KARNATAKA WATERSHED DEVELOPMENT PROJECT

WATER RESOURCES AUDIT

KAWAD REPORT 17
JUNE 2000

DFID Department for International Development

KARNATAKA WATERSHED DEVELOPMENT SOCIETY

KARNATAKA WATERSHED DEVELOPMENT PROJECT

WATER RESOURCES AUDIT

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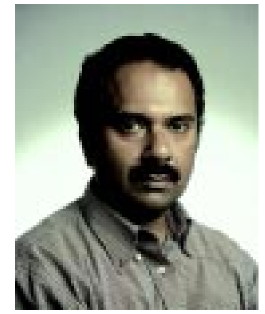
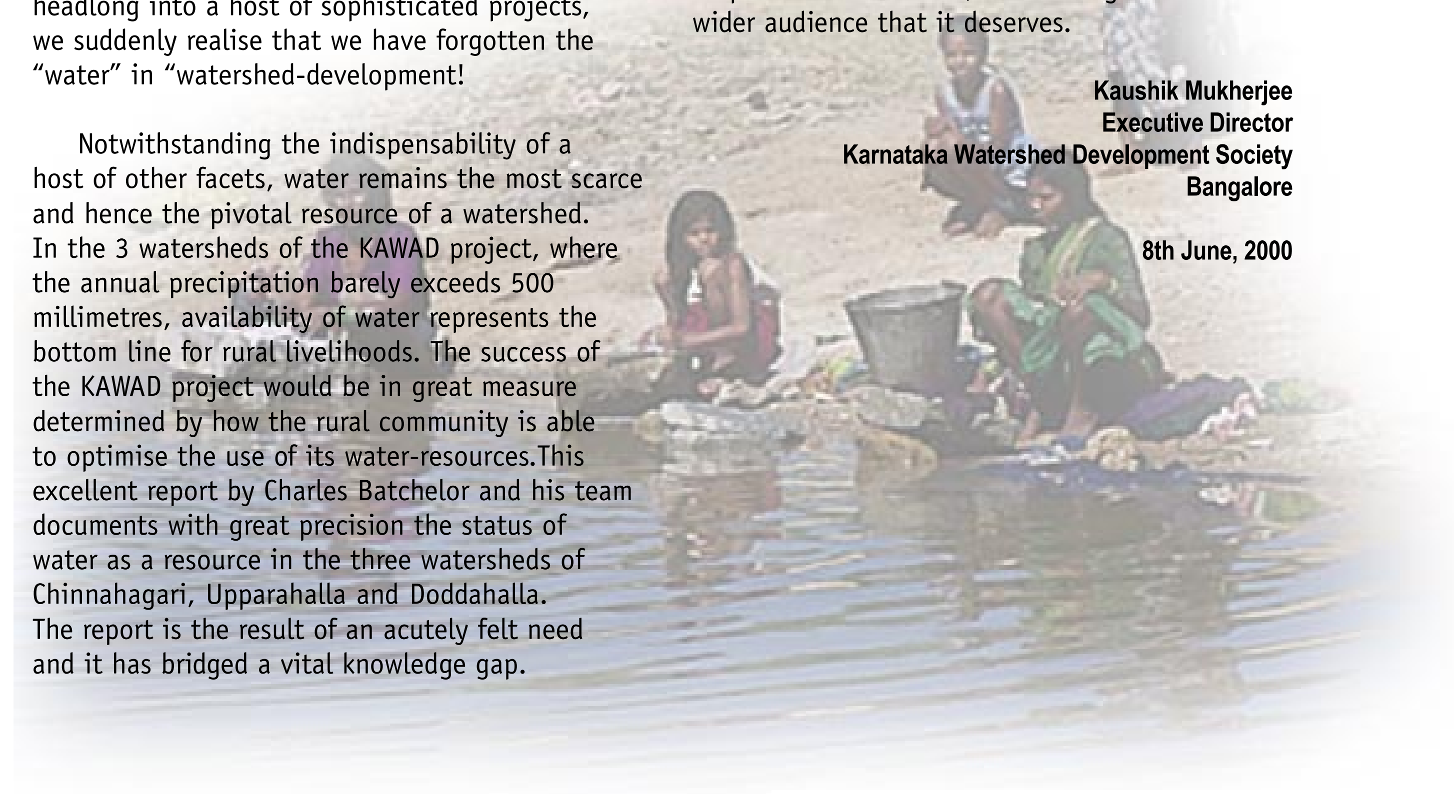
Cover Photo: Water spilling from a community stand pipe in Molakalmuru village, Chinnahagari

FOREWORD



"Watershed-Development" means different things to different people and this is probably an understatement. I know of no other pair of words in the English language which has evolved so drastically in terms of meaning in the last decade. Starting initially in the limited realm of soil and water conservation, watershed-development became relevant in the areas of horticulture, agricultural productivity and diversity, livestock, creation of off-land employment and management of communal tracts. Today, it encompasses additional dimensions of "equity", "sensitivity to gender" and "participation". As a powerful and"wellsharpened" tool, the concept of "watersheds" can be used to enhance the quality of a wide range of rural livelihoods and perhaps, the very quality of life in villages. However, as practitioners of rural-development, while we rush headlong into a host of sophisticated projects, we suddenly realise that we have forgotten the "water" in "watershed-development!

Notwithstanding the indispensability of a host of other facets, water remains the most scarce and hence the pivotal resource of a watershed. In the 3 watersheds of the KAWAD project, where the annual precipitation barely exceeds 500 millimetres, availability of water represents the bottom line for rural livelihoods. The success of the KAWAD project would be in great measure determined by how the rural community is able to optimise the use of its water-resources.This excellent report by Charles Batchelor and his team documents with great precision the status of water as a resource in the three watersheds of Chinnahagari, Upparahalla and Doddahalla. The report is the result of an acutely felt need and it has bridged a vital knowledge gap.



It has perhaps even changed our tenor of thought. We know for sure that our watersheds, even with our best efforts, cannot turn into tropical forests. We also realise that, managing available water equitably and optimally is more desirable in the long run than creating structures that harvest more water. In the KAWAD watersheds the mantra should be of "watershed-management" in terms of literally creating "more crop per drop" as opposed to building unnecessary barriers to the flow of water.

In many watershed projects, the enthusiasm and the participation of the rural community is generated in abundant measure. But then, the lack of a complete and accurate scientific picture forces the projects on predictable lines, doing familiar things; thus losing out on opportunities to carry out activities which could have had a greater positive impact. This report provides sufficient "food for thought" for the rural community in the watersheds as well as for all of us who are partners in the KAWAD family. The findings of the report suggest changes on the farmers' fields and also in the rulebooks of policy-makers. The authors, while playing down the disastrous consequences of the unbridled use of water, have called for a consensus regarding equity in the use of water. It was for this reason that this report needed to be published as a book, so that it gets the wider audience that it deserves.

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8th June, 2000

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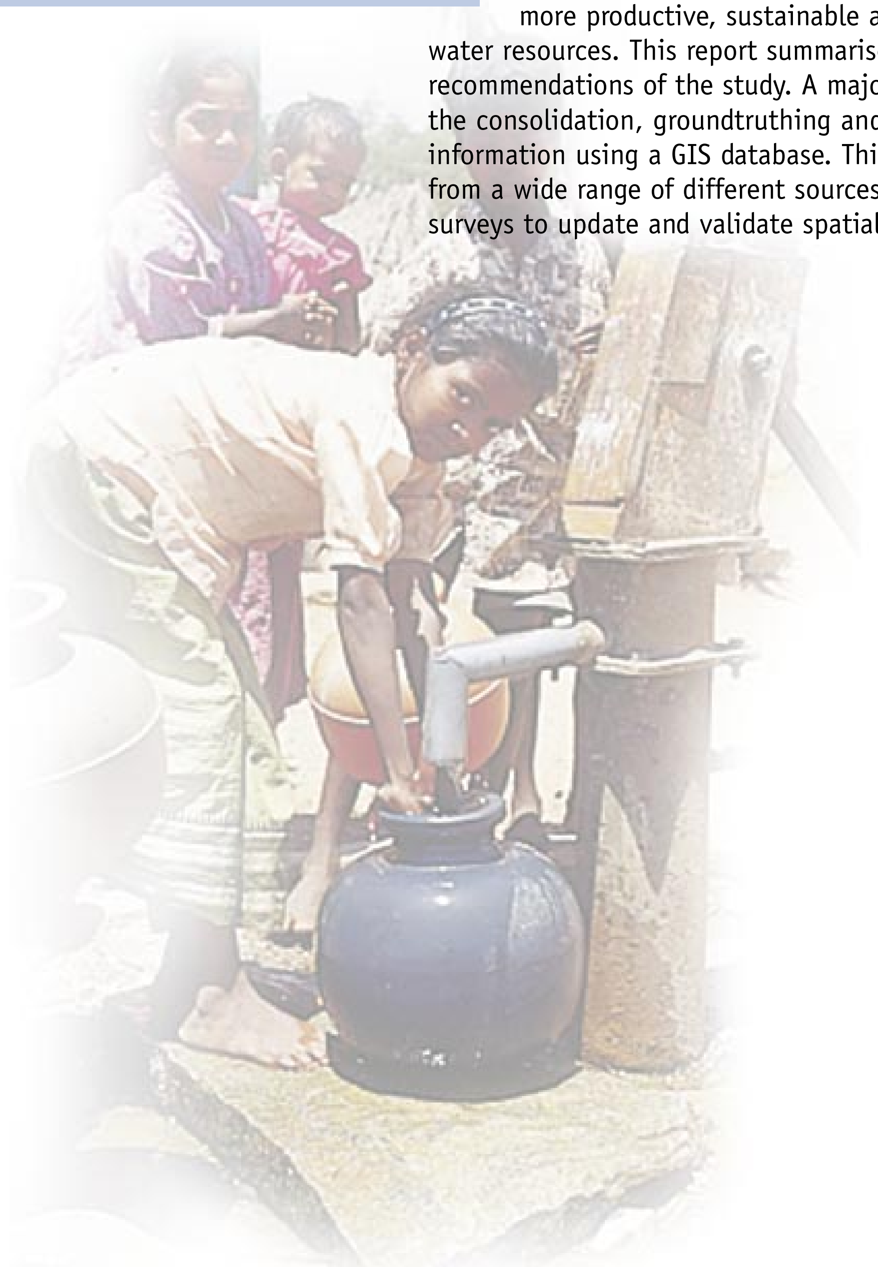
Background

The Karnataka Watershed Development Project (KAWAD) is located in the northern districts of Karnataka State, India. This is an area characterised by limited water resources for which there is increasing competition. In addition to piloting different institutional approaches to watershed development, KAWAD aims to improve the livelihoods of the inhabitants of three selected watersheds: Chinnahagari in Chitradurga district, Upparahalla in Bellary district and Doddahalla in Bijapur district. The total area of the three watersheds is around 45,000 ha.

EXECUTIVE SUMMARY

KAWAD Water Resources Audit

The main aims of the KAWAD Water Resources Audit (WRA) were to assess the status of water resources in the project watersheds and to provide a framework for more productive, sustainable and/or equitable use of water resources. This report summarises the main findings and recommendations of the study. A major feature of the study was the consolidation, groundtruthing and analysis of water-related information using a GIS database. This involved collecting data from a wide range of different sources and carrying out field surveys to update and validate spatial and non-spatial data.



Physical Characteristics of Watersheds

Two of the project watersheds, namely Chinnahagari and Upparahalla, are located in a predominantly red soil (alfisol) area that is underlain by granites and gneisses. The other watershed, Doddahalla, is located in a black soil (vertisol) area that is underlain by deccan basalts. Mean annual rainfall is approximately 472, 576 and 573 mm in Chinnahagari, Upparahalla and Doddahalla respectively. However, there is considerable inter- and intra-annual rainfall variability and droughts and years of relatively high rainfall are not uncommon. The climate of all three watersheds is semi-arid with potential evaporation exceeding rainfall in all but a few months in any year.

Typical village tank in Upparahalla

Planting groundnut in Upparahalla

Land Use

The main land use in all three watersheds is rainfed arable cropping. On the red soils, a single crop is grown each year and around 80% of the rainfed arable area is under groundnuts. On the shallow and medium-depth black soils, rainfed double-cropping is possible and bajra and jowar are the most common first and second arable crops respectively. At 25%, Doddahalla has the largest percentage area under irrigated cropping. In comparison, Chinnahagari and Upparahalla have only 6% and 3% of the land area under irrigation. At more than 20%, Chinnahagari has by far the largest percentage area that is government land or wasteland. At 7%, Doddahalla has the smallest percentage area that is uncultivated.

Analysis of the net revenues of the main rainfed and irrigated crops shows that, in most cases, the relative percentage area under different crops is consistent with the relative net revenue. Anomalies occur in the case of crops that are grown for subsistence purposes (e.g. jowar, ragi, bajra, seteria) or crops that have high risks associated with them (e.g. mulberry and onion). As might be expected, in the case of irrigated crops, comparisons of net revenues per unit area and net revenues per unit volume of water show that farmers are currently more interested in maximising profit per unit of land. Analysis of data from on-farm trials shows that substantial improvements in net revenue per unit area (for irrigated and rainfed crops) and per unit volume of water are possible if a range of improved practices is adopted by farmers.

General Resource Status of Project Watersheds

Groundwater

There has been a dramatic increase in groundwater extraction for irrigation during the last ten years. As a result, groundwater levels have fallen and, in Chinnahagari and Upparahalla Watersheds, shallow wells have failed as borewells have been constructed and as extraction from the deep aquifer has become the norm. Falling groundwater levels have led to changes in the surface hydrology of the project watersheds. Springs and seepage zones have dried and now flow or become saturated only after exceptionally wet periods. Flow in ephemeral streams is less prolonged after large rainfall events and, as a consequence, flows into tanks are reduced. Even though local perception is that cutting down trees is the main cause of the reduction in tank inflows, arguably, it is falling groundwater levels that have had the greatest impact.

Borewell construction next to a new check dam. Construction of new borewells and increased groundwater extraction near water conservation structures is a common practice

Livestock grazing in an arable area during the summer season, Chinnahagari

Doddahalla's annual groundwater recharge and, hence, availability is estimated to be 21% of annual average rainfall. It appears that one positive consequence of groundwater depletion in this watershed has been an increase in groundwater recharge. This is because groundwater depletion has made it possible for additional rainfall to infiltrate and be stored in the aquifers on a seasonal basis (i.e. less rainfall is rejected due to lack of available storage in high recharge zones such as below drainage lines). Average recharge estimates for Upparahalla and Chinnahagari are around 6% and 8% of annual rainfall. Although there may be small areas of unexploited aquifer in Chinnahagari and Upparahalla, all the evidence points to the conclusion that current levels of groundwater extraction approximate to annual recharge. Over large areas, wells are pumped for irrigation each year until they fail.

Estimates of groundwater use on a village-by-village basis, show that extraction is far from uniform. Levels of groundwater extraction in some villages are more than 2-5 times higher than average recharge values. Although there is certain to be some real variability in recharge, in many cases, this situation is only sustainable if water is flowing into these village areas from neighbouring areas. This finding has important implications for the implementation of the project. If the project promotes activities that reduce these flows, there will be winners in one village area but only at the expense of losers in another.

Chinnahagari river during the dry summer season. Pools fed by dry-season river flow provide an important habitat for birds and other wild life

Marketing of vegetables in Upparahalla during the dry summer season

Surface Runoff

In the project area, annual surface runoff at the large watershed scale is somewhat lower than is often reported or than accepted wisdom would suggest. Although there is large inter-annual variation, average runoff as a percentage of rainfall is around 6% and 2% for the Doddahalla and Chinnahagari Rivers respectively. Although runoff for individual or sequences of rainfall events is often higher (as is runoff at the plot and field scale), this finding shows that there are not large volumes of additional surface water that can be harvested in the project watersheds. The low values of runoff are not surprising given the physical characteristics of the region and the large number of check dams, nala bunds and contour bunds built prior to the project. It should be noted also that tanks in the area now only spill when the rainfall pattern is particularly conducive to the generation of runoff.

Urban water use

Current extraction of groundwater for domestic and livestock purposes is estimated at around 3%, 10% and 12% of average annual recharge in Doddahalla, Upparahalla and Chinnahagari respectively. By 2030 these figures are likely to double and, for future demands to be met, there will have to be a reduction in groundwater use for irrigation. In some villages, there are already increasing problems of water shortage in the summer season. In these cases, it is the poor and, in particular, women and children who suffer the most. Even more worrying is the prospect of a major groundwater drought in the region. Levels of groundwater extraction are such that, in many areas, there is no longer a groundwater "buffer" that can be used as a source of supply during periods of meteorological drought when no recharge will take place.

Challenges and constraints

Although KAWAD was originally conceived as a watershed development project, it has become increasingly clear that that the project needs to adopt a *sustainable rural livelihoods* approach if it is to meet the sometimes conflicting challenges of improving productivity, sustainability and equity.

Backyard horticulture in Chinnahagari. A whole range of horticultural crops can be grown using household waste waters

A Watershed Development Committee meeting in Chinnahagari. Improved long-term management of water and other natural resources is crucial to the success of watershed development projects

Key challenges include the establishment of resource management practices such that:

- **There is an overall increase in production in project watersheds and a concurrent improvement in the livelihood assets of poorer social groupings;**
- **Resource extraction and use does not lower the future availability of resource endowments (e.g. as a result of deteriorating water quality, increased groundwater extraction in the areas in which over-extraction is already taking place; upstream development of resources at expense of downstream users or *vice versa*);**
- **Access, entitlements and patterns of resource extraction meet basic needs for drinking water as well as providing opportunities for land-based and non-land-based income generation;**
- **Vulnerability of the poor, in particular, to external shocks to their livelihoods, due to the environment (e.g. droughts and floods) and social and political change, is diminished.**

Raising awareness at all levels of the real nature of water-related challenges in the region needs to be given a high priority. Current watershed development publicity or propaganda is often misleading in that it suggests that there are quick fixes to water-related problems in semi-arid areas (e.g. check dam construction, contour bunding and tree planting). While these activities have an important role to play, alone they can only have a limited and mainly localised impact. Unlike higher rainfall areas, the semi-arid areas now only have limited additional resources that can be developed. The challenge, therefore, is to make better use of existing water resources bearing in mind that the majority of changes in resource use or management involve tradeoffs.

Selection of water-related options

The report lists 34 general and 13 specific water-related options that could be selected by individuals or groups in the project watersheds. It is clear that selection of options needs to take place at the village level if local-level ownership is to be achieved. However, the project has an important role to play if wider policy objectives are to be achieved (e.g. protection of drinking water supplies, inter-village equity, rural-urban equity, environmental protection). KAWAD's implementing agencies and NGOs should promote options that are consistent with wider objectives. Project resources should not be made available for options, selected during the participatory planning process, that are contrary to the project's wider objectives. A key objective should be to select options that maximise the social and economic value of water in any given setting at the watershed scale. In many cases, this means giving drinking water supplies the highest priority and then allocating water to uses that have the next highest social and economic value.

Water-related recommendations and options

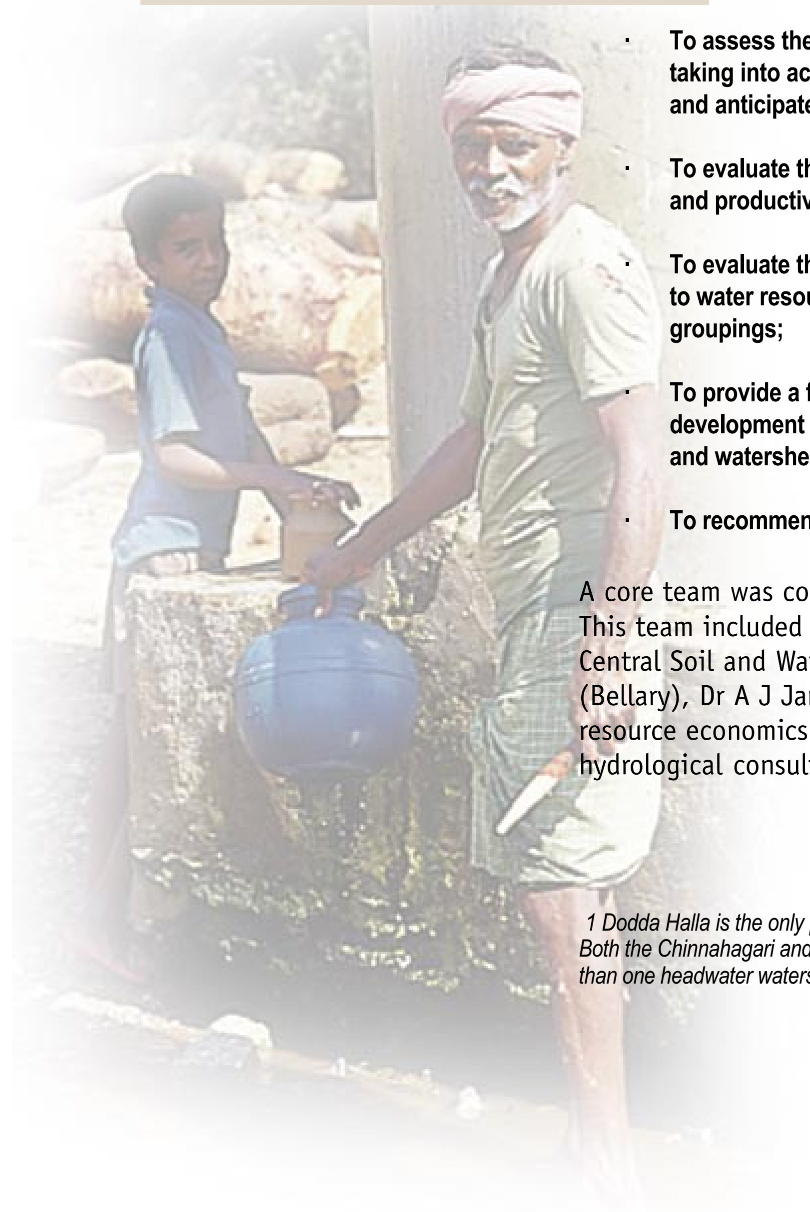
The results of the study show clearly that the focus of KAWAD should be on resource management as opposed to resource development. The study shows also that there is a much wider range of available options than are currently being used by most watershed development programmes in the region. These range from options that are essentially institutional (e.g. groundwater management by affinity groups) to those that are essentially technical (e.g. more productive use of runoff and waste waters in urban and peri-urban areas). In contrast to many higher rainfall areas, there is a fundamental need to consider the potential tradeoffs, at a range of scales, of changes in resource use or management. Finally, there is a fundamental need to create a policy and legislative framework that provides incentives for more productive use of water by individual users and disincentives for practices that are wasteful or lead to environmental degradation. Recent and current state-level policies (e.g. grants for well construction and free electricity for pumping irrigation water) have the unintended consequence of encouraging inefficient and inequitable use of water.

A typical wall painting in one of the KAWAD project watersheds. Unfortunately, such watershed development publicity is often misleading in that it suggests that there are quick fixes to water-related problems

1.1 Aims of the Kawad Water Resources Audit

In addition to piloting different institutional approaches to watershed development, the Karnataka Watershed Development Project (KAWAD) aims to improve the livelihoods of the inhabitants of three selected watersheds[1] via the restoration of degraded and eroded lands, optimal and productive use of renewable natural resources and promotion of non land-based income generating activities. Although it was designed during the mid 1990s, implementation of the project began only in 1998 after the establishment of the KAWAD Society. The three project watersheds are located one in each of the districts of Bijapur (Doddahalla Watershed), Bellary (Upparahalla Watershed) and Chitradurga (Chinnahagari Watershed).

1 INTRODUCTION



The KAWAD Water Resources Audit (WRA) commenced in March 1999 with the following objectives:

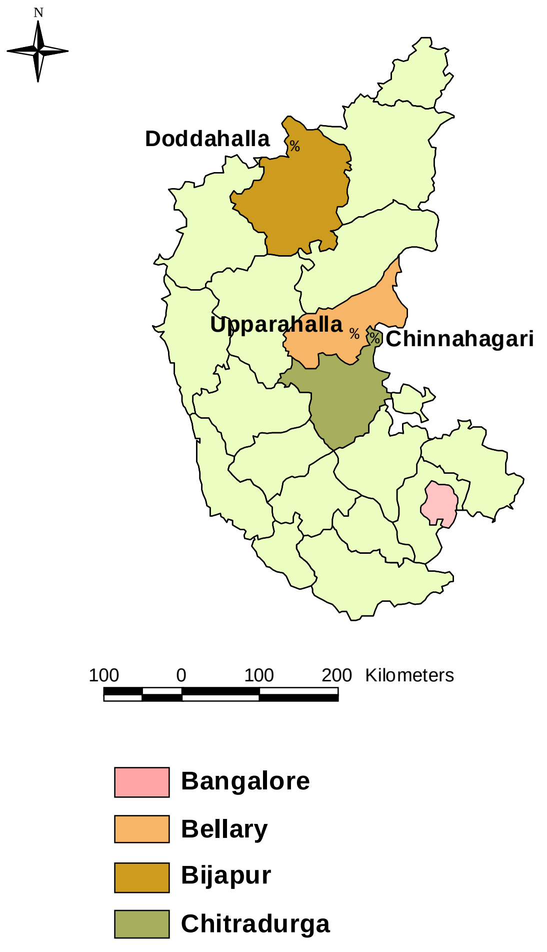
- **To assess the status of water resources in the project watersheds taking into account temporal and spatial variability and current and anticipated demands;**
- **To evaluate the scope and potential for making more sustainable and productive use of water resources at a range of scales;**
- **To evaluate the potential for improving access and entitlements to water resources of, in particular, the project's target social groupings;**
- **To provide a framework for planning and managing the development of water resources at the village, micro-watershed and watershed levels; and**
- **To recommend a physical M&E programme for each watershed.**

A core team was contracted to carry out the water resources audit. This team included Dr M S Rama Mohan Rao and staff of the Central Soil and Water Conservation Research and Training Institute (Bellary), Dr A J James (DFID environmental and natural resource economics consultant) and Dr Charles Batchelor (DFID hydrological consultant).

1 Dodda Halla is the only project area that is a single headwater watershed. Both the Chinnahagari and Upparahalla project areas comprise more than one headwater watershed.

Groundwater based irrigation of paddy in an area immediately below the Hosahalli tank, Upparahalla. Tank releases are no longer used in this area

Figure 1. Location of the KAWAD project watersheds



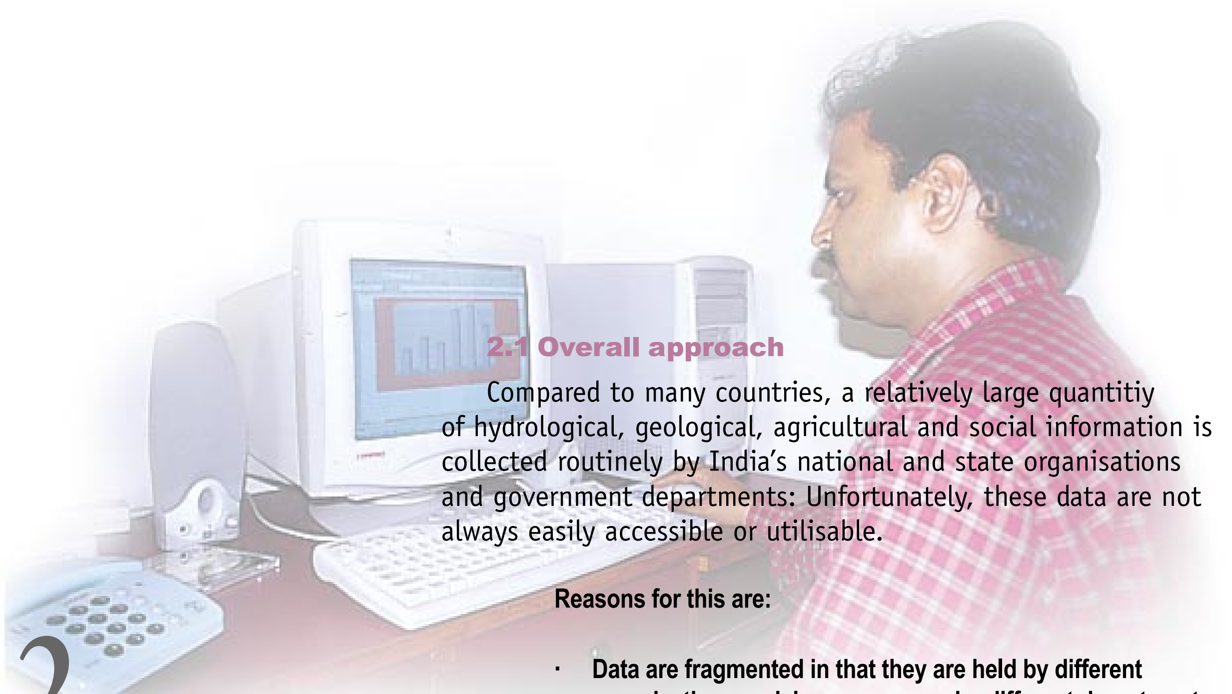
1.2 Background to the KAWAD Water Resources Audit

The KAWAD Water Resources Audit was prompted, in part, by the findings of a rapid hydrological assessment that was carried out in October 1997 (Batchelor and Rosier, 1997). This assessment highlighted some water-related issues that need to be addressed by KAWAD. The methodology that was adopted by the KAWAD Water Resources Audit resulted from field visits that took place during the period December 1998 – February 1999 (KAWAD Reports 3 and 6 – see Appendix 2), discussions that involved Mr Kaushik Mukherjee (KAWAD Executive Director), Mr Karl Goeppert (DFIDI/KAWAD Field Manager) and others in DFIDI's Rural Development Group and discussions and workshops that involved the project's implementing agencies and NGOs.

1.3 KAWAD Water Resources Audit

This report summarises the main findings of the KAWAD Water Resources Audit and makes recommendations related to future development and management of water resources in the project watersheds. A number of additional reports were produced during the execution of the Water Resources Audit. These are listed along with other KAWAD reports in Appendix 2.

A village tank in Chinnahagari. Tanks have multiple uses (e.g. bathing, washing clothes, watering livestock, sources of water for irrigation, pisciculture etc)



2 METHODOLOGY

2.1 Overall approach

Compared to many countries, a relatively large quantitiy of hydrological, geological, agricultural and social information is collected routinely by India's national and state organisations and government departments: Unfortunately, these data are not always easily accessible or utilisable.

Reasons for this are:

- **Data are fragmented in that they are held by different organisations and, in some cases, by different departments or individuals within these organisations[2];**
- **Spatial and non-spatial data are stored in a wide range of formats (e.g. maps, remotely-sensed images, tables of figures, text, graphs, etc.) and media (e.g. in year books, on computer disks etc.);**
- **Spatial and temporal scales, at which data have been collected, vary enormously;**
- **Data quality is extremely variable.**

The approach adopted and, to some extent, developed by the Water Resource Audit involved collecting secondary data from a wide range of different sources, groundtruthing these data and then consolidating spatial and non-spatial data on a geographical information system (GIS) database (ARCVIEW, ESRI Inc, USA). Once consolidated, further quality control checks were made. Data manipulation and analysis was carried out primarily by exporting data files to spreadsheet software. Results were then re-imported into the GIS database and displayed using the GIS software.

Provisional outputs were combined into computer-based slide shows that were used to promote discussion and comment at all levels. In many cases, this led to further quality control and analysis. A key principle adopted by the study was that quality control and groundtruthing was best carried out with the involvement of local people and specialists from research organisations and government departments who are based near the project watersheds or who were responsible for the relevant districts.

2 In the future, the National Hydrology Project should make hydrological data more accessible. In addition to upgrading data collection networks, this project is in the process of setting up hydrological databases.

2.2 Collection of physical data

Rainfall data

Daily rainfall data (for 15-30 years duration) for stations, that were located in or near project watersheds, were collected from the taluk headquarters of relevant government departments or from research stations. These data were quality controlled by inspection and by verifying the consistency between individual stations and adjacent stations. Daily data were transformed into weekly data and rainfall probability analysis was carried out.

