with surface water; and the removal of sediment for both agricultural use and to maintain the storage of the structure.

viii. Monitoring of surface water inflow and outflow from the recharge structure. This will require calibration of flow over the structure's dam for high flows and temporary V-notch weirs above and below the dam for low flows.

ix. Installation of an automatic weather station to enable evaporation from the water in the recharge structure to be estimated and relative humidity to be measured to support the isotope investigation. The feasibility of also using an evaporation pan floating in the water in the recharge structure will be explored.

x. Monitoring of direct surface water abstraction from the recharge structure for irrigation etc.

xi. Assessment of the impact of fine sediments on infiltration through the base of the structure using a combination of infiltrometry, augering and soil pits.

xii. Monitoring of inorganic and microbiological water quality in the recharge structure and surrounding piezometers, wells and boreholes.

Surveying and monitoring of the satellite recharge structures

i. Hydrogeological survey to assess the groundwater flow system. This may involve limited geophysics, dedicated borehole drilling and/or borehole tests to estimate aquifer parameters.

ii. Monitoring of a network of groundwater level observation points in the vicinity of the recharge structure, restricted to suitable existing wells.

iii. Detailed topographic survey of the recharge structure to enable the volume of water being stored to be calculated from the standing water level.

iv. Monitoring seasonal changes in the volume of the recharge structure due to the ingress of sediment with surface waters and the removal of sediment for agricultural use and to maintain the structure.

v. Installation of a gauging post at the lowest point in the recharge structure and subsequent monitoring of water level.

vi. Monitoring of periods of no inflow to the recharge structure during which recharge can be calculated using water-level changes and approximated surface water evaporation.

vii. Monitoring of daily rainfall at the site.

viii. Monitoring of direct surface water abstraction from the recharge structure for irrigation etc.

ix. Assessment of the impact of fine sediments on infiltration through the base of the structure using a combination of infiltrometry, augering and soil pits.

2.1 TOPOGRAPHIC SURVEY

2.1.1 Topographic survey at catchment scale

A topographic survey needs to be carried out in the study area to:

- identify the surface water catchment of the main recharge structure;
- obtain the geodetic heights at observation and monitoring points within the catchment.

It may be possible to estimate the catchment area of the recharge structure from a large scale topographical map (e.g. 1:25 000 scale). Where this is not available, a topographic survey should be carried out using surveyor's levels. This will give readings accurate to within a centimetre or two. It is anticipated that experienced personnel will carry this out and therefore the methodology for undertaking such a survey is not discussed here.

At catchment scale, large scale topographical maps may give a rough estimate of altitude of observation points which might be of sufficient accuracy, however, near the recharge structure observation points should be accurately surveyed in. The position of every observation point within the study area can be recorded using a Global Positioning System (GPS). However, the altitude of the point should be determined using a surveyor's level, as the accuracy of altitude readings of a GPS is not adequate. With most low cost GPS receivers, the horizontal error is specified to be within about +/– 15 meters 95% of the time and larger for the remaining 5% of readings (Yeazel and Mehaffey, 2003).

2.1.2 Topographic survey of the recharge structure

The main purpose of undertaking a topographic survey of the recharge structure is to allow water levels to be translated into volumes. In addition, if a large build up of sediment occurs during the monsoon, a survey before and after the rainy season will indicate the amount of sediment deposited in the structure.

Again, the methodology for carrying-out this survey will be determined by the experienced personnel involved. However, it is emphasised that detailed surveying will be required if accurate estimates of volumes are to be made. It is suggested that the density of spacing of measurements of topographic elevations is varied according to the degree of undulation of the base of the recharge structure. The output of the topographic survey of the recharge structure should be a contoured map of the elevation of its base. This will allow the area of water corresponding to a level of the water surface in the structure to be estimated. The volume of water in the recharge structure between two water levels can be calculated from the water level difference and the start and end surface water areas. If the water level difference is large the volume should be calculated by summing the volumes from smaller increments **Figure 2.1**.

The value of carrying out a topographic survey at the end of the monsoon season for the purpose of measuring the amount of sediment deposited will depend on whether the volume of sediment is significant in relation to the degree of error in the topographic survey. This can be judged from the other approaches to measuring sediment deposition described in Section 2.8.

When undertaking the survey of the recharge structure, the top of the spillway wall should also be levelled in accurately along its length. This will help to assess if the use of the spillway as a means to estimate the flow rate downstream of the recharge structure is appropriate and whether it is necessary to render the top of the spillway wall to make it horizontal.

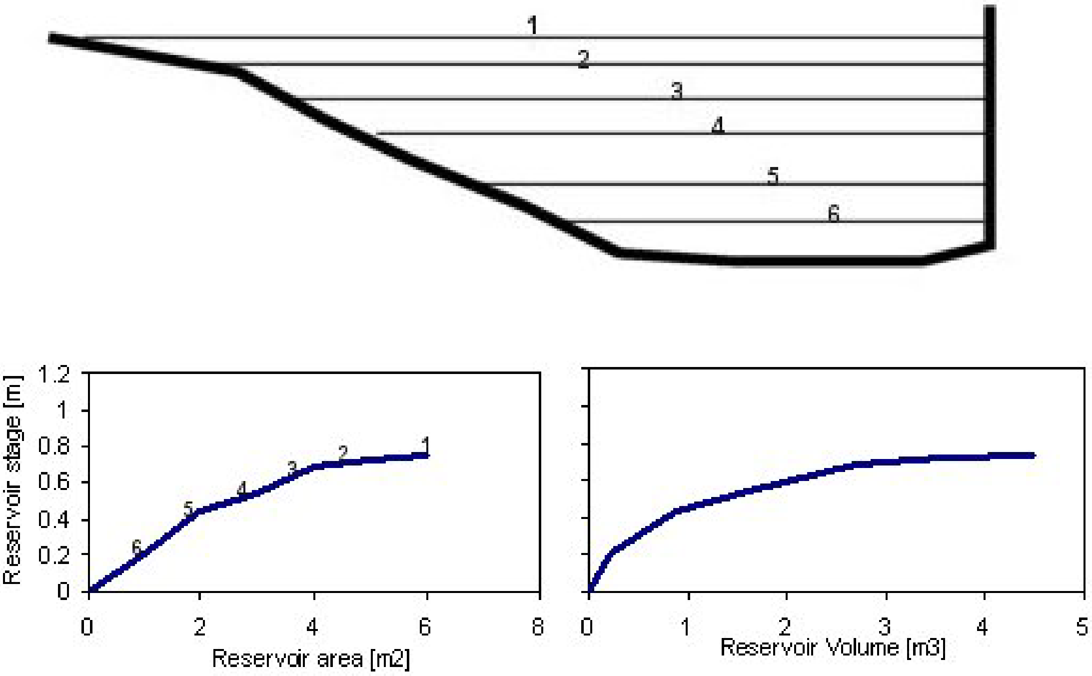

Figure 2.1 Translation of reservoir surface area at various water levels into a volume of water

2.2 HYDROGEOLOGICAL SURVEY TO ASSESS THE GROUNDWATER FLOW SYSTEM

To be able to interpret the groundwater level data collected in the vicinity of the recharge structure requires an understanding of the regional hydrogeology, including the groundwater flow system. The basis of this understanding is knowledge of the geological setting. With this knowledge, the type and extent of the aquifers can be defined. If the properties of the aquifer(s) (hydraulic conductivity and storage) can be estimated then with actual or inferred information on the groundwater levels in the aquifer and localised recharge and discharge zones, a conceptual model of the groundwater flow system can be developed. This model can be refined as more groundwater level data become available during the life of the project. The activities that can be undertaken to help develop the conceptual model are described here.

2.2.1 Logging of drilled boreholes

It will be necessary to drill a network of boreholes around the recharge structure to monitor the groundwater level (see Section 2.3.1). These boreholes can also provide very useful information on the geology and hydrogeology when they are being drilled. The rock type should be logged as the borehole is drilled by examination of the drilled cuttings. This should provide a vertical profile of the geology. Of particular interest are: the depth and lithology of the shallow layer, i.e. weathered hard-rock in the case of Kolwan Valley and Coimbatore and unconsolidated sediments in the case of Satlasna; the thickness and nature of the transition zone between this shallow layer and the underlying bedrock; and the nature and degree of fracturing in the bedrock. Observations on the type of water strikes (if any) during drilling would also be useful. For example, are water-bearing fractures intercepted, does the groundwater level settle at a shallow level even though it has been first intercepted at a deeper level i.e. it is confined? In addition, the time to penetrate each metre of rock can be noted to provide further information on changes in lithology.

2.2.2 Geological survey

A trained geologist would best do this task. On the basis of existing regional geological maps, the borehole data and a brief survey of the region, it should be possible to develop a larger scale geological map and cross-section for the area including the recharge structure.

2.2.3 Surface geophysics

Surface geophysics should only be undertaken by an experienced geophysicist with knowledge of the geology and a clear appreciation of the issue. This would normally be the mapping of a sharp boundary between rocks of clearly different properties e.g. the boundary between the shallow weathered or unconsolidated layer and the bedrock. If surface geophysics is a cost-effective solution to a specified problem then a survey should be undertaken. Control on the interpretation using data from boreholes is always valuable.

2.2.4 Aquifer tests

These tests are undertaken on the drilled boreholes and allow the aquifer properties to be estimated. They are discussed in greater detail in Section 2.10.

2.2.5 Assessing groundwater flow system

A well inventory is needed, to identify all known wells and boreholes in the area, as well as a list of recharge structures in the area. The depth to groundwater has to be determined at observation points related to the height above the geodetic datum. Thus, a water table contour map can be produced for the area and flow lines can be drawn that will illustrate the groundwater flow pattern in the catchment. This can be related to areas of groundwater recharge and discharge, springs and reaches of streams that are in contact with the aquifer. The groundwater contour map will:

- guide the installation of a monitoring network around the recharge structure by outlining flow direction and areas upstream and downstream of the structure;
- give information on the position of the recharge structure within the catchment, e.g. is the structure positioned in a recharge area or close to, or even in a discharge area?
- give an indication of the available underground storage for artificial recharge from the structure;
- outline areas influenced by abstraction.

The groundwater contour map will change over the duration of the hydrological year. While discharge and recharge areas might stay the same, the depth to water level will change, depending on measurements being taken during the monsoon or in dry periods. Hence, it is necessary to undertake this regional groundwater level monitoring at least twice a year: at the end of May and at the end of September when groundwater levels are at their minimum and maximum values respectively. Monitoring at more frequent intervals can provide additional understanding of groundwater level fluctuations as can continuous reading of water levels at selected observation points.

2.3 DEVELOPMENT AND MONITORING OF GROUNDWATER LEVEL OBSERVATION POINTS

2.3.1 Development

The main purpose of the monitoring network is to monitor the influence of the recharge structure on groundwater levels. The network will also allow the background water level fluctuations to be monitored (i.e. not under the influence of the recharge structure) and the water quality in the aquifer to be sampled.

It is suggested that monitoring boreholes are drilled in a cross pattern centred on the recharge structure (**Figure 2.2**). Clearly boreholes should be drilled at locations where they will not be seriously damaged by flood waters and where they can be accessed while the recharge structure is full. The borehole that is the greatest distance from the structure upstream will allow the background water level fluctuations to be monitored. The remaining boreholes should enable the shape and size of the mound of groundwater underneath the recharge structure to be defined although it is recognised that the siting of boreholes is difficult given that the many of factors that influence the choice are currently unknowns. In general, the smaller the hydraulic conductivity of the aquifer, the closer to the recharge structure the observation boreholes should be sited. **Figure 2.3** illustrates the aerial extent of a one metre rise in groundwater levels after one month of recharge at a rate of $5m^3/d$ for a range of hydraulic conductivities. Depending on the hydraulic conductivity of the aquifer material, the one metre and greater rise in water level is observed out to distances of 7.5, 12 and 25 metres from the recharge structure, respectively. The example demonstrates that in general, considerable rises in groundwater levels will only be detectable in boreholes situated close to the recharge structure.

