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ORIGINAL PAPER

Watershed development in India. 1. Biophysical and societal impacts

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Abstract This paper recommends a revision of watershed development policy in India in relation to the planning of development interventions involving agricultural intensification and rainwater harvesting following biophysical and societal impact studies carried out on two watershed development projects in Karnataka. A need for changes in policy has arisen in response to progressive catchments closure at the basin level and declining volumes of water flowing into village level reservoirs (known locally as tanks). Flow reductions have occurred largely as a result of increased agricultural intensification over the past 10–15 years. Field levelling, field bund construction, soil water conservation measures, farm ponds, the increase in areas under horticulture and forestry and the increased abstraction and use of groundwater for irrigation are all contributing factors to reduced flows. Planning methodologies and approaches, which may have been appropriate 20 years ago for planning water harvesting within watershed development projects, are no longer appropriate today. New planning approaches are required which (1) take account of these changed flow conditions and (2) are also able to take account of externalities, which occur when actions of some affect the livelihoods of others who have no control or influence over such activities and which (3) contribute to the maintenance of agreed minimum downstream flows for environmental and other purposes.

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Abbreviations

BIRDS	Bijapur integrated rural development society an NGO for the Inchigeri area
CLUWRR	Centre for land use and water resources research
DANIDA	Danish international development agency
DFID	Department for international development
EXCLAIM	EXploratory, climate, land, assessment, and impact, management tool
HYLUC	HYdrological land use change
JSYS	Jala samvardhane yojana sangha, a World Bank program responsible for implementing the Karnataka community based tank management project
KAWAD	Karnataka watershed development society
NGO	Non-governmental organisation
SCS	Soil conservation service
SHG	Self-help-group.

1 Introduction

It is increasingly being recognised that interventions within watershed development projects may not always be having the presumed beneficial impacts on water availability and people's livelihoods. In many parts of the world rain water harvesting practices involving for example field levelling, field bund construction, soil water conservation measures, check dams and farm ponds, have been shown to improve agricultural yields by providing farmers with additional irrigation water and by improving the viability and productivity of rainfed farming systems. However, concerns have been raised regarding the potential for excessive use of rainwater harvesting practices to produce negative externalities, i.e. impacts, not only on the communities within the watershed area, but also on downstream communities (Batchelor, Singh, Rama Mohan Rao, &, Butterworth, 2002; Batchelor, Rama Mohan Rao, &, Manohare Rao, 2003; Rama Mohan Rao et al., 2003; ETC, 2004; Sakthivadivel and Scott, 2005; Sharma and Scott, 2005).

Similar concerns have been raised (Calder, 2005; Calder et al., 2005) that other watershed interventions which alter catchments water flows, either by way of evaporative vapour flows (green water—using Falkenmark (1995) terminology) or liquid water flows (blue water), may be having similarly unforeseen and negative consequences. These interventions might include land use changes involving greater areas under irrigation, forestry, horticulture, agroforestry and intercropping.

Two studies are reported here that have investigated the water flow and societal impacts of watershed interventions in Department for International Development (DFID) and World Bank supported watershed development projects in southern India. The studies were focussed on the Inchigeri and Mustoor catchments (Fig. 1). Some of the interventions were implemented by the development projects and some occurred or would have occurred without development project implementation. They include the construction of rainwater harvesting structures, tank rehabilitation,

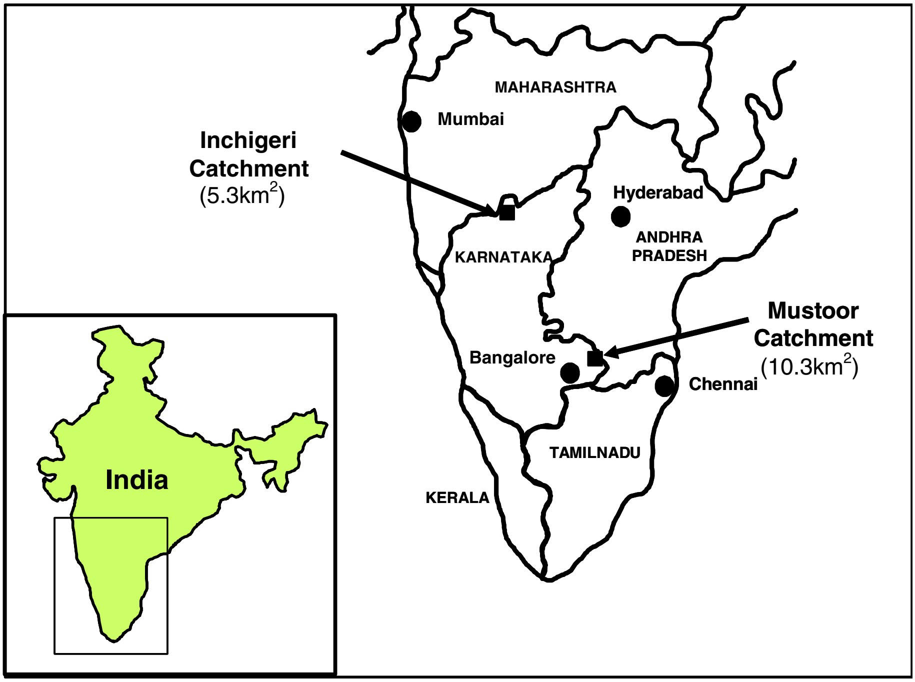

Fig. 1 Location of the Inchigeri and Mustoor catchments

increased areas under irrigation using borewell water, increased areas under forestry and the general intensification of agricultural activities, which might involve field levelling and field bunding, on rainfed as well as irrigated areas and increased areas under horticulture.