NGO staff checking field data in a project office in Chinnahagari

Amkundi bridge on the Chinnahagari river. This is the location of a Central Water Commission gauging station

Groundwater level and quality data

Groundwater level data for observation wells, that are in or near project watersheds, were collected from the Department of Mines and Geology. Water samples were taken from wells in each of the project watersheds and analysed by the CSWCRTI to give an indication of the suitability of these wells as sources of water for drinking and irrigation. Water sampling and analysis for fluoride concentration is planned.

Stream flow data

Stream flow data were collected for the gauging stations on the Chinnahagari and Doddahalla which are maintained by the Central Water Commission. Run-off data at the field and micro-catchment scales were extracted primarily from research reports published by the CSWCRTI.

Watershed boundaries

Topographical sheets of the project watersheds were collected and glued together to make one large base map on a scale of 1:50,000 for each project watershed. Individual maps were aligned by lining up common features on the relevant maps. Using the drainage pattern as a guide, ridge boundaries were marked on the maps. These ridge lines were then verified by CSWCRTI staff who walked the ridge lines and used clearly identifiable features as bench marks.

Contours and elevation

Contours, spot heights and latitude and longitude were transferred from the topographical sheets to the watershed boundary base maps.

Drainage lines, water bodies and water harvesting structures

After groundtruthing, drainage lines within the project watershed boundaries were also transferred to the base maps. In most cases, cadestral maps obtained from land records offices were used as the data source. Groundtruthing also involved measuring the width and depth of 1st and 2nd order streams at every confluence point and/or at intervals of 500 m. These spot data were marked on the base maps. The location of tanks and roads of different types were transferred from topographical sheets to the base maps. As CSWCRTI and NGO staff groundtruthed drainage lines, they marked the location of water harvesting structures on the cadestral maps. Information was also recorded on the dimensions, construction, condition and viability of these structures. Spatial data were marked on the base map and the non-spatial data recorded for subsequent entry into attribute tables.

Farmer standing in his dry open well in Doddahalla during April 2000

One of the many check dams that existed in Chinnahagari prior to the start of the KAWAD project

Wells

Working in most cases with NGOs, information on the location, size, type, year of construction and ownership of wells was collected by CSWCRTI staff in each project village. If appropriate, information was also collected on the area irrigated by each well and the crops that were being grown. As the study staff did not have experience of using or access to a portable GPS, wells were located according to the survey numbers of the parcels in which they were situated. (It is recommended that a GPS be used in the future to geo-reference existing wells in the project watersheds and new wells as and when they are constructed).

Village information

Census information for each project village was collected from respective village accountants. This included data on human population, livestock numbers and infrastructure with respect to water supply and sanitation.

Land-holding information

Akarbandhi areas, record of revenue (ROR) and land holding information were also collected from village accountants. Information on crops grown was collected, tabulated and marked on cadestral maps according to the survey numbers of individual parcels. Information was also collected on the ownership of parcels. In cases where parcels had been split between more than one owner, this was also recorded.

Vegetation maps

Information pertaining to forest areas was transferred from the topographical sheets to the 1:50,000 scale base maps of each project watershed. Vegetation maps were obtained from the Survey and Settlement Division of the Forestry Department and, using latitude and longitude as a guide, information was transferred to the base map. Subsequently each watershed was surveyed for the type and density of vegetation in different areas (e.g. forest, agricultural and community lands). Information from these field surveys was also transferred to the base maps.

Soil Maps

Soil and land capability maps of the respective taluks, in which project watersheds are located, were obtained from the regional centre of the National Bureau of Soil Surveys and Land Use Planning (NBSSLUP) in Bangalore. Latitude and longitude were used as a guide for transferring data from the NBSSLUP maps to the base maps of the project watersheds. Groundtruthing of the resulting maps was carried out by soil scientists from CSWCRTI. Differences that were observed were incorporated into the base maps

Granite hills near Molakamuru, Chinnahagari

Hosahalli tank in Upparahalla. Average annual inflows to this and other tanks in the area have decreased in recent years

Geomorphic and lineament maps

1:50,000 scale base maps showing watershed boundaries and containing details of village locations, major roads and water bodies were extracted from the toposheets. These maps were placed on a light table over respective geocoded IRS-IB satellite FCC images for visual interpretation of lineaments and geomorphic units. Groundtruthing was then carried out involving geologists from the Department of Mines and Geology and changes were made to base maps where necessary.

2.3 Data reconciliation and digitisation

Digitisation and linking of spatial and non-spatial data proved to be more difficult and time consuming than was anticipated. Some of the lessons learnt during the process of collecting and digitising information included:

- **Although fragmented, nearly all the information that is required for determining the resource status of watersheds in Karnataka, can be obtained from relevant organisations and line departments. This information does, however, require groundtruthing and verification by specialists with appropriate knowledge and experience.**
- **Reconciling information from different sources is a challenge, given that maps are often drawn to different scales and latitude and longitude are not always marked.**
- **GPS equipment should be used to fix the location of common features.**
- **Obtaining (or borrowing) original maps is essential. Photocopiers introduce significant distortions.**
- **ROR data are rarely up to date. If current data are required, field surveys are needed.**
- **Close collaboration between staff collecting data and staff digitising and reconciling data is essential if work is to proceed smoothly and if mistakes are to be avoided. A mutual understanding and appreciation of needs and constraints with regard to data collection and processing is also essential. This can only be**

- achieved by appropriate training and exposure visits and by developing and using a common language.

- **Upgrading the computing skills of field staff, so that they can take an active and constructive role in data manipulation improves quality control and speeds up data processing considerably.**

2.4 Analysis of physical data

The main method of analysis was the estimation of the components of the water balances at a range of different spatial and temporal scales. It should be noted that GIS databases and software make this type of analysis and subsequent interpretation relatively easy. Wherever possible, components of the water balance were estimated by a number of independent method. Checks were also made to ensure that upper physical limits were not exceeded (e.g. that actual crop water use did not exceed potential crop water use, that the sum of the components of the water balance did not exceed the volume of rainfall in a given area). As mentioned earlier, maximum use was made of the often-qualitative knowledge and experience of local people and specialists.

As a caveat, it must be stated that there are uncertainties in the absolute values presented in this report and it can be anticipated that these uncertainties will be reduced as more reliable data become available. However, as the same methodologies were used for each village area and watershed, relative differences can be used with a higher level of confidence.

In the future, it might be useful to use more sophisticated modelling techniques for data analysis and hypothesis testing. In particular, there would be definite merit in using Bayesian Belief Networks for interdisciplinary data analysis. However, it was decided that using such techniques was not appropriate during this study, given the objectives of the study and the time and resources that were available.

2.5 Collection of economic data

Crop yield data

Current yields of major rainfed and irrigated crops in red soil and black soil areas were obtained from the Bellary and Molakalmuru field stations of the Department of Agriculture, Government of Karnataka, the farmers' survey in Molakalmuru by the CSWCRTI, Bellary, and from the agricultural research stations of the University of Agricultural Sciences (UAS) in Dharwad, Bellary and Bijapur. Information on mulberry production and cost was collected from Agricultural officers in the Molakalmuru field station of the Department of Agriculture, Government of Karnataka.

Cost data

Actual costs of cultivation incurred by farmers were only available from the Molakalmuru farmers' survey and from previous surveys carried out by the CSWCRTI in the watershed projects in GR Halli (red soil area), Joladarasi (black soil area) and Chinnatekur (mixed red and black soil area). Data from the Molakalmuru survey were for one year whereas data from the watersheds were for a period of 10-15 years ending in 1994/95.

2.6 Analysis of economic data

Potential yields

Although a previous KAWAD consultation report (Report No. 8) stated that there was not enough reliable and up-to-date data available to conduct an economic analysis, sufficient data were available from the CSWCRTI (Bellary) to make the analysis of potential yields possible. Initial analysis used the yield series from the earlier soil and water conservation field trials conducted by the CSWCRTI in GR Halli, Joladarasi, Chinnatekur, and the off-station trials conducted by the UAS (which comprised improved seeds, better crop management practices and soil and water conservation measures). However, this average yield after 'treatment' turned out to be lower than current yields (without treatment) reported by farmers in Molakalmuru. Straight line statistical extrapolations resulted in future yields without treatment being higher than treated yields. Finally, an average figure was taken by applying to current yields the percentage of improvement recorded in off-station trials conducted by the UAS. Improvements in yield were a result of better seeds, better crop management practices and the introduction of soil and water conservation measures.

Harvesting groundnut in Chinnahagari. In red soil areas, over 80% of the rainfed arable area is under groundnut cultivation

Potential net revenues

Information on the prices of grain and straw was collected from the Bellary and Bijapur field offices of the Department of Agriculture and local markets. Straw production was calculated using straw-to-grain ratios calculated from the farmers' survey by CSWCRTI, Bellary, in Molakalmuru. Since up-to-date cost information was available only for red soil areas, these were assumed to hold good for black soil crops as well.

Data quality

The fact that the data came from different sources makes quality control difficult. Also, it is difficult to say whether or not the sample of farmers used to generate these data is statistically random and hence representative of the farmers in the watershed as a whole. Future data collection could be organised and structured so that farmers choosing to adopt improved seed varieties, cultivation practices or soil and water conservation techniques supplied by the project are monitored over time, along with a 'control' sample of farmers who do not.

Further, a large enough sample of farmers from each watershed would enable more sophisticated statistical and econometric analysis that can ascertain reasons behind improvements in yields, output and incomes. In particular, such techniques can assess whether or not improved water management and reduced water use has resulted in greater production. The present study could not initiate a separate data collection exercise, and instead opted to consolidate available information.

3 PHYSICAL CHARACTERISTICS OF PROJECT WATERSHEDS

3.1 Agro-climate

The climate prevailing in the three watersheds is semi-arid to arid. There are three major seasons: winter, hot and rainy. Maximum and minimum temperatures are around 45° C and 9° C respectively. The area experiences high winds, of around 5-6 ms^{-1}, from mid-May to mid-September. High wind speeds coupled with high solar radiation lead to high evaporation rates, particularly during the period March to July. In climatic terms, the area does not have distinct kharif and rabi seasons as cropping takes place continuously throughout these periods (except on deep black soils).

3.2 Annual rainfall

Average annual rainfall values for the project watersheds are presented in Table 1. It should be noted that the scoping study (ODA, 1995a), that was carried out prior to the inception of the project, suggested incorrectly that average annual rainfall in Upparahalla is 350 mm.

Table1. Average annual rainfall

Watershed	Rain gauge location	Rainfall (mm)
Doddahalla	Bijapur	573
Upparahalla	Kudligi	576
Chinnahagari	Molakalmuru	472

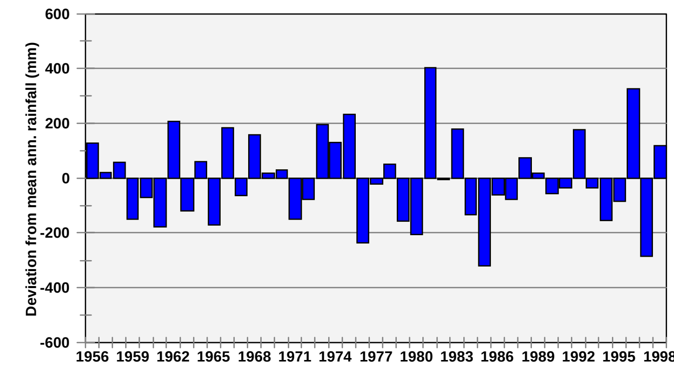


Figure 2.
Deviation in annual rainfall from the long - term mean

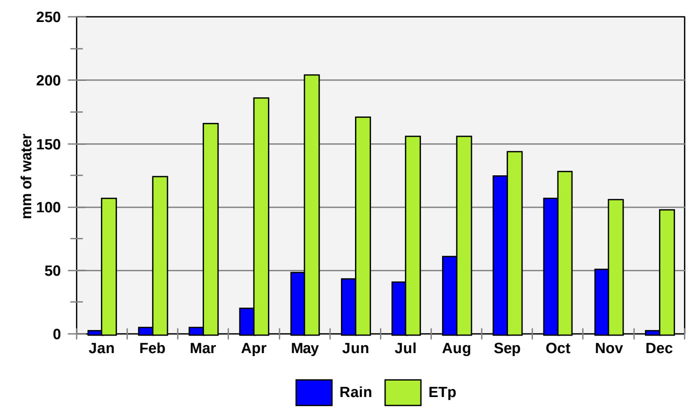


Figure 3.
Monthly mean rainfall and Penman potential evaporation (ETp) for Bellary. Source: FAO CLIMWAT

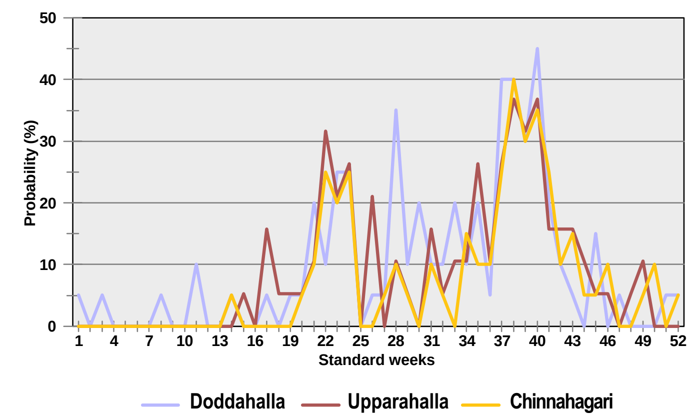


Figure 4.
Weekly probability of 40 mm of rainfall

Using data from Bellary, Figure 2 shows that there is considerable variation in annual rainfall around the average value. In some years during the period 1956-98, rainfall was as much as 400 mm higher than the average and in others it was more than 300 mm less than the average. Extreme inter- and intra-annual rainfall variability is an important characteristic of the climate of the project watersheds. A major challenge facing farmers in this area is the adoption of farming systems that both cope with periods of low rainfall, bearing in mind the fact that drought is a natural and recurring phenomenon, and capitalise on years of above average rainfall. The general perception is that in every ten year period, there will be five droughts of different intensities. Two of these droughts will be moderate, two will be severe and one will be catastrophic.

Figure 3 compares average monthly rainfall and potential evaporation. The FAO define potential evaporation (or reference crop evapotranspiration as they refer to it), as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". The difference between rainfall and potential evaporation gives an indication of the aridity of a climate. Potential evaporation rates in the project watersheds are high such that on average, rainfall does not exceed potential evaporation in any month. Hence, in an average year, it is not possible for a rainfed crop that completely shades the ground to use water or grow at potential rates. Figure 3 also shows that rainfall in the area is concentrated in the months April to November. The rainfall pattern is bimodal with a less-defined peak in May/June and a well-defined peak in September.

Figure 4 compares the probability of receiving 40 mm of rainfall in any given week in the three watersheds. The bimodal nature of the rainfall in Chinnahagari and Upparahalla is more pronounced than is the case for Doddahalla. It can also be seen that Chinnahagari has generally lower probabilities than Upparahalla particularly at the onset of the rainy season.

General view of Chinnahagari

General view of Doddahalla during the summer season. Areas of irrigated sugarcane can be seen clearly

3.3 Geology

Chinnahagari and Upparahalla: Chinnahagari and Upparahalla are both underlain by crystalline basement geology. The major portion (95%) of Chinnahagari comprises granite and gneiss. In the extreme north-east corner around Molakalmuru, younger granites can be found. These are exposed as residual hillocks. There are three major dykes in the watershed. Two are near Molakalmuru and the other is located in the east of the watershed.

Upparahalla is comprised entirely of granite and gneiss intruded by dolorite dykes and thin pegmatite veins. Residual hills and ridges located at SW and NE parts of the watershed also comprise granite and gneiss.

Hydro-geological conditions in both watersheds are poor in the areas in which fresh granites and gneiss occur. In the areas of moderately-weathered granite, the groundwater potential is moderate to poor. Although variable, depth of weathering is up to 20 m. Fracturing of the underlying bedrock is also variable.

Doddahalla: The entire area of Doddahalla is underlain by basaltic trap formations of the Eocene age. Formations are in the form of nearly horizontal beds (flows). A total number of 3 flows are recognised in this region. All the flows are of the Pahaehoe type and are mixed in character. Each lava flow has its own system of joints resulting largely from contraction during cooling and each flow is more or less uniform in thickness and physical characteristics. In most of the watershed only a shallow water table exists. Hence, open or wide diameter wells tend to be used for extracting groundwater, and not borewells. The overall ground water potential of the watershed is qualitatively assessed as poor to moderate.

Table 2. Physiographic and other characteristics of project watersheds

Physiographic Features	Chinnahagari	Upparahalla	Doddahalla
(a) Longitude	76°36’- 76°46’	76°22’-76°33’	75°39’-75°44’
(b) Latitude	14°38’-14°46’	14°33’-14°42’	17°04’-17°18’
(c) Altitude	536 to 880 m	600 to 711 m	460 to 641 m
(d) Average ann. rainfall (mm)	472	576	573
(e) Soil type	Red	Red	Black
(f) Watershed area (ha)	11,907	18,774	14,230
(g) Difference in elevation between remote and outlet point (m)	344	111	181
(h) Average slope range %	0.5-2.5	1.5-3.0	1-8

3.4 Soils

General description

Table 2 summarises the main physiographic characteristics of the project watersheds.
All three watersheds are located in an erosional landscape that appears to be in an advanced stage of pediplenation. Soils of Chinnahagari and Upparahalla are predominantly red loams of varying soil depths while the soils of Doddahalla are black soils of different depths. Red soils and shallow and medium black soils are cropped in kharif and deep black soils are cropped during post rainy season. The major soil constraints common to these watersheds are: undulating topography, poor organic matter and instability in aggregates, all of which restrict the movement of already inadequate rainfall into the soil and subsequently within the soil. Both the soil groups are poor in nitrogen and phosphorus. Black soils are well supplied with bases while red soils suffer from deficiency of potassium and zinc. Much of the area suffers from moderate to severe erosion as a consequence of the undulating topography and absence of vegetative cover. The specific details of the soils in the different watersheds are given below.

Table 3. Distribution of different soil series in project watersheds

Chinnahagari		Upparahalla		Doddahalla	
Series	Extent (ha)	Series	Extent (ha)	Series	Extent (ha)
Hagari	34	Kudligi	1,295	Sasalatti	6,051
Konasagara	283	Parasarampura	1,217	Mangoli	258
Kudligi	1,592	Tallak	1,113	Savalgi	24
Molakalmuru	1,277	Devalapur	11,336	Sindgi	924
Tallak	8,721	Virapuram	186	Rugi	1,859
		Billichodu	3,482	Yarnal	3,765
		Moderately affected by salt/alkali	145	Bisnal	1,349
	11,907		18,774		14,230

Chinnahagari: Soils of the area are red sandy loams derived from granite and gneiss. They belong to the ferruginous red soil groups of India having neutral reaction and high base saturation. Shallow gravelly soils occur at the base of the foot-hills with 3 to 5% slope. The percentage of gravel in these soils ranges from 50 to 85% and is a major limitation for farming. Moderately deep to deep soils occupy 80 to 85% of the area and these have a gravelly sub-surface layer. As a result, the soils are well drained and have a low water holding capacity.

The major soil series that are encountered in the watershed along with their extent are given in Table 3. Tallak series, having the characteristics of loamy sand texture and good drainage, occupy 74% of the area. 75% of the area belongs to capability class II with limitations of erosion and presence of gravel (see Table 4). A very small area of 33 ha exists that has limitations on account of salinity. An area of 15% exists under class VI.

Upparahalla: Soils in Upparahalla are very similar to those found in Chinnahagari. Of the six soil series, the Devalapur series occupies the largest area at around 61%. There are no capability class I lands in the watershed. The largest part of the area (85%) belongs to IIIes to IIIcs (at times associated with IVes and IVcs). An area of 145 ha is affected by salinity and needs improved drainage.

Doddahalla Watershed: Soils of the watershed are heavy clays derived from basalt. These soils swell upon receiving water and large deep cracks form when they dry. They have high water storage capacity due to high clay content. Soils vary greatly in respect to depth. Shallow and light soils occur near foothills with slopes ranging from 3 to 5%. Depth is the major limitation for their use in agriculture. Eight soil series are encountered in the watershed of which Sasalatti in association with Mangoli occupies 43% of the area. Nearly half the area (48%) falls under capability class II with soil erosion as the major limitation. The rest of the area falls under classes IV to VI with erosion and shallow soil depth as major constraints.

Availibility of roads and transport has a bearing on the ability of farmers to market produce with a short shelf life

Table 4. Area under different land capabilities classes

Chinnahagari		Upparahalla		Doddahalla	
Capability class	Area (ha)	Capability class	Area (ha)	Capability class	Area (ha)
IIIes	9,251	IIsw – IIs	2,700	IIIs- IIe	94
IIsw	726	IIIc – IVe	1,069	IIe	6,834
VIes	1,897	IIIcs – IVes	4,633	VIII – VIIes	630
IIes	33	IVc-IVe	186	VIII – VIes	1,457
		IIIes	10,186	VIes- IVes	3,440
				VIes – VIII	1,775
	11,907		18,774		14,230

Boy swimming in a tank in Upparahalla

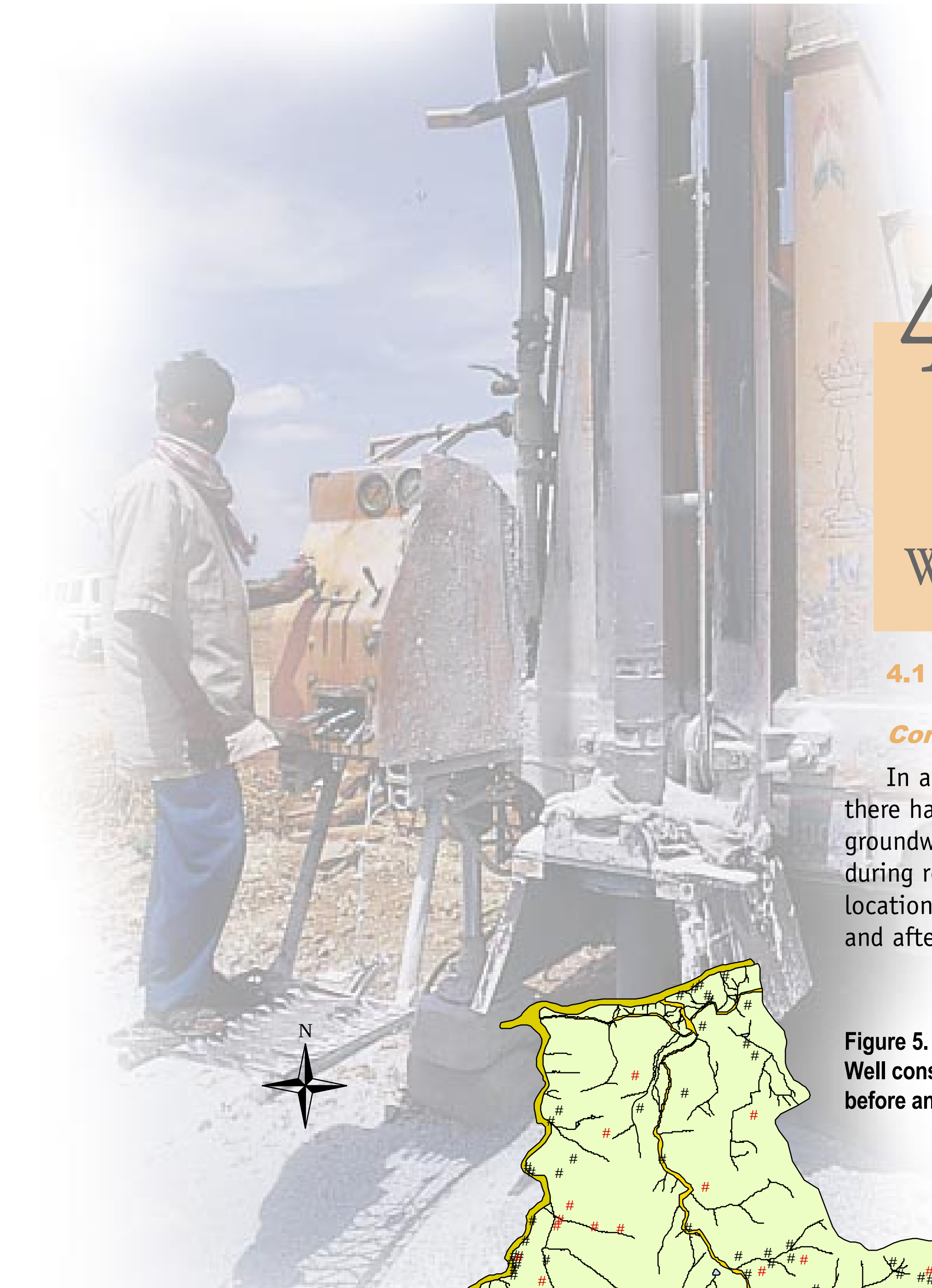
3.5 Tanks

The use of tanks for catching runoff is a traditional practice in the project area that is more prevalent in the red soil areas. Originally, tanks were managed by user groups. They are now managed by government departments or the local panchayati raj system. In Chinnahagari, there are 9 tanks of which three are percolation tanks and six are irrigation tanks. There are six irrigation tanks in Upparahalla and two irrigation tanks in Doddahalla.

All the tanks are in poor condition, siltation has occurred and, as a consequence, dead storage and average depth have been reduced. It is remarked frequently that inflows to tanks have decreased and management systems are now defunct or ineffective. In many cases, arable land in tank command areas is now being irrigated using groundwater rather than surface water released from the tank.

3.6 Vegetation

Vegetative cover in all the watersheds is highly degraded due to biotic interference. In general, community lands are devoid of any trees and even reserve forest areas have become degraded. Gullies are characterised by *prosophis juliflora* growth. Although trees have been planted on agricultural land in some areas, in other areas there are very few trees.



4 GENERAL RESOURCE STATUS OF PROJECT WATERSHEDS

4.1 Groundwater

Construction of wells

In all three project watersheds, there has been a dramatic increase in groundwater extraction for irrigation during recent years. Figure 5 shows the location of wells constructed before and after 1990 in Chinnahagari.

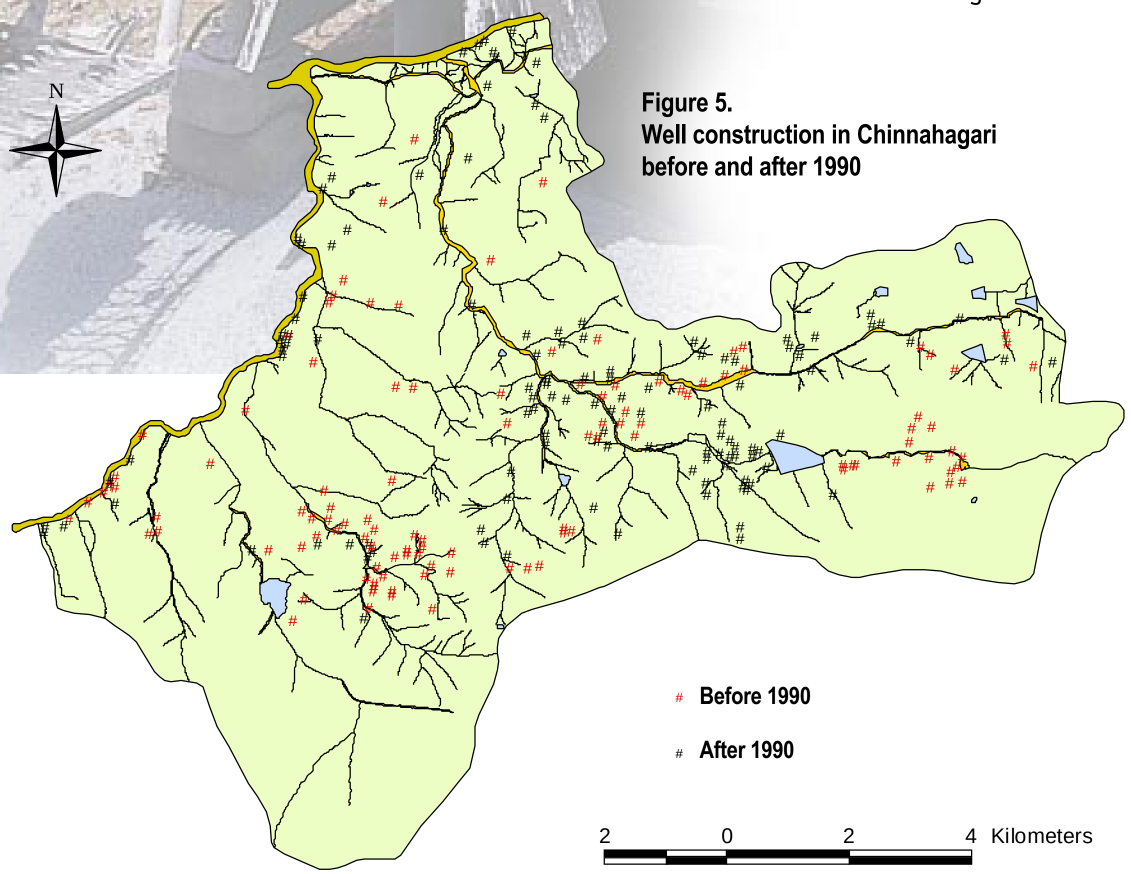


Figure 5.
Well construction in Chinnahagari before and after 1990

Figure 6. Well construction in the Chinnahagari watershed

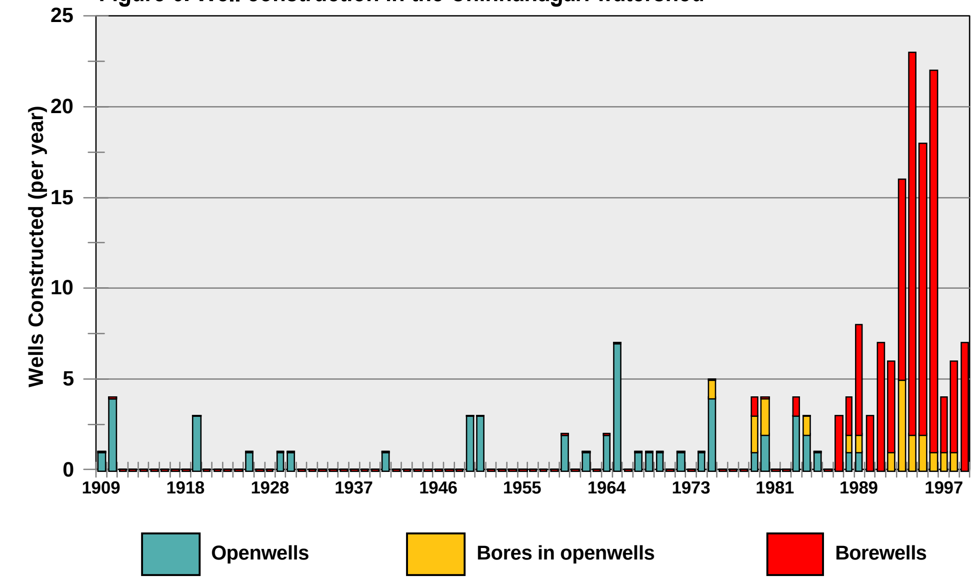


Figure 7.
Well construction in Doddahalla before and after 1990

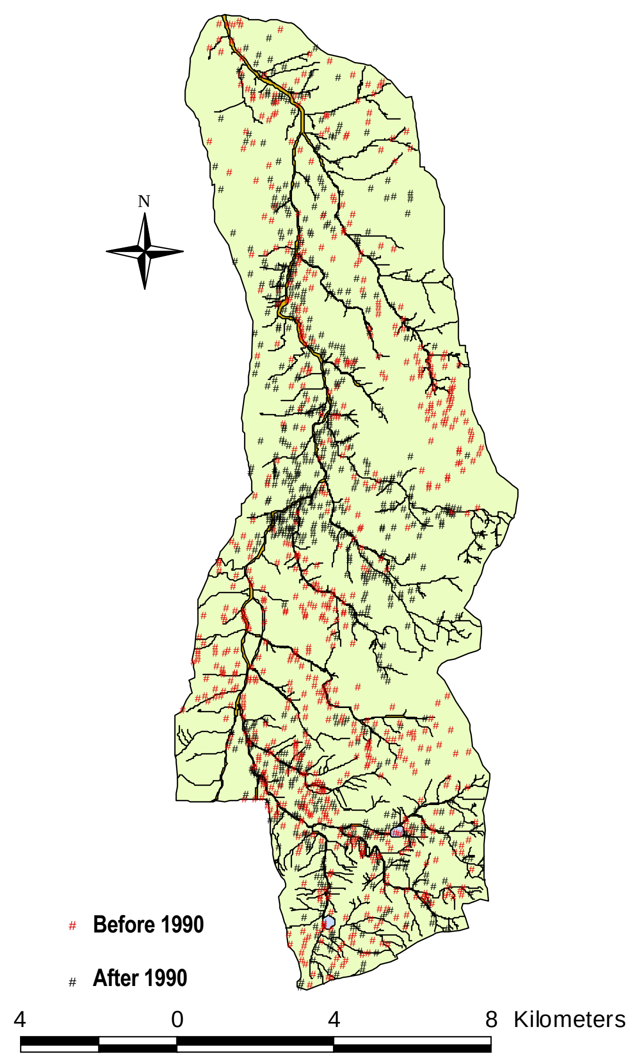


Figure 6 presents the number of wells of different types constructed in Chinnahagari during the period 1909-1999. In addition to showing the big increase in well numbers from the late 1980s onwards, this figure shows that, in the last ten years, new wells have been predominantly deep borewells or borewells constructed in the base of open wells. Hence, there has been a shift from groundwater extraction that exploited the shallow regolith aquifer to extraction from the deeper bedrock aquifer. It should be noted also that during this period there has been an equally rapid rise in the use of submersible pumps. Hence, there has been an increase both in the number of wells and volume of water extracted per well. The Upparahalla watershed, which has the same geology as Chinnahagari, has experienced the same increase in exploitation of the deep aquifer.