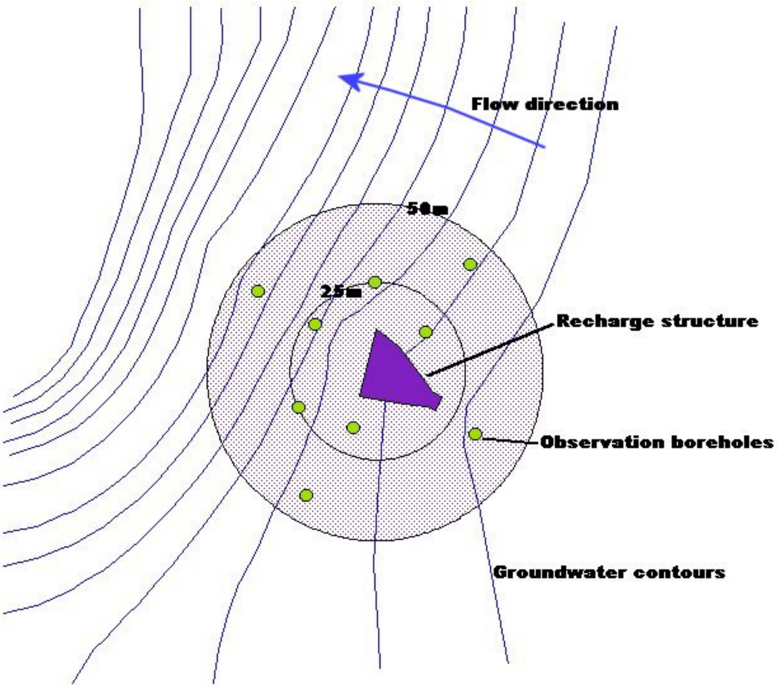

Figure 2.2 Example for a set-up of observation boreholes

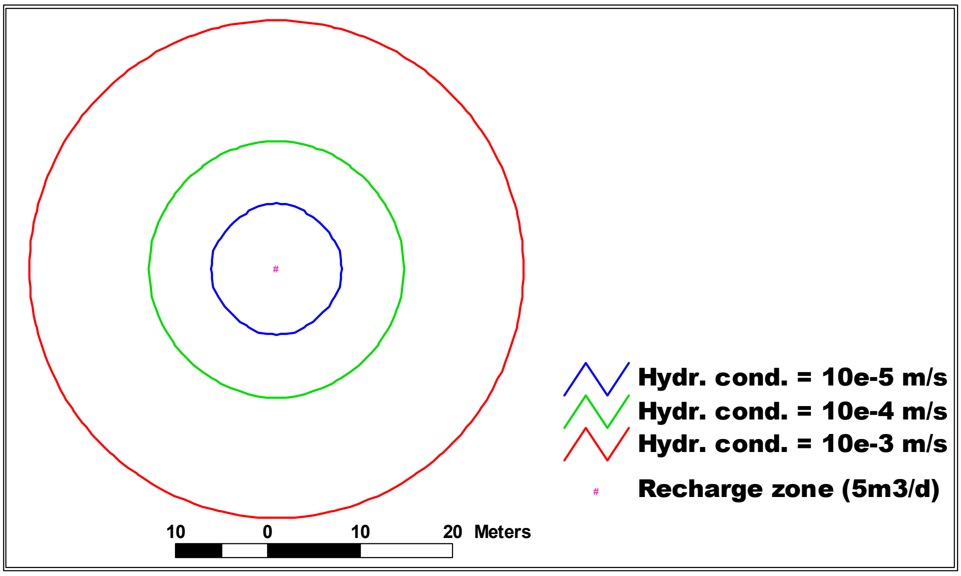

Figure 2.3 Rise in groundwater of 1m around a recharge point depending on the hydraulic conductivity of the aquifer

The assumption is made in the cases of the alluvium on basement in Satlasna and the weathered basement in Coimbatore, that the shallow aquifer is in total hydraulic connection with the underlying bedrock. In the Kolwan Valley there is a layered system of basalts and it is possible that groundwater may leak from the shallow aquifer at the recharge structure into the underlying deeper aquifers. In this case a monitoring borehole drilled into the deeper aquifer (with the shallow aquifer cased off) would allow the piezometric head to be measured and help assess whether leakage occurs. This would help interpret water level fluctuations around the recharge structure in the shallow aquifer, monitored using the main water level network. In Satlasna and Coimbatore the monitoring boreholes need only be drilled through the unconsolidated/weather zone and a few metres into the bedrock, although it is imperative that the boreholes are deep enough to measure groundwater levels all year round and should not go dry when levels are at their lowest at the end of the dry season.

The lithology of each monitoring borehole should be logged as discussed in Section 2.2.1

The datum for each borehole/open well/piezometer, which is part of the network needs to be levelled in during the topographic survey to relate the depth to groundwater to the elevation above the geodetic datum.

2.3.2 Using existing wells and boreholes

If existing wells or boreholes are to be part of the monitoring network, these should ideally be disused. If abstraction takes place, the water level measured might be the pumping level rather than the standing water level. If wells or boreholes currently in use are part of the monitoring network, arrangements should be made, where possible, to record water levels after prolonged periods of no abstraction, e.g. early in the morning after the water level has had 12 hours to recover from any pumping. In all such cases, the farmer should be asked to keep records of the duration and rate of pumping prior to each water level measurement. If long-term data records exist for a supply borehole, it might be possible to judge which water level fluctuations are related to pumping and which represent the rest water level. N.B. boreholes must be drilled as part of the project to create the monitoring network shown in **Figure 2.2**. The use of existing wells and boreholes must only be additional to this basic network.

2.3.3 Monitoring

Water level depths have to be recorded from a fixed datum, which has been levelled in during the topographic survey (see Section 2.1). This ensures that water levels can be converted into elevations above the geodetic survey datum of India and hence correlated to other observation points.

Water levels should be measured using a water-level dipper, (**Figure 2.4**) which will either have a light or buzzer that activates when the dipper touches the water table. Dippers allow quick and easy readings to be taken and the tape can be read to the nearest half centimetre.

Manual groundwater level measurements should be taken on a daily basis during the monsoon period. Subsequently the interval between readings can be increased gradually. It is expected that during the dry season weekly monitoring will be sufficient (**Figure 2.5**).

If it were possible to measure groundwater levels continuously, this would provide useful additional information. To obtain continuous water-level measurements, a water-level recorder has to be used. These come in form of float-operated recorders, pressure transducers or acoustic transducers. Float-operated recorders use a float to sense the water level, which is connected to a paper chart. A pressure transducer is installed in a well or borehole at sufficient depth below the water table and changes in water level are recorded via the changes in weight of water above the transducer. The device is either connected to a paper chart or to an electronic data-logger.

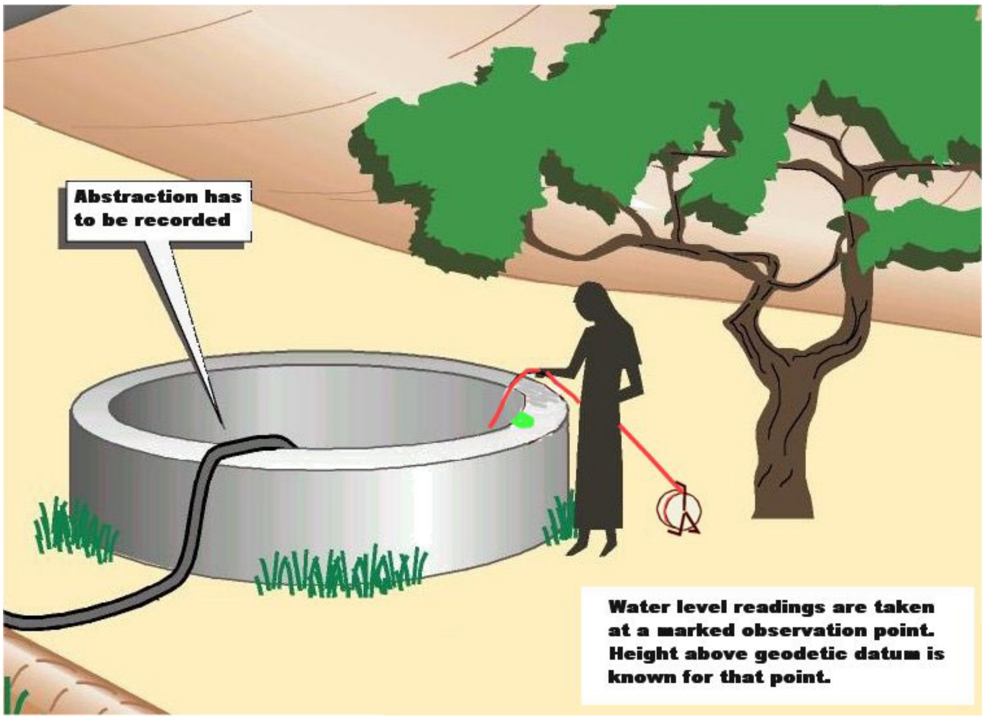

Figure 2.4 A water level measurement has to be taken from a fixed marked datum, which is levelled relative to a geodetic datum

AGRAR project Data record sheet

Observation	Open well No 6
Location	Chikhalgaon
Grid	73deg 31' 13" 18deg 36' 04"
Name of data	Uma Badarayani
Elevation of fixed	604.25 **m.a.g.d.**

(m.a.g.d. metres above geodetic datum)

Water level record				Abstraction record			
Date	Time 24 hour	Depth to water (metres)	Depth m.a.m.s.l	Time start 24 hour	Time end 24 hour	Quantity m3	Comments
02-Jul-03	09:00	23.512	580.738				
03-Jul-03	09:00	23.470	580.780				
04-Jul-03	09:15	23.420	580.830				
05-Jul-03	09:00	23.211	581.039				
06-Jul-03	09:05	23.100	581.150				
06-Jul-03	18:00	23.050	581.200				
07-Jul-03	09:10	22.960	581.290				
08-Jul-03	09:00	22.930	581.320				
08-Jul-03	18:00	23.110	581.140			ca. 60	in the afternoon
09-Jul-03	09:00	22.935	581.315				
09-Jul-03	18:15	22.911	581.339				
10-Jul-03	09:15	22.821	581.429				
11-Jul-03	09:00	22.800	581.450				

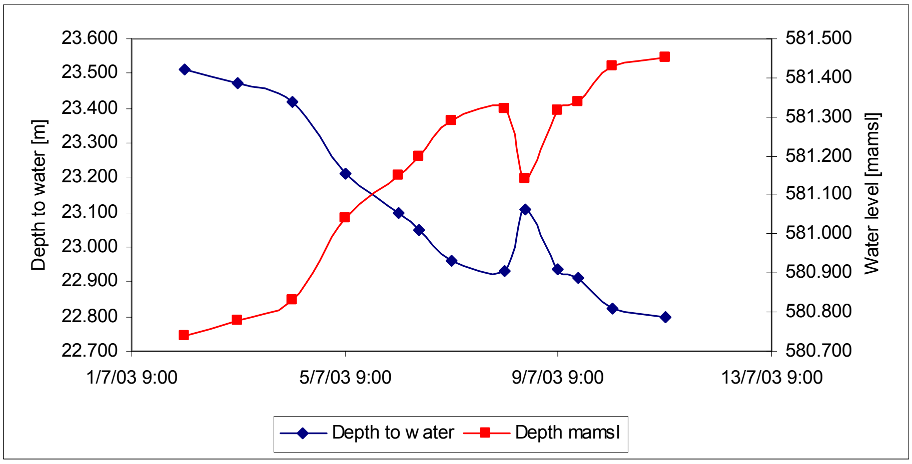

Figure 2.5 Example field sheet and data plots of groundwater level

2.4 MONITORING OF THE WATER LEVEL IN RECHARGE STRUCTURES

In order to quantify groundwater recharge from the structure, the change in water level in the recharge structure needs to be recorded. The changes in water level are converted to volumes of water using the output from the topographic survey of the base of the recharge structure (see Section 2.1.2). During periods of no precipitation, and when surface flow in and out of the recharge structure can be neglected, the volume of water that recharges the aquifer during a specified period can be calculated by subtracting the open water evaporation from the reduction in the storage in the recharge structure. Evaporation is estimated from the measurements obtained from the meteorological station (see Section 2.9).