There are important differences in the way interventions have been implemented in the two catchments. The Inchigeri catchments has a greater than average concentration (per unit catchments area) of rainwater harvesting structures while the Mustoor catchments has a greater than average concentration of tanks and a high concentration of irrigation boreholes. In both areas, there has been an intensification of farming systems that include adoption of improved varieties, increased use of fertilisers and a move towards intercropping. There are important differences in soil types and geology of the two areas: Inchigeri is located in an area of vertisols (i.e. black cotton soils) underlain by Deccan basalt whilst Mustoor is in an area of alfisols underlain by crystalline basement geologies.

2 Modelling impacts of watershed interventions on catchments water flows

The impacts of watershed interventions on water flows within the study catchments were investigated using a new development (Bishop, 2005) of the Hydrological Land Use Change (HYLUC), model (Calder, 2003). The 'HYLUC-Cascade' version uses runoff calculated by the HYLUC model for the sub-catchments area of each water retention structure in the catchments, and routes this through the cascade of rainwater harvesting structures or village tanks that may exist within the catchments. The

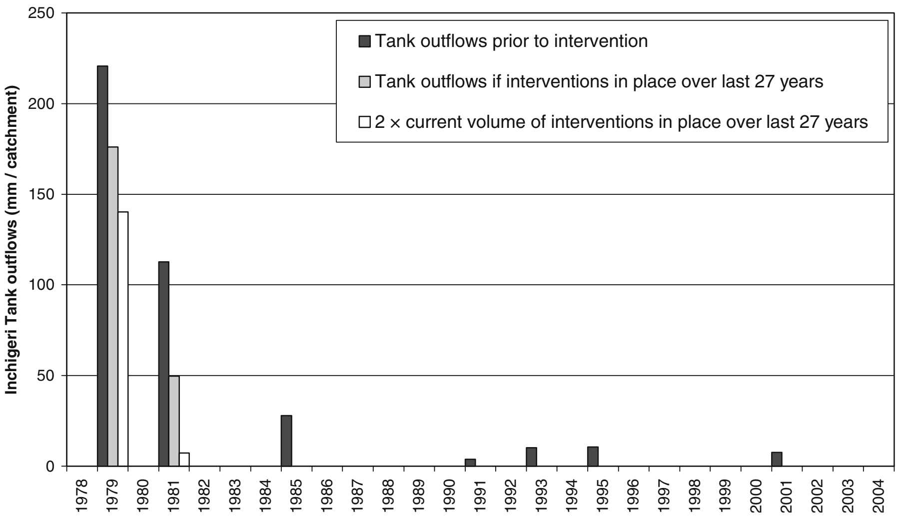

Fig. 2 HYLUC-Cascade model predictions showing annual outflows from the Inchigeri tank, with and without rainwater harvesting interventions introduced by the KAWAD project

evaporation of water together with the infiltration of water retained within structures are explicitly accounted for in the model. The model has been calibrated for each catchments such that the surface runoff inflows to the structures matches that given by the use of a local Soil Conservation Service (SCS[1]) rainfall to runoff relationship.

2.1 Karnataka watershed development society watershed study Inchigeri

For the Inchigeri catchments the HYLUC-Cascade model surface runoff calculations were based on land use distributions for all sub-catchments within the Inchigeri catchments of 9% irrigated agriculture, 3% natural vegetation, 7% water bodies from structures and tanks and 81% rainfed agriculture, with no significant areas under forest. These values were based on discussions with field staff (BIRDS Personal communication, 2005) and observations from the field.

The predicted changes to the catchments flows, in terms of volume and frequency of annual outflows, were calculated by the HYLUC-Cascade model for three different intervention scenarios. Results for these scenarios representing (1) no interventions, (2) the present scenario of 28 major soil water conservation structures and (3) a possible future doubling of the volume of the present level of interventions, are shown in Fig. 2.

The model shows that even without the interventions introduced by the Karnataka Watershed Development Society (KAWAD) development project the average annual outflows from the Inchigeri tank was only a very small proportion (3.1%) of the rainfall. After the interventions this value was reduced to 1.8%. With a doubling of volume of the interventions the outflow would be only 1.2% of the rainfall.

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[1] The method, called the Soil Conservation Service (SCS) method was developed in the USA and has been adapted to various regions in India, based on soil type. It determines runoff based on a series of curves which are based from gauged flow and rainfall records in India (Tideman, 1998).

The frequency of annual outflow events from the Inchigeri catchments is also influenced by the intensity of interventions. Under scenario (1) 'no interventions', there are 8 years in the 26 years record with outflows. Under scenarios (2) and (3) there are only 2 years with outflows.

These results indicate that no further increases in the number of rainwater harvesting structures can be introduced into a catchments such as the Inchigeri without serious impacts on the surface flows exiting the catchments.

2.2 World Bank mustoor catchments studies

The HYLUC-Cascade model was also used to investigate how watershed interventions involving tank sedimentation and tank rehabilitation might affect water flows in the Mustoor catchments tank system, Fig. 3. Two siltation scenarios were considered: (1), reflects the 'no silt' situation when the tanks were originally constructed, for which tank volumes were set to their original design capacity, i.e. prior to any tank siltation, (2) reflects the present day 'silted' situation with tanks assumed to be at 60% capacity with 40% siltation. For both scenarios HYLUC parameters reflecting soil infiltration properties of the land surface were chosen to give average annual runoff rates from the land surface of 11% of annual rainfall (as predicted by the SCS model). Infiltration rates of 7.2 mm/day were assumed for water infiltrating within tanks and rainwater harvesting structures.

As would be expected, both the frequency and volume of outflows increase as