Figure 7 shows the location of wells constructed before and after 1990 in the Doddahalla watershed. The figure shows that a huge number of wells have been constructed during the last ten years. By comparing Figures 5 and 7, it can be seen that the density of wells is much higher in Doddahalla than in Chinnahagari. It can be seen also that the density of wells in both watersheds tends to be highest along the drainage lines.

Figure 8. Well construction in the Doddahalla Watershed

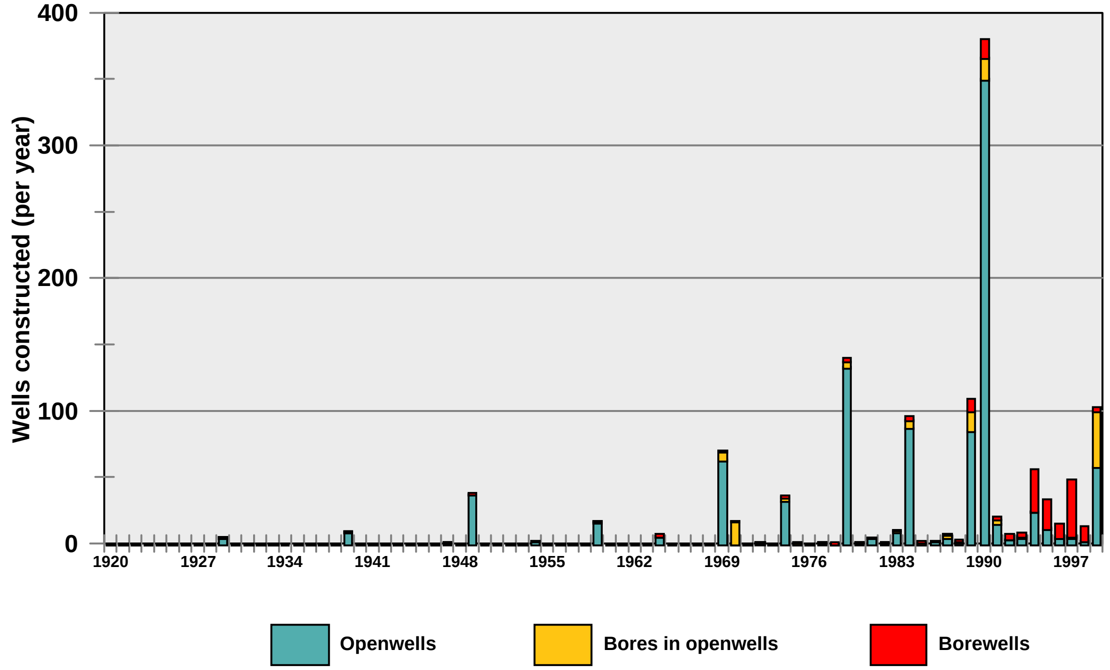
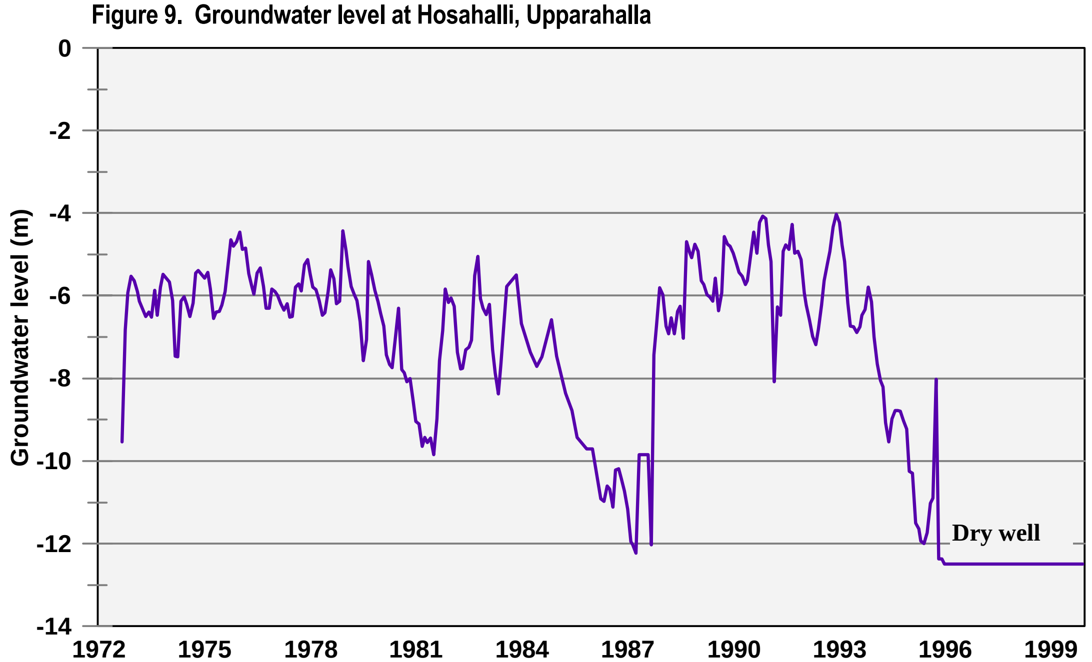


Figure 8 presents the number of wells of different types constructed in Doddahalla during the period 1920-1999. Comparison between Figures 6 and 8 shows that the number of wells constructed in Doddahalla (1264 wells) is much higher than in Chinnahagari (234 wells). To date, 606 wells have been constructed in Upparahalla. Droughts and government-supported programmes have had a big impact on well construction. For example, low rainfall years in the mid 1980s coupled with incentive schemes contributed to a surge in well construction and deepening in Doddahalla in subsequent years. Over 350 wells were constructed in one year alone (in 1990).

Figure 9. Groundwater level at Hosahalli, Upparahalla



Driving forces behind well construction

Factors that have encouraged the increase in well construction include the:

- **Markedly higher and more reliable returns that farmers get from irrigated cropping as opposed to rainfed cropping (see Section 5.4 of this report);**
- **Government programmes that have provided loans or part/full funds for well construction;**
- **Government policy of providing free electricity for pumping ground water for irrigation. Note that electricity is completely free when farmers use pumps rated at less than 5 H P. There is a nominal annual fee for larger pumps;**
- **Improved drilling technology and competition between contractors. Both have ensured that the cost of borewell construction is relatively low;**
- **Competition for water between farmers sharing the same aquifer. This has led to deepening of open wells and construction of new borewells.**

Groundwater levels

In large parts of Upparahalla and Chinnahagari (i.e. in crystalline basement areas), the shallow aquifer has become completely depleted. Figure 9 presents typical observation well data for an open well located at Hosahalli in the Upparahalla watershed. This well has been dry since the beginning of 1996. It is interesting that this well came close to failing in the mid 1980s primarily as a result of a sequence of low rainfall years. It then recovered only to fail again in 1996. As this observation well is located in the village, it is an area in which localised groundwater extraction was high for domestic purposes prior to the 1990s. This is indicated by the fact that groundwater levels have been sensitive to periods of low rainfall throughout the period of observation. Since the late 1980s, the installation of a large number of borewells and pumpsets near and within Hosahalli village has led to a sharp increase in extraction rates. As a consequence, the Hosahalli observation well and other open wells in this area are unlikely to recover unless there is: a sequence of high rainfall years, a large increase in localised groundwater recharge and/or a reduction in groundwater extraction.

Figure 10 presents groundwater level data from an observation well located in Molakalmuru village in Chinnahagari. The depth of this observation well was 15.5 m until October 1986, when a borewell was constructed to a depth of 48 m. This figure shows clearly that the groundwater level fluctuations, that have been taking place in recent years, tend to be within the deep bedrock aquifer (i.e. below 14 m depth).

Figure 10. Groundwater level at Molakalmuru, Chinnahagari

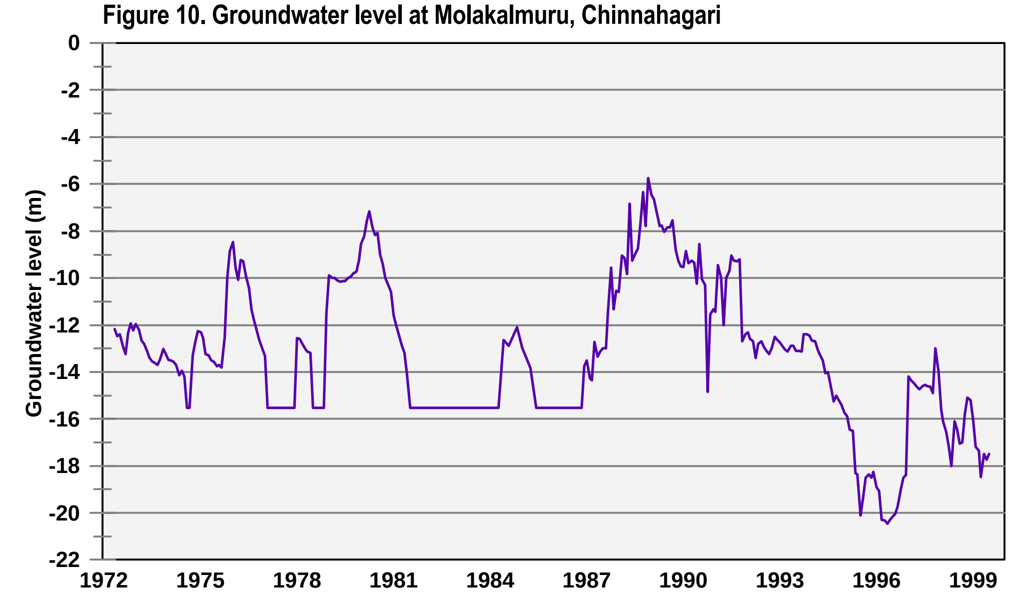
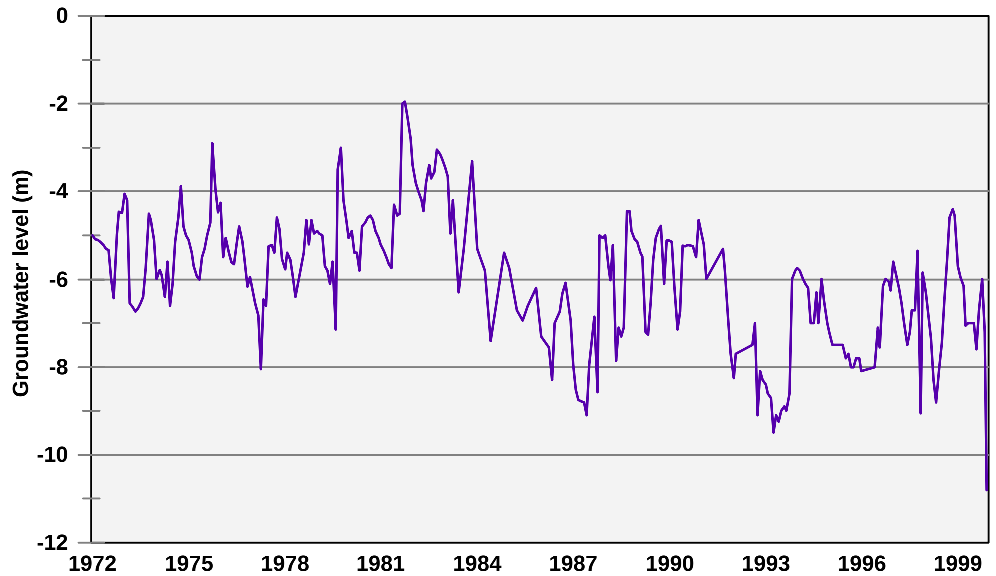


Figure 11. Groundwater level at Chadchan, near Doddahalla



In Doddahalla also, groundwater levels have fallen and many wells fail routinely during the summer season. Figure 11 presents groundwater level data from Chadchan which is a village near Doddahalla. During the period 1972-1986, the average groundwater level was around 5 m below the ground surface. Since 1986, the average groundwater level has been 7 m below ground surface. Given that the water bearing strata in the deccan basalt in this area tend not to be any deeper than 7-10 m, this well has failed or come close to failing on a routine basis in recent years.

The groundwater status of the Chinnahagari and Upparahalla is currently classified as grey[3] whereas the Doddahalla is classified as dark. Arguably, this classification system, which is based on the sustainable yield concept of groundwater development is not applicable to semi-arid areas such as the one in which the project watersheds are located (Moench 1995a and 1995b). The fact that groundwater levels have been falling indicates clearly that extraction rates have been exceeding recharge rates. The reduction in base flow into tanks also supports the conclusion that there has been dramatic regional decline in groundwater levels. A common observation by local people is that ephemeral streams now tend to flow only for a few days after a rainfall event (i.e. storm flow) and that the prolonged flow after rainfall no longer occurs (i.e. base flow). Groundwater levels now no longer rise sufficiently in the rainy season to re-establish the springs and seepage zones that used to support base flows in ephemeral streams.

Groundwater recharge

Table 5 presents estimates of average annual recharge for each of the project watersheds. These estimates were made using the simple water balance equation:

$$R = Q_p + Q_a + R_d + E_t + B_f \triangle s$$

Where:

- R is annual groundwater recharge
- Q_p is groundwater pumped from wells
- Q_a is aquifer throughflow
- R_d is recharge to deep aquifers
- E_t is groundwater extraction by deep-rooting vegetation
- B_f is baseflow contribution to streams
- $\triangle s$ is change in aquifer storage

3 "Grey" classification corresponds to 65-85% groundwater utilisation, "dark" to more than 85% utilisation.

It was assumed that Q_a is very small given the level of regional aquifer depletion and the fact that these are headwater catchments. R_d was also assumed to be negligible because deeper aquifers have not been identified in Doddahalla and extraction is taking place from the deep aquifers in Upparahalla and Chinnahagari. E_t and B_f were assumed to be negligible because of aquifer depletion. $\triangle s$ was also assumed to be small because the tendency during recent years has been for farmers to pump wells until they fail. Hence, recharge was estimated as being equivalent to groundwater extraction for irrigation which, in turn, was estimated using areas under different crops and information gathered locally on actual irrigation application rates for these different crops. In each watershed, drainage was estimated to be 20%, 20% and 10% of water applied during the kharif, rabi and summer seasons, respectively. For Doddahalla, it was estimated that 500 ha was irrigated using water from tanks whereas, for Upparahalla and Chinnahagari it was observed that the areas under tank irrigation were negligible.

It can be seen that the recharge estimates for Upparahalla and Chinnahagari, although different in terms of percentage of rainfall, are very similar in absolute terms. The estimates in Table 5 should be taken as indicative values as, in reality, recharge will be highly variable in space and time and that recharge will be close to zero in low rainfall years and considerably higher than these values in years during which the rainfall pattern favours widespread recharge. The values for Upparahalla and Chinnahagari are similar to published estimates for recharge in crystalline basement areas with similar rainfall, soils, land use and terrain.

Table 5. Estimates of average annual groundwater recharge

	Recharge (% rainfall)	Recharge (mm)
Doddahalla	21.1	121
Upparahalla	5.9	34
Chinnahagari	7.8	37

The groundwater recharge estimate for Doddahalla in Table 5 is higher than many published estimates for deccan basalts. However, the estimate is very similar to estimates published by Macdonald et al (1995) for recharge in an area of Maharashtra with almost the same geology and rainfall as Doddahalla. Another similarity between the two locations is severe depletion of the aquifers. It appears that one positive consequence of groundwater depletion is that average annual recharge increases substantially. This is because groundwater levels no longer approach the ground surface at the end of the monsoon and therefore rainfall infiltration is not rejected due to lack of available storage within the aquifer. Additional confidence can be gained in this study's estimate of recharge by considering Doddahalla's land use statistics. Approximately 25% of the watershed is under irrigated arable cropping and the gross irrigated area approximately 6,400 ha. This high level of irrigation would not be possible without recharge of around 20% rainfall.

Water going to waste in Doddahalla

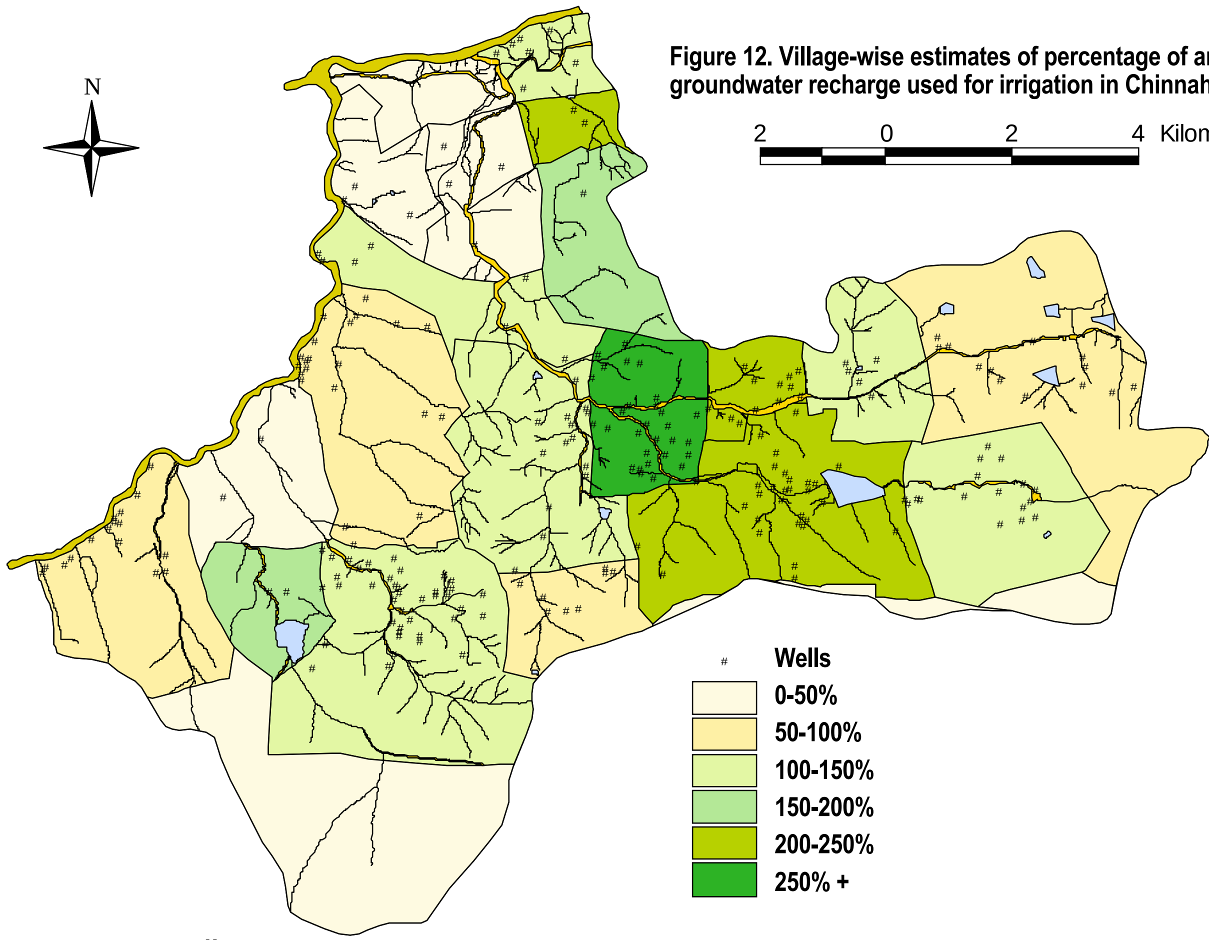


Figure 12. Village-wise estimates of percentage of annual groundwater recharge used for irrigation in Chinnahagari

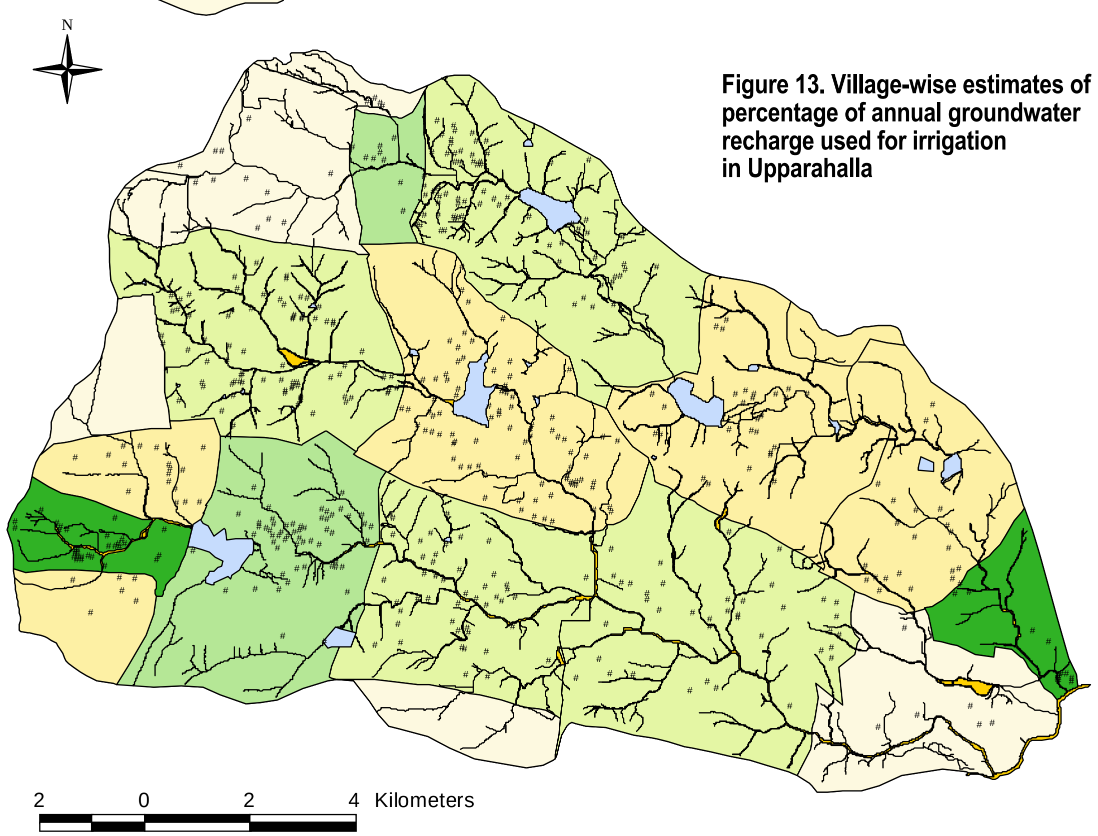


Figure 13. Village-wise estimates of percentage of annual groundwater recharge used for irrigation in Upparahalla

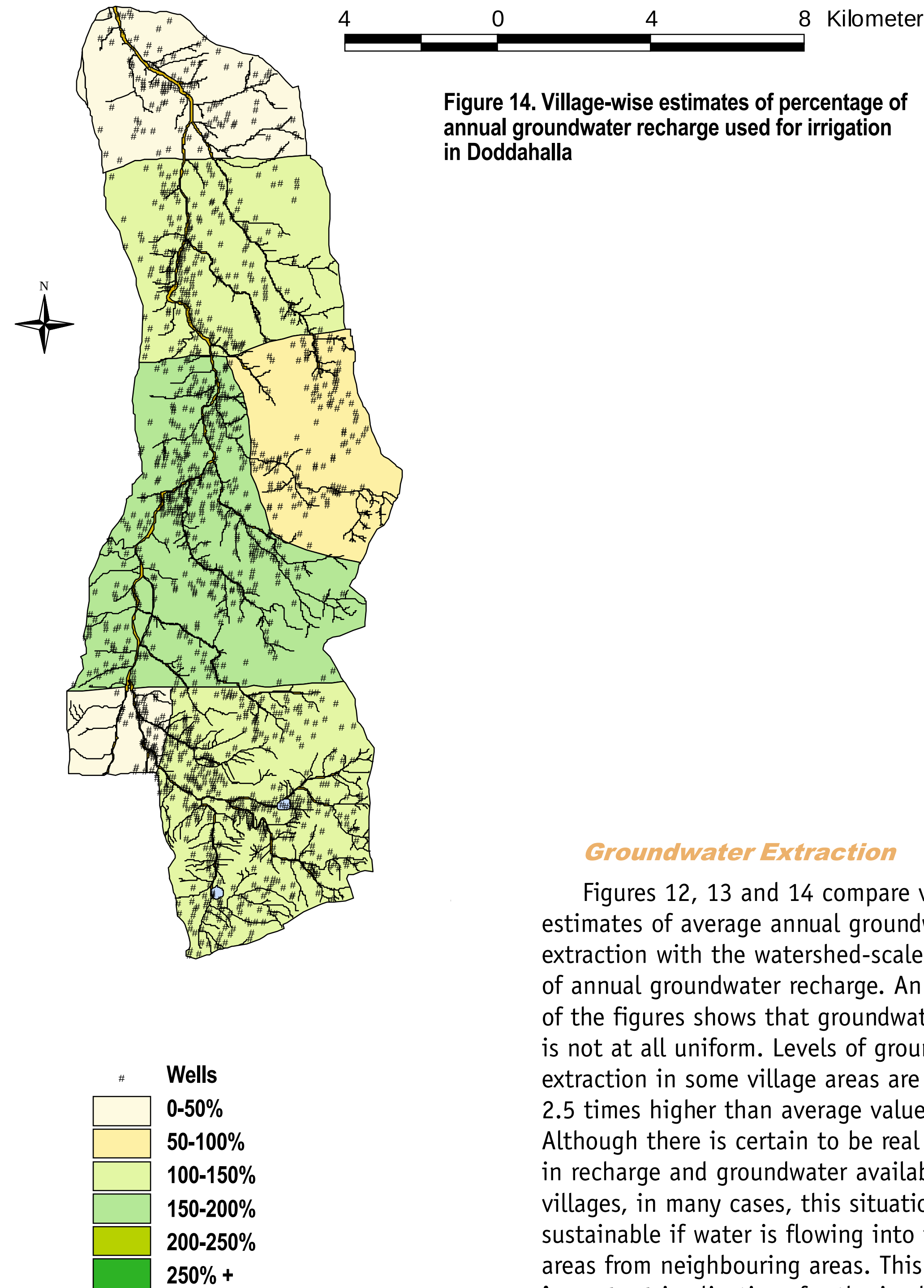


Figure 14. Village-wise estimates of percentage of annual groundwater recharge used for irrigation in Doddahalla

Groundwater Extraction

Figures 12, 13 and 14 compare village-wise estimates of average annual groundwater extraction with the watershed-scale estimates of annual groundwater recharge. An inspection of the figures shows that groundwater extraction is not at all uniform. Levels of groundwater extraction in some village areas are more than 2.5 times higher than average values of recharge. Although there is certain to be real variability in recharge and groundwater availability between villages, in many cases, this situation is only sustainable if water is flowing into these village areas from neighbouring areas. This finding has **important** implications for the implementation of the project. If the project promotes activities that reduce these flows (e.g. by in situ soil moisture conservation), there will be clear winners and losers and not necessarily an improvement in overall productivity or equity at the watershed scale.

Figure 15. Pumps rated at more and less than 5 H P in Upparahalla

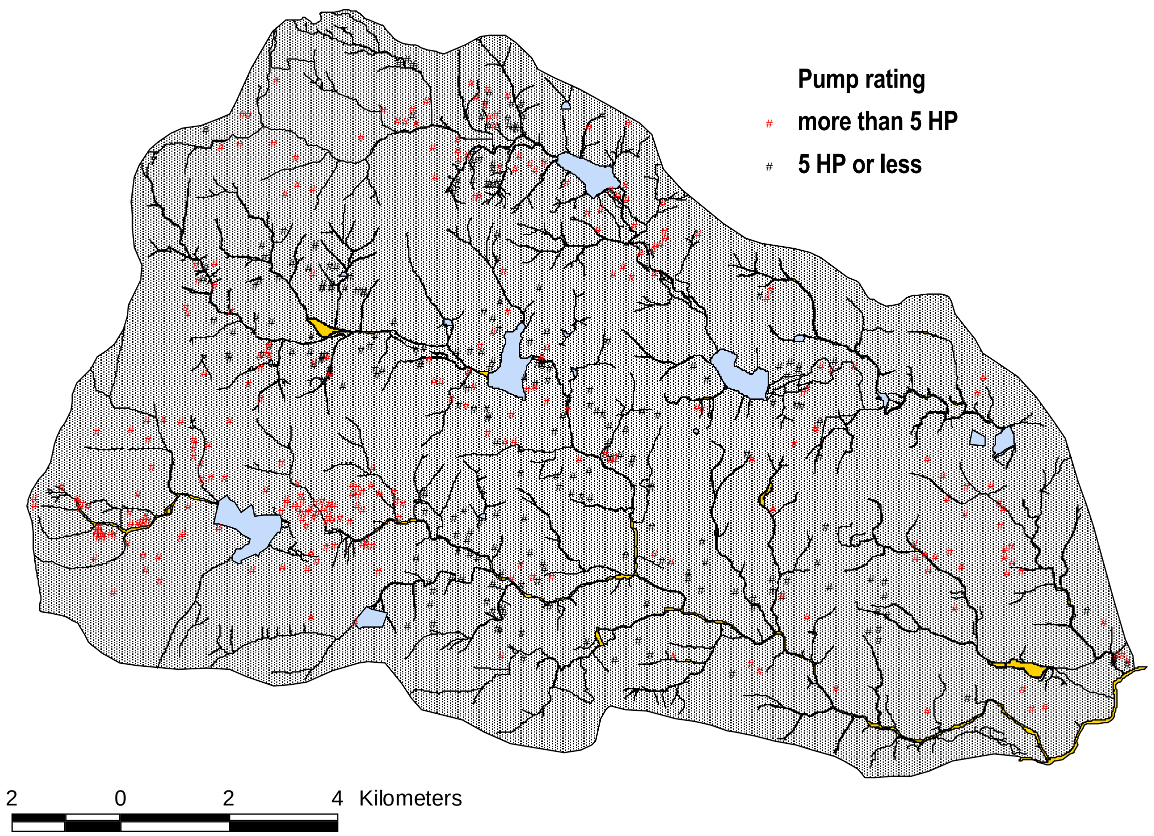
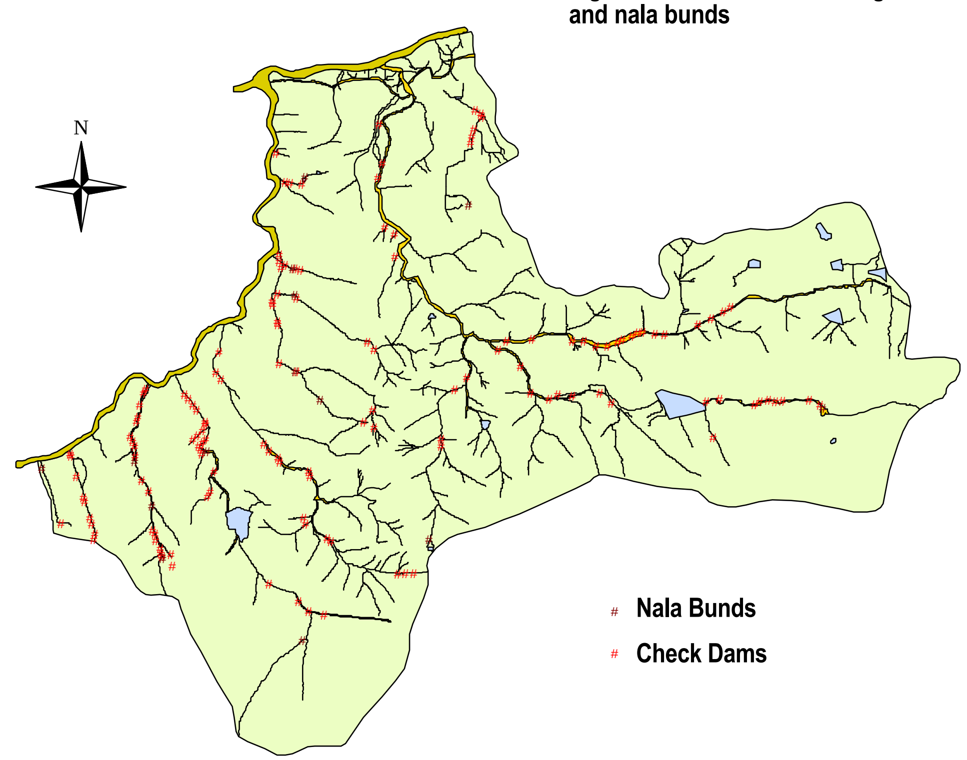


Figure 15 shows the distribution of pumps with submersibles rated at more or less than 5 H P in Upparahalla. It can be seen that there is a relatively higher concentration of higher-rated pumps in the upper reaches of this watershed. A consequence is that villages in the headwater areas are able to extract water more rapidly than would have been the case had they had smaller pumps (or fewer borewells). This enables these villages to utilise water that might otherwise have reached villages further downstream. In contrast, Figure 12 shows that in Chinnahagari there is a greater concentration of wells and groundwater extraction in downstream villages as opposed to in headwater village areas.