The water level (or stage) needs to be measured in relation to a fixed datum point that has been levelled in during the topographical survey (Section 2.1). The stage needs to be monitored using an automatic digital water level recorder. This needs to be positioned at the lowest point in the recharge structure but at least 2 m upstream of the spillway wall so that the water level readings can be used in the calculation of flow over the wall during heavy rainfall periods. It may not be possible to meet both criteria; if so the latter should take precedence. It may be necessary to construct a gantry for access to download data from the digital water level recorder. The recorder should be housed within a stilling well (a large diameter tube with slots drilled to that the water level inside is the same as that surrounding it). It is suggested that data are downloaded from the water level recorder every week.

It is also suggested that a staff gauge is erected within the recharge structure to allow back-up water level readings to be taken. This should be done on a daily basis. The staff gauge should also ideally be located at the lowest point of the recharge structure although the spillway well is likely to be most practical. Readings should be taken at the same time each day, (e.g. 9.00 a.m. every morning) and should be accurate to within half a centimetre. Alternatively, it may be appropriate to install a simple manometer tube running from the stilling well to the downstream side of the spillway wall where the staff gauge is located. This may allow more accurate measurements of water level to me made.

In addition to allowing flow rates over the spillway to be estimated, the advantage of having an automatic digital recorder over a staff gauge is:

- the preciseness and accuracy of the digital recorder (within 1 millimetre) which may be valuable if small changes in water levels are significant
- it allows water level decline at night and during the day to be compared which may be helpful in identifying if water level decline is a result of evaporation or infiltration.

Table 2.2 provides an example of a field record sheet used to record the components of the water balance of a recharge structure, including the stage and periods of inflow and outflow.

Table 2.2 Example of a data sheet to record components of the water balance of a recharge structure.

AGRAR project Data record sheet

Artificial recharge structure name

Name of data recorder

Elevation of staff gauge zero m.a.g.d.

Elevation of overflow m.a.g.d.

Maximum area of water surface hectares

Date	Time 24 hour	Staff gauge reading (metres)	Time 24 hour	Raingauge reading (mm)	Rainfall since last reading? Yes/No	Flow into structure? Yes/No	Overflow from structure? Yes/No	Seepage from structure? Yes/No

2.5 MONITORING OF ABSTRACTION AND SURVEY OF LAND USE

2.5.1 Recharge structure catchment scale

It is desirable to estimate abstraction of groundwater on the scale of the catchment of the recharge structure, as this will form part of the annual catchment water balance. It is likely that no accurate records of abstraction are available and in such circumstances quantities should be estimated from pump capacities and hours run. Alternatively, a survey of groundwater use can form the basis for the estimate. The socio-economic study being carried out in every field site should provide this information.

Additionally a survey of land use should be carried out, to estimate the amount of water used within the catchment for irrigation. Every crop type has a specific irrigation water requirement, e.g. for paddy rice irrigation, water is needed to flood the paddy fields. On the basis of the land use data the consumptive water use for irrigation can be assessed. The impact of irrigation on the water balance in the catchment then requires an estimate of the water effectively withdrawn, i.e. the volume of water extracted from rivers, recharge structures and the aquifer for irrigation purposes.

2.5.2 Reservoir Scale

Groundwater abstraction needs to be monitored in wells and boreholes in the vicinity of the recharge structure as they may have an impact on groundwater levels. Groundwater abstraction also needs to be monitored in those wells and boreholes that are part of the wider monitoring network.

Additionally, any surface water abstracted directly from the recharge structure needs to be recorded, as it will form part of the water balance. Records of abstraction should include the duration and rate of pumping. N.B. as the surface water abstraction estimate will be approximate, but could be significant in terms of the water balance.

2.6 MONITORING OF SURFACE WATER IN THE VICINITY OF THE RECHARGE STRUCTURE

It is proposed that the spillways for the recharge structures be used as a means for gauging the flow downstream from the structure. This will allow the run-off from the catchment of the recharge structure to be estimated. The aim is to set the additional groundwater recharge produced by the structure in the context of the other components of the water balance in the catchment. Is this extra recharge significant in comparison with the diffuse recharge and is the water held-up by the structure a significant proportion of the downstream flow?

In addition, it may be necessary to measure low flows at times. It is planned that measurements of the water-level decline in the recharge structure are made during periods when there is no inflow from upstream. However, there may be periods during which a water balance of the structure could be undertaken when there are still small rates of inflow occurring via the upstream channel. Equipment for estimating this inflow is also described here. It is also possible that some leakage may occur from the recharge structure, under the spillway. If this is the case, the equipment described may also be used to estimate these low flows downstream of the structure.

2.6.1 Flow over the spillway

The calculation of flow over the spillway can be approximated by the following equation for a broad-crested weir:

$$Q = C.b.h^{\frac{3}{2}}$$

Where b is the width of the spillway; h is the head of water in the recharge structure above the height of the spillway wall; and C is a coefficient that depends on factors such as the roughness of the top of the spillway wall and the ground conditions in the few metres upstream of the spillway. The assumption that the spillway acts like a broad-crested weir is a significant approximation given, for example, that the spillway wall is unlikely to be horizontal. Even so, the approximation of the flow over the spillway wall may be sufficiently accurate to allow a catchment-scale water balance.

An automatic water-level recorder will measure the head of water in the recharge structure above the spillway wall. This would be difficult if reliant solely on manual readings as the flow events may be during times when there is no one available to take readings. Clearly it will not be possible to estimate flow using the above methodology when all the water does not flow over the spillway. It is therefore important, where possible, that someone from the local community has the responsibility to visit the structure during high flow periods to monitor how flow is occurring.

As mentioned above, a critical aspect of the use of the spillway as a broad-crested weir is the assumption that the top of the spillway is horizontal. To assess to what degree the top of the spillway wall is horizontal, its height should be measured at intervals of 0.5 m or less along the top of the wall. This can be done as part of the main topographic survey. If the top of the wall undulates or is significantly off the horizontal, the potential for levelling it should be explored.

2.6.2 Measuring low flows

Should there be periods during which low flows need to be measured either upstream or downstream of the recharge structure, the only practical approach is likely to be the use of a temporary thin plate weir. This will only be feasible where the stream channel is narrow enough that the plate can block it. The plates are usually made from a steel sheet with a rectangular notch or a 'V' shaped notch, through which water flows. It is suggested that a 'V' shaped notch weir is used. Equations exist to relate the height of the water flowing through the notch to the flow for standard shapes of thin plate weirs. **Table 2.3** relates the head of water above the apex of the 'V' to discharge rates. The dimensions of the 'V' notch weir will depend on the width and gradient of the stream channel and on the typical flow rates to be measured.

The frequency at which the low flows need to be measured will be very much dependent on the rate at which they are changing. If the weir can be left in place for a few days or weeks then it may be possible for local field staff to take readings on a daily or more frequent basis.

Table 2.3 Head-discharge relationships for a 90-degree V-notch weir

Head	Discharge	Head	Discharge
(mm)	(l/s)	(mm)	(l/s)
40	0.44	180	18.9
50	0.73	190	21.7
60	1.21	200	24.7
70	1.79	210	27.9
80	2.49	220	31.3
90	3.34	230	35.1
100	4.36	240	38.9
110	5.54	250	43.1
120	6.91	260	47.6
130	8.41	270	52.3
140	10.2	280	57.3
150	12.0	290	62.5
160	14.1	300	68.0
170	16.4	350	100

2.7 GROUNDWATER CHEMISTRY

2.7.1 Monitoring of inorganic and microbiological water quality

Monitoring of water quality in the structure and in surrounding wells, bore wells and piezometers will identify any beneficial or detrimental impacts, due to the structure, on the potability of drinking water supplies as well as determining the regional quality of groundwater. Water quality sampling programmes of rain water, pond water, well and borehole water will be undertaken during the main recharge period and towards the end of the dry season. The main species to be analysed for are Ca, Na, K, Mg, HCO_3 Cl, SO_4, NO_3, Fe, Mn, As, F as well as pH and stable isotopes of oxygen and hydrogen. These programmes will enable the background water quality to be determined and the impact of enhanced aquifer recharge to be assessed. For example, in areas where there are naturally high concentrations of Fluoride in the groundwater, enhanced recharge may 'dilute' the concentrations to acceptable levels.

The water sampling programmes, undertaken in May 2003 by BGS at the Pune and Coimbatore study sites, will contribute to the understanding of groundwater quality and provide reference analyses for a wide range of species. The samples will be analysed at the BGS laboratories in Wallingford.

The microbiological quality of water from recharge structures and large diameter wells can be expected to be low as these sources are unprotected from contamination from birds, animals etc. The quality of groundwater from boreholes is however usually good if the wellhead is properly constructed and maintained. A survey of microbiological quality of groundwater from boreholes would therefore give an indication of the effectiveness of the unsaturated zone in protection of the aquifer and where rapid transport routes may have resulted in contamination of groundwater. Protocols for sampling and analysis should be taken on advice from the experts undertaking the exercise and recorded to assist interpretation of the results.

2.7.2 Sampling procedure

- Clean sample bottles are required to collect the water. Consult with the analysing laboratory what size of bottle is needed. 500 ml is in most cases sufficient. Liaise with the laboratory on preservation techniques and record sampling protocol and analytical techniques.
- Boreholes which are disused will yield stagnant water; hence, ideally, pumped water samples should be taken. To remove stagnant water, it is necessary to empty the disused well by 2 to 4 volumes.
- Note name of monitoring point, depth of the well/borehole, time taken to purge the well/borehole, date, time and sample number.
- Rinse the bottle with the well water before you collect the sample.
- Consult with the laboratory on what samples are required. Generally, filtered samples are collected, of which a part is acidified. The acidification stops bacterial growth, blocks oxidation reactions (important for e.g. iron, manganese) and prevents adsorption or precipitation of cations. To acidify 100 ml of sample, ca. 1 ml of concentrated nitric acid (65% HNO_3) is added. Filtering is needed, to remove any suspended material, which could dissolve when acid is added. The normal procedure is to filter through 0.45 µm membrane filters. An unfiltered and unacidified sample is necessary if microbiological parameters, organic compounds, pesticides, isotopes or the total suspended solids content of the water is to be measured. Samples for microbiological analyses should be stored cool and be analysed within 24 hours. Samples to analyse for the isotopic composition of the water should be collected in a glass bottle, to prevent any evaporation.
- If probes are available to measure parameters in the field, the following measurements should be taken:

  pH, temperature, conductivity, dissolved oxygen, alkalinity and redox potential (Eh).

2.7.3 Frequency of measurements

A background survey of water quality should be carried out in the vicinity of the recharge structure once a year. The timing of this survey in relation to the monsoon season should be noted. Preferably it should be at the end of the dry season, but, as in the case of the Satlasna site, most wells are dry so the survey needs to be carried out at an earlier period of the year. It should include a range of samples from boreholes upstream and downstream of the recharge structure, as well as samples from the recharge structures themselves. This will provide information on the background water quality within the catchment. **Table 2.4** provides an example of a field data sheet used for chemical sampling.

Besides sample collection for background water quality, chloride and isotopic analysis should be carried out in the recharge structure and surrounding boreholes on a more frequent basis. (see Section 2.7.2).

Table 2.4 Example of a field record sheet for water chemistry sampling

AGRAR 2003

Field number: ________________________

Locality: ____ Date: ________

Grid Ref: *(12 figure)* (E)________________ (N)________________ Time: ________

Sample Source: ________ Water Condition: ________

Land use of catchment: *(e.g. grassland, coniferous forest, deciduous forest, rough grazing, arable)*

Comments:

Water temperature: ________

Conductivity: ________

Standard (0.005M KCl, 718 µS/cm): ________

Alkalinity: ________ ________ ________ *mean:* ________

Acid concentration: 0.16N ~ *1.6N* ~ *HCO_3 (mg/l)*: ________

pH, redox potential (Eh), dissolved O_2:

pH in flow cell: ________ *Standard (10^{-4} N H_2SO_4, pH 4.06):* ________

Eh standard (Zobells solution, 190 mV @ 20 EC, *210 mV @ 10* EC*):* _______

Absolute + reference (mV) ________

Time	*T(oC)*	*pH*	*SEC*	*DO (mg l^{-1})*	*Eh absolute (mV)*

Samples taken: *F/A* ~ *F/UA* ~ *TOC* ~ *DOC* ~ *Stable isotopes* ~ *Sr iso.* ~ *N species* ~
*other:*______________

F = filtered, A = acidified

2.7.4 Isotopic and chloride studies

ESTIMATING EVAPORATION FROM RECHARGE STRUCTURES USING ENVIRONMENTAL CHLORIDE

The chloride mass balance method is based on the assumption that there are no sources or sinks of chloride other than natural input from precipitation and runoff and that there is no loss of water from the reservoir other than evaporation and recharge. The total chloride content of the water at any time is estimated from the volume of water in the reservoir and its chloride concentration, which is measured regularly (Sukhija et al., 1997). There is no loss of chloride by evapotranspiration and therefore, the concentration increases as evaporation proceeds. Thus, by measuring the volume of water and its chloride concentration over time, an estimate of the evaporation can be made and consequently, the percentage recharge can be calculated.

The mass balance of chloride in the tank water between time t_1 and t_2 can be written as follows:

$$(V_1 \text{ x } C_1 - V_2 \text{ x } C_2) / C_d = (V_1 - V_2) \text{ x } (1-f)$$

with

V_1 = volume of water in the tank at time t1
V_2 = volume of water in the tank at time t2
C_1 = chloride concentration of water in the tank at time t1
C_2 = chloride concentration of water in the tank at time t2
C_d = time weighted average concentration of chloride in percolation water ($\Sigma C_i V_i / \Sigma V_i$)
f = fractional loss by evaporation
(V_1-V_2)x $(1-f)$= loss of water by recharge.

To apply the method, the following measurements need to be taken repeatedly:

- reservoir stage (to be converted into volumes of water) preferably recorded digitally;
- chloride concentration of reservoir water.

The method should be applied during dry spells, generally after the monsoon, when no precipitation and no surface water inflow occur. Ideally, there is no surface water outflow from the recharge structure during that period either, other than recharge. If seepage/leakage from the recharge structure is observed (e.g. through the dam wall), this has to be quantified, so as to not overestimate the recharge.

Figure 2.6 gives an example of the increase in chloride over time in a recharge structure, and presents the volume of water lost through evaporation, based on the measured volume and chloride concentration of the tank water over time. The example is taken from a study into the effectiveness of a percolation tank near Singaram village, Yacharam mandal, Rangareddy district in Andhra Pradesh (Sukhija, B.S. et al. 1997).

FREQUENCY OF MEASUREMENTS

The method is applicable only if water remains in the recharge tank after rainfall events long enough for evaporation to have a measurable impact on chloride concentrations.

As a rule of thumb, a recharge structure holding water less than two weeks is not likely to show significant differences in the chloride concentration. For a structure holding water for one month and longer, a weekly sampling frequency is recommended. It might be difficult to predict when to start sampling, so samples can be collected and stored until the best start date is known when relevant samples can be selected and analysed.

Date	Water column loss cm	Tank Volume m3	Chloride conc. mg/l	Time weighted Cl conc. mg/l	fractional loss by recharge 1-f
25-Nov-1992		3219	13	13.75	-
2-Dec-1992		2879	14	14.85	-
9-Dec-1992	16.50	2564	16	16.00	0.25
16-Dec-1992	15.00	2328	17	17.00	0.26
22-Dec-1992	14.00	2214	18	18.00	0.34
29-Dec-1992	14.00	1999	19	19.00	0.38
5-Jan-1993	15.50	1801	20	20.05	0.49
12-Jan-1993	15.00	1621	21	21.05	0.49
19-Jan-1993	20.00	1455	22	22.05	0.43
26-Jan-1993	20.00	1337	23	24.80	0.21
8-Feb-1993	22.00	1018	27	30.00	0.21
15-Feb-1993	24.00	895	33	35.05	0.15
22-Feb-1993	19.50	726	37	40.55	0.13
3-Mar-1993	20.00	603	44	46.20	0.24
18-Mar-1993		514	48	53.50	-
15-Mar-1993		416	59	58.60	-

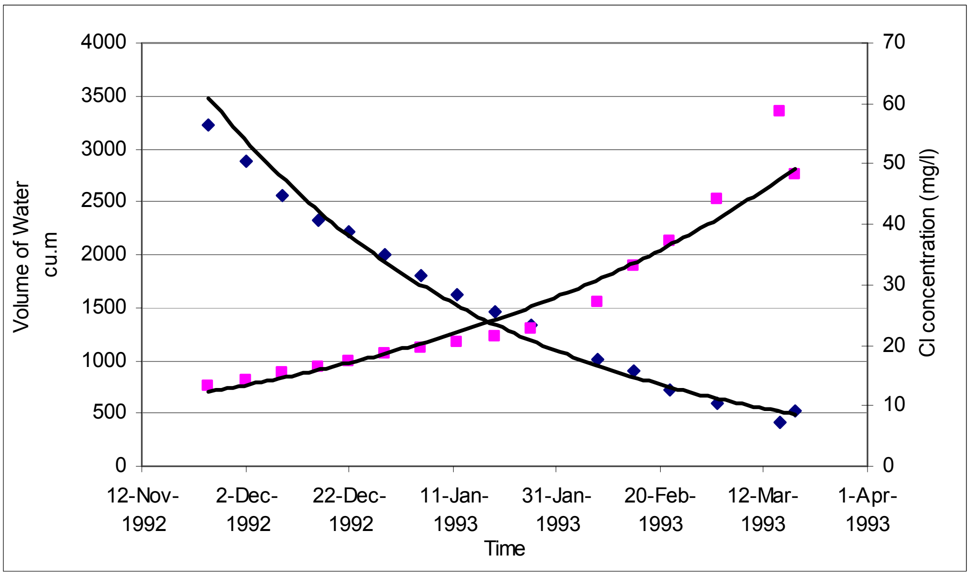

Figure 2.6 Volume of the Singaram tank and chloride concentration as a function of time

2.7.5 Estimating evaporation from recharge structures using stable isotopes ($\delta^{18}O$ and $\delta^{2}H$)

Similar to the chloride mass balance, an isotope mass balance can be written in order to obtain the water budget. The method utilizes the measured isotopic enrichment in a surface water body, as evaporation progresses, to indicate the proportions of water recharged and evaporated respectively. The isotope mass balance for a well-mixed water body can be written as follows:

$$d(\text{Volume}\delta_l)/dt = \text{Inflow}\delta_i - \text{outflow}\delta_o - \text{evaporation}\delta_e$$

with:

d(Volume)/dt = change of volume over time interval dt.
Inflow; Outflow; Evaporation = Inflow, outflow and evaporation from the recharge structure
δ_l ; δ_i ; δ_o ; δ_e = Isotopic composition of the water in the recharge structure, the inflow, the outflow and of the evaporative flux.

If it is assumed, that during a dry spell, when no precipitation and surface flow into and out of the recharge structure occurs, the tank volume variations are caused only by evaporation and recharge, δ_i and δ_o can be neglected. δe is difficult to measure directly but can be estimated, if the water temperature and the atmospheric relative humidity are known. The isotopic composition of the water can be measured directly.

For more details on this method, the reader is referred to the following literature: Stolf, R., Leal, J.M., Fritz, P., Salati, E. (1979): Dincer, T. (1968): Gibson, J.J. (2001):

To apply the method, the following measurements need to be made periodically:

- stage (to be converted into volumes of water);
- isotopic composition of water in the recharge structure;
- water temperature;
- atmospheric relative humidity.

FREQUENCY OF MEASUREMENTS

This method is applicable only if water remains in the recharge tank after rainfall events long enough for evaporation to have a measurable impact on the isotopic composition of the water. Sampling frequencies depend on the duration of water standing in the recharge structure. For a structure holding water for one month, a weekly sampling frequency is recommended. In general, it is good practice to sample on a higher frequency, e.g. twice-weekly but not necessarily analyze all the samples subsequently. The collection method, sample container used etc, should be on the advice of the analysing laboratory and should be recorded.

ENVIRONMENTAL ISOTOPES ($\delta^{18}O$ AND $\delta^{2}H$) AND MAJOR ION CONCENTRATION TO MAP ZONE OF INFLUENCE OF RECHARGE STRUCTURE

Unlike some chemical species, stable isotopes of O and H behave conservatively in groundwater systems, and can therefore be used as tracers. During a dry spell, when no water is added or removed other than by evaporation and recharge, the water becomes increasingly enriched in deuterium and oxygen-18 due to evaporation. This enriched water can be used as a tracer, thus delineating the zone of influence by the recharge structure. Environmental chloride, electrical conductivity (EC) or total dissolved solids (TDS) can be used as a tracer as well, if a sufficient difference in concentration between the reservoir water and groundwater exists. These measurements provide an estimate of the rate of spread of water away from the recharge structure through the aquifer. In addition, it allows the comparison of groundwater composition and reservoir water composition to estimate the origin of water in boreholes.

To apply the method, the following should be measured:

- Chloride, EC or TDS concentration in reservoir water.
- $\delta^{18}O$ and $\delta^{2}H$ concentration in reservoir water.
- Chloride, EC or TDS and $\delta^{18}O$ and $\delta^{2}H$ concentration in observation boreholes and wells close to the recharge structure. Selection of sampling points needs to be based on the hydrogeology of the area and the water level fluctuations.

FREQUENCY OF MEASUREMENTS:

Measurements have to be taken after recharge events, during dry spells. Reservoir water as well as borehole water samples should be taken weekly for at least one month after the recharge structure is filled up and precipitation has ceased.

2.8 ASSESSMENT OF THE IMPACT OF SEDIMENTATION AND BACTERIAL GROWTH ON INFILTRATION

Suspended solids or bacterial growths in the river water may cause clogging by accumulating on the bed of the recharge structure and within the first metres of the underlying aquifer. With the formation of this ‘filter cake’, infiltration into the aquifer will decrease with time. The impact may be significant within a single year or it may be a longer-term decline. To help assess the impact of sediment build-up, measurements should be made of the thickness of recently deposited sediment and the infiltration rates at various times during the monsoon season using an infiltrometer.

2.8.1 Sediment deposition

The build-up of sediments can be assessed through a number of approaches:

- Graduated pegs hammered into the base of the reservoir. This could be done on a grid basis or at strategic locations. It is appreciated that it is likely that cattle etc may disturb these pegs. Measurements of sediment deposition can be made after each major inflow event, assuming water levels decline sufficiently.
- Augering or digging a shallow small diameter hole should enable the depth of newly deposited sediment to be assessed. This can be done at strategic locations within the recharge structure after the water levels have declined. Augering may also be used to examine the depth and nature of the sediments underlying the recharge structure, particularly if this information is not available through the drilling of the piezometers.
- If sediment deposition is very large, it may be appropriate to undertake topographic surveys at the end of each recharge season to assess the change in volume of the recharge structure. This will help to assess the sediment deposition but crucially will be necessary to ensure that the estimate of the volume of water in the reservoir is as accurate as possible.

2.8.2 Infiltration rates

In situ measurements of infiltration rates should be undertaken before and after the monsoon season to establish the influence of the filter cake on infiltration rates. It may also be appropriate to measure infiltration during the monsoon season if the recharge structure fills and empties periodically. The most common method to measure the infiltration rate is by a field test using a ring infiltrometer.

Two concentric steel rings are driven halfway into the bed of the empty reservoir. A measured volume of water is put into the protruding part of the rings and the rate of fall of water level is monitored. This rate of fall will vary at the same location according to the soil moisture. To achieve good measuring results, measurements should be carried out at field capacity, when the soil is saturated. In dry soil, water infiltrates rapidly. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate, which is called the basic infiltration rate.