Flower sellers at a market in Upparahalla

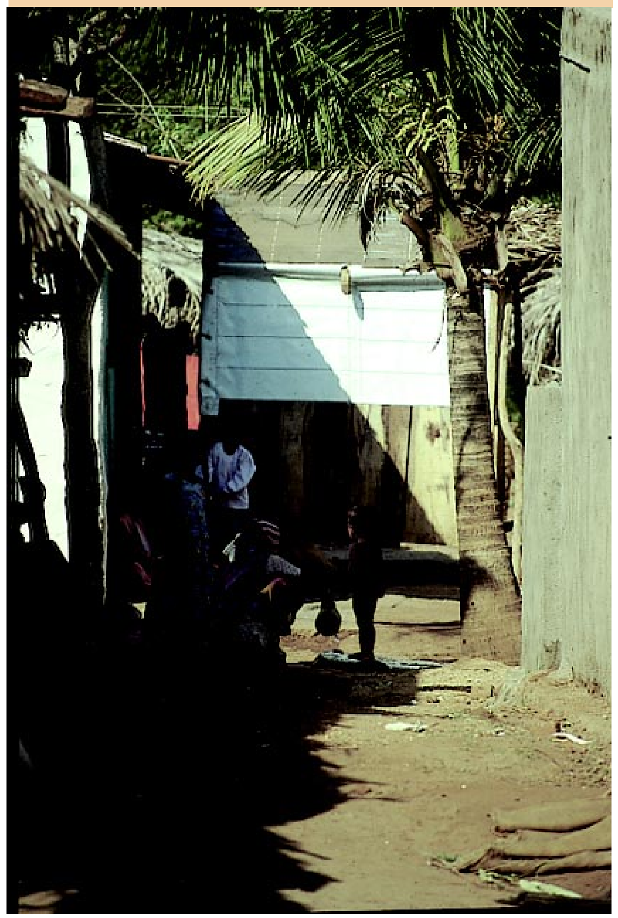
Vegetable market in Upparahalla

Figure 16. Location of existing check dams and nala bunds



Hand pump in Chinnahagari

A street in a village in Upparahalla. Lack of space can be a constraint on rainwater harvesting and storage



Density of wells

Table 6 shows the average density of wells in terms of the area around each well and the spacing between wells. Given that the distribution of wells is far from uniform in Doddahalla and the other project watersheds, it is clear that the government norm (of a 250 m spacing between wells) is not being respected in many village areas. In Doddahalla, farmers recognise that groundwater extraction from wells belonging to neighbours often interferes with the yields of their wells. For farmers with sufficient finances, the normal response is to embark on a programme of well deepening.

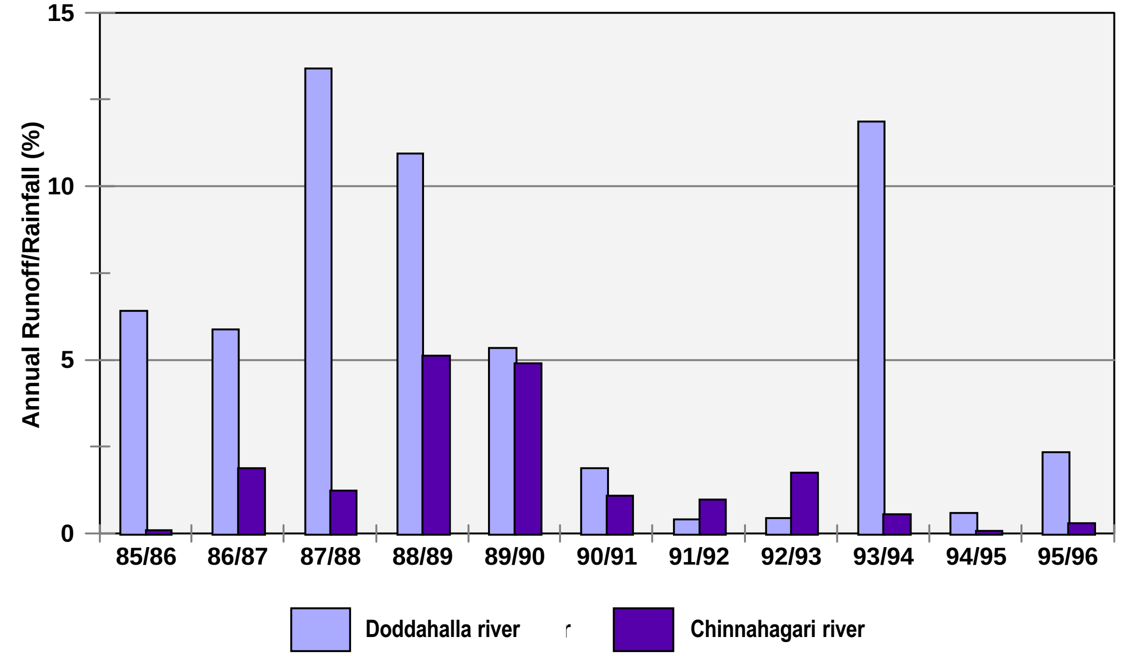
Table 6. Density of wells

	Average area around wells (ha)	Average spacing (m)
Doddahalla	11.3	336
Upparahalla	3.1	557
Chinnahagari	51	714

4.2 Existing water conservation structures

The original design of KAWAD put a strong emphasis on the promotion of activities such as: soil and water harvesting structures, gully checks, gully plugs, nala bunds, improved agronomic practices and tree planting. However, it should be noted that many of these activities have been promoted in project watersheds prior to the commencement of the project. Figure 16 shows the location of check dams and nala bunds that currently exist along drainage lines in Chinnahagari. Although additional structures may be justified in some parts of this watershed, extra structures will not bring about a dramatic change in the overall availability of water resources. There are fewer existing structures in the Doddahalla and Upparahalla. In these watersheds there are small and large nala bunds but no check dams.

Figure 17. Annual rainfall/run-off percentage for the Doddahalla and Chinnahagari rivers



4.3 Surface water resources

Surface runoff

In the project area, annual surface runoff at the large watershed scale is somewhat lower than is often reported or than accepted wisdom would suggest. Figure 17 compares the percentage of rainfall that runs off the catchment areas upstream of gauging stations at Shirdhon on the Doddahalla river and Amkundi bridge on the Chinnahagari river. It can be seen that there is large variation in annual runoff. The average percentage runoff was 5.9% and 1.8% for the Doddahalla and Chinnahagari rivers respectively. These low figures are not surprising given the region's rainfall, landscape and soils and the presence of large numbers of tanks and other structures that retain runoff.

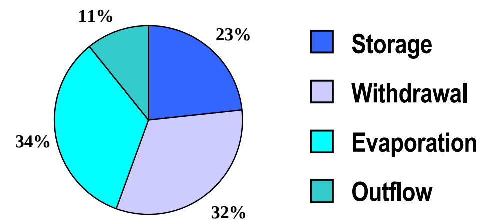
The CSWCRTI (Bellary) has undertaken a number of interesting runoff studies at both the plot and field scale. Mean annual runoff of 8.5% of rainfall has been recorded for field scale (7 ha) experiments on red soils in the GR Halli watershed in an area with no bunding. Concurrent measurements for a micro-catchment (120 ha) in an area with bunding produced an annual runoff estimate that was 2.3% of rainfall. Experiments on run-off from black soils and the effects of different surface treatments have also been carried out at Bellary. Rama Mohan Rao and Chowdary (1994) reported runoff of 2.4%, 5.0% and 8.8% from forest and treated and untreated agricultural land on experimental areas that were 31, 108 and 14 ha in size respectively.

Although the average annual runoff figures given above are low, it should be noted that runoff resulting from individual or sequences of rainfall events will often be much higher than these values. Runoff will also tend to be relatively higher from small plots or from certain features on the landscape (e.g. rock outcrops, roads, areas of hard pan). However, it is the annual large-watershed scale runoff figures that give an indication of the scope for developing additional surface water resources in the project areas. It is clear that there is almost no scope in Chinnahagari and Upparahalla and only limited scope in Doddahalla.

As electricity supplies are unreliable, groundwater is normally pumped into earthern-bunded storage tanks using submersible pumps that switch on automatically whenever power is available. Typical irrigation practices involve releasing water from these tanks along unlined channels to fields that are to be irrigated

Deepening of an open well in Doddahalla. during April 2000. Acute water shortages prompted many farmers in Doddahalla to deepen wells during the 2000 summer season

Figure 18. Narihalla Tank Water Balance 1989/90



Evaporation from tanks

Evaporation from tanks and other perennial and ephemeral water bodies constitutes a large non-productive loss of water in the region. For example, the Narihalla tank has a live storage of 20.87 MCum and a catchment area of 429.4 km^2. During the period June 1989 to May 1990, inflow to this reservoir was 11.29 MCum. Figure 18 presents the balance of outflows, storage, evaporation and abstraction. It can be seen that open-water evaporation constituted around 34% of the water balance in this particular year. In general, evaporation from shallow open-water bodies will be around 2 m depth of water annually.

4.4 Water balance estimates

Figure 19 presents indicative estimates of the components of the annual watershed-scale water balance. This figure shows that the largest component of the water balance in all three watersheds is evaporation. For Doddahalla, evaporation from irrigated areas is highest followed by evaporation from rainfed arable areas and non-arable areas such as government, forest and wasteland area. For Upparahalla and Chinnahagari, evaporation from rainfed arable areas is highest followed by evaporation from non-arable and irrigated areas. In all three watersheds, runoff, evaporation from urban areas and groundwater recession are relatively small components of the water balance. Differences between the watersheds can be explained by differences in the areas under different land uses (see Figure 22). Figure 20 presents indicative estimates of the components of the annual field or plot scale soil water balance. Although evaporation remains the largest component of the water balance at this scale, it can be seen that runoff and groundwater recharge (or deep drainage) become relatively more important.

Figure 19. Estimates of the components of the annual watershed-scale water balance

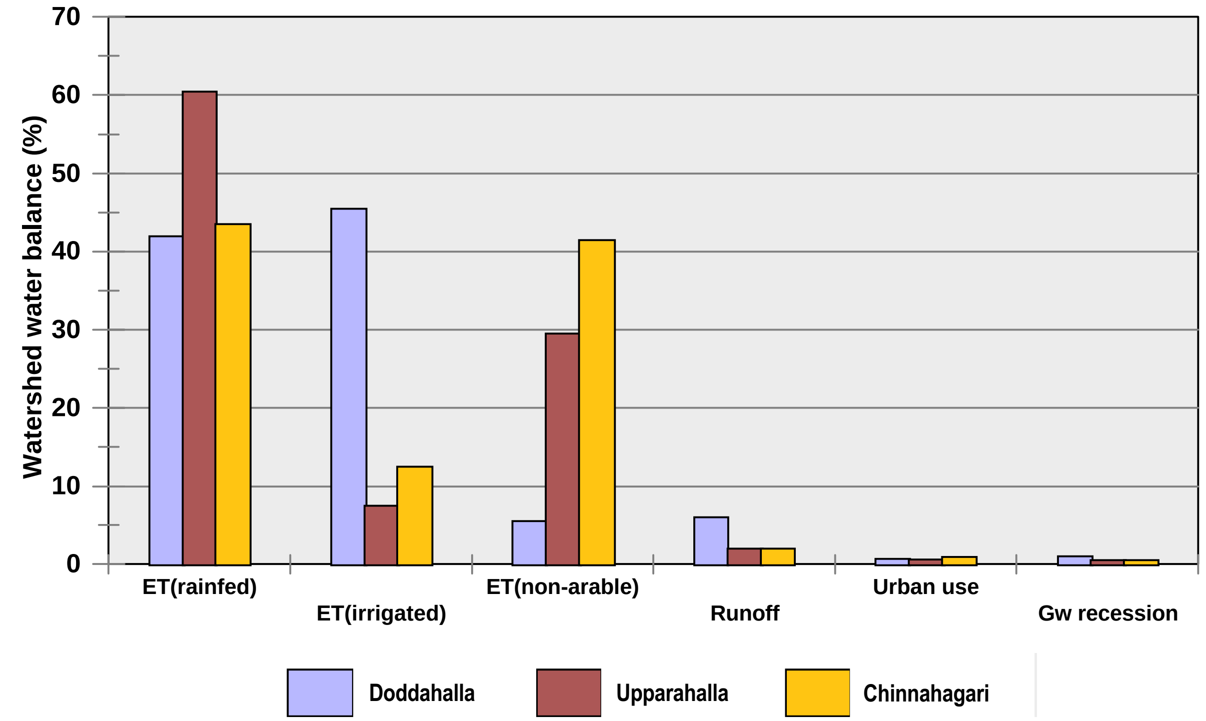
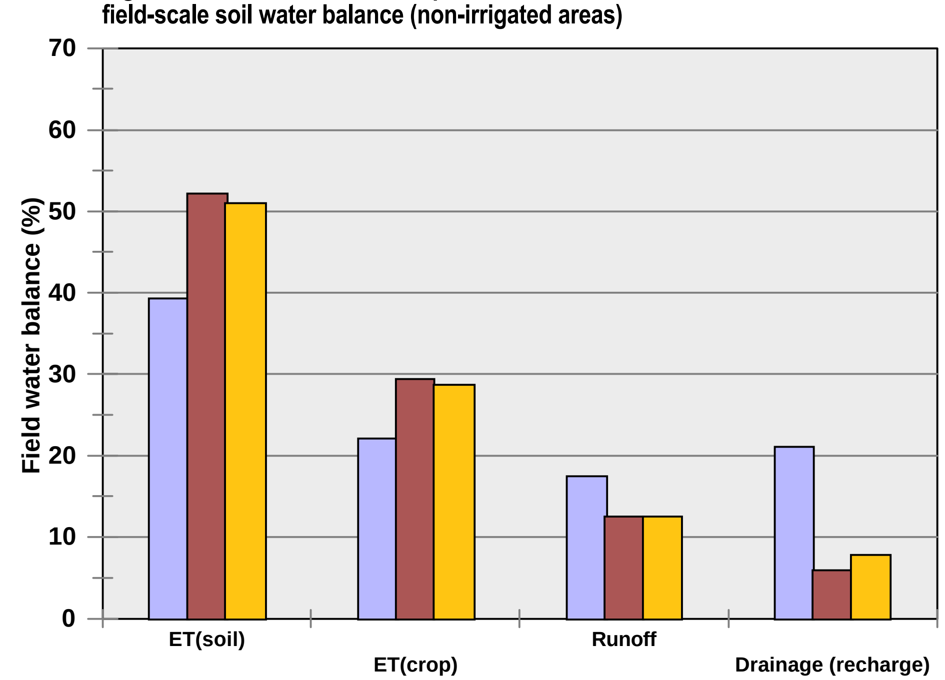


Figure 20. Estimates of the components of the annual field-scale soil water balance (non-irrigated areas)



5 CURRENT AND FUTURE RESOURCE USE

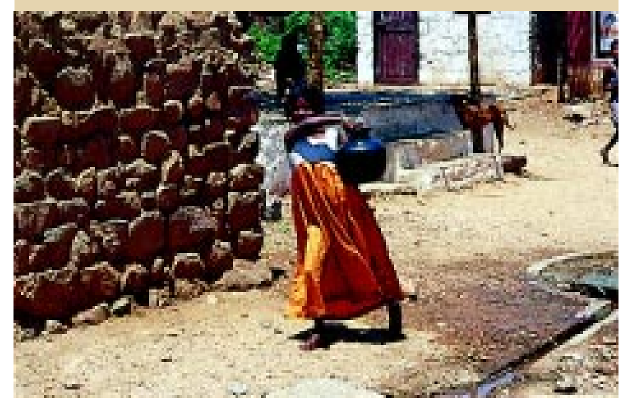
5.1 Domestic Water Supply and Sanitation (WSS)

Current human populations in Chinnahagari, Upparahalla and Doddahalla watersheds are estimated to be approximately 27,000, 34,000 and 29,000 respectively. Domestic water supply is provided almost entirely from groundwater. Groundwater extraction takes place primarily from borewells using hand pumps and, in some villages, using submersible pumps that feed into village water-supply systems. The condition of the village water-supply systems is generally poor. In fact, in some villages the mini water-supply systems have never functioned properly. Sanitation and hygiene awareness programmes have been conducted and are still taking place in all the project watersheds. However, it is clear that there is still much that could be done in this respect.

Discussions with village women and men, during the Water Resources Audit, highlighted increasing problems of water shortage in many of the project villages during the summer season. In most cases, this short supply is a result of well failure, which in turn, is being caused by extraction of groundwater for irrigation.

Large volumes of water are wasted around water points often creating a health hazard

Much of the burden of fetching and carrying water falls upon children



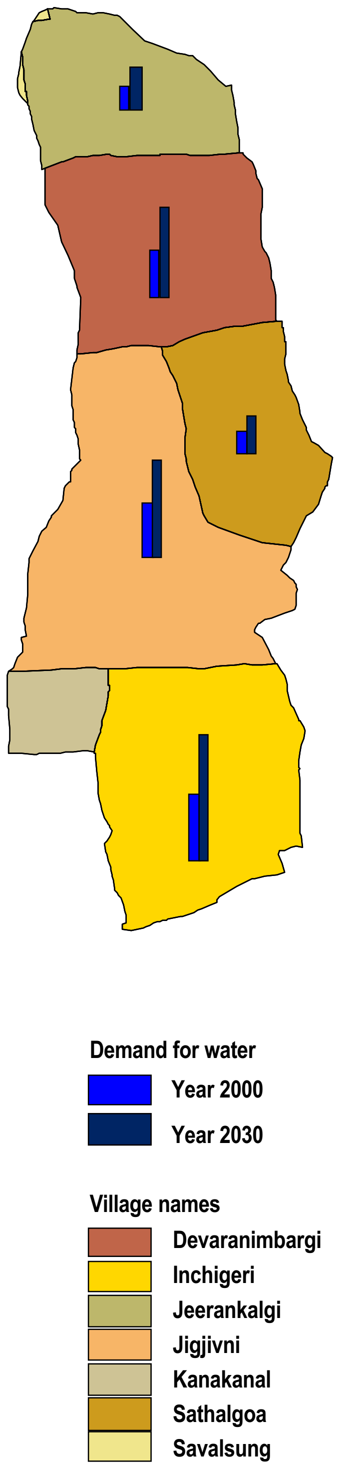
Estimates were made of the current use of water for domestic water supply and sanitation (WSS) and for watering livestock. Estimates were also made of future demands based on human and livestock population growth rates of 2.5% and 1% respectively. A constant figure of 40 litres capita/day (lpcd) was used for WSS use and demand. Figures of 30 and 1.5 (lpcd) were taken as the water use of cattle and small ruminants respectively. Figure 21 presents, in non-dimensional terms, the relative WSS and livestock water requirements of villages in Doddahalla watershed in the years 2000 and 2030. This figure shows that there is some variability in demand between villages and that demand is set to double in the next 30 years. Table 7 presents current and future demand for water as a percentage of average annual rainfall and annual groundwater recharge. It can be seen that in years of normal rainfall, demand for water is currently a small component of the watershed-scale water balance (i.e. of total rainfall). However, in Upparahalla and Chinnahagari, it is already a relatively large percentage of groundwater recharge. By 2030, demand for groundwater in Upparahalla and Chinnahagari will be around 19% and 22% of annual recharge respectively. This becomes a significant demand when one considers that, for this demand to be met in full, some farmers will have to reduce and, in some areas, cease pumping water for irrigation.

In years of low rainfall, competition between urban, livestock and irrigation water users intensifies. When this happens, it is generally the poor that are hit the hardest. Either more time and effort has to be devoted, by women and children, to collecting water from greater distances or more money is needed to buy tanker water.

Table 7. Current and future demand for water for domestic water supply and sanitation (WSS) and for livestock as percentage of average annual rainfall and groundwater recharge

Watershed	Domestic water supply and sanitation & livestock demand			
	Year 2000		Year 2030	
	% rainfall	% recharge	% rainfall	% recharge
Doddahalla	0.7	3.2	1.3	6.2
Upparahalla	0.6	9.8	1.1	19.0
Chinnahagari	0.9	11.6	1.8	22.3

Figure 21. Village-wise annual domestic and livestock water requirements



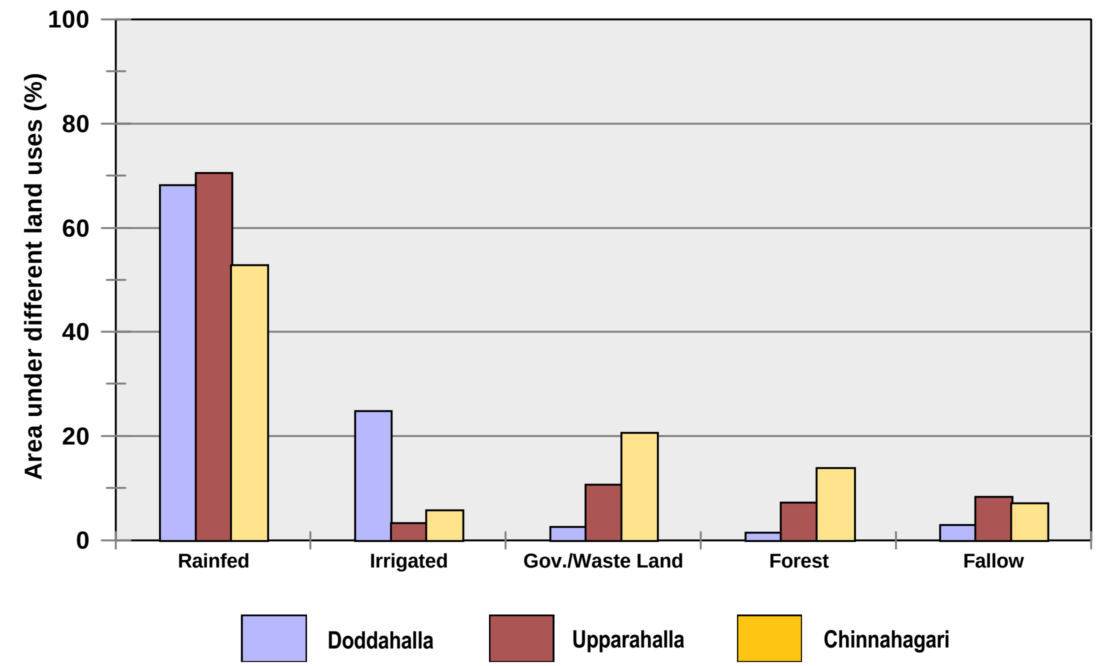
During the summer season and periods of drought, groundwater is the only significant source of water for WSS, livestock and other productive purposes. In the past, levels of groundwater extraction have been such that, in most areas, there have been sufficient groundwater reserves to meet WSS and livestock demands during summer seasons and longer periods of meteorological drought (i.e. periods of low rainfall). These groundwater reserves have provided a buffer that have reduced the shock of drought on livelihoods. As, in much of the project area, this buffer is no longer maintained, groundwater droughts occur frequently, even during normal summer seasons. Competition between urban, livestock and irrigation water users intensifies and as this happens, it is generally the poor that are hit the hardest. Either more time and effort has to be devoted, by women and children, to collecting water from greater distances or more money is needed to buy tanker water from private vendors. Even more worrying is the fact that groundwater extraction is at such high levels in the project watersheds that severe groundwater drought can be expected during the next meteorological drought. The impact on livelihoods and agricultural production will be catastrophic.

5.2 Watershed land use

Figure 22 shows the percentage area of each watershed under different land uses. It can be seen that:

- **Around 70% of Doddahalla and Upparahalla is used for rainfed crop cultivation whereas the figure for Chinnahagari is nearer 50%;**
- **At 25%, Doddahalla has the largest percentage area under irrigation. In comparison, Chinnahagari and Upparahalla only have 6% and 3% of the land area under irrigation;**
- **At more than 20%, Chinnahagari has the largest percentage area of government and wastelands. Doddahalla has the smallest percentage area that is uncultivated.**

Figure 22. Percentage areas of project watersheds under different land uses



5.3 Agricultural land use and irrigation water use

Overview of agricultural land use

Table 8 presents information on cropped areas in the three project watersheds during the 1998-99 season. In all three watersheds, kharif rainfed cultivation represented the largest cropped area. Doddahalla was the only watershed in which rainfed rabi cultivation took place. This was possible, in part, because the black soils in this watershed have higher water retention capacities than the red soils found in the other two watersheds.

Table 8. Distribution of cropped area in the project watersheds (1998-99)

Season	Type of Crop	Area cultivated (ha)		
		Chinnahagari	Upparahalla	Doddahalla
Kharif	Rainfed	6,289	13,229	9,703
	Irrigated	678	610	3,530
Rabi	Rainfed	0	0	4,535
	Irrigated	182	502	2,310
Summer	Irrigated	159	257	536
Total = Gross Cropped Area		7,308	14,598	20,614
Kharif = Net sown area		6,967	13,839	13,233
Total irrigated area		1,019	1,369	6,376

Rainfed agricultural land use

Table 9 shows the distribution of different rainfed crops by area and percentage of cropped area during kharif. It can be seen that:

- **82% and 79% of the cultivated area was under groundnut cultivation in Chinnahagari and Upparahalla respectively with Upparahalla having the largest cultivated area.**
- **Bajra was cropped over a larger area than any other crop in Doddahalla.**

Table 9. Rainfed kharif cropping (1998-99)

Crop	Chinnahagari		Upparahalla		Doddahalla	
	(ha)	%	(ha)	%	(ha)	%
Groundnut	5,169	82	10,419	79	1,266	13
Seteria	340	5	151	1	-	-
Horsegram	278	4	-	-	-	-
Bajra	180	3	11	<1	4,221	44
Sunflower	120	2	545	4	572	6
Redgram	66	1	-	-	43	<1
Ragi	60	<1	417	3	-	-
Cowpea	36	<1	-	-	-	-
Greengram	19	<1	-	-	814	8
Niger	14	<1	-	-	-	-
Jowar	3	<1	723	6	414	4
Til	3	<1	-	-	0	-
Wheat	-	-	-	-	193	2
Vegetables	-	-	-	-	81	<1
Other Pulses	-	-	-	-	1,651	17
Minor Pulses	-	-	-	-	235	2
Others	-	-	923	7	215	2
Total	6,288	100	13,229	100	9,703	100

Crop	Doddahalla	
	(ha)	%
Jowar	3,277	72
Wheat	740	16
Groundnut	196	4
Sunflower	189	4
Vegetables	44	>1
Bajra	9	>1
Other pulses	12	>1
Cotton	34	>1
Redgram	26	>1
Horticulture	2	>1
Others	4	>1
Total	4,535	100

Table 10. Rainfed rabi cropping (1998-99)

Table 10 shows the distribution of rabi rainfed cropping in Doddahalla. It can be seen that jowar was by far the most common crop. The only other crops to be cultivated over significant areas were wheat, groundnut and sunflower.