Several ring infiltrometer tests have to be carried out at different locations in the recharge structure, as soil conditions will vary across the bed.

The following list provides details on the execution of ring infiltrometer tests in the field:

1. The two steel rings are driven halfway into the ground. The sides of the rings should be kept vertical.
2. The volume of the cylinder above the soil has to be measured (diameter, depth). A gauge is fixed to the inner wall so that changes in the water level can be read.
3. A pre-measured volume, about 80-90 percent of the infiltrometer capacity, is poured quickly into the inner ring. The outer ring needs to be kept at approximately the same water depth. The water within the outer ring prevents a lateral spread of water from the inner ring during infiltration. When the water surface is still, an initial reading should be taken.
4. Measurements are recorded periodically at intervals of ca. 5 to 10 minutes at the start of the test, expanding to 30 to 60 minute intervals after 3 or 4 readings, depending on how rapidly the water level drops in the inner ring. The water level in the outer ring has to be kept similar to that in the inner ring during the test. When the water level has dropped about one-half of the depth of the cylinder, water has to be added to the inner and outer ring to bring the water level back to approximately the original level at the start of the test. The water level before and after filling is recorded.
5. Measurements should be continued until the drop in water level remains constant over the same time interval.

Figure 2.7 provides an example of a field spreadsheet used to measure infiltration with a ring infiltrometer, and the resultant data plots. In this example, it takes about 5 hours for water to infiltrate at a steady rate; the basic infiltration rate.

AGRAR field sheet

Recharge tank
Location in tank
Date

Time Readings		Gauge Readings	
Clock	Cumulative	Gauge	Cumulative
hrs	min	mm	mm
900	0	189	0
901	1	185	4
902	2	184	5
904	4	183	6
906	6	182	7
910	10	181	8
920	20	179	10
930	30	178	11
1000	60	175	14
1100	120	171	18
1200	180	168	21
1300	240	165	24
1500	360	160	29
1700	480	155	34
1900	600	151	38
100	960	139	50
400	1140	133	56
700	1320	128	61
940	1480	124	65

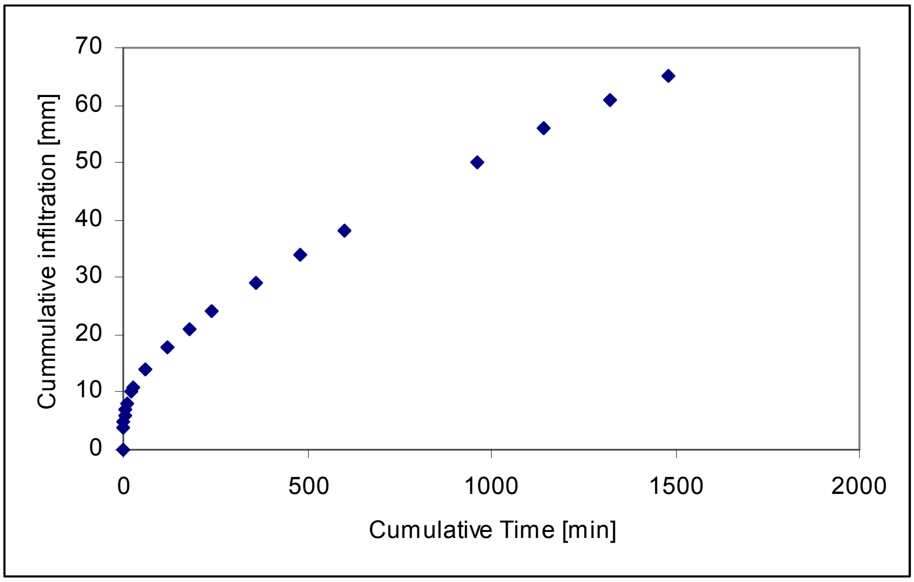

Figure 2.7 Example for a field record sheet used for infiltrometers tests and plot of data

2.9 METEOROLOGICAL DATA

2.9.1 Installation and monitoring of automatic weather station and evaporation pans

The primary approach to be taken to estimate evaporation of water from within the recharge structure is to measure the meteorological variables which can then be used to calculate evaporation using an empirical equation e.g. Penman Equation. In addition, direct measurements of evaporation using a pan evaporimeter should be undertaken. However, given that this method can be less accurate, this should only be used as a back-up.

The variables that need to be measured to calculate evaporation using the Penman Equation are: air temperature, air humidity, wind speed and net radiation. Net radiation is the difference between incoming and outgoing short-wave and long-wave radiation. Net radiation can be estimated using a solarimeter, which measures of incoming shortwave radiation, and standard coefficients for the ground surface type.

Automatic weather stations (AWS) record all the above variables electronically and require operators to visit the site to download data on, at most, a weekly basis. Manually operated stations would require operators to visit the site each day. In this case, instruments should be in place that would enable variables to be averaged over the day: air temperature being an average of measurements from minimum and maximum thermometers; wind speed measured by anemometers with built-in counters; humidity from wet and dry bulb thermometers that can average over a day; net radiation calculated from solar radiation measurements, e.g. a sunshine recorder with a daily chart. It is probable that the manually operated weather station will provide evaporation of sufficient accuracy, however, the extra cost of the AWS may be justified if the staffing of the manually operated station on a daily basis is problematic.

Guidance on positioning and installation of weather stations and evaporation pans can be found in standard hydrological textbooks such as ‘Field Hydrology in Tropical Countries’ (Gunston, 1998) and advice should be taken from local experts and the equipment supplier. Ideally both should be located on a platform in the middle of the water within the recharge structure. This is unlikely to be practical due to lack of access and security. The dominant variable in the calculation of evaporation from open water is net radiation. Incoming radiation will not vary significantly within kilometres from the structure so in this respect the location of the weather station is not crucial. However, long-wave radiation emitted from soils or vegetation and shortwave reflected radiation will be different to that from the water surface, although no references have been found in which the significance of this difference is assessed. If solar radiation as well as net radiation is measured then calculations of net radiation from the former can act as a check. One means to test the representativeness of the evaporation calculated at distance, if feasible, would be to move the weather station to within the recharge structure for a short period (a few days) during a time of relatively stable weather conditions and compare evaporation estimates.

2.9.2 Installation and monitoring of rainfall gauges

NON-RECORDING RAIN GAUGE

Non-recording rain gauges are read manually and provide a record of total precipitation for the period between readings, e.g. daily. These gauges provide an indication of local rainfall distribution patterns in the catchment.

RECORDING RAIN GAUGES

To record the temporal distribution of precipitation recording rain gauges have to be used. These provide in addition to the total amount of rainfall, the intensity and precise timing of rainfall events. Various designs exist from older mechanical rainfall recorders to digital gauges.

INSTALLATION

Rain gauges should be placed as close to the ground as possible to avoid disturbance through wind. They should be positioned in the open, away from trees and buildings and should be clear of bushes and shrubs, which may act as windbreaks.

The number of rain gauges to be installed in the study area depends on the spatial variability of rainfall. In general the larger the catchment and the more mountainous the area, the more gauges are needed. A minimum of 5 rain gauges should be installed in each study area.

MONITORING

If non-recording rain gauges are used to determine the local rainfall distribution patterns, then daily recording (every 24 hrs, e.g. always at 09:00) is necessary during the monsoon period. Obviously, during dry periods, recording is not necessary, however the start and end day of dry periods have to be recorded. At least one recording rain gauge is needed in each field area; which might be installed as part of the weather station. **Table 2.5** provides an example for a field record sheet. Measurements were taken using a measuring cylinder calibrated in mm depth of rainfall.

2.10 AQUIFER TESTING

The purpose of aquifer testing is to quantify the parameters that determine the groundwater flow rate and storage of the aquifer. This will help develop the conceptual model of the aquifer and will provide input the groundwater modelling exercise. In all three case study areas the hydrogeology is relatively heterogeneous and anisotropic and therefore, especially given the limited resources available, the aquifer testing programme will not allow the aquifer parameters to be fully understood.

Table 2.5 Example of a field data sheet to record rainfall data

Station name	
Name of recorder	

Date	Time 24 hour	Rainfall mm	Comments
02-Jul-03	09:00	2.00	
03-Jul-03	09:00	Trace	
04-Jul-03	09:15	1.70	
05-Jul-03	09:00	3.30	
06-Jul-03	09:05	7.10	
06-Jul-03	18:00	7.00	
07-Jul-03	09:10	-	
08-Jul-03	09:00	-	
08-Jul-03	18:00	8.10	
09-Jul-03	09:00	10.60	
09-Jul-03	18:15	8.00	
10-Jul-03	09:15	0.50	
11-Jul-03	09:00	-	

Aquifer tests, in this context, refer to pumping and slug or bail-down tests. Slug tests involve the removal or addition of a known (and relatively small) volume of water from or to a borehole. Pumping tests involve pumping of the borehole at a fixed rate over a longer period. Pumping tests impose a greater stress of longer duration on the aquifer than slug tests, and thus provide estimates of aquifer properties over a larger region around the monitoring borehole. However, pumping tests require more resources, both in terms of cost of installation and personnel time for the monitoring.

It is recommended that a pumping test be carried on at least one of the newly drilled boreholes at the main recharge structure site. The other boreholes will act as observation points. Slug tests can be carried out on three or four of the newly drilled boreholes, including the borehole on which the pumping test has been carried out (after it has fully recovered). The pumping-test borehole should have a diameter large enough for the submersible pump. The borehole on which the pumping test is carried out should be one that penetrates the full depth of the shallow aquifer but does not carry-on too far into the deep aquifer. The timing of the pumping test(s) will be restricted to periods when the saturated thickness of the shallow aquifer is sufficiently great. This may only be during and in the weeks following the monsoon. However, this will be a crucial period for monitoring groundwater levels to assess the impact of the recharge structure.

Table 2.6 Example of a data sheet used for pumping test data recording

Name of borehole	
Location	
Date	
Borehole radius [mm]	
Discharge rate Q (m3/d)	
Rest water level at beginning of test	
Available Drawdown	
Pumping time (min)	

Pumping		Recovery	
Time (min)	Water level (m)	Time (min)	Water level [m]
1	22	1	52.32
1.5	22.56	1.5	51.79
2	22.66	2	51.79
2.5	22.68	2.5	51.78
3	22.73	3	51.78
4	22.77	4	51.78
5	22.86	5	51.78
6	22.9	6	51.78
7	23	7	51.78
8	23.1	8	51.78
9	23.17	9	51.78
10	23.23	10	51.78
12	23.33	12	51.78
15	23.78	15	51.75
20	24.09	20	51.68
25	24.53	25	51.59
30	24.88	30	51.51
40	25.59	40	51.34
50	26.3	50	51.17
60	27	60	51
70	27.7	70	50.84
80	28.26	80	50.67
90	29.06	90	50.5
100	29.41	100	50.35
120	30.56	120	50.06
150	32	150	49.64
180	33.23	180	49.24
210	34.56	210	48.96
240	35.78	240	48.42
300	38	300	47.39
360	39	360	46.36
420	40	420	45.65
480	44.6	480	44.69
540	48.94	540	43.7
600	51.7	600	42.68
660	52.3	660	41.44
720	53.08	720	40.47

2.10.1 Pumping test procedure

A pumping test is performed on an abstraction well and usually one or more observation boreholes. It usually includes a multiple discharge test (step test), a constant discharge test and a recovery test. N.B. the pumped water should be discharged well away from observation points to avoid recirculation. Further information on drilling, testing and analysing results can be found in standard texts, including Driscoll, F.G. (1986).

MULTIPLE-RATE DISCHARGE TEST

The multiple-rate discharge test or step test is used to determine the hydraulic efficiency of the borehole at different pumping rates and to recommend a suitable pumping rate for the constant pumping test. Thereby, the drawdown in a borehole is monitored while the discharge is increased in steps. Each step is usually carried out for long enough for the drawdown to stabilize, usually no less than 60 minutes. This will give an estimate of the maximum yield the borehole can sustain. This discharge rate will then be used for the constant-rate pumping test.

CONSTANT-RATE DISCHARGE TEST

The constant-rate discharge test involves monitoring the drawdown in a borehole and possibly in observation boreholes while the discharge is kept constant. The duration of the test depends on the level of information and reliability required and the pumping rate applied. In general, the drawdown should be monitored until water levels have reached equilibrium. This might take several days.

RECOVERY TEST

Once abstraction ceases, the recovery of the water level is monitored. The duration of a recovery test depends on the ability of the aquifer to recover, however the following guidelines help with the decision for how long the recovery test should be continued for:

- monitoring until the water level recovers to its pre-pumping level; or
- monitoring until the water level recovers to less than 5% of the total drawdown experience during the constant rate test; or
- three readings in succession are identical; or
- the test is carried out for at least half the length of the constant-rate discharge test.

Various methods exist to analyse pumping test data, depending on the conditions of the aquifer, e.g. confined, unconfined. Textbooks on pumping test analyses have been developed by various authors of which a selection is provided in the list of references. The reader is referred to this literature for more details on conducting and analysing pumping tests. **Table 2.6** provides an example of a data field sheet used in pumping tests.

2.10.2 Slug test/Bail-down test

Slug or bail-down tests can be performed in small-diameter monitoring wells. A known volume of water is abstracted or added rapidly from or to a well. The subsequent falling or rising of the water level in the well is recorded until its return to the original static level. Adding or removing a volume of water or solid into the well can achieve the instantaneous change in head. A slug test provides a very local estimate of hydraulic conductivity in the near vicinity of the monitoring well. If the aquifer material is of high conductivity, these tests can recover within minutes and readings have to be taken within a short period of time. It might be necessary to use automatic water level recorders. It is advisable to repeat slug or bail-down tests 2 or 3 times with different volumes of water being added or removed.

There are, as for pumping tests, several analytical methods for the analysis of slug tests. The reader is referred to the specific literature for details, of which some examples are given in the list of references.

3 Socio-economic evaluation

The purpose of this part of the document is to elaborate on issues and methods of relevance to the socio-economic research component of AGRAR. It is intended as an initial tool, to serve as a basis for the development of a consistent methodology that can be applied at each of the research sites.

It is organized as follows: Section 3.1 contains a brief recap of the overall research objectives and goals of the project. Section 3.2 reviews the literature on economic evaluation of artificial recharge (and more generally, watershed development), and identifies the main issues that emerge out of this literature. The central research themes to be explored are set out in section 3.3, and indicative question sets are developed for each theme. Section 3.3 also identifies some of the tools that can be used to investigate each of the research themes. Finally, section 3.4 lists some examples of studies that have made use of qualitative and participatory research methods.

3.1 RECAP OF OBJECTIVES

The social science component of the AGRAR project aims at an improved understanding of the potential impact of artificial recharge interventions in different socio-economic settings. This is important because there is a growing concern that artificial recharge is being viewed as a panacea to groundwater depletion in developing countries, without any systematic evaluation of its effectiveness in different environments. The purpose of the study is to increase the capacity of water sector institutions to make informed judgements on the contribution artificial recharge activities make to sustaining rural water supplies and livelihoods, in the wider context of water resource management.

The objectives for the socio-economic component of the project are, specifically, to:

- Study the operational and institutional issues at each site.
- Assess the impacts of artificial recharge interventions on livelihoods, both positive and negative.
- Report the results of the studies at each research site.

An initial checklist of livelihood impacts and indicators was included in the review report of the project, and this was further elaborated in the inception report (see **Table 3.1**). At the Pune meeting in May 2003, another checklist was developed, which listed the main topics to be investigated in order to query water use in the case study sites (see Box). This document builds upon the Pune discussions. It is intended to highlight some of the important issues and methodological concepts of relevance for the socio-economic research, in order to serve as a starting point for the partners to develop their own site-specific research plans.

Table 3.1 Livelihoods impacts and indicators from AGRAR project inception report (Gale et al, 2002)

KEY 'LIVELIHOODS IMPACT' ISSUES	EXAMPLE TOOLS AND INDICATORS
CHANGES IN ASSET BASE – AVAILABILITY; ACCESS; USE OF WATER RESOURCES To explore whether, and how, AR activities within the watershed have changed (positively or negatively) the water resources asset base of different groups:	TOOLS Based on a combination of village/group meetings, followed up by key informant interviews (project staff; households within and outside zones of AR influence). Mix of qualitative (e.g. water point mapping) and quantitative (e.g. water level calendars) *Example indicators*
• Availability of groundwater in wells and boreholes (irrigation and drinking); changes in numbers of recharged wells/boreholes and those defunct; changes across seasons and between years	• Reported/recorded changes in water levels, well/borehole numbers; reliability; quality
• Access to groundwater: changes in patterns of access to groundwater from wells and boreholes (private and communal); change in numbers of wells and boreholes; changes to access rights.	• Reported/recorded changes in patterns of groundwater abstraction; collection and queuing times; pumping periods; views on access rights.
• Use of groundwater: changes in patterns of domestic and productive uses of groundwater between groups, areas and over time.	• Reported/recorded changes in 'adequacy' of supply and end uses – domestic and production
• AR-induced changes in surface water flows: upstream-downstream externalities; incidence and magnitude of flooding.	• Reported/recorded changes in levels, seasonality, flooding events and storm protection
CHANGES IN LIVELIHOOD STRATEGIES To explore whether, and how, changes in the asset base of households resulting from AR activities have affected the livelihood strategies of different groups – tracing through impacts of AR:	TOOLS Based on a combination of village/group meetings, followed up by key informant interviews and household discussions (using e.g. seasonal and activity calendars) within and outside zones of AR influence. Mix of qualitative (views; perceptions) and quantitative (e.g. farm budget analysis). *Example indicators*
• Crops: changes in crop production and sources/levels of income	• Reported/recorded changes in cropping patterns, cropping intensity, yields, irrigated vs. rainfed production
• Livestock: changes in livestock production	• Reported/recorded changes in livestock production – cattle rearing, milk production
• Common pool resources (CPRs): changes in access to CPRs; changes in 'rights'	• Reported/recorded changes in use/dependency on CPRs (e.g. grazing, firewood); views on access rights
• Labouring – farm economy: changes in patterns and level of agricultural wage labour	• Reported/recorded changes in levels, types and patterns of labour income. Patterns of short and longer term migration
• Labouring – non-farm economy: changes in patterns and level of no-agricultural labouring	• Reported/recorded changes in levels, types and patterns of labour income. Patterns of short and

• Investment: changes in long term investment in assets	longer term migration • Reported/recorded changes in investment strategy: types of asset invested in (land and irrigation infrastructure? Non-farm economy? Loan/savings ratio?
CHANGES IN LIVELIHOOD OUTCOMES AND VULNERABILITY To explore whether, and how, changes in the asset base and livelihood strategies of households resulting from AR activities have affected the livelihood outcomes of different groups – tracing through impacts of AR into outcomes: • Food security: changes in food security status of household across seasons; between good and bad years • Water security: changes in water security status of households across seasons, between good and bad years • Other livelihood priorities – locally defined – that help define poverty, or the lack of it, including asset status of households; security of income; sense of control, inclusion, state of dependence	TOOLS: Based on a combination of village/group meetings, followed up by key informant interviews and household discussions. Use of 'secondary' outcome indicators *Example indicators:* • Food stores across year; distress sales of assets; reliance on remittances and food for work activities, number of months of own production; no. of meals/day • Reliance on water tankering and poorer quality (and more distant) sources to meet domestic needs • Changes in presence/absence of consumer durables e.g. bicycle, radio, TV; in e.g. agric equipment; in housing condition • Area/type of land owned/rented/leased? • Changes in savings/loan status; remittances • School attendance and payment; access to and payment for health services; group membership and participation

Checklist developed by AGRAR team at Pune meeting, 18 May 2003

- ❖ Points bulleted thus also apply to other sections.

I. Water for Domestic Use

- ❖ Sources: What types of sources are used (both surface water and groundwater); alternatives to groundwater; water markets
- ❖ Quantity: Is it sufficient for basic needs?
- ❖ Seasonality issues and availability across "good" and "bad" years
- ❖ Quality of drinking water and health implications
- ❖ Distribution of drinking water within the community: availability, access, and use patterns across different socio-economic groups
- ❖ Who collects drinking water and the gender perspective
- ❖ Direct and indirect costs of obtaining drinking water; who pays?

II. Water for Irrigation

- Area under cultivation and crops grown; crop-wise and season-wise demand for water (develop irrigation calendars with focus groups)
- Crop yields per cubic metre and value of production
- Land values (possibly illustrated through a map)
- Irrigation methods, technologies and efficiency – abstraction, distribution and application
- Dual purpose crops, e.g. crops that also provide fodder for livestock
- Abstraction volumes (volumetric estimates if available *or* estimate by crop-wise demand *or* estimate by pumping hours)
- Vulnerability of production to variability in water supply
- ❖ Contribution of agriculture to household income (cash, non-cash) across seasons and across "good" and "bad" years

III. Water for Livestock

- Types, numbers and water requirement of livestock
- Distribution of livestock across different socio-economic groups
- Contribution of livestock to household income (how does this differ by type of livestock? What is the contribution to different categories of households?) across seasons and in "good" and "bad" years
- Fodder sources and markets
- Any joint use of sources by humans and livestock?

IV. Water for Other Economic Activities

- Query economic activities by water use and the dependency of each activity on water (in terms of volume used and the reliability of water supply)
- Pollution issues?
- Contribution of other economic activities to household income

In terms of the deliverables of the project, a progress report on each site is to be prepared by October 2003, in preparation for the AGRAR meeting in November 2003. The steps towards the progress report are as follows: the partners will check secondary data sources and determine what data needs to be collected by the end of August. They will develop a task list, outline of research methodology, and a timetable, and send the same to BGS by the end of September. Following a process of circulation and revision, the progress report will be completed in October.

3.2 LESSONS FROM THE LITERATURE

3.2.1 Evaluating watershed development projects

We have not been able to identify any studies that deal with the socio-economic evaluation of artificial recharge structures in particular. However, since artificial recharge typically is one of a menu of activities comprising watershed development in arid and semi-arid regions, it is useful to look at the literature around the evaluation of watershed development projects.

Observers have made the point that, while a vast literature exists on watershed projects in developing countries, it is mainly confined to anecdotal evidence, and systematic evaluations of such projects are rare (Kerr, 2002). This is perhaps not surprising, given the complexity of watershed development projects, the numerous objectives they aim to simultaneously accomplish (for instance, increasing agricultural productivity, reducing soil erosion, conserving natural vegetation, and controlling run-off), and the multiplicity of approaches that would have to be employed for a truly meaningful evaluation exercise. In addition, some project benefits – such as the control of soil erosion, for example – may only be realised over long periods of time, and impacts may not be immediately perceptible. There is also the issue of spatial externalities. Watershed projects typically impact upstream and downstream villages in very different ways. In the absence of cooperative agreements between the two, one group may well turn out to lose heavily from the project (Kerr and Chung, 2001). In such cases, it is difficult to assess whether the overall impact of the project is positive or negative.

3.2.2 Multiple objectives

Several of the problems mentioned above with regard to watershed projects apply to the evaluation of artificial recharge structures as well. Depending on local user needs and hydrogeological conditions, it is entirely possible that artificial recharge activities accomplish very different objectives in different areas. In one case, their primary impact may be to directly augment the supply of groundwater for irrigation and drinking, in another it may be to conserve soil moisture in order to improve agricultural productivity, and in yet another it may be to increase base flow to rivers, leading to greater availability of surface water for irrigation. As a result, a detailed and site-specific understanding of both physical and socio-economic conditions is necessary before the impact of artificial recharge activities can be evaluated.

3.2.3 Spatial externalities

With an increase in the availability of groundwater, there is the potential for higher abstraction by upstream users, by way of growing more crops, switching to water-intensive crops like sugarcane, or using more water-intensive irrigation technologies such as flood irrigation instead of drip irrigation. This can lead to negative consequences for downstream livelihoods. On the other hand, under certain conditions the main benefit of artificial recharge activities upstream may be to increase base flow to rivers, and hence the supply of surface water for downstream users.