Table 11. Irrigated land use

Crop	Chinna-hagari (ha)	Uppara-halla (ha)	Dodda-halla (ha)
LONG SEASON CROPS			
Cotton	118	79	195
Mulberry	33	33	-
Sugarcane	-	-	386
Flowers	8	-	-
KHARIF			
Jowar	237	117	141
Paddy	65	66	-
Bajra	-	-	1,086
Ragi	103	24	-
Onion	59	108	-
Vegetables	8	32	67
Maize	16	10	107
Chillies	16	-	-
Groundnut	-	137	499
Redgram	-	-	43
Greengram	-	-	419
Minor pulses	-	-	299
Betal	-	2	-
Sunflower	-	2	212
Horticulture	-	-	76
Tomato	14	-	-
RABI			
Paddy	68	63	-
Vegetables	28	151	52
Maize	31	-	6
Wheat	25	2	591
Jowar	11	22	1,339
Sunflower	10	-	156
Onion	6	-	-
Groundnut	-	264	76
Minor pulses	-	-	65
Horticulture	-	-	25
Ragi	3	-	-
SUMMER			
Groundnut	70	141	392
Jowar	33	-	-
Paddy	28	-	-
Vegetables	13	39	37
Greengram	-	-	54
Horticulture	-	-	13
Maize	-	-	11
Wheat	13	-	5
Sunflower	-	77	24
Onion	3	-	-
Gross Irrigated Area	1,019	1,369	6,376

Irrigated vegetable gardens near Mokalmuru, Chinnahagari

Irrigated land and water use

Table 11 presents the land area under different irrigated crops in 1998/99. It can be seen that:

- **Cotton and mulberry were the main long season crops in Chinnahagari and Upparahalla whereas sugarcane and cotton were the main long season crops in Doddahalla;**
- **In kharif, jowar was the most common irrigated crop in Chinnahagari followed by ragi, paddy and onion. In Upparahalla, the largest area was under irrigated groundnut followed by jowar, onion and paddy. Bajra was by far the most common irrigated rabi crop in Doddahalla;**
- **Paddy and groundnut were the most common irrigated rabi crops in Chinnahagari and Upparahalla respectively. Jowar was the most common irrigated rabi crop in Doddahalla followed by wheat and sugarcane. There was no paddy cultivation in Doddahalla.**
- **In summer, groundnut was the most common irrigated crop in all three watersheds.**

Figure 23. Seasonal irrigated water use (1998/99)

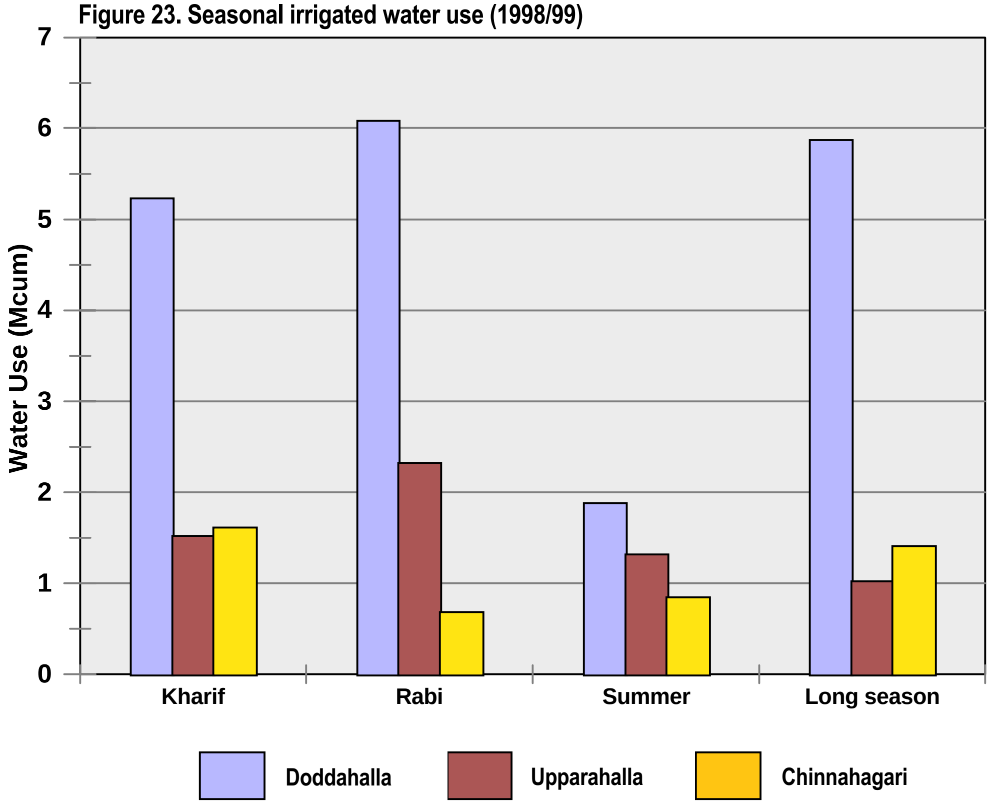
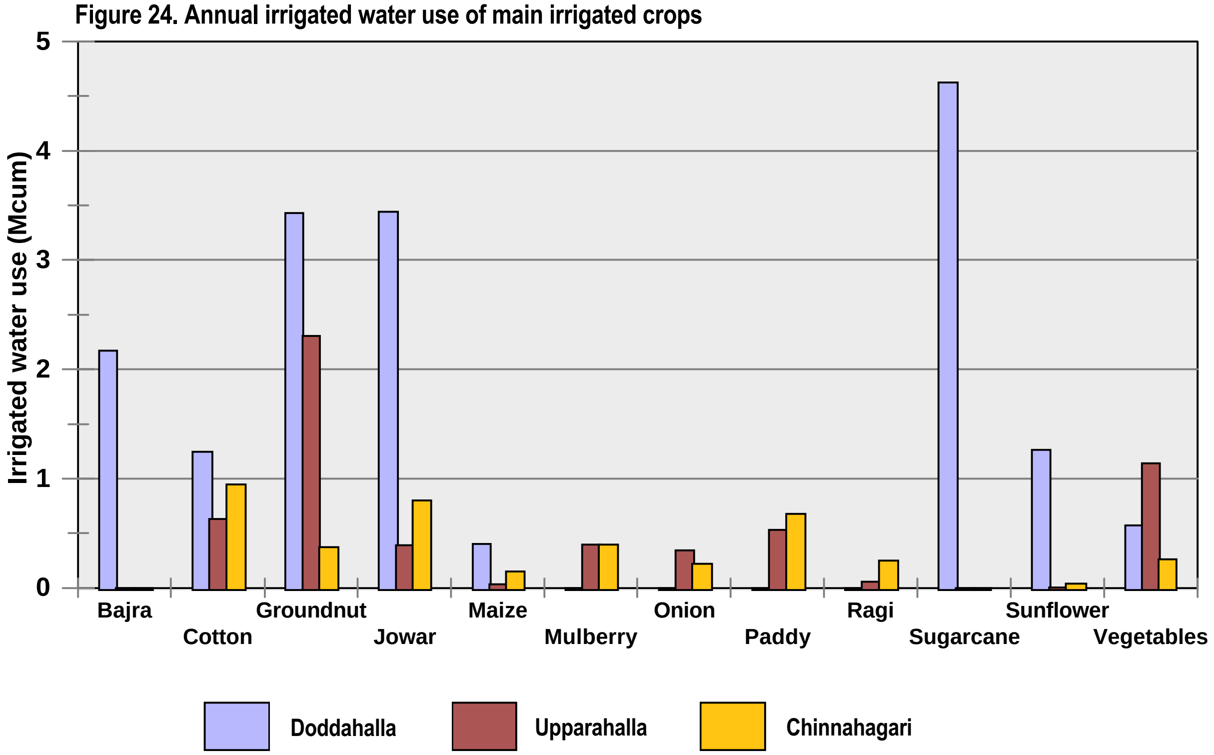


Figure 24. Annual irrigated water use of main irrigated crops



Intercropped sugarcane in Doddahalla

Irrigated cotton in Chinnahagari

Figure 23 shows the total irrigated water use in each of the project watersheds in each crop season based on the 1998/99 cropping statistics. It can be seen that:

- **In every season, more irrigation water was used in Doddahalla than the other two watersheds.This is due, in part, to Doddahalla having the highest groundwater availability and accessibility of the three project watersheds both in terms of groundwater recharge and number of wells;**
- **Seasonal water use was similar in the Chinnahagari and Upparahalla watersheds except during the rabi season during which large areas of irrigated groundnut and vegetables were cultivated in Upparahalla;**
- **The low irrigation water use in all watersheds during the summer season was due primarily to well failure as a consequence of aquifer depletion. Frequent power cuts were also cited by farmers as a reason for reducing irrigated areas during this season;**
- **The water use of long-season crops was highest in the Doddahalla watershed. This was due mainly to the large area of irrigated sugarcane in this watershed.**

Figure 24 presents the total annual water use of the main irrigated crops. It can be seen that:

- **In Doddahalla, sugarcane is the biggest user of irrigation water followed by jowar, groundnut and bajra;**
- **In Upparahalla, groundnut is the biggest user of water followed by vegetables, cotton and paddy;**
- **In Chinnahagari, cotton is the biggest user of water followed by jowar and paddy. Paddy is considered by many to be the largest user of water in Chinna-hagari and Upparahalla. However, the results of this study do not support this perception or the proposition that banning paddy cultivation would significantly improve water availability in these watersheds.**

Figure 25. Yields of rainfed crops grown on red soils and black

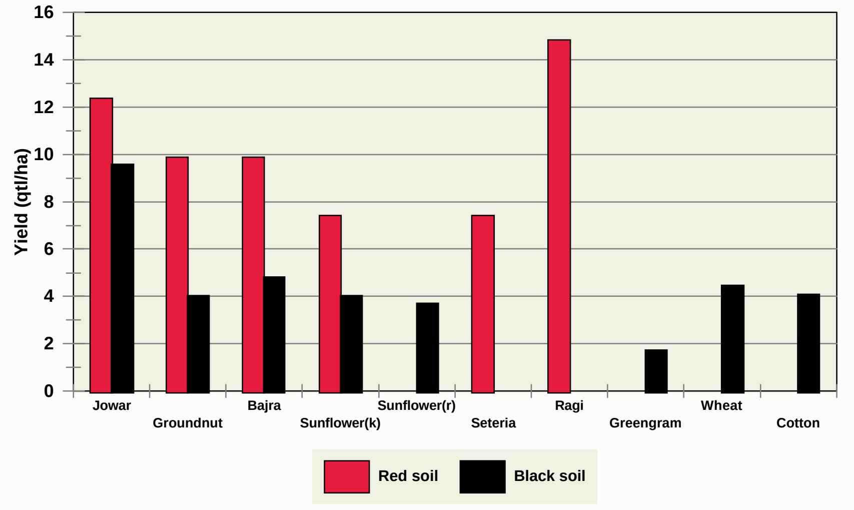


Figure 26. Net revenue of rainfed crops

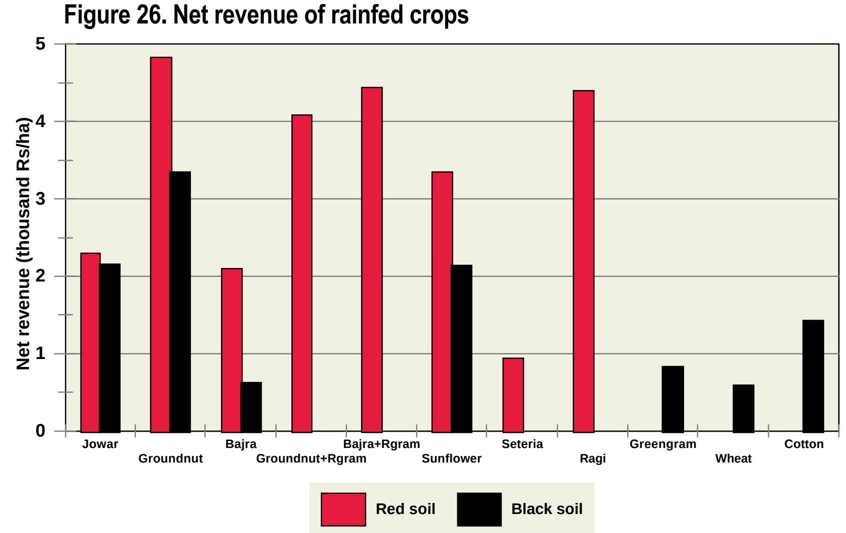
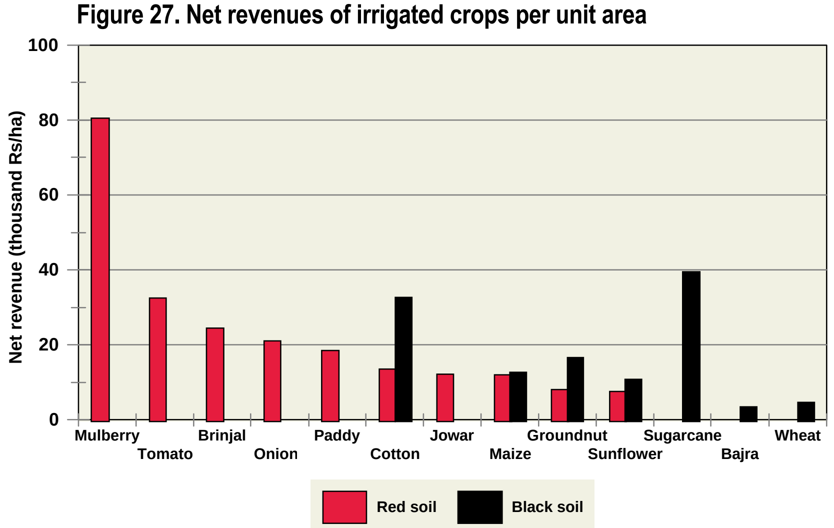


Figure 27. Net revenues of irrigated crops per unit area



5.4 Current crop yields and revenues

Rainfed crops

Figure 25 presents typical yield figures for a range of rainfed crops that are currently being cultivated on red and black soils in the project area. These and other economic data presented in this section are based on field and experimental data and the local knowledge and experience of CSWCRTI, UAS and Dept. of Agriculture staff.

Figure 26 presents the net revenues of some of the main rainfed crops and crop combinations grown in the project area. It can be seen that:

- **On red soils, pure stand groundnut is the most profitable crop in terms of revenue per unit of land, followed by bajra intercropped with redgram, ragi and groundnut intercropped with redgram. On black soils also, groundnut is the most profitable of the rainfed crops for which data are available.**

- **Table 9 shows that, in Chinnahagari, the largest rainfed cultivated area is under groundnut, which also has the highest net returns per hectare. A larger area is under seteria and bajra than under sunflower and ragi, contrary to the net returns per hectare for these crops.This reinforces the observation that the former set of crops is grown for their subsistence and/or fodder value rather than for sale.**

- **In Upparahalla also, the ranking of crops according to area cultivated (in Table 9) reflects relative profitability and subsistence and/or fodder value. Groundnut and sunflower are the two main rainfed cash crops, and ragi, jowar, seteria and bajra are subsistence and fodder crops.**

Well managed furrow irrigation of cotton in Doddahalla

Irrigated crops

Figure 27 presents the net revenue per unit area of some of the main irrigated crops. It should be noted that, for any given crop, net revenue varies considerably as a result of many factors. These include: quantity and quality of inputs, market fluctuations, labour availability, timeliness of cultivation and a range of seasonal factors. Hence, these figures presented here are only indicative. Vegetables, for instance, give revenues of around Rs. 10,000 per hectare in rabi, and Rs. 18,000 in summer. Cotton prices varied from Rs. 1,000 to Rs. 2,000 per quintal in one year alone (1999-2000). Yields also vary: irrigated groundnut yields in summer (14 quintals per hectare) are 40% higher than in rabi (10 quintals per hectare). Notwithstanding the above, Figure 27 suggests that:

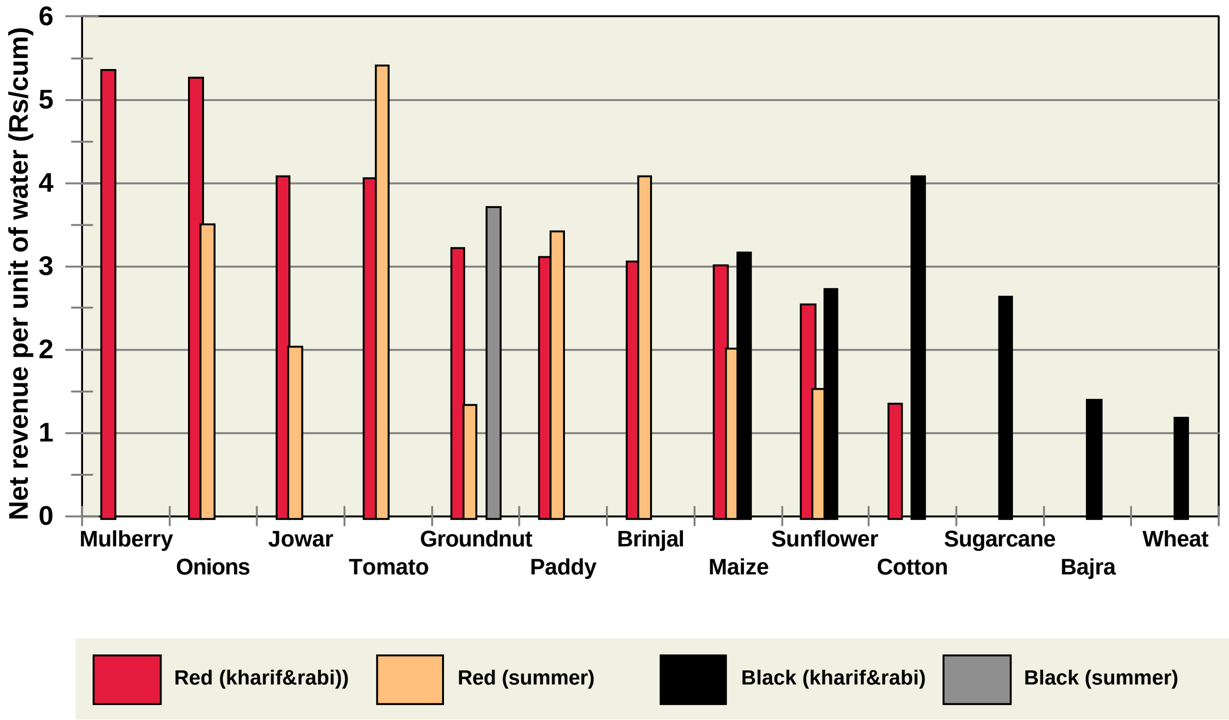
- **Based on single crops in red soil areas, mulberry, tomato, brinjal and onion give higher returns per unit area than paddy. Clearly, however, revenues of crops such as tomato, brinjal and onion will be highly variable and dependent on market fluctuations;**

- **Table 11 shows that among long-season crops, much more land is under cotton than mulberry in Chinnahagari and Upparahalla, despite the latter's higher net return, which probably reflects the high investment and management cost of mulberry. Two major factors constraining mulberry production are the need for space for setting up cocoon beds and the actual cost of production material (e.g. the cocoon beds). Thus, despite the production risk of cotton (for example, from pests) farmers still seem to prefer it to mulberry cultivation;**

- **In Chinnahagari, crops requiring less water (e.g. jowar, groundnut) appear to be chosen over more profitable but more water-intensive crops like onion and mulberry. Water intensive, and high-investment crops like onion and mulberry are grown only by "richer" farmers who can afford the risk and the water needed to grow them;**

- **Table 11 shows that in Upparahalla, a larger total cultivated area is under paddy than onion and sunflower, even though paddy gives a lower net return per hectare than onion or sunflower. But the larger area under onion in Upparahalla than in Chinnahagari suggests that farmers here have overcome the limiting factors noted in the latter**

Figure 28: Net revenues of irrigated crops per unit of water



case. The larger area under vegetables in Upparahalla maybe due to a combination of the relatively high netrevenues of vegetables and market accessibility. Upparahalla is located next to National Highway 13. The area under mulberry is less than warranted by net returns, perhaps for the same reasons as in Chinnahagari (i.e. higher investment required);

- For the black soils, sugarcane produces the highest net revenue. The relative difference in revenues is reflected in the area under sugarcane and cotton (see Table 11). Groundnut, maize and sunflower have the next highest returns per hectare of land. While groundnut has the largest area in summer, bajra is by far the most dominant kharif crop, probably reflecting its subsistence and fodder value. Wheat is grown over a large area in rabi despite its low net revenue. Perhaps this is due to its importance as a subsistence crop.

5.5 Returns per unit of water

Figure 28 presents the net revenues per unit of water of some of the main irrigated crops. Figure 28 suggests that on average:

- For red soils, mulberry and onion have the highest net returns per unit of water, followed by jowar and tomato. Comparison of Figures 27 and 28 shows that there is some similarity between the ranking of returns per unit area and returns per unit of water.
- For red soils, although accepted wisdom is that paddy is a crop that “wastes” water, it can be seen that paddy’s returns per unit of water are similar to irrigated groundnut in kharif and rabi and much higher than groundnut in the summer season.
- Whereas cotton gives a very low return per unit of irrigation water on red soils, on black soils, cotton gives the highest net return per unit of water, followed by groundnut and maize. Sugarcane has a higher net return per unit of water than irrigated bajra and wheat, largely because of its high revenues. As with paddy, this fact tends to undermine the statement that sugarcane “wastes” water. Leaving aside possible equity considerations, it is clear that, in economic terms, sugarcane is an efficient user of water on these soils.
- Somewhat paradoxically, relatively water-intensive crops like paddy, onion, and vegetables have high returns per unit of water, largely because of the higher price they command in the market. More paddy, thus, would bring higher net returns per unit of water.

Figure 29. Potential yield increases for rainfed crops grown on red and black soils

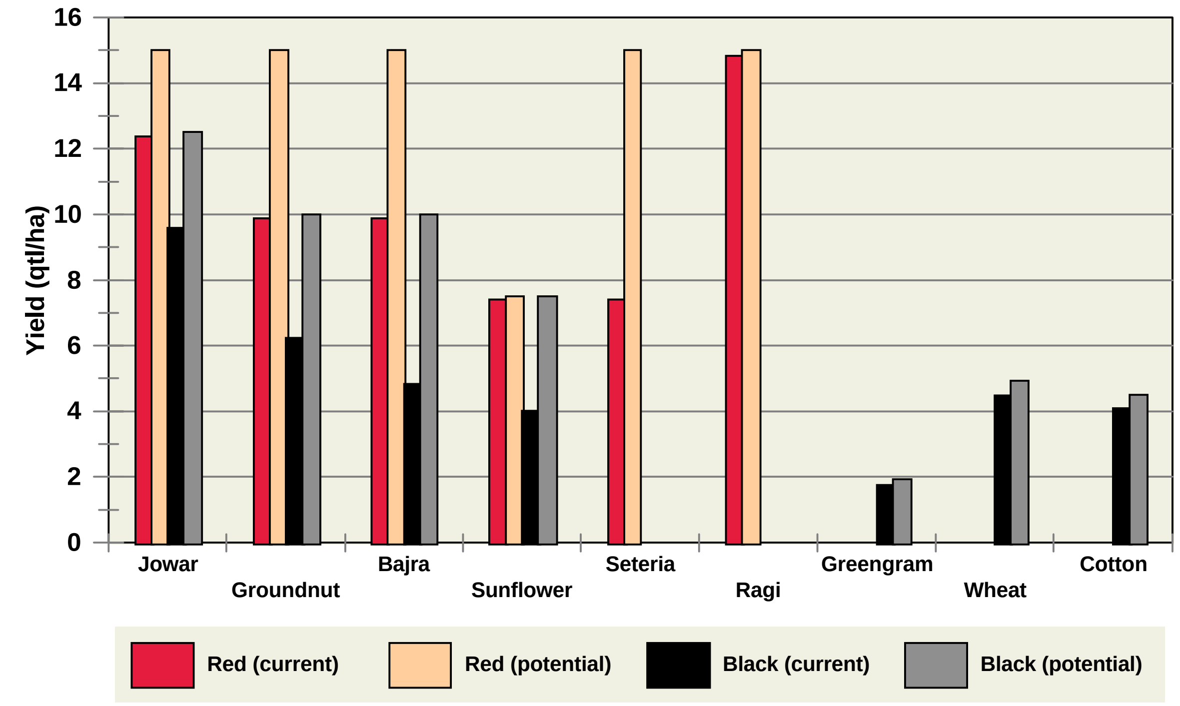


Figure 30. Potential net revenue increases for rainfed crops grown on red and black soils

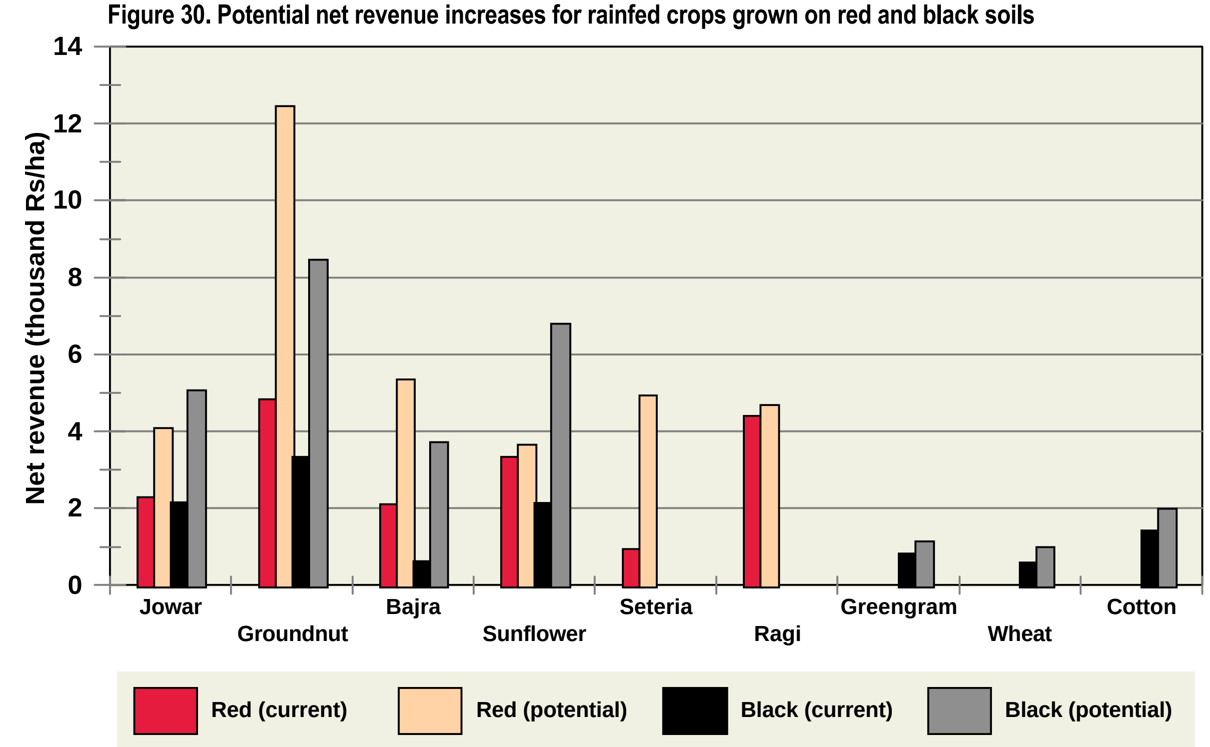


Figure 31. Potential yield increases for irrigated crops grown on red and black soils

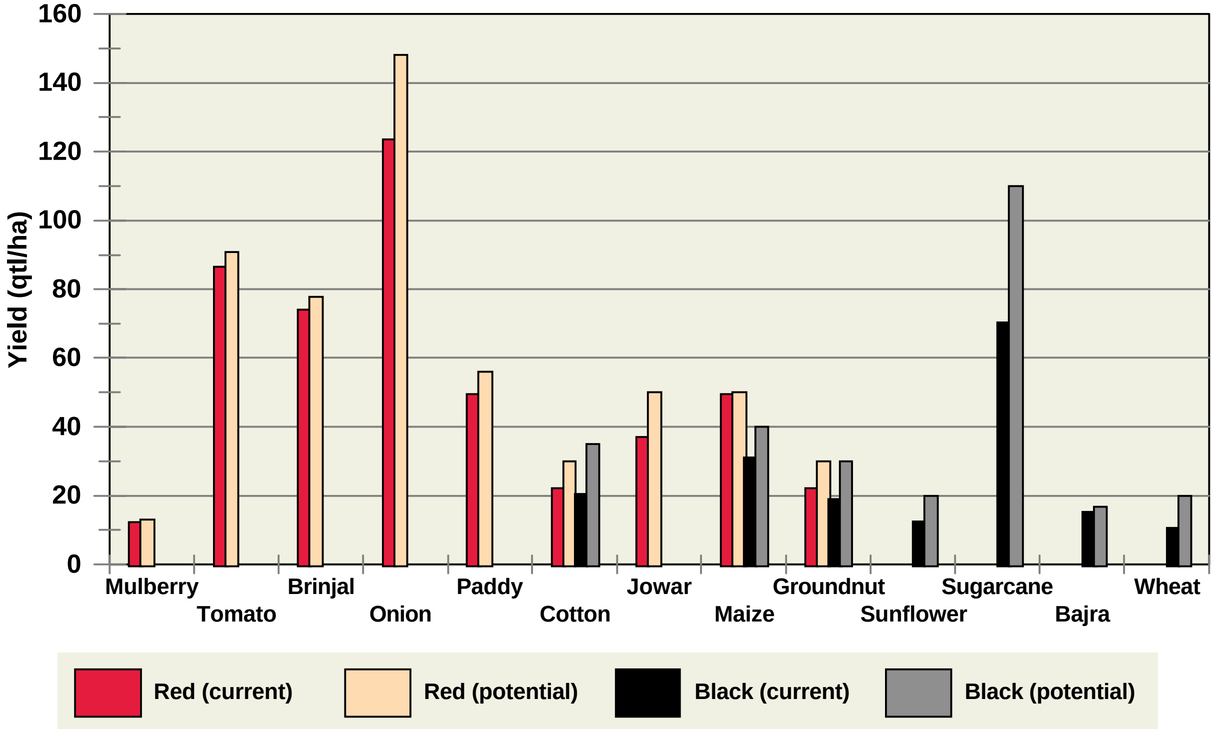
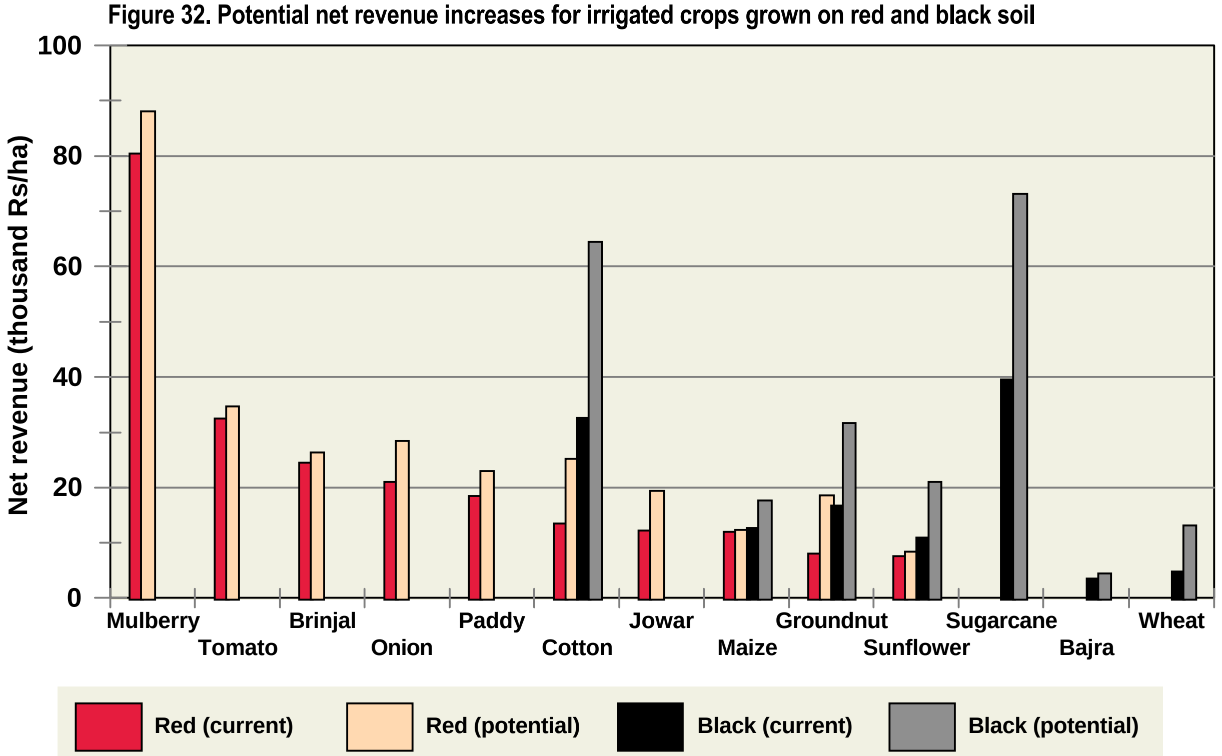


Figure 32. Potential net revenue increases for irrigated crops grown on red and black soil



5.6 Potential yields and net revenues

Potential increases in yield are based on increases achieved in off-station research trials as a result of adoption of a range of improved farming practices that include: improved crop and land husbandry, use of better quality seed and in-situ soil and water management.

Figure 29 presents estimated average yield increases for rainfed crops. It can be seen that relatively larger yield increases can be expected from improved practices with crops such as groundnut, seteria, sunflower and bajra.