3.2.4 Timing

As in the case of watershed projects, some of the benefits of artificial recharge activities may either be difficult to perceive, or may take a long time to be realised. An increase in soil moisture content, for instance, does not instantly imply an increase in agricultural production, but may make itself felt in terms of higher yields over a long period of time. For purposes of evaluation, this implies that the time frame used matters a great deal; *when* artificial recharge structures are studied may significantly influence our understanding of their benefits.

3.2.5 Comparison and benchmarking

In addition to selecting an appropriate time frame, a systematic economic evaluation of artificial recharge involves careful sample selection. Two groups are necessary for comparison – a treatment group (with artificial recharge) and a control group (without artificial recharge) – so that we can compare the effects of artificial recharge with what would have happened had it *not* taken place. Ideally, this would be in the nature of a before/after comparison, i.e. the same villages would be studied both before and after the intervention, so that the "before" picture could serve as a baseline against which to monitor impacts.

The problem with this approach, of course, is that it requires data from a previous point of time, which is usually not available. The other option is to do a with/without comparison, i.e. compare villages that have artificial recharge structures with others that do not, but are as similar as possible in all other respects. In this case, the latter group of villages serves as the baseline.

In the case of a with/without comparison, it is important for purposes of statistical evaluation that all other possible sources of difference in outcomes between the two groups of villages are accounted for (e.g. do some villages have better access to infrastructure? Are there differences in natural soil fertility? Have other rural development programmes operated in some villages but not others in the past?). In addition, in order to evaluate artificial recharge, we would need to isolate its impact from the impacts of other watershed development interventions. However, this is very difficult to do, since artificial recharge is rarely conducted in isolation; it is typically one of several activities that are carried out under the broad umbrella of watershed development.

3.2.6 Endogenous choice of location

Finally, there is the endogeneity problem. A village may be selected for artificial recharge (or, more generally, watershed development) because it is particularly backward and poor. Even with artificial recharge, it may perform much worse than many other villages in the sample that have not received the intervention. However, it would be misleading to conclude from this evidence that artificial recharge does not work, since the true test would be to see what would have happened to the village in the *absence* of the intervention. To take another example, a village may be selected for artificial recharge because it possesses strong community institutions. Such a village may perform well post-artificial recharge, but it is very likely that it would have performed well anyway, since the presence of good local institutions might have facilitated community management of natural resources. In this case, not taking into account the intrinsic characteristics of the community will overstate the effectiveness of artificial recharge.

3.2.7 A way forward

The preceding discussion makes it clear that an evaluation of artificial recharge activities is fraught with pitfalls. As a result, it was decided in the 2003 Pune meeting that the way forward for the socio-economic component of the AGRAR project would be to examine, on the basis of the case study sites, the general role played by groundwater in rural economies and in sustaining rural livelihoods, rather than focus narrowly on an evaluation of particular artificial recharge structures. The technical side of the AGRAR project is exploring how artificial recharge activities impact the *supply* of groundwater under differing physical and hydrogeological conditions. The intent is to combine this information with a broad understanding of the *demand* for groundwater and the effects of groundwater depletion in different socio-economic environments, in order to lead to a clearer understanding of the potential livelihood impacts of artificial recharge.

3.3 RESEARCH APPROACH AND TOPICS

3.3.1 Framing the research question

Based on the above discussion, the central research question for the socio-economic component of the AGRAR study can be framed as follows:

> *What are the linkages between the livelihood strategies of rural households and the availability of and access to groundwater?*

An in-depth examination of these linkages will throw light on the issue of how rural communities, and different households within them, might benefit from groundwater supply augmentation through artificial recharge activities.

Apart from livelihoods issues, however, there are other factors that are instrumental in determining the overall impacts of artificial recharge interventions, and whether or not such impacts can be sustained over time. These factors include the institutional and policy framework, and the operational, management and implementation issues relating to artificial recharge structures. Finally, the resource context needs to be properly understood in order to appreciate the role that artificial recharge can potentially play.

3.3.2 Methodological mix

A range of qualitative, quantitative and participatory methods will be required to carry out research on water and livelihoods linkages. Quantitative methods are typically in the form of sample surveys using a structured questionnaire, and are useful for collecting detailed data on tangible and measurable topics, such as agricultural production, numbers of livestock, time required for water collection, etc. The structured questionnaire format is much less useful when it comes to investigating complex or sensitive issues, or probing perceptions, or reasons for peoples' behaviour. Qualitative and/or participatory methods are more suited to investigating issues of this kind. They are also particularly useful in the initial stages of research, and should ideally precede and influence the development of the structured questionnaire. This is especially important in a study of the present type, where there is a need for a relatively open-ended enquiry process that does not prejudge people's priorities or the expected livelihood outcomes of artificial recharge interventions.

The most commonly used qualitative research methods are qualitative interviews (which can be in the form of individual interviews, key informant interviews, focus groups, or community-level meetings) and case studies (of individuals, households, communities, institutions or markets). Qualitative approaches may (e.g. community meetings) or may not (e.g. key informant interviews) be participatory.

A few tips … Key Informants

- Try to give key informants advance notice of your visit, and of the issues you will want to discuss.
- Arrange to meet key informants through people they know: their superiors (if in an organisation) or people who work with them (for communities),
- Prepare carefully. Have a good idea of the types of things they need to know, and background information to help you ask relevant questions.

Choose a variety of key informants, Include women and people with different social/technical backgrounds.

Source: SC UK (2000). The household economy approach: A resource manual for practitioners

Participatory research techniques, often called Participatory Learning and Action (PLA), Participatory Rural Appraisal (PRA), or Rapid Rural Appraisal (RRA) methods, consist of a wide variety of techniques suitable for a rapid exploration of livelihoods issues. Some of these techniques are enumerated in **Table 3.2**.

In the following sections, we describe each of the issues to be researched in more detail, and briefly describe some of the methodological tools that can be used to analyse how they play out in practice in the case study sites.

Table 3.2 A summary of participatory research tools

Types of tools	Definition	Goal
Review of secondary data	Reviewing data from both formal (such as published studies) and informal sources	To review information that already exists for planning further research
Semi-structured interviewing	Interviews (without visual or other tools) using open-ended questions, usually on a specific topic	To gather specific information on an issue, or verify previous information obtained in a group, with individuals and specific households
Direct observation		Observation of behaviour, events and indicators (such as those of wealth)
Group interviews		To cross-check and elaborate on information obtained in one-to-one sessions, and for discussion of sensitive issues
Analytical tools and games, e.g. ranking and scoring games		Often complement group interview sessions by eliciting complex information in a unique manner. For example, ranking and scoring games using pair-wise comparisons can elicit preferences regarding crop species
Participatory mapping (village maps, family resource maps, social maps)	Visual tool that uses spatial analysis to gather information about a range of issues related to village life	To collect information on village life and visually record it with the participation of villagers. Types of information that can be mapped are village landmarks and infrastructures, social structures, settlement patterns, markets, relations with other villages, and dwelling places of village authorities
Transect walk	A walk through the community with village guides to directly observe the village environment. The information is then recorded in a diagram or map of main land use zones in the community	To collect information through observation of the village environment, including outer territorial limits. Helps to document and compare features, resources, uses and problems of different zones
Historical profile	Dated list of key events in the history of the community. The events are then recorded on a map or matrix	To better understand local and national events that villagers consider as important
Venn diagram	Diagram that illustrates social relationships in the village, particularly with regard to internal community organization and the village's relationships with the larger community	Often used to depict community relationships and to identify the key actors in decision-making on a particular topic (such as water supply or education). Information can be collected on the role of organizations, the role of external forces, community leaders, decision-making processes, and relationships with other villages
Seasonal calendars	Diagrams that focus on seasonal issues (e.g. significant events, income patterns, labour constraints, consumption patterns, agriculture patterns, incidence of disease, and migration) and how things change throughout the year	To better understand how village conditions (labour, water availability, food security, agriculture) change during different times of the year, while avoiding a "seasonality bias" related to the time of the year when the team conducts its study. Can help to plan interventions during appropriate weeks or months of the year

Sources: The Enterprise Development Impact Assessment Information Service (EDIAIS) website (http://www.enterprise-impact.org.uk/informationresources/toolbox.shtml).

The Food Aid Management website (http://www.foodaidmanagement.org/worddocs/foodsecurity/ARCCRS/3brrapra3.doc).

3.3.3 Institutional and operational issues

Specific programmes such as artificial recharge are not carried out in isolation, but are part of a broader institutional and policy framework. Progressive macro-level policies can create an enabling environment in which poor people can gain access to resources and become less vulnerable to external shocks over time. At the other extreme, policies may be designed centrally without due consideration of local needs and conditions, and institutions may be subverted by local elites. What impact, if any, a particular programme has depends very much on the policy and institutional environment in which it is situated.

The institutional dimensions of artificial recharge in India are located within the wider context of watershed programmes, since activities aimed at enhancing recharge typically form part of a broader set of activities aimed at developing or rehabilitating watersheds. Institutional approaches to watershed development – and therefore artificial recharge – have changed markedly in recent decades. In particular, there has been a major shift towards more participatory, bottom-up approaches involving, at least in theory, the involvement of local communities in both the planning and implementation (including financing) of interventions.

The operational issues regarding artificial recharge activities relate to how such activities are designed, implemented, monitored and maintained. This is valuable information, since (a) it would indicate whether or not stated policies on participatory development actually translate into participation of local communities on the ground, (b) whether and how local physical, environmental and socio-economic conditions are taken into account when planning and implementing artificial recharge, and (c) whether or not vulnerable and disadvantaged groups have a voice, and hence are likely to benefit from these activities.

RESEARCH QUESTIONS

Within the AGRAR project, developments in the policy framework at the national and sub-national level have already been reviewed in Gale et al (2002). For the case studies, therefore, it might be appropriate to focus more closely on the institutional and operational issues at the local level. The following list of questions represents a starting point to think about the kinds of issues that are relevant at the local/community level[1]:

- How does stated water policy translate into practice on the ground?
- What are the roles and responsibilities of different organisations (both formal and informal) involved in the local watershed programme, and in artificial recharge in particular? How do they relate and interact with one another?
- What is the capacity (organisational, technical) of decentralised decision-making bodies to implement policy?
- What are the main social groups in the community, and how are they represented in the local organisations? What conclusions can be drawn about participation of vulnerable groups such as the poor and landless, lower castes and women?
- What are the implications of policies for different groups: who wins and who loses under current arrangements?
- How are siting and design/technology decisions made within the watershed for artificial recharge activities?
- How are the structures financed? Who pays and how are contributions decided?

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[1] All question lists compiled from inception report, Nicol (2003) and Nicol and Slaymaker (2003)

- Who is responsible for repair and maintenance of the structures?
- Are there any targets or guidelines for the inclusion of poorer communities and of women in the decision-making processes? Are they followed?
- What are the views of different groups (e.g. large, medium and marginal landowners, the landless) regarding the priorities in watershed development and artificial recharge?
- Is the potential for upstream-downstream effects factored into decision-making? Are views canvassed from the wider watershed on artificial recharge interventions?

METHODS

The following is an illustrative (not exhaustive!) list of methods that can be used to research the institutional and management issues:

- Information regarding the institutional and operational issues surrounding artificial recharge activities can be obtained through a mix of community meetings and key informant interviews with members of the community, local government officials and NGO staff. Information thus obtained can be used to do an institutional mapping and stakeholder analysis.
- Focus groups with participants from particular social and economic categories of the village population can be done to determine whether stated inclusion and participation goals in artificial recharge activities are actually implemented, and how such activities affect the different groups.
- Members of different socio-economic groups can be asked to rank preferences for watershed development and artificial recharge, in order to find out whether the perceptions of priorities within the village community differ.
- Data on attendance and participation at meetings, if available, can provide useful information on how inclusive the decision-making process is.

For some more examples, see **Table 3.3** below, which is reproduced from the inception report.

Table 3.3 Institutional and operational issues and methods of analysis

KEY OPERATIONAL AND INSTITUTIONAL ISSUES	EXAMPLE TOOLS AND INDICATORS
ACTORS AND ORGANISATIONS	
• How do AR activities 'fit' organisationally within the broader context of watershed development locally?	• Institutional mapping based on key informant interviews
• What are the roles, responsibilities and accountabilities of different organisations – formal and informal - involved in the local watershed programme, and in AR in particular? How do they relate and interact with one another?	• Institutional mapping and stakeholder analysis based on key informant interviews/group meetings
• What is the membership of such organisations? What conclusions can be drawn about participation – different interest and wealth groups, women?	• Village/group meetings and key informant interviews (local project staff; government officials; households) around semi-structured questionnaires; analysis of meeting attendance, decision-making, participation (different wealth groups; women)
• Who is involved in the targeting (e.g. site selection), design (e.g. technology choice) and implementation (construction and maintenance) of AR activities?	
PROCESSES	
• How are priorities established, both between AR and other watershed activities, and within AR (e.g. between different AR interventions); sequencing of activities	• Key informant interviews; timelines; actor network analysis; priority/objective ranking
• Are priorities shared? What are the views of different groups (e.g. large, medium and marginal land owners; the landless)	• Group meetings and key informant interviews; questionnaires; preference ranking
• How is 'community mobilisation' initiated and managed? Are targets/guidelines set for involvement of poorer communities and households? Are they followed?	• Group meetings and key informant interviews; timelines; reporting/recording of meeting attendance and participation
• How are siting decisions made within the watershed for AR activities?	• Group meetings and key informant interviews
• How is construction and financing of structures dealt with?	• Group meetings and key informant interviews; reporting/recording of payments, loans etc
• Is the potential for upstream-downstream interference factored into decision-making? Are views canvassed from within the wider watershed on AR interventions?	• Village meetings; key informant interviews; transect walks

3.3.4 The resource context

The resource context needs to be studied in depth in order to understand the availability of groundwater for the community, and how it varies across seasons in a year and across "good" and "bad" years. The resource context should also provide us with information on the effective access rules to different sources of water, since it is not the physical availability of water, but the rules and limits to accessing it, which is often the constraining factor for under-privileged groups within communities.

RESEARCH QUESTIONS

- What are the main types of water sources available for use by the community?
- What are the key determinants of water availability from each source? Is it prone to seasonal influences?
- What are the key ownership types within the community of water sources (private/common/group etc)?
- What social structures, if any, surround the use of each type of source?
- What rules govern access and usage? Is there any special provision for bad years (drought)?
- What are the key factors affecting quantities of water accessed by different households (e.g. labour availability, water tariff/cost, social exclusion, storage facilities)?
- Have there been any changes in the availability of groundwater in wells and boreholes since the introduction of artificial recharge?
- Have there been any changes in the number of wells and boreholes influenced by the recharge structures?

METHODS

- Key informant and community interviews can be used to get a broad initial understanding of the main water sources and water uses in the area.
- Maps of water points can be constructed, based on information gathered through transect walks.
- In the course of household interviews, water source calendars can be filled out in order to understand seasonality issues associated with water availability, access and use.
- Interviews can be conducted with users at water points, to get information about the history of particular water sources, problems associated with them, and changes observed in the availability of water.
- Ranking or scoring games can be used to elicit information on how households obtain water when one or more of the usual sources fail, and the preferences associated with using alternative sources.
- Reported or recorded information should be obtained on change in water levels; well and borehole numbers; reliability of water sources; collection and queuing times; pumping periods, etc.

3.3.5 Water and livelihoods

The May 2003 AGRAR meeting in Pune led to the formulation of a checklist (Box 1), to identify the main issues that should be explored in the research on linkages between water and livelihood strategies. It was decided that the research would focus on the four main categories of water use: drinking water and domestic use, irrigation, water for livestock, and water for other productive uses.

RESEARCH QUESTIONS

A few key points need to be kept in mind when carrying out this research:

- One of the core principles of the Sustainable Livelihoods (SL) framework[2] is the necessity for a disaggregated analysis. When exploring water uses, the community should not be treated as a homogenous entity, but should be disaggregated into different socio-economic wealth groups, since the range of livelihood options is likely to be very different for each of the different groups. Possible criteria to identify distinct socio-economic groups may include ownership of livestock; land ownership or rental; level of education of household members; the ability to employ outside labour or rely upon others for employment; diversity of income sources from different occupations; and assets and savings held by households (Nicol, 2003). It is also important to explicitly consider especially vulnerable or disadvantaged groups, e.g. to get the gender perspective on the issue.
- The issue of seasonality and variations in “good” and “bad” years needs to run through the entire livelihoods analysis.
- What are the principal uses of water in the area?
- How are the different water uses prioritised? How does this vary within and between households?
- What are the key determinants of source preference and relative costs of access by source?
- How significant are access issues in determining use of different source types?
- What uses, if any, are specific to particular sources?
- What are the relationships between access, use and livelihoods security for different groups?

METHODS

- Key informant interviews with village elders and/or local leaders, using a semi-structured interview format, can be used to identify the distinct socio-economic and wealth groups in the local economy, for purposes of a disaggregated analysis. See **Table 3.4** for an example of a community classification by wealth groups.
- Household interviews using a structured questionnaire can be used to collect information on the more tangible aspects of livelihoods, such as agricultural production, livestock numbers, non-agricultural employment, etc.
- Seasonal calendars can be used to understand how livelihood strategies of households vary by season. It would be very useful to combine such a calendar with another one that records water availability and access by season, to see the inter-linkages between the two. Table 5 presents an example of a “livelihoods” calendar.

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[2] See DFID Sustainable Livelihoods Guidance Sheets at http://www.livelihoods.org/info/info_guidancesheets.html

3.3.6 Combining different methods

It is envisaged that quantitative techniques will be used for more detailed investigation of certain aspects of the livelihood options of households. In administering a sample survey, the sampling procedure needs to be carefully defined. In the present case, it is likely that some form of stratified random sampling will have to be used, so that all the socio-economic and wealth groups are adequately represented.

Some guidelines…semi-structured interviews

- Be flexible in your approach. Let the informant explain points fully, and allow them to "wander" if it is necessary for them to make their point.
- Ask direct (not leading) questions: the questions to which you want to know the answers.
- Only ask questions to which the key informant can be expected to know the answer.
- Ask questions about groups of people, not about the informant.

Continually remind the informant of the terms of the conversation: who you are talking about, what kind of year you mean, etc.

Source: SC UK (2000) The household economy approach: A resource manual for practitioners

The sequencing of the different research tools is important. The first step is usually a review of secondary sources. In the AGRAR study, it is likely to be particularly useful if the sample survey is preceded by the qualitative and participatory research. The latter can provide valuable guidance on the issue of identification of the main socio-economic and wealth groups. Through the use of focus groups and qualitative interviews, the primary water "issues" in the region, and the linkages between water and livelihoods, will also become clear, and this can influence the development of the survey instrument for quantitative research.

Table 3.4 Identification of wealth groups

Category/Criteria	No. of HHs by caste	Livelihoods
I. Land owners	**29**	
More crop produce	Reddys – 12	Cash crop cultivation
Live in own house (pucca)	OBCs – 3	Land and water leasing
More (common use) assets	STs – 14	Paid employment outside the village
available in households		Animal produce
Adequate livestock		(Note: Scheduled tribe families were able to dig their own shallow wells for irrigation after land was provided to them through a govt. scheme. However, there is severe water depletion and water from these sources is not reliable)
All children go to school and complete primary and also secondary education		
9 of the Reddy families have their own irrigation sources, 7 other families have own domestic/drinking water sources		
On average, families in category I use about 36 pots/day		
(Large plastic or metal pot, holding 10-12 litres of water)		
II. Smaller farmers	**34**	
Less land than category I	Reddys – 10	Agricultural labourers and wage workers
Less assets and livestock, bought with own resources	OBCs – 3	Dairy/poultry
Dependence on rain for agriculture	STs – 23	Temporary migration during dry periods/droughts
Do not own personal borewells or other water sources		
ST children attend schools under special scheme		
On average, families use 20-30 pots/day		
III. Landless agricultural labourers	**28**	
Do not own any land	Reddys – 1	Agricultural labourers and wage workers
Have own houses (kutcha)	OBCs – 9	Temporary migration during dry periods/droughts
No water sources	STs – 17	Bonded labour (mostly children)
Animals bought through govt. loans		Collect and sell firewood
Children attend local school, irregular attendance and drop-outs common		
On average, families use 20-30 pots/day		
IV. Landless agricultural labourers	**7**	
	SCs – 1	Wage labourers
No land	STs – 6 (all were	Collect and sell firewood

Little property, live in makeshift huts No assured wages Key family members sick and invalid Dependent on benevolence of relatives and other villagers Few or no animals	women-headed households)	

Source: SecureWater project, ODI

Table 3.5 Agricultural labour calendar and seasonal availability of work

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Availability of ag labour	18 days @ 250/day	18 days @ 250/day	22 days @ 250/day	10 days @ 350/day	18 days @ 250/day	11 days @ 250/day	11 days @ 250/day	22 days @ 250/day plus food	4–5 days	0	0	2-4 days @ 250/day
Land preparation				(veg on paddy land) Yala paddy (4 yrs in 10)				Chena 30 days mainly hh labour	Chena			Ploughing with tractor 3000/acre mostly hh or ploughing/ sowing 8 mandays +meals
Plant	Sowing mostly hh labour	Protection mostly hh labour			(veg on paddy land) Yala paddy (4 yrs in 10)				Chena 14 days mainly hh our	Chena		
Weed		Weeding/ Fertiliser mostly hh labour	Weeding/ Herbicides 12 days hh labour			(veg on paddy land) Yala paddy (4 yrs in 10)				Chena 8 days hh labour	Chena	
Harvest	Chena 30 days entire hh	Chena harvest 20-25 hh labour	Chena 12 days post-harvest hh labour	Harvesting			(veg on paddy land) Yala paddy (4 yrs in 10)					Chena 30 days entire hh
Thresh					Threshing 7 days work (women)							
Other activities	Sand/ Bricks/ Calving/ milking	Firewood/ Sand/ Bricks/ Milking	Firewood/ Sand/ Bricks/ Milking	Firewood/ Bricks/ Milking	Sand/ Milking	Firewood/ External irrigation schemes	Firewood/ External irrigation schemes	Firewood				calving

Source: Nicol and Slaymaker (2003)

3.4 SOME EXAMPLES AND ILLUSTRATIONS

As mentioned above, while the output from the qualitative and participatory techniques should serve as input for the survey phase of the research, this output is also interesting and valuable information in its own right, and should be presented in the final report, in order to supplement the results from the quantitative analysis. A few examples of research that have utilised a mix of qualitative and quantitative approaches are presented below:

1. Deb, U K et al (2002) Diversification and livelihood options: A study of two villages in Andhra Pradesh, India, 1975-2001, . ODI Working Paper 178 (available online at *www.livelihoodoptions.info/papers/178_web.pdf*).
2. Results from a household census as well as focus group discussions are reported. The latter are presented in the form of short case studies of particular households and are interspersed with the quantitative findings.
3. Ellis, F and G Bahiigwa (2003) Livelihoods and rural poverty reduction in Uganda, World Development 31(6), pp. 997-1013.
4. Paper illustrates the use of a mix of research techniques in livelihoods research, especially the use of a PRA-type wealth ranking exercise, on the basis of which sampling is later conducted.
5. Tumwine, J K (2002) Drawers of Water II: 30 years of change in domestic water use and environmental health in East Africa – Uganda country study, IIED (available online at *http://www.iied.org/docs/sarl/dow_uganda.pdf*).
6. Paper uses several PRA techniques, including community meetings, focus groups, key informant interviews, maps, Venn diagrams, and ranking exercises.
7. Moriarty, P and J Butterworth (2003) The productive use of domestic water supplies: How water supplies can play a wider role in livelihood improvement and poverty reduction, IRC International Water and Sanitation Centre (available online at *http://www.irc.nl/page.php/256*).

   Thematic overview of research on domestic uses of water. Contains useful references to relevant articles and web sites.

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