Figure 30 presents estimated net revenue increases for rainfed crops. This figure shows that:

- **In principle, large improvements in profitability are possible. Potentially, groundnut will continue to be the most profitable rainfed crop if expected increases in net revenues are realised. This could lead to an increase in the area under rainfed groundnut in all three watersheds, particularly in Doddahalla, at the expense of other cash crops.**

Figures 31 and 32 present estimated average yield and revenue increases for irrigated crops. It can be seen that:

- **There are six crops for which large percentage increases in yield are possible. These are jowar, cotton and onion on red soils, and wheat, cotton and sunflower in black soil areas.**
- **Percentage yield increases are higher for the black soils as compared to the red soils, even for the same crops.**
- **On black soils, the highest additional net revenue that might be expected is around Rs. 30,000 per hectare from sugarcane and cotton. In red soil areas, the potential revenue increases are less with cotton and groundnut expected to bring in only an additional Rs. 10,000 per hectare.**
- **Considering only the crops for which data are available, potential increases in yield and net revenue could result in an average increase in productivity in Chinnahagari equivalent to Rs 4.5 crores of additional net revenue. Around 90% of this additional revenue would come from improved rainfed cropping. Upparahalla could gain nearly twice as much, again mainly from rainfed cropping. In Doddahalla, however, more than two-thirds of the anticipated gain of around Rs 5.5 crores will come from irrigated cultivation.**
- **In principle, improved practices could change the profitability ranking on different crops according to revenue per unit area and per unit of water. In principle also, this might have the wider benefit of improving the watershed-scale productivity of water use. However, it is unlikely that improved cropping or irrigation practices alone will lead to improved equity of water use or reduced competition between agricultural and urban (i.e. village) water users. In cases where improved practices might lead to more efficient and lower water use per unit area, any water that is "saved" is likely to be used for increasing the area irrigated, given that it is water and not land area that tends to be the limiting factor for most farmers.**

Producing compost in a vermiculture pit in Doddahalla

6 CHALLENGES AND CONSTRAINTS

6.1 Is KAWAD a "sustainable livelihoods" project?

Although KAWAD was originally conceived as a watershed development project, it has become increasingly clear that the project needs to adopt a sustainable rural livelihoods approach (see Box 1) if it is to meet the sometimes conflicting challenges of improving productivity and reducing poverty. Hence, KAWAD is considering all aspects of the activities through which the rural communities and, in particular, the poor gain the means of their livelihoods, the 'assets base' on which these activities are based and the external factors that condition access to and the sustainability of these assets. In cases where the project does not have resources to support or promote certain livelihood activities (e.g. for improving domestic water supply and sanitation), the project is adopting a facilitatory or intermediary role, whereby the project is improving the capacity of communities to access and/or demand services or support from outside the project.

Box 1 *Sustainable Rural Livelihoods*

Livelihoods in the project watersheds are intimately linked to the availability of water and other natural resources. However, people, and the poor in particular, need access to and control over a wider range of capital assets if they are to have sustainable livelihoods (see Ambler, 1999). These additional capital assets include:

- **_Physical capital_ - refers to the basic infrastructure, goods and services needed to support livelihoods (e.g. water supply and sanitation systems, affordable transport, shelter, energy etc.).**
- **_Social capital_ - refers to relationships of trust and reciprocity that support cooperative action, membership of formal and informal groups and networks that increase people's ability to work together and access institutions and services. Formal law (statutory and religious) and informal law (customary) can also be seen as forms of social capital.**
- **_Human capital_ - refers to the skills, knowledge, beliefs, attitudes, ability to labour and good health that enable people to pursue different livelihood strategies.**
- **_Financial capital_ - refers to the financial resources including savings, credit provision and regular inflows of money (e.g wages, remittances, subsidies etc.).**

All of these assets come into play in the development and management of natural resource assets. KAWAD can play an important role in helping improve these assets and hence the livelihoods of people in the project watersheds.

6.2 Water-related issues

The main water-related issues that need to be addressed in all three project watersheds include:

- **Generally low and erratic land-based productivity;**
- **Inefficient and, in general, low productivity of agricultural water use at all scales;**
- **Domestic water supplies that are becoming increasingly threatened as a consequence of groundwater depletion and increasing demand;**
- **Poor or non-existent management of common-property resources (e.g. government lands, tanks, groundwater);**
- **Inequitable access and entitlements to water and land resources;**
- **Increasing risks of aquatic pollution, particularly, in urban and peri-urban areas.**

6.3 Water-related constraints common to the KAWAD watersheds

When addressing the issues listed above, there are a number of fundamental constraints that are relevant to all three watersheds. These constraints limit the number of resource-focused options that can and should be promoted by KAWAD. Water-related constraints common to all three KAWAD watersheds are:

- **_Climate_: The climate of the area is semi-arid and, consequently, rainfall is extremely variable in time and space. Hence, groundwater recharge and runoff into tanks is also extremely variable, as is the productivity of rainfed arable and non-arable lands.**
- **_Aquifer characteristics_: The watersheds are underlain by hardrock aquifers that store only limited quantities of water in shallow weathered and deeper fractured layers.**
- **_Water resource availability:_ Current usage of water resources approximates to annual replenishment and there are no additional surface water resources that can be developed (e.g. rivers flowing into or through the area).**
- **_Government policy_: Currently, there are no incentives or disincentives to encourage individual water users to maximise water use efficiency and/or productivity. In fact, many government policies have the unintended effect of encouraging individuals and, particularly, farmers to be inefficient in their water use. Although new groundwater legislation is in the process of being ratified by the Government of Karnataka, it may take some time before the effects of this legislation are seen at the village level.**
- **_Specialist knowledge_: Although specialist knowledge and experience exists, this is not always readily available to or used by villagers and/or the implementors of watershed development programmes.**
- **_Population increase_: Year by year a larger proportion of groundwater recharge and surface storage is needed to meet domestic and urban water requirements. As a consequence, the water available for other uses is reducing. It should also be noted that, with increasing population, the proportion of the population that can base its livelihood on land-based activities is decreasing.**
- **_Small and fragmented land holdings_: In general, farmers have fragmented holdings and this makes good husbandry and good water management difficult.**
- **_Encroachment of common property land_: In many areas, common property land (e.g. Government Land) has been encroached.**
- **_Indebtedness_: Small and marginal farmers tend to have high levels of debt. Debt repayments and the cost of borrowing reduce their ability to use land and water resources efficiently.**

Self-help group meeting in Siddayyanakote village, Chinnahagari

- *Corruption:* Even low levels of corruption can have a bearing on the implementation of watershed development projects. Dubious practices, for example, can influence levels of participation, whether or not wells or water supply schemes are constructed and the quality of materials and workmanship

- *Electricity supplies*: Frequent and prolonged power cuts, particularly during summer months, encourage farmers to overirrigate when power is available.

- *Labour*: In general, there is a lack of labour during rabi and summer seasons due to migration.

- *Awareness*: In general, there is a lack of awareness, at all levels, of the severity and complexity of water resource problems in the project watersheds. There is also a belief, generated in part by watershed development propaganda, that there are quick fixes to these problems.

6.4 Water-related constraints specific to individual project watersheds

Chinnahagari watershed

- *Agro-climate*: At 472 mm Chinnahagari has the lowest mean annual rainfall of the three project watersheds. Low and highly variable rainfall, combined with the low water holding capacity of the red soils, makes this a precarious area for rainfed crop production even when soil water conservation measures are used.

- *Water resources*: Over-extraction of groundwater primarily for irrigation has led to drying up of shallow wells and reduction of inflows to tanks. Variable fracturing in the hardrock layer of the crystalline basement aquifer means that sites for productive boreholes are limited to only those areas with fracturing and good recharge.

- *Water quality*: Groundwater salinity affects the drinking water supplies of Molakalmuru and the suitability of water in some areas for irrigation.

- *Water harvesting structures*: Large numbers of water harvesting structures (e.g. check dams and nala bunds) already exist. Additional structures will affect the distribution of runoff but not necessarily the total volume of water harvested.

Upparahalla watershed

- *Agro-climate*: As compared to Chinnahagari, Upparahalla has a higher mean annual rainfall at 576 mm. However, as both watersheds have red soils with low water holding capacity, rainfed crop production is sensitive to mid-season dry spells.

- *Water resources*: As in Chinnahagari, over-extraction of groundwater primarily for irrigation has led to drying up of shallow wells and reduction of inflows to tanks. The fact that existing borewells are more uniformly distributed in Upparahalla suggests that fracturing in the hardrock layer may be more uniform than in Chinnahagari.

- *Water harvesting structures*: Although there are some nala bunds, there are no check dams in Upparahalla. However, as the tanks in this watershed rarely spill, construction of check dams will affect the distribution of runoff but not the total volume of water harvested.

Doddahalla Watershed

- *Agro-climate*: At 573 mm, Doddahalla has similar rainfall to Upparahalla. This combined with the relatively higher water holding capacity of the black soils makes this watershed more suitable for rainfed cropping and double cropping in the rainy season. However, years of lower than average rainfall and periods of mid-season drought occur frequently.

- *Water resources*: The deccan basalt aquifers in Doddahalla are not suited to deep borewells except in the north of the watershed where fracturing can occur to depths of 70-80 m. Doddahalla has by far the highest density of wells of the three watersheds. Wells tend to be concentrated in areas on either side of the drainage lines. As the water table at the end of the dry season is normally at the base of the aquifer, additional wells will only impact on the distribution of access to groundwater and not the total resource available.

- *Water harvesting structures*: Although there are some nala bunds, there are no check dams in Doddahalla. There is some limited scope for making better use of runoff in this watershed.

6.5 Water-related risks

Experience in the region has shown that there are a number of water-related risks associated with watershed development. These result in part from the very nature of participatory watershed development and in part from the promotion of inappropriate interventions. Risks include:

- *Increased borewell construction and increased irrigation by individual landowners*: In most cases, the prime motivation of farmers to become involved in soil water conservation and the construction of water harvesting structures is not altruistic. It is to increase the water resources that are available to them for irrigation. At the watershed scale, this is justified only if the resources that are being "harvested" do not have higher economic and social value if they are put to other uses.

- *Increased borewell construction and increased irrigation by "poor" landowners*: Successful watershed development projects often improve the financial status of relatively poor farmers such that they are able to take loans for constructing borewells and installing pumps. As above, this is fine as long as the water they "harvest" does not have alternative higher-value uses (e.g. as a source of domestic water supply).

- *Deterioration in village water supplies*: There is a risk that project interventions will lead to increased pumping of groundwater for irrigation in urban and peri-urban areas and that this will cause failure of village water supplies during the summer months. Additionally, project interventions could lead to increased consumption of water: per household, by livestock, by horticulture within the village and by non-land-based activities.

- *Conflicts within villages and between villages*: Some interventions, that involve changing land use or patterns of water availability and use, result in distinct winners and losers. If there is a risk of this happening, conflicts should be managed by ensuring that losers are compensated in some way. As above, decisions on whether an intervention should take place should be based on economic and social value.

- *Reduction in net productivity*: There is a risk that promotion of interventions with a high social value will lead to reductions in net productivity at the village or watershed scale. For example, using water for irrigation on marginal lands (usually owned by poorer farmers) will tend to be less productive than using the same water on better quality land (usually owned by relatively richer farmers). Ultimately, determining the balance between acceptable social and economic value is a political decision.

- *Increase in environmental degradation*: It is generally assumed that increase in forestry equates to environmental improvement in watersheds and that this is sufficient. In many cases, increased forestry will lead to significant improvements in biodiversity, particularly if indigenous tree species are planted. There are risks, however, that changing patterns of land and water use and, hence, the hydrology of watersheds will lead to reduction in biodiversity in areas other than forested areas (e.g. in wetland areas). There is also a risk that project interventions will adversely affect water quality.

Washing clothes: Resulting waste waters can be used to irrigate backyard horticultural crops. Note also the roof drain pipes - water from roofs can be collected in water tanks and cisterns and used for a variety of purposes

7 SELECTION OF WATER-RELATED OPTIONS

7.1 General framework for selecting options

Where appropriate, recommendations in Section 8 have been laid out in the form of option tables and decision trees. This is in recognition of the fact that the project is not taking a "top down" approach and final selection of options rests with individuals (e.g. farmers, self-help group members) and village-level institutions. It is important, however, that the KAWAD Society, PIAs, NGOs and village-level organisations promote options that are either "win-win" interventions or that, potentially, have the highest net economic or social value. In most cases, these will be options with the lowest negative tradeoffs. It is important also, that the KAWAD Society, PIAs, NGOs and village-level organisations promote options that are consistent with the project's wider objectives (see Box 2).

Drip irrigation of pomegranate. Many farmers of Bijapur district are successfully using drip irrigation

An NGO planning meeting in Upparahalla

Box 2 *KAWAD's Wider Water-related Policy Objectives*

For KAWAD to be successful, it needs to demonstrate improvements in productivity, equity and sustainability:

- **on spatial scales ranging from the land holding, to the micro-watershed, to the macro-watershed;**
- **on demographic scales ranging from the individual to the household, to the village, to a cluster of villages;**
- **on time scales from a few years to many years into the future.**

This cannot be achieved by village-level participatory planning alone. Hence, the KAWAD Society, PIAs and NGOs must take responsibility for ensuring that village level plans are consistent with wider objectives that include:

- **Inter-village equity and/or upstream-downstream equity;**
- **Rural-urban equity and anticipated increases in demand for water in urban and peri-urban areas and by industrial users;**
- **Inter-generational equity and consequences arising from demographic change and increased demand for water per household;**
- **Protection of biodiversity and rare habitats in a given micro-watershed;**
- **Protection of surface and groundwater from pollution whether this be domestic, agricultural or industrial;**
- **Flood protection. Poorly-rehabilitated tanks can pose a threat to communities living downstream.**

A privately owned water tanker being filled. As competition and demand for water rises, water tankers are becoming an increasingly common sight in North East Karnataka

It can be anticipated that participatory planning at the village level will lead to the selection of options that are outside the scope of the project or inconsistent with the project's wider objectives. In the first case, it is recommended that KAWAD act as a broker, facilitator or intermediary. In the second case, it is recommended that resources are not made available for the relevant activities or interventions. In such cases, transparency is vital and every attempt should be made to promote alternative options.

It is recommended that decisions with respect to resource allocation for different options be dependent, in part at least, on M&E information. NGOs and PIAs should submit M&E information from the preceding year(s) along with annual budget plans. Relatively more resources should be directed to activities that have been shown to produce good results or positive trends.

7.2 Water-related tradeoffs and "win-win" options

Opportunities for improving water use efficiency or productivity in the project watersheds fall into four categories:

- **Increasing output per unit of evaporated water;**
- **Reducing pollution and degradation that diminishes the value of usable water;**
- **Reallocating water from lower valued uses to higher valued uses in both financial and social terms;**
- **Reducing losses of usable water to sinks.**

All the options listed in Section 8 fall into one or more of the categories listed above. Wherever possible KAWAD should promote win-win options. Unfortunately, when a range of scales is considered, there are few options that can be classified as being win-win regardless of the physical and social setting. Hence, matching options to a given setting is crucially important. It should be noted also that most options have tradeoffs or risks associated with them if implemented incorrectly.

People queueing to buy water from a tanker. In this case Rs 15 per day was being charged as a flat rate for the delivery service. Quantities of water provided for this charge was varying from day to day

7.3 Drinking water supplies

If the project is to improve the livelihoods of the poor and, in particular poor women and children, it must promote options that lead to improvements in village water supplies and, clearly, it must not support options that could potentially lead to deterioration in domestic water supplies. It is recommended that the project consider India's official approach to groundwater development[4] when selecting options. This consists of two main themes which are: 1) the natural right of the population to basic resources (such as drinking water) that are necessary for survival and; 2) maximising irrigation development in order to achieve food security. The National Water Policy gives first priority in water allocation to "fundamental rights" for drinking and domestic use. Agriculture has second priority followed by industry.

In higher rainfall areas, groundwater can be treated as a renewable resource as the probability of low rates of groundwater recharge in any given year is small. This is not the case in lower rainfall areas that, in particular, are underlain by hardrock geologies. In these areas, aquifer storage (storativity) is generally low, movement of water (related to permeability) can be very slow and recharge rates tend to be low and localised even in years of normal rainfall. In drought years, recharge rates will be even more localised and close to zero. Hence in areas in which groundwater is the main (or only) water source, there is a fundamental need for a groundwater "buffer" that can be used as a source of supply during long periods of drought when "renewal" of groundwater does not take place. Increased depth and density of wells and increased groundwater extraction has meant that, for many villages in the project area, groundwater "buffers" have become smaller and smaller. The net result is that the number of years in which groundwater drought is being experienced, by the poor in particular, is increasing as is the scale of the shock to livelihoods. Selection of options should reflect this fact.

4 See Moench (1995a and 1995b) for a more detailed discussion.

8 GENERAL WATER-RELATED RECOMMENDATIONS AND OPTIONS

8.1 Project implementation

As far as resources are concerned, management rather than development is the fundamental need in the project watersheds. The findings presented in this report have shown that the scope for developing **additional** water resources is limited. Hence, the focus of KAWAD should be on improved, long-term management of **existing** water resources. Although there are some "win-win" management options that can be adopted, in most cases, changes in water management in one part of a watershed will impact on the access and entitlements of water users elsewhere in the watershed or even outside the watershed. The tradeoffs associated with different management options need to be considered during planning process and, wherever possible, management options should be promoted and selected that maximise the economic and social value of available water resources at the watershed scale.

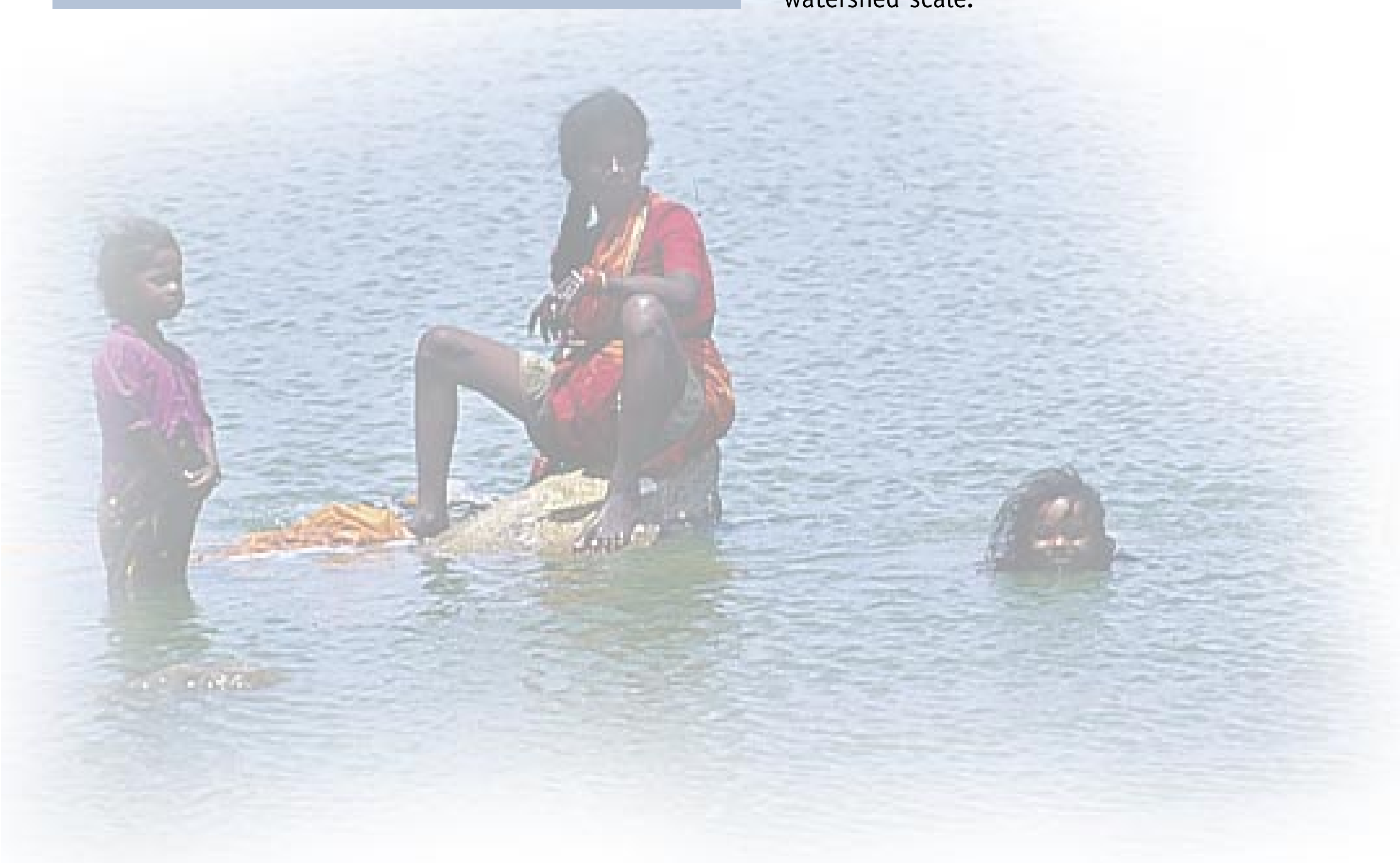


Table 12. Water-related recommendations relevant to the pre-planning and planning phases of the project

Phase	Activity	Recommendations
Pre- Planning Phase	Raising awareness	· Organise wall paintings and street plays that put an emphasis on long-term resource management rather than quick fixes · Publish WRA findings in a reader-friendly format · Set up "demonstration" villages and micro-water sheds that can be used for exposure visits and NGO training
	Institution building	· Promote village-level institutions that take responsibility for resource management. These should be based on affinity groups that are linked to and/or recognised by the Panchayati Raj Institutions (PRIs) · Facilitate the link between these village institutions and the PRIs, to ensure they are allowed to work without interference from PRIs · Re-establish traditional resource management practices where appropriate
Planning Phase	Village-level plans	· Promote village-level planning that uses the WRA option lists and decision trees as a guide. Provide training where necessary · Carry out local-level participatory planning within a wider resource management framework, the aim being to maintain local-level ownership of resource plans whilst not ignoring wider policy objectives (see Box 2) · Make full use of the skills and experience of local specialists · Set up a procedure for rationalising village-level plans at the sub-watershed and watershed levels · Discuss and agree village group-level M&E during the planning phase
	NGO, PIA and KAWAD Soc. plans	· Allocate resources to activities that are part of wider planning framework · Resources not to be allocated to activities that have a high risk of: impacting negatively on livelihoods of other communities, causing environmental degradation and/or mining of resources · Act as a broker or intermediary when village level demands are within the scope of KAWAD's wider objectives but outside the scope of KAWAD's funding limits (e.g. for WSS)

Table 13. Water-related recommendations relevant to the implementation and withdrawal phases

Phase	Activity	Recommendations
Implementation Phase	Village-level implementation	· Emphasise village-level collective responsibility and management of resources. Promote village-level collection and utilisation of resource-related M&E information as a basis for decision making · Call in local specialists to advise and train when necessary · Encourage and facilitate access to relevant government programmes and schemes
	NGO, PIA & KAWAD Soc. - level implementation	· Allow project to proceed at the pace dictated by the development process rather than spurious targets, even if this is potentially incompatible with budget cycles and the project's logical framework · Wherever feasible, allocate resources on basis of M&E information rather than "shopping lists" · Conduct externally-facilitated annual community assessments of project performance.This is to provide an objective forum to clarify issues, hear grievances, resolve conflicts, and take on board local suggestions for improved performance · Set up a procedure to incorporate lessons learnt from past performance into future project implementation procedures and practice · Promote interaction with Zilla Parishads (ZP) to ensure that wider resource management and development objectives are being achieved (see Box 2)
Withdrawal Phase	Village-level NGO withdrawal	· Put plans for withdrawal in place from outset of project · Ensure that village institutions have the information and capacity required to access ZP and Line Department services after project withdrawal · Facilitate a handing-over meeting between NGOs, PIAs, villagers and the concerned local officials and Line Department staff, at the start and end of the withdrawal phase

Tables 12 and 13 summarise water-related recommendations that are relevant to the execution of the project during the pre-planning and planning phases and the implementation and withdrawal phases respectively

8.2 Management of surface water resources

General comments

Surface water resources in the project watersheds include: ephemeral streams and rivers, natural ephemeral water bodies and large and small tanks. The main uses of surface water include: irrigation, livestock watering, bathing, water for non-agricultural activities (e.g. brick making) and pisciculture. In recent years, duration of flows in streams and rivers has been much reduced primarily as a result of depletion of the shallow aquifers. Change in land use in catchments areas (i.e. deforestation) has also had an affect on the stream flows. However, the really dramatic changes have occurred in the last 10-15 years as a result of groundwater extraction. In-flows into tanks have also been reduced for the same reason and as a consequence of water-storage structures located upstream of tanks.

Surface water management options

The availability and management of surface water resources can be improved by:

- *Option 1:* Encouraging or, in some cases, re-establishing traditional tank management systems. **These should be based on the affinity groups that benefit directly from use of the tank water. Groups should be linked to or coordinated by the relevant Panchayati Raj Institutions. The focus of affinity groups could include: irrigation, livestock watering and pisciculture.** Tradeoffs: There is a risk that changing and introducing tank management procedures will lead to exclusion of some social groups.

- *Option 2:* **Where appropriate,** repairing the sluices and bunds of tanks **to reduce leaks and seepage losses and make management of releases possible.** Tradeoffs: Seepage losses may be an important source of recharge downstream of the tank.

- *Option 3:* Reducing evaporative losses by deepening tanks. **Desilting tanks reduces the surface area to volume ratio. Evaporation losses from perennial water bodies in the project area are around 2 m depth of water per year. Desilting tanks also increases storage and reduces the likelihood of the tank spilling following heavy and prolonged rains.** Tradeoffs: Deepening tanks may reduce the fodder and forage value of the areas on which grasses grow as the tank water recedes. This option may also impact on the environmental and biodiversity value of tanks and the areas surrounding tanks.

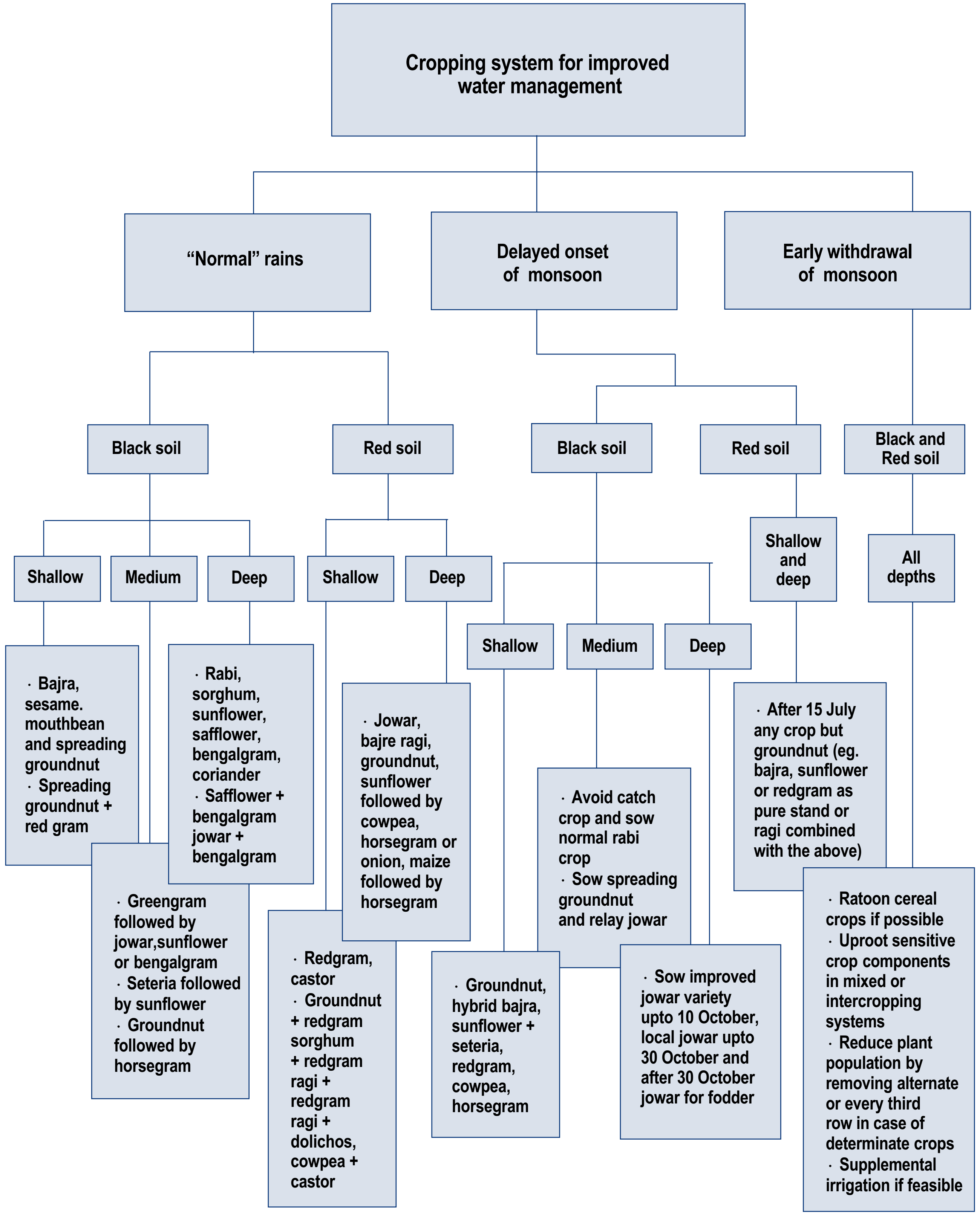
- *Option 4:* Increasing inflows into tanks. **This can be achieved by increasing storm flows by adding or removing gully control structures; in some cases, by filling old brick pits and by increasing base flows by raising water tables in tank catchment areas.** Tradeoffs: In most cases, this option will result in distinct winners and losers. Increasing tank flows significantly can only be achieved at the expense of current water users in the tank catchment areas.

- *Option 5:* Reducing silt inflows to tanks. **Figure 33 summarises gully control recommendations (see also MYRADA (1997)).** Tradeoffs: Less silt will be available to farmers who traditionally use silt as a means of improving soil fertility of their fields.

Groundwater being pumped into a header tank, Chinnahagari

Washing clothes in a tank, Chinnahagari

Figure 31. Cropping system for improved water management



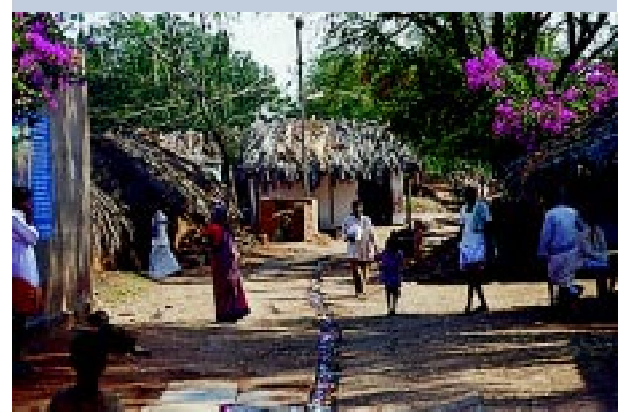
Box 3 ***Conditions under which joint management of common property can be successful***

These conditions are related to both the resource and the user group.They include:

- **the resource is small and clearly defined;**
- **there is a close physical proximity between the resource and the users;**
- **the users have a high level of dependence on the resource;**
- **a small and defined set of users already has established arrangements for discussing common problems;**
- **decision-making power within the user community is in the hands of sub-groups favouring communal action;**
- **cheating with regard to resource use is easily noticed;**
- **the costs of exclusion from the resource are high;**
- **the relevant institutions have legal and political backing.**

Discussions involving men and women during a watershed development committee meeting, Chinnahagari

A drainage channel in a village in Upparahalla. Drainage water can be used for a range of productive purposes



8.3 Management of groundwater resources

General comments

Groundwater has high social and economic value in the project watersheds. It is the primary source of drinking and irrigation water. Increased groundwater exploitation for irrigation is leading to shortages of drinking water in some villages. Increased groundwater depletion has also increased the likelihood of a severe and, possibly, catastrophic groundwater drought when the next meteorological drought occurs. Given its importance, it is recommended that the project gives the highest priority to improving long-term groundwater management.

Groundwater management options

The availability and management of surface water resources can be improved by:

- ***Option 6:*** **Promoting use of shallow wells for agriculture and deep wells for WSS particularly in peri-urban areas. In crystalline basement areas, this approach will ensure that there is a groundwater "buffer" that can be used to maintain drinking water supplies during drought years. This approach will also reduce energy required for pumping and, in general, farmers who adopt measures to improve groundwater recharge are more likely to see the benefits of their efforts. Recharge of shallow aquifers tends to be localised whereas recharge of deep aquifers is much more haphazard.**
  Tradeoffs: Initially, groups of farmers will have to reduce groundwater extraction until the shallow aquifer is replenished. Once it is replenished, they can return to extracting groundwater at rates that are equivalent to annual recharge. The transition costs of this approach would be high as in many areas farmers would have to switch from using borewells to wide diameter wells or collector wells[5]. Note that this approach will only be successful if carried out in conjunction with Option 7.

- ***Option 7:*** **Establishing of local-level groundwater management groups. These affinity groups may share wells and pumps, as is the case with community irrigation, or they may be farmers on adjacent land holdings sharing the same aquifer. Establishing a common-property approach to**

5 A collector well is a shallow hand-dug well of large diameter with horizontal boreholes drilled radially from the base to a distance of approximately 30 m, typically in four directions groundwater management is difficult unless certain affinity-group criteria are met (see Box 3). Tradeoffs: There is a risk that this approach will lead to exclusion of some social groups.

- *Option 8:* Improving groundwater recharge in areas in which groundwater usage has maximum social and/or economic value. Gully control structures and percolation tanks will improve recharge (see MYRADA (1997)) as will the soil and water conservation measures summarised in the two decision trees that are presented as Figures 34 and 35. Tradeoffs: In some cases, improving groundwater recharge in one part of the watershed may be at the expense of existing users elsewhere.

- *Option 9:* Although it is outside the scope of KAWAD, piloting innovative water allocation mechanisms is an activity that is urgently needed in the region. Mechanisms that could be piloted include: zoning of areas from which village drinking water supplies are extracted (this approach could involve compensation payments to current landowners); tradeable water rights, user-based allocation or demand management that includes electricity and water charges. The project could also assess the utility of new groundwater legislation that is being considered by the Government of Karnataka. Tradeoffs: Some innovative approaches to water allocation may not be popular initially and, hence, establishing local-level participation and/or acceptance will require NGO time and effort.

A tea stall in a village in Upparahalla. Such commercial initiatives require a reliable water supply

8.4 Management of water in urban and peri-urban areas

General comments

The population of villages in the project areas is set to double within the next 25-30 years. Consequently there is a steady rise in demand for water for domestic purposes and for industrial and other urban uses. Another consequence of increasing population and the development of urban services and industries is the increasing volume of waste water and industrial effluents that is being produced.

Urban and peri-urban area management options

The availability and management of water in urban and peri-urban areas can be improved by:

- *Option 10:* Using waste water for income-generation. In village areas, large quantities of water are wasted around water points as a result of spillage, bathing, washing of pots and leaks. Run-off during rainfall and household waste water also represent a substantial resource that could be used productively. With the agreement of Gram Panchayats, waste water could be used for community or backyard horticulture or fodder production. Adopting this option would also reduce the health risks posed by stagnant pools of waste water and reduce pollution risks to shallow aquifers. Tradeoffs: No significant tradeoffs.

- *Option 11:* Increasing groundwater recharge of water of acceptable quality. Run-off from roads and open areas represents a significant resource that can be channelled into percolation tanks. Tradeoffs: In some cases, there is a risk that shallow aquifers will become polluted. This can be minimised by channeling only "good" quality water to percolation tanks.

- *Option 12:* Harvesting water from roofs, rock outcrops or areas of compacted soil, tarmac or concrete. This water can be piped into water tanks or underground cisterns. Although the quality of this water may be variable, it can be used as a source of water for washing, bathing and livestock. Given sufficient storage and annual rainfall of 500 mm, up to 50 m^3 of water can be harvested from 100 m^2 of roof. For example: this is sufficient water to meet the annual water requirements of 4 milk cows or 90 sheep. Tradeoffs: No significant tradeoffs.

- *Option 13:* Minimising risks of ground and surface water pollution. This includes safe handling and storage of agro-chemicals and ensuring that industrial effluents and sewage are treated or disposed of in such a way that aquifers and water courses do not become polluted. Tradeoffs: Additional costs may be incurred by industries that have to meet the costs of effluent treatment or safe storage of chemicals.

8.5 Rainfed agricultural production

General comment

In the project watersheds, rainfed agricultural production is the largest user of rainfall and rainfed cropping takes place over the largest area. When compared to irrigated agricultural production, rainfed production produces more income and forms an important part of the livelihood systems of a larger number of households. Rainfed agricultural production includes: rainfed arable cropping, fodder and livestock production, fuelwood production and production of timber and non-timber forest products.

Rainfed arable cropping options

The productive use of rainfall in arable cropping systems can be improved by:

- *Option 14:* Reducing soil evaporation by planting early in kharif and maintaining crop cover throughout the periods when rainfall occurs. Unproductive soil evaporation accounts typically for 30-50% of rainfall that falls on arable lands. Figure 36 is a decision tree which gives an indication of crop selections and cropping practices that will make most productive use of rainfall taking into account the different soil types found in the project watersheds. Tradeoffs: Drainage and, hence, groundwater recharge may be reduced as a result of increased vegetative cover and healthier deeper-rooting crops.

- *Option 15:* Increasing the production of useful output per unit of water (more crop per drop) by: selecting appropriate crops, using good genetic material, seed priming, minimising weed water use (unless the weeds have a high fodder value), ensuring good crop nutrition and land husbandry and minimising post-harvest losses. Tradeoffs: Same as Option 14.

- *Option 16:* In-situ moisture conservation that reduces the 10-20% of rainfall that, on average, runs off arable land. In-situ moisture conservation practices can also be used to concentrate water where it is most needed (e.g. along crop rows). Figure 37 is a decision tree that summarises recommendations relating to in-field soil moisture conservation that are relevant to the soil types of the project watersheds. It must be emphasised that there is no single soil and water conservation method that has universal application in the project watersheds. Figure 38 is a decision tree that summarises the different purposes of moisture conservation. The most appropriate technique at a given location will depend on many factors. These include: intended purpose, soils, slope, rainfall regime, agricultural systems, size of land holding and cultivation economics. Tradeoffs: Same as Option 14.

- *Option 17:* Matching agricultural activities to land capability. Water and land resources will be used most productively if the physical characteristics of an area are considered when discussing and selecting appropriate land use options (see Box 4). Tradeoffs: No significant tradeoffs.

Oxen being washed by water points is a common sight in the summer season

Bare hill sides in the upper reaches of Doddahalla

Figure 32. Soil and water conservation measures

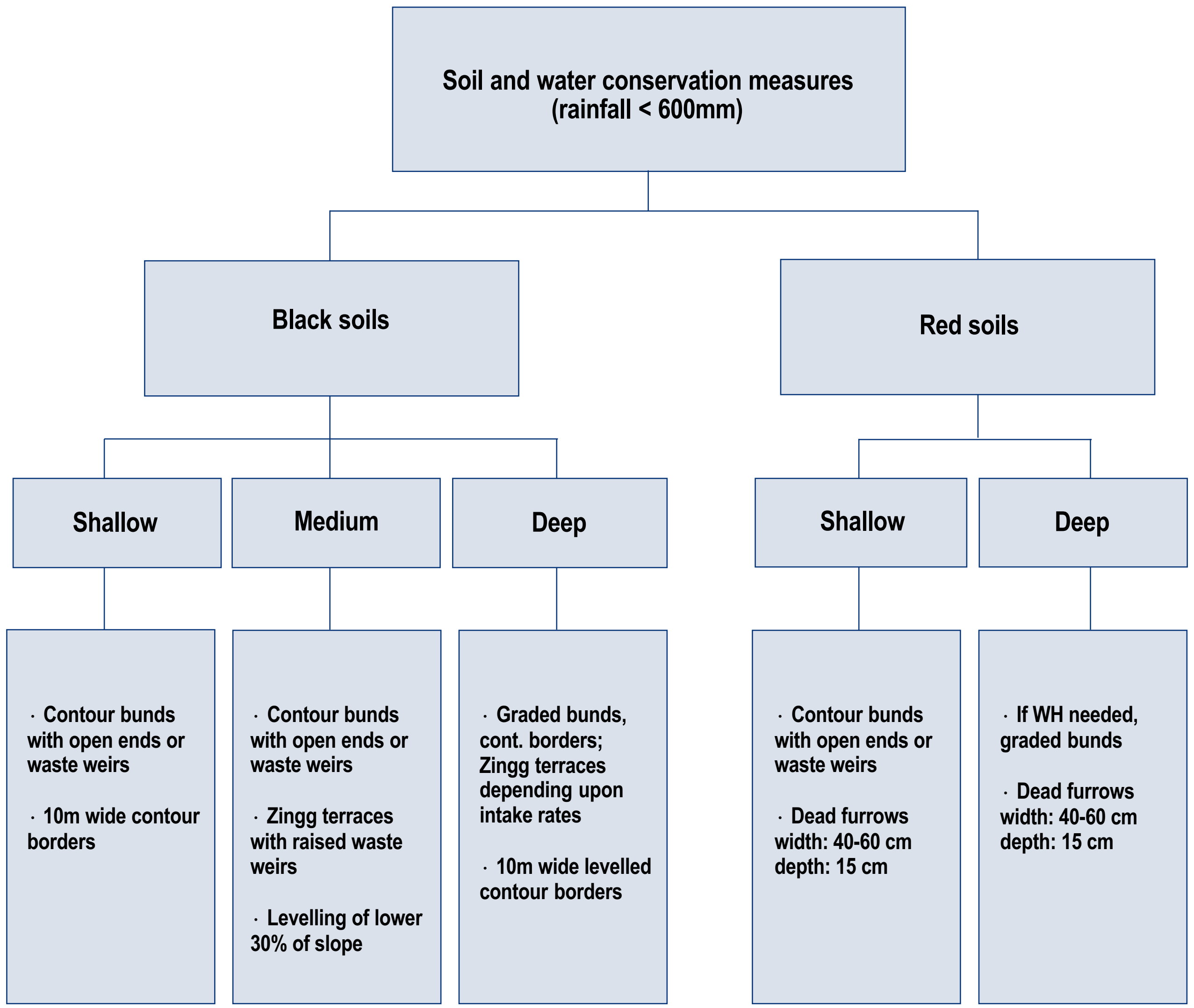


Figure 33. Design of contour bunds

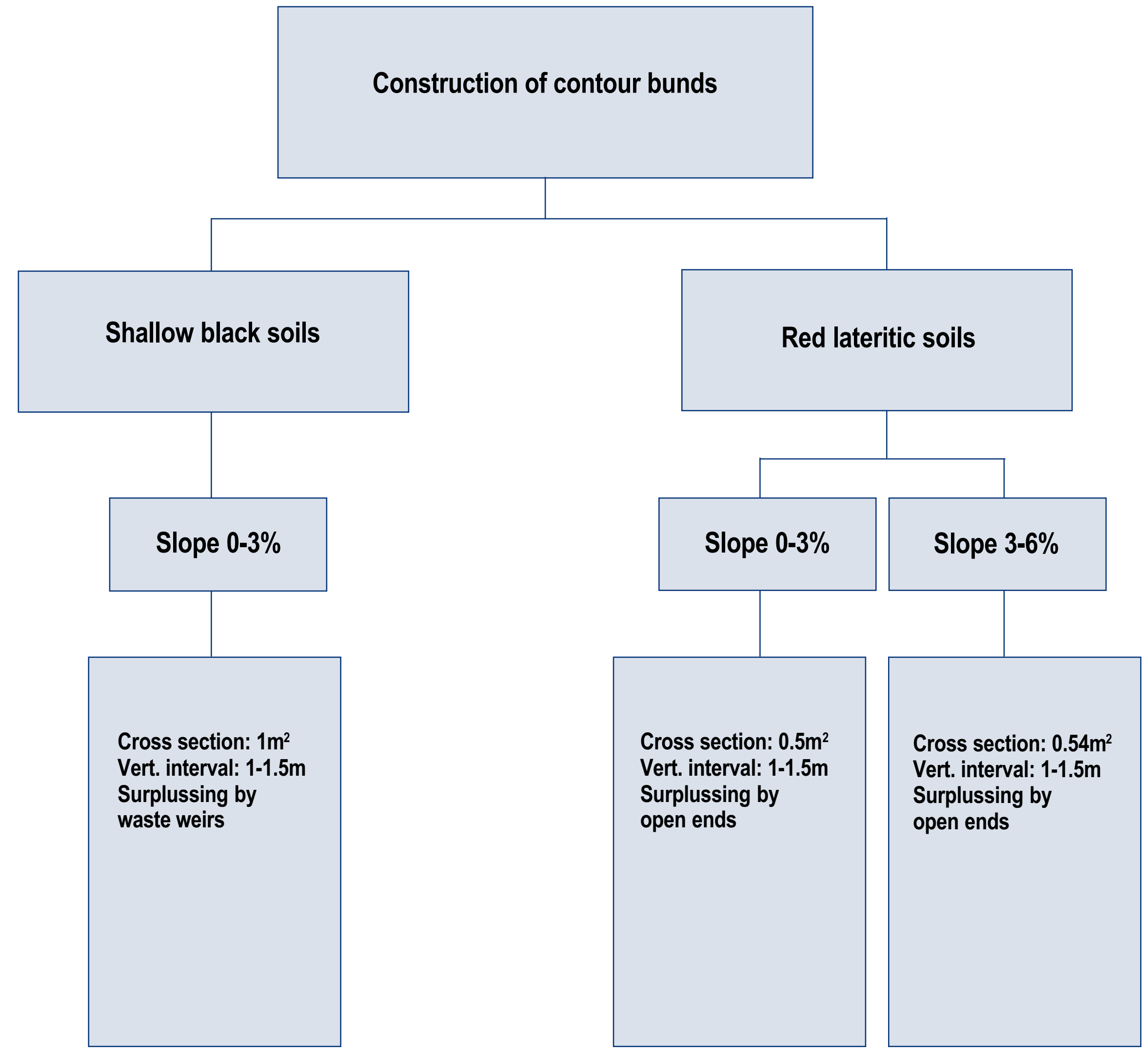
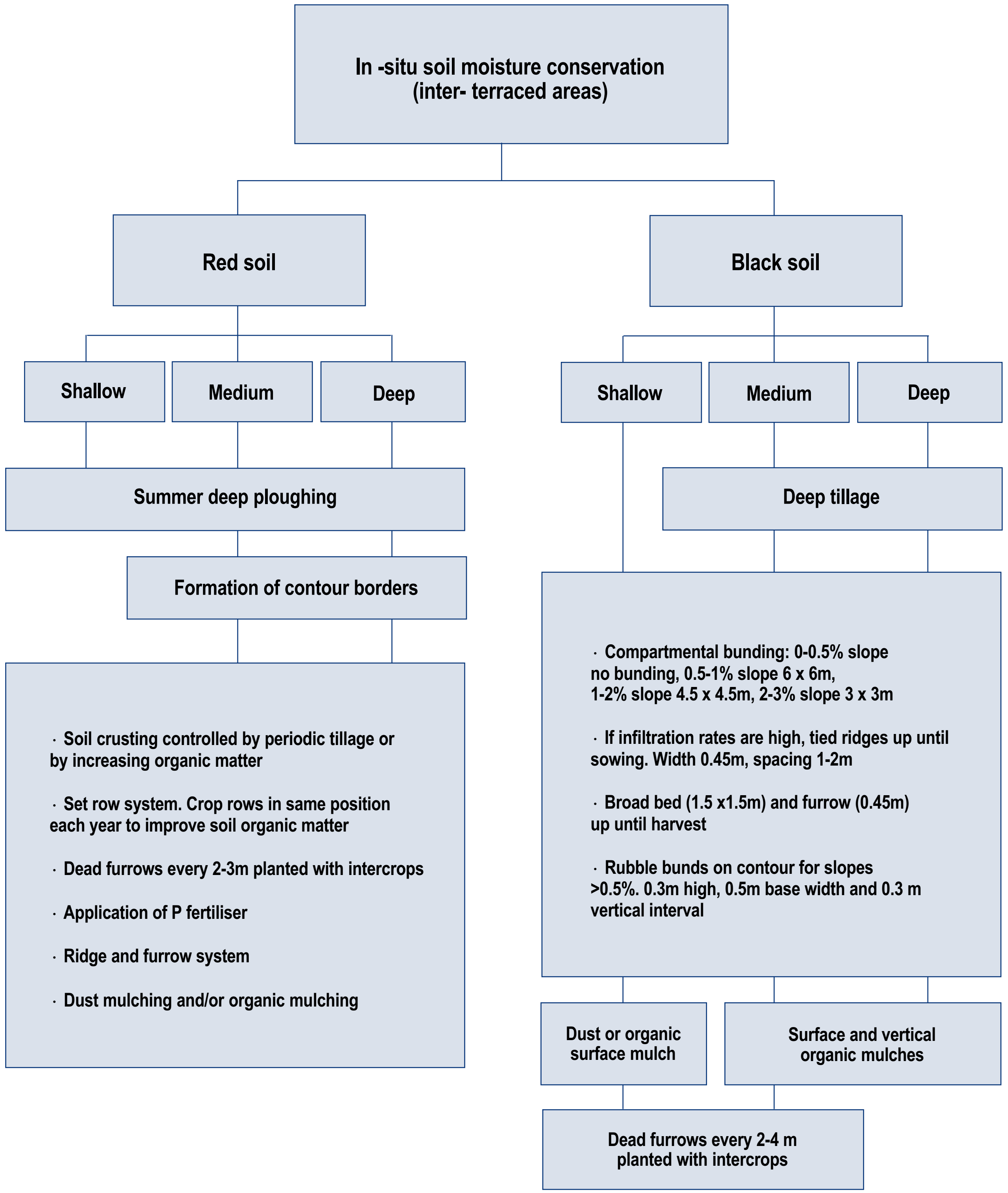


Figure 34. In-situ soil and moisture conservation



Rainfed non-arable land production

Non-arable lands comprise government land, wasteland, fallow areas and village forest areas. The productive use of rainfall in non-arable cropping systems can be improved by:

- *Option 18:* **Reducing soil evaporation, maintaining vegetative cover and by concentrating rain wherever it can be used productively (see Figure 33). Planting of grasses, fodder legumes and trees and application of fertilisers will also help improve the productivity of water use.** Tradeoffs: Changing land use and management in publicly-owned non-arable areas may result in distinct winners and losers.The rights of existing users (e.g. livestock owners, gatherers of fuelwood) may not be catered for in new management arrangements. In some cases, soil water conservation measures, maintaining vegetative cover and tree planting may reduce groundwater recharge and storm-related runoff into tanks.

- *Option 19:* **Drought-proofing through alternative land use systems. This can be achieved in part by planting trees that make productive use of rainfall. These will provide a source of income during both good and bad rainfall years (see MYRADA (1997) for more details). Income should be based on multiple uses of timber and non-timber forest products.** Tradeoffs: Same as Option 18.

- *Option 20:* **Improving the management of publicly-owned non-arable areas. This can be achieved through management arrangements such as: joint forestry management, community grazing schemes or community fuelwood schemes.** Tradeoffs: There is a risk that changing management arrangements will lead to exclusion of some social groups.

- *Option 21:* **Making more productive use of privately-owned non-arable land by improved fodder and forage production, establishment of energy coppices, timber production and dryland horticulture. In some areas, silvo-pastoral systems that support dairying could be a good option.** Tradeoffs: In some cases, these practices will reduce groundwater recharge.

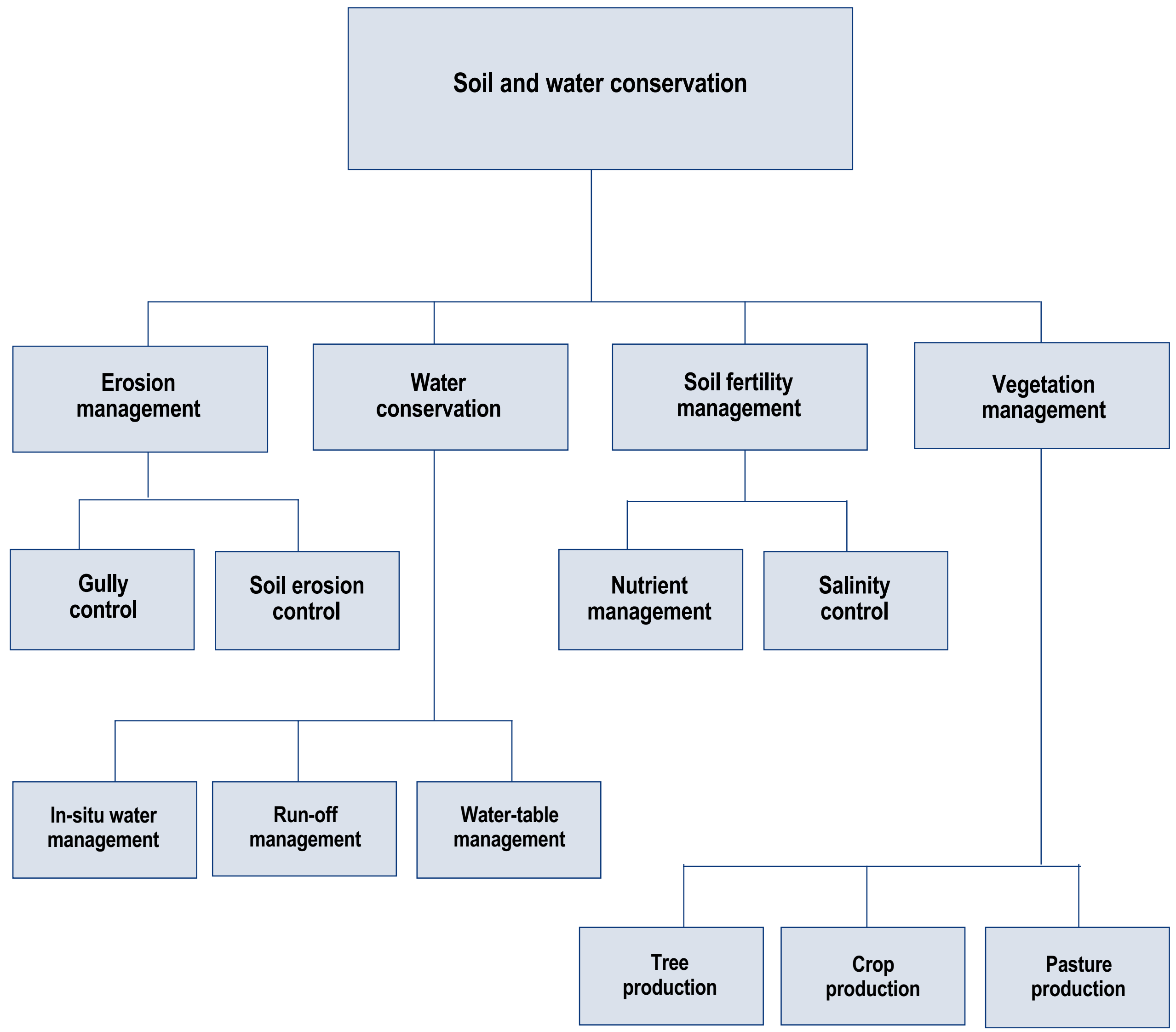
Household waste water being used to irrigate horticultural crops

8.6 Irrigated agricultural production

General comment

Irrigation is the biggest user of stored water. In the past, irrigated agricultural production used surface water stored in tanks as the main source of irrigation water. Groundwater from shallow wells was used predominantly as a source of water for domestic and livestock purposes. In recent years, there has been an increase in irrigated area using groundwater and a reduction in irrigation using water from tanks. The positive impact of groundwater-based irrigation has been a big increase in agricultural production in the project watersheds and a large improvement of the living standards of farmers who have irrigated land. The negative impact has been that groundwater-based irrigation has led to severe groundwater depletion, reduced in-flows into tanks and, in some villages, shortage of domestic water during summer months and low-rainfall years. In the project watersheds, current groundwater use for irrigation approximates to annual groundwater recharge.

Figure 35. Purposes of soil and water conservation



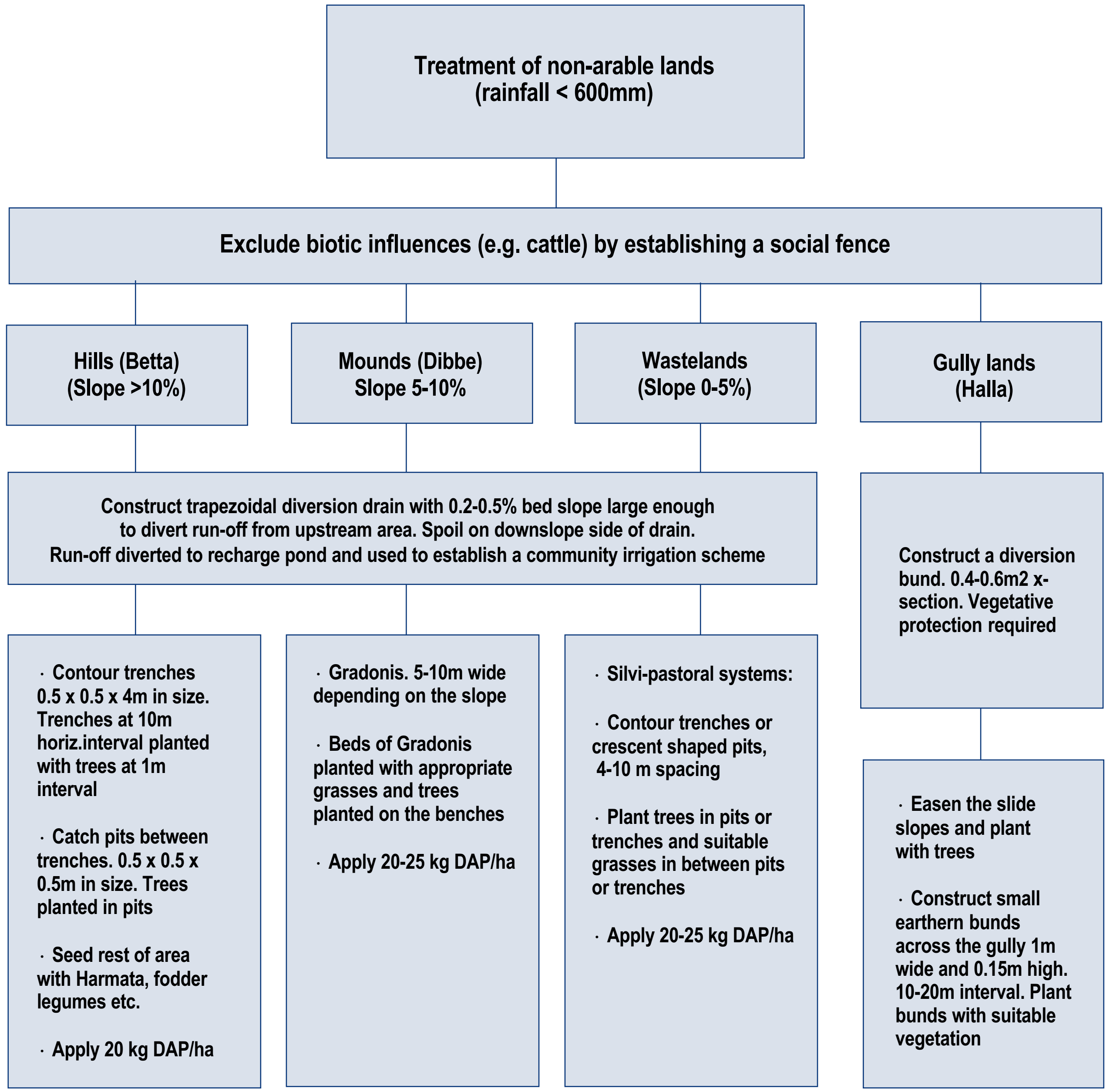
Box 4 ***Matching agricultural activities to land capability classes***

Increased land use intensity →

Increased limitations and hazards ↓ / Decreased choice of users

Land capability classes	Wildlife	Forestry	Grazing			Arable			
			Limited	Moderate	Intense	Limited	Moderate	Intense	Very Intense
I									
II									
III									
IV									
V									
VI									
VII									
VIII									

Figure 36. Treatment of non-arable lands



Water use productivity

The productive use of water in irrigated arable cropping systems can be improved by:

- *Option 22:* **As with rainfed arable crops, by increasing the production of useful output per unit of water (more crop per drop) by: reducing "non-productive" soil evaporation, selecting high value crops and crops that are responsive to irrigation, using good genetic material, minimising weed water use (unless the weeds have a high fodder value), adopting integrated nutrient and pest management and minimising post-harvest losses (see MYRADA (1997)).** Tradeoffs: Increasing agricultural productivity is not concordant with farmers reducing their irrigation water use. In some cases this might happen but, for many farmers, it is water that is limiting rather than land. These farmers are likely to use any additional water to increase their gross irrigated area. Hence, improvements in water availability or equity, resulting from increased water use productivity or efficiency, are unlikely.

- *Option 23:* **Making more effective use of rainfall. This can be achieved by planting early in kharif and concentrating irrigated cropping during the periods that rainfall occurs. This strategy reduces soil evaporation losses and minimises the proportion of crop water requirements that is met by groundwater. Irrigation scheduling that takes account of rainfall will also lead to more effective use of rainfall.** Tradeoffs: Same as Option 22.

- *Option 24:* **Adopting improved irrigation practices that lead to more uniform in-field distribution of water. Levelling fields and using furrow irrigation will minimise the quantity of water needed to ensure that all parts of a field have received adequate water. More uniform application also reduces the risk of waterlogging and soil salination in low-lying parts of fields.** Tradeoffs: Same as Option 22.

- *Option 25:* **Using localised irrigation (e.g. drip irrigation, pitcher irrigation, subsurface pipe irrigation) with field or horticultural crops that are spaced such that the canopy does not close. This will lead to reduced soil evaporation and more uniform application of water. Pitcher and subsurface irrigation are particularly well suited to backyard establishment and irrigation of trees and vegetables.** Tradeoffs: Same as Option 22.

- *Option 26:* **Reducing conveyance losses. The current practice of pumping water into small earthen water tanks and conveying water along unlined channels leads to high evaporation losses from the open water and from areas of seepage. Lining header tanks and channels would reduce these losses.** Tradeoffs: Same as Option 22.

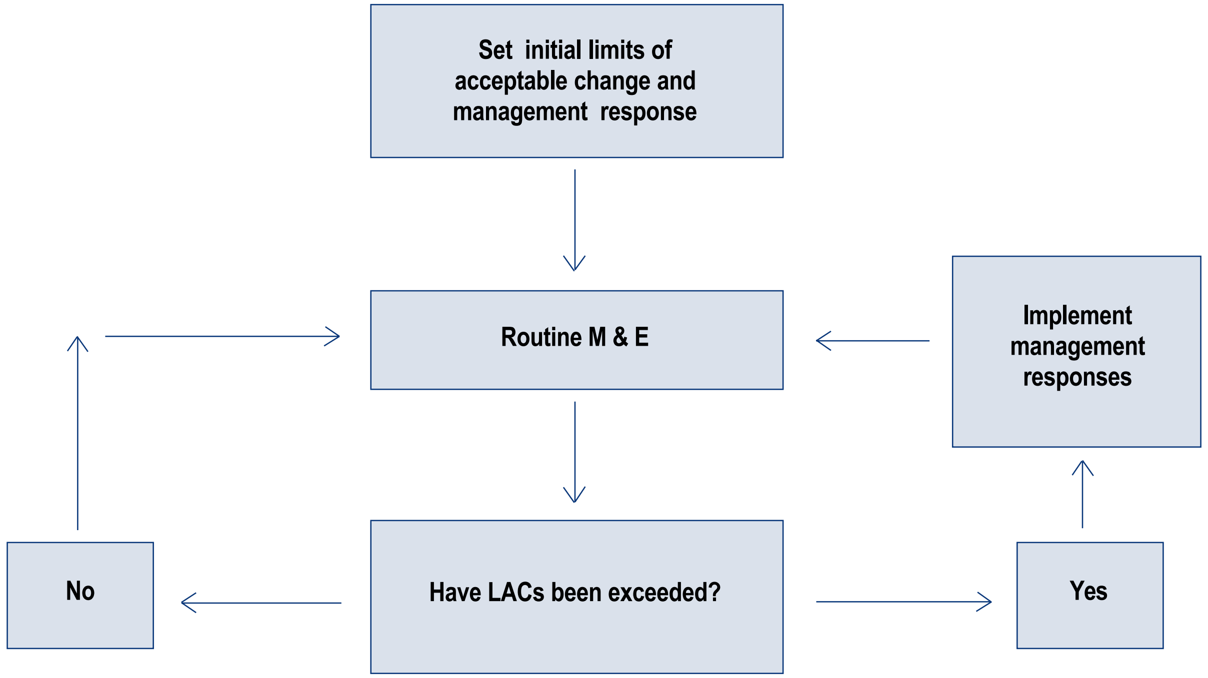
- *Option 27:* **Reducing the need for "insurance" irrigation. Although it is not really within the scope of the project, it is clear that if electricity supplies were more reliable, farmers would be able to improve their water management. Many farmers currently use automatic starters on their pumps and pump water whenever power is available. Farmers also tend to over-irrigate as "insurance" against long spells when they cannot pump.** Tradeoffs: Same as Option 22.

- *Option 28:* **Establishing community irrigation schemes. Some farmers are already forming groups in the project watersheds and sharing the costs of irrigation. A number of innovative "share-cropping" approaches are being piloted by MYRADA in the Challakere Project. These include arrangements whereby:**
  - **A group of landless villagers use around 2 ha of land rent-free if they take a loan and install a borewell and pump. The land (along with the pump) is returned to the owner after 12 years.**
  - **Land belonging to one person (approximately 2 ha) is split between four people one of whom is the original landowner. The other three are landless cultivators. The landless cultivators take a loan to install a borewell and pump in lieu of paying rent.**

  Tradeoffs: Increased irrigation, for whatever purpose, may exacerbate groundwater depletion and competition for water between domestic and agricultural water users.

Chillies that were grown locally, being sold at a market in Upparahalla

Figure 37. Use of M & E information in routine decision making



Fish farming in Hosahalli tank. The current practice is for the gram panchayat to contract out the use of the tank to people from outside the village

8.7 Fish production

Pisciculture is already being practised in tanks in the project watersheds. Fish production could be increased and improved by:

- ***Option 29:*** **Increasing the number of water bodies used for pisciculture. This can be achieved by bringing unused water bodies into production by: forming groups that take an interest in pisciculture, relevant exposure visits and training. Although pisciculture does not require perennial water bodies, production can be enhanced by increasing the length of time in which water bodies contain water.** Tradeoffs: Existing contract fishermen could bid for and receive contracts for more water bodies, reducing equity of distribution. Although more fish in local diets could improve health, the chances are that this additional fish production will be sold in distant urban markets, where fish fetch higher prices.

- ***Option 30:*** **Promoting equitable access to pisciculture. The current practice is for pisciculture to be contracted out by the Gram Panchayats. With sufficient support and training, self-help groups could bid for the right to use water bodies. Self-help groups could also become involved in backyard fingerling production.** Tradeoffs: No significant tradeoffs.

8.8 Water-related monitoring and evaluation

General comments

M&E information is required for performance and impact assessment. It is also required for long-term management of natural resources and, in particular, decision-making related to the management of common property resources (including tanks and groundwater).

Improved resource management using M&E information

The management of water resources can be improved by:

- ***Option 31:*** **Promoting collection and use of M&E information by affinity groups that take responsibility for managing tanks and groundwater (see Options 1 and 7). Traditionally, decisions related to the management of tanks were based on tank water levels at different times of the year. This approach should be re-established for tank management and extended to groundwater management.**

- ***Option 32*:** **Promoting decision-making on the basis of limits of acceptable change.[6] Indicators (e.g. depth of water in a tank, or depth of water in a well) alone cannot be used easily for resource-related decision-making, particularly when groups are involved. Figure 39 is a schematic diagram that shows the basic steps that need to be taken when using this approach. Initial limits of acceptable change are set (e.g. groundwater level of 20 m) along with management response (e.g. all the farmers in the group will reduce the irrigated area by a certain amount in the next crop season). Groundwater level is then monitored routinely and the agreed management response is applied only if and when the limit of acceptable change is reached. Note that this decision-making process is similar to that used traditionally for tank management.**

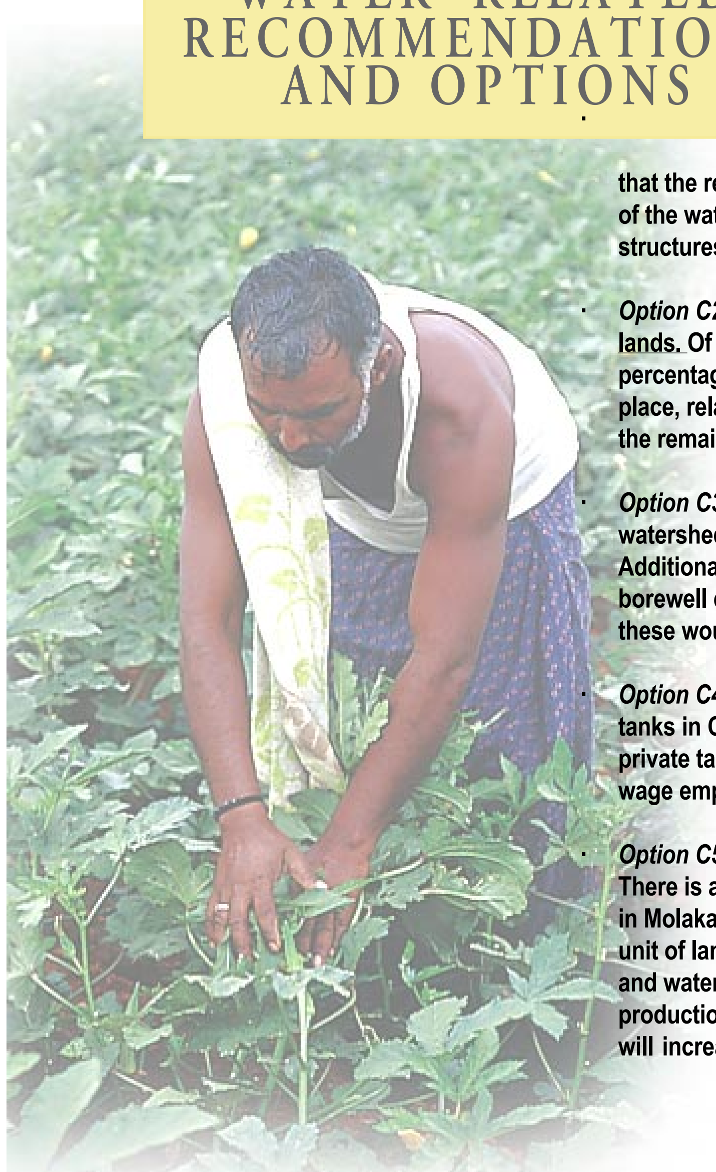
- ***Option 33:*** **Promoting local decision-making systems that have the support of Panchayati Raj Institutions and that are consistent with larger-scale resource management initiatives. In the long-term, this may involve a change in the legal and political status of affinity groups and/or watershed development committees such that collective decisions relating to tanks, groundwater, revenue and forest lands have improved legal and political standing. Even formalising the relationship between affinity groups and the local panchayat would be a step in this direction.**

- ***Option 34:*** **Using a modified OECD Pressure-State-Response (PSR) approach for project or district level M&E and resource-related decision-making. In the modified PSR M&E approach, natural resource indicators are grouped and classified according to whether they are indicators of *state, pressure, productivity* or *equity*. The main justification being that this facilitates interpretation and analysis of the M&E information that is collected. For example, information on the *state* of a resource (e.g. groundwater level) is much more useful if it is used in conjunction with information on the *pressures* on this resource (e.g. volume of water being extracted for irrigation), the *productivity* of this resource (e.g. value of irrigated crops produced using this resource) and the "*equity*" of this resource (e.g. number of people benefiting from the groundwater irrigation and the distribution of benefits).**

6 Limits of acceptable change can also be referred to as safe minimum standards, critical loads, norms or threshold values.

Computer and GIS software can be used to improve data management and to provide information that can be assimilated easily by decision makers at all levels

9 SPECIFIC WATER-RELATED RECOMMENDATIONS AND OPTIONS



9.1 General comments

In the previous section, options were listed that are applicable to all three watersheds. In this section, options are listed that are relevant to the specific characteristics of the individual watersheds.

9.2 Specific to Chinnahagari

The management, availability and productivity of water resources can be improved by:

- *Option C1:* Removing or repositioning some check dams. Detailed investigation may show that the relative economic and social value of water in different parts of the watershed justify removing or repositioning some of the many structures that already exist along drainage lines in Chinnahagari.

- *Option C2:* Improving the management and productivity of non-arable lands. Of the three project watersheds, Chinnahagari has the largest percentage area of non-arable lands. Although encroachment has taken place, relatively more attention should be given to the management of the remaining non-arable and CPR lands in this watershed.

- *Option C3:* Constructing additional borewells. Of the three project watersheds, Chinnahagari has the lowest density of borewells. Additional hydrogeological investigation, may show that additional borewell construction is feasible in some village areas. Ideally, these would be used for community irrigation.

- *Option C4:* Rehabilitating private tanks. There are four privately-owned tanks in Chinnahagari. Although the direct benefits of rehabilitating private tanks go to the owner, indirect benefits result from increased wage employment and from improved wetland habitats.

- *Option C5:* Increasing mulberry production and sericulture. There is already a well developed sericulture and sari weaving industry in Molakalmuru. Switching from crops which are less profitable per unit of land and per unit of water to mulberry will increase net revenues and water use productivity. Recommendations for improved mulberry production can be found in MYRADA (1997). Water use productivity will increase further if well-managed drip irrigation is used.

9.3 Specific to Upparahalla

The management, availability and productivity of water resources can be improved by:

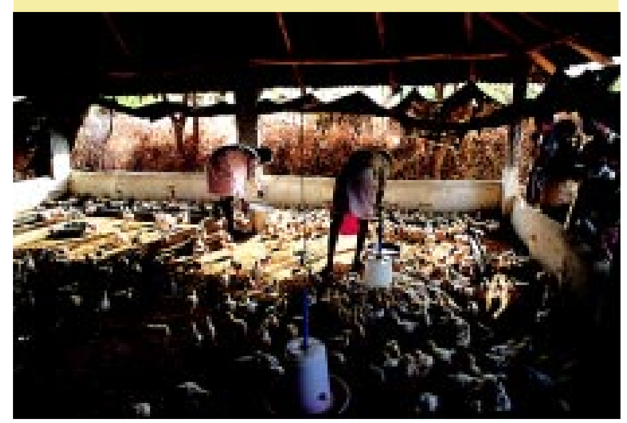
- *Option U1:* Rehabilitating salt-affected lands[7]. Salt affected non-arable land can be rehabilitated by mound planting, selection of salt-tolerant plant species, particularly those that can be browsed by cattle, sheep and goats and/or applying acid to pits in which planting takes place (see MYRADA (1997) for more details). Salt affected arable lands can be rehabilitated by improving drainage where feasible.

- *Option U2:* Promoting dryland horticulture, particularly in areas where protective irrigation is feasible, the justification being the fact that Upparahalla has large areas of Class IV and V lands and it has a relatively high rainfall. Upparahalla's location on National Highway 13 makes transportation of produce to markets relatively cheap and easy.

- *Option U3:* Promoting crop rotation in areas that are under constant rainfed and irrigated groundnut cultivation as this will reduce the risk of build up of pests and diseases (see MYRADA (1997)). Alternative crops that could be tried include maize and castor.

- *Option U4:* Increased mulberry production and sericulture. There is already a well developed sericulture and sari weaving industry in the area. Switching from crops which are less profitable per unit of land and per unit of water to mulberry will increase net revenues and water use productivity. Water use productivity will increase further if well-managed drip irrigation is used.

A small poultry unit in a village in Chinnahagari



Backyard dairying in Bellary District

9.4 Specific to Doddahalla

- *Option D1:* Creating additional storage of runoff. The scope for making more productive use of runoff, at a range of scales, is highest in Doddahalla. In good rainfall years significant volumes of water are lost from the watershed. Ideally, additional storage should be created at field level using farm ponds that are constructed and managed on a community basis. With ponds, there is the option that they can be converted into wells by deepening.

- *Option D2:* Promoting triple cropping in areas that are currently under sugarcane. This will improve the productivity of water use and create additional wage employment opportunities.

- *Option D3:* Promoting cultivation of horticultural crops. Well-developed markets for horticultural crops already exist in Bijapur district and some farmers are switching from crops such as cotton to grapes, chickoo and limes. This trend should be encouraged especially with farmers who are willing to use drip irrigation.

- *Option D4:* Promoting cultivation of crops that can also be used as fuel. These crops include castor and redgram as either pure stand or intercrops.

7 "Uppara" translates as sodic salt or washing soda. In the past local residents used to extract washing soda from the nala bed to the north of Kenchammanahalli village of Jagalur taluk

ABBREVIATIONS AND ACRONYMS

ARCVIEW	A GIS software package
CPR	Common Property Resources
CSWCRTI	Central Soil and Water Conservation Research and Training Institute
DFID	British Department for International Development
DFIDI	British Department for International Development (India)
D&L	Domestic and livestock
ETp	Potential evaporation (defined as potential evapotranspiration by the FAO)
ET	Actual evaporation
FAO	United Nation's Food and Agriculture Organisation
FCC	False Colour Composite
GIS	Geographical Information System
GO	Government Organisation
GPS	Global Positioning System
HP	Horse Power
IMD	Indian Meteorological Department
KAWAD	Karnataka Watershed Development Society
LAC	Limit of Acceptable Change
LBA	Land Based Activities
MCum	Million cubic metres of water
M&E	Monitoring and Evaluation
MYRADA	MYRADA is an NGO
NBSSLUP	National Bureau of Soil Surveys and Land Use Planning
NGO	Non-Government Organisation
ODA	British Overseas Development Administration (now named DFID)
OECD	Organisation for Economic Cooperation and Development
PIA	Project Implementing Agency
PRA	Participatory Rural Appraisal
PRI	Panchayati Raj Institution
PSR	Pressure-State-Response
ROR	Record of Revenue
SHG	Self Help Groups
SWC	Soil Water Conservation
UAS	University of Agricultural Sciences
VDA	Village Development Association
WDA	Watershed Development Association
WRA	Water Resources Audit
WRM	Water Resources Management Ltd
WSS	Water Supply and Sanitation
ZP	Zilla Parishad

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REFERENCES AND BIBLIOGRAPHY

Agarwal A and Narain S, 1997. Dying Wisdom: Rise, fall and potential of India's traditional water harvesting systems. Centre for Science and Environment, New Delhi.

Allen C, et al. 1999. Enhancing natural resource management capacity of local communities through indicators and enabling technologies. ICRA Working Doc. 78, ICRA, Wageningen.

Anschutz J, et al. 1997. Water harvesting and soil moisture retention. Agrodok-series No.13, CTA, Wageningen, The Netherlands.

Anon. 1995. Environmental Measures: indicators for the UK environment. New Economics Foundation, UK

Anon. 1997. Land-management techniques for watershed development in Karnataka. Department of Agriculture, Gov. of Karnataka, Bangalore.

Anon. 1999. Synopses of lectures and land utilisation pattern in Karnataka. State level seminar on "Water and Land Resources Management in Karnataka". IAT, Bangalore.

Ambler J, 1999. Attacking poverty while improving the environment: toward win-win policy options. Tech. Paper prepared for 1999 Forum of Ministers, UNDP-EC Poverty and Environment Initiative.

Batchelor C H, 1999. Improving water use efficiency as part of integrated catchment management. Agric. Wat. Manage., 40, 249-263.

Batchelor C H, Lovell C and Mharapara I, 2000. Productive water points as a means of coping with drought. In Wilhite D A (Ed.): Drought: A Global Assessment. Routledge, London & New York, 17-28.

Batchelor C H, 1999. Optimising soil water use from a watershed perspective. In N van Duivenbooden, M Pala, C Studer and C L Builders (Eds.): The key to sustainable crop production in the dry areas of West Asia and North and Sub-Saharan Africa. Procs of the 1998 (Niger) and 1999 (Jordan) workshops of the Optimizing Soil Water Use (OSWU) Consortium. Aleppo, Syria: ICARDA and Patancheru, India: ICRISAT, 283-297.

Batchelor C H, Cain J D, Farquharson F A K F and Roberts J M, 1997. Improving water utilisation from a catchment perspective. SWIM Paper 4. Colombo, Sri Lanka, International Water Management Institute.

Batchelor C H and Rosier P T W, 1997. Report on a visit to the KAWAD Project Watersheds. IH Report DFID 97/7. Institute of Hydrology, Wallingford, UK, pp24.

Ben-Asher J and Berliner P R, 1994. Runoff Irrigation. In Tanjii K K and Yaron B (Eds.): Adv. Series in Agricultural Sciences, Vol 22, Springer-Verlag, Berlin-Heidelberg.

Berg C, Bredenbeck K, Schurmann A, Stanzick J and Vaneker C, 1998. NGO-based participatory impact monitoring of an integrated rural development project in Holalkere Taluk, Karnataka State, India. CATAD, Berlin.

Bollom M W, 1998. Impact Indicators: An alternative tool for the evaluation and management of watersheds. Indo-German Watershed Management Project, New Delhi.

Chandrakanth M G, Shyamasundar M S and Ananda K K, 1998. Interplay of markets, externalities, institutions and equity in groundwater development – An economic study in hard rock areas of Karnataka. Dept of Agric. Economics, UAS Bangalore.

DFID, 1999. Sustainable livelihood guidance sheets. DFID, London

Dinar A, Rosegrant M W and Meinzen-Dick R, 1997. Water allocation mechanisms. Policy Research Working Paper No. 1179. World Bank / IFPRI, Washington DC, USA

Dixon J A, 1997. Analysis and management of watersheds. In Dasgupta P and Maler K (Eds): The Environment and Emerging Issues. Clarendon Press, Oxford, 371-397.

Epstein T S, Suryanarayana A P and Thimmegowda T, 1998. Village Voices: Forty years of rural transformation in South India. Sage Publications, New Delhi.

Evans B, 1996. Institutional incentives and urban sanitation. Proc. 22nd WEDC Conf., New Delhi, 38-40.

Farrington J, Carney D, Ashley C and Turton C, 1999. Sustainable livelihoods in practice: early applications of concepts in rural areas. ODI Natural Resource Perspectives No. 42., ODI, London.

Farrington J, Turton C and James A J, 1999. Participatory Watershed Development: Challenges for the Twenty-First Century. Oxford University Press, New Delhi.

Fernandez A, 1999. The impact of technology adaptation on productivity and sustainability: MYRADA's Experiences in Southern India. In Hinchecliffe F, Thompson J, Pretty J, Guijt I and Shah P (Eds.): Fertile Ground: "The impacts of participatory watershed management", IT Publications, London, 75-89.

FAO. 1993. Guidelines for land use planning. FAO, Rome.

FAO. 1995. Reforming water resources policy. FAI Irrigation and Drainage Paper 52, FAO, Rome.

FAO. 1995. Agricultural investment to promote improved capture and use of rainfall in dryland farming. Investment Centre Technical Paper No. 10, FAO, Rome.

Hodnett M G and Bell J P, 1981. Soil physical processes of groundwater recharge through Indian black cotton soils. IH report No. 77, Institute of Hydrology, Wallingford, UK.

Honore G, 1998. Impact assessment of soil and water conservation activities: experiences with hydrological monitoring of small watersheds in India. CBIP Watershed Management Conference, Delhi.

Hudson N, 1995. Soil Conservation. Batsford Ltd., London.

IRR. 1998. Agro-forestry Technology Information Kit. International Institute for Rural Reconstruction, Philippines.

van Lanen H A J (Ed.). 1998. Monitoring for groundwater management in (semi-)arid regions. IHP Programme, UNESCO, Paris.

Lovenstein H M, Berliner P R, and van Keulen H, 1991. Runoff agroforestry in arid lands. Forest Ecology and Management, 45, 59-70.

Lloyd J W, 1998. Specific monitoring. In van Lanen H A J, (Ed.): Monitoring for groundwater management in (semi-)arid regions, UNESCO, Paris.

Macdonal D M J, Kulkarni H C, Lawrence A R, Deolankar S B, Barker J B and Lalwani B, 1995. Sustainable groundwater development of hard-rock aquifers: the conflict between irrigation and drinking water supplies from the deccan basalts of India. BGS Technical Report WC/95/52, Wallingford, UK.

Miloradov M and Marjanovic P, 1998. Guidelines for conducting water resource assessments. Studies in Hydrology No 55. UNESCO, Paris.

Moench M (Ed.). 1995a. Groundwater Management: The supply dominated focus of traditional, NGO and government efforts. VIKSAT, Ahmedabad.

Moench M (Ed.). 1995b. Groundwater availability and pollution: The growing debate over resource condition in India. VIKSAT, Ahmedabad.

MYRADA and (IRR). 1997. Resource management in rainfed drylands: an information kit. MYRADA, Bangalore, India.

NRI, 1998. Indo-UK Collaboration on Biomass Monitoring: project document. NRI, Chatham, UK.

ODA, 1995a. KAWAD: Supporting Studies for Development of Renewable Natural Resources: Uppara Halla. ODA (now DFID), Delhi.

ODA, 1995b. KAWAD: Supporting Studies for Development of Renewable Natural Resources: Chinna Hagari. ODA (now DFID), Delhi.

ODA, 1995c. KAWAD: Supporting Studies for Development of Renewable Natural Resources: Dodda Halla. ODA (now DFID), Delhi.

OECD, 1998. Towards Sustainable Development: Environmental Indicators. OECD, Paris.

Palanisami K, 1990. Tank irrigation in South India: What next? ODI-IIMI Network Paper 90/2e. ODI, London.

Put M, 1998. Innocent Farmers? : A comparative evaluation into a government and an NGO project located in semi-arid Andhra Pradesh (India), meant to induce farmers to adopt innovations for dryland agriculture. Thela Publishers, Amsterdam.

Rama Mohan Rao M S and Chowdary P N. Watershed management for sustainable development: Chinnatekur Watershed – A case study. CSWCRTI Report, Bellary, Karnataka.

Rhoades R E, 1998. Participatory water research and management: where the shadow falls. IIED Gatekeeper Series, IIED, London.

Rockstrom J, 1999. On-farm green water estimates as a tool for increased production in water scarce regions. Phys. Chem. Earth (B), 24, 4, 375-383.

Sainath P, 1996. Everybody loves a good drought. Penguin, New Delhi

Salman Salman, 1999. Groundwater: Legal and Policy Perspectives. World Bank Technical Paper No. 456, Washington D.C.

Sauerhaft B, Berliner P R and Thurow T L, 1998. The fuelwood crisis in arid zones: runoff agriculture for renewable energy production. In Bruins H J and Lithwick H (Eds): The Arid Frontier. Kluwer Acad. Publishers, 351-363.

Saxena A and Yuvaraj M, 1999. Economics of watersheds. Postgraduate Diploma Report. Indian Institute of Forest Management, Bhopal.

Scheng T C, 1990. Watershed management field manual: watershed survey and planning. FAO Conservation Guide 13/6, Rome.

Seckler D, 1996. The new era of water resources management: from "dry" to "wet" water savings. Research report 1, Colombo, Sri Lanka: International Irrigation Management Institute.

Singh H P, Venkateswarlu B, Vittal K P R and Ramachandran K, 2000. Mangement of rainfed agro-ecosytem. In Yadav J S P and Singh G B (Ed.): Natural Resource Management for Agricultural production in India. Indian Soc. of Soil Science, Delhi.

Stankey G H, Cole D N, Lucas R C, Petersen M E and Frissell S S, 1985. The limits of acceptable change (LAC) system for wilderness planning. USDA Forest Service General Technical Report INT-176. Intermountain Forest Range Experiment Station, Ogden, USA.

Tideman E M, 1996. Watershed Management: Guidelines for Indian Conditions. Omega Sci. Publishers, Delhi.

Turton C, 2000. Sustainable livelihoods and project design in India. ODI Working Paper127, ODI, London

Turton C, 2000. Enhancing livelihoods through participatory watershed development in India. ODI Working Paper 131, ODI, London

UN (ESCAP). 1997. Guidelines and manual on land use planning and practices in watershed management and disaster reduction. UN(ESCAP), Bangkok.

Vincent L, and Dempsey P, 1991. Conjunctive water use for irrigation: good theory, poor practice. ODI Network Paper No. 4, ODI, London.

Visscher J T, Bury P, Gould T and Moriarty P, 1999. Integrated water resource management in water and sanitation projects. Report OP 31 E, IRC International Water and Sanitation Centre, Delft, The Netherlands.

Wade R, 1987. The Management of Common Property Resources: Finding a Cooperative Solution. Research Observer, 2:2, IBRD.

Wallace J S, and C H Batchelor, 1997. Managing water resources for crop production. Phil. Trans. R. Soc. Lond. B, 352, 937-947.

Wright E P, and Burgess W G, 1992. The hydrogeology of crystalline basement aquifers in Africa. GSSP No. 66, Geological Soc., London.

Zaal F, Laman M and Sourang C M, 1998. Resource conservation or short term food needs? Designing incentives for natural resource management. IIED Dryland Programme Issue Paper No. 77, London.

Appendix 1. KAWAD Water Resources Audit Team

Core Team: Dr Charles Batchelor (hydrologist, team leader), Dr M S Rama Mohan Rao (soil scientist/agronomist, co-ordination), Dr A J James (natural resource economist, responsible for economic component of audit).

Field Teams: Upparahalla: **Dr M S Rama Mohan Rao, Mr M Chandrappa, Mr W Muralidar, Mr B N Seshadri.**
Chinnahagari: **Dr S K N Math, Mr S Mana Mohan, Mr W Muralidar, Mr B C Eranna.**
Doddahalla: **Dr S L Patil, Mr K K Reddy, Mr V Husenappa, Mr B K N Murthy, Mr H Basappa.**

Economic support team: Dr M S Rama Mohan Rao, Dr V C Veeranna and Mr Channabasappa.

Appendix 2. KAWAD Reports (July 1998 - March 1999)

1. First visit report of the crop breeding consultant for KAWAD - D S Virk and J R Witcombe, 21 - 25 September 1998. (59 pages)

2. Report of a visit to the Karnataka Watershed Development Project (KAWAD) by the Gender and Community Development Consultant - Elizabeth Mann, 23 November - 13 December 1998 (22 pages)

3. KAWAD Project - Visit Report - C H Batchelor, 14 - 16 December 1998 (14 pages)

4. Report on Orientation Programs - James Mascarenhas, January 1999 (7 pages)

5. DFID support to Renewable Natural Resources Programmes in India - Elizabeth Mann, February 1999 (29 pages)

6. KAWAD Project - Visit Report - C H Batchelor, 21 - 27 Februrary 1999 (17 pages)

7. Development support for HRD and training strategies, Karnataka Watershed Development Project (KAWAD), Final Report, 18 March 1999 - Dr Philip Scott Jones, 7 - 17 March 1999 (20 pages)

8. Visit Report by Consultant Agricultural Economist/ Rural Development Specialist - Brian Duncan, March - April 1999 (37 pages)

9. KAWAD Water Resource Audit - Report on a visit to the MYRADA Holalkere and Challakere Projects: 30 March - 1 April 1999 (13 pages)

10. Start-up workshop on Resources of KAWAD Watersheds – C H Batchelor and M S Rama Mohan Rao, 7 - 9 April 1999 (12 pages)

11. Project Implementation workshop for KAWAD, Bijapur, 13 - 16 April 1999 - P S Jones (26 pages)

12. Karnataka Watershed Development Project - Draft 1st Annual Progress Report (January 1998 to June 1999) and 2nd Annual Work Plan (July 1999 to June 2000), Karnataka Watershed Development Society (55 pages ?)

13. KAWAD Water Resource Audit - Monitoring, Evaluation, Information Management and Decision-making within a Single Resource Management Framework. Draft Discussion Document. C H Batchelor and M S Rama Mohan Rao (26 pages)

14. Report of Training and Human Resources Development Consultant. Mary Underwood, May 1999.(28 pages)

15. Second visit report of the Crop Breeding Consultant for KAWAD Daljit S Virk, 26 April - 9 May 1999 (52 pages)

16. Monitoring the Performance and impact of Watershed Development in Karnataka, India. Report of a consultancy on support for developing systems for monitoring and evaluation. David Mosse, July 1999 (45 pages)

17. KAWAD Water Resources Audit - Final Report. C H Batchelor, M S Rama Mohan Rao & A J James , January 2000 (33 pages)

Appendix 3. Glossary

Aquifer. A geological formation that has sufficient water-transmitting capacity to yield a useful water supply in wells and springs. All aquifers have two fundamental characteristics: a capacity for groundwater storage and also for groundwater flow. However, as a result of natural geo-diversity aquifers vary widely in hydraulic properties (storativity and permeability) and reservoir volume (effective thickness and geographical extent).

Bajra. Pearl millet.

Base flow. That portion of flow in streams that originates from springs or groundwater seepage.

Bund. A ridge of earth used to control runoff and soil erosion. Sometimes used also to demarcate a plot boundary.

Catch crop. A fast maturing crop that is often planted as an additional crop to make use of late rains or residual soil moisture.

Check dam. A structure that is placed across a water course primarily to reduce or check the velocity of water flow. Check dams can be constructed using a wide range of designs and materials.

Chickoo. Sapota – a horticultural crop.

Contour. An imaginary line joining all points of equal elevation on a land surface.

Contour bunds. Earthen ridges or embankments that are constructed along the contours.

Dead furrows. These are furrows that are created in rainfed arable areas between crop rows generally 30-45 days after sowing. The aim is to conserve moisture and dispose of excess water.

Ephemeral stream. Streams in which water flows for only part of the year.

Evaporation. Process in which water passes from the liquid state to the vapour state.

Geographical Information System (GIS). A computer system for storage, analysis and retrieval of information, in which all the data are spatially referenced by the geographic coordinates.

Gradonis. Bench terraces of small width formed on contours by disturbing soil in areas having mild to steep slopes.

Gram panchayat. Village council.

Groundwater drought. A period during which aquifers become severely depleted such that wells run dry and demands for water are not met. In general, groundwater droughts are caused by a combination of *meteorological drought* and unsustainable extraction of groundwater for irrigation and other purposes.

Indicator. A parameter or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/ environment/area, with a significance extending beyond that directly associated with a parameter value.

Information Management. Process of gathering, storing and analysing information needed for a specific purpose, such as planning or making management decisions.

Intercropping. Growing two or more crops in the same field at the same time.

Jowar. Sorghum.

Limit of Acceptable Change (LAC). Indicators only have meaning in the light of specific targets and threshold values (Bollom, 1998). These targets or threshold values can be used as triggers for management responses, as warning signals or as means of evaluating project performance. Depending on the context LACs may also be referred to as *safe minimum standards, critical loads* or *critical thresholds*. LACs may be determined locally, nationally or as part of international conventions.

Livelihood. A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living.

Management. The decision-making process whereby a plan or a course of action is implemented. Planning forms part of this process as does the allocation of resources and the resolution of conflicts of interest. Effective management is only possible if managers have access to reliable information.

Mandal. Sub-taluk administrative area.

Meteorological drought. A period during which rainfall is low and/or insignificant. Short periods of meteorological drought lead to depletion of soil moisture and damage to plants. In general, long periods of drought lead *surface-water drought* and subsequently to *groundwater drought*.

Nala. A small river or stream.

Nala Bund. A structure or bund of suitable dimensions that is located across a water course with the primary intention of capturing runoff for periods of days or weeks.

Panchayati Raj. Local government.

Parameter. A property that is measured or observed.

Planning. The exercise of foresight, systematically examining alternative proposals for action to attain specified goals and objectives. Includes a description of the desired future state of affairs and the actions needed to bring about this state.

Rabi. Crop season that runs from mid-Sept to early January. Corresponds with the N E monsoon.

Ragi. Finger millet.

Runoff (or surface runoff). The portion of rainfall that flows over the land surface. Runoff can concentrate in depressions or behind impounding structures or it can continue to flow over the land surface into water courses.

Seteria. Fox-tail millet.

Surface-water drought. A period during which surface water resources become severely depleted. In general, surface-water droughts are caused by a combination of meteorological drought and unsustainable use of surface-water and groundwater.

Sustainable rural livelihood. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain its capabilities and assets both now and in the future, while not undermining the natural resource base.

Taluk. Sub-district.

Tank. Water reservoir.

Watershed. In this report, a watershed is considered to be a natural drainage area that extends from a ridge or watershed boundary to some point on a water course. All the surface runoff in the watershed will drain to this point. It should be noted that water flow in aquifers underlying watersheds follow the same flow paths as surface runoff.

Zilla parishad. District council.

Zingg Terrace. Sometimes called a *conservation bench terrace*. A water harvesting practice that consists of a contributing area with natural or slightly altered slope and a receiving area with no slope in any direction. Rainfall runs off the contributing area and concentrates in the receiving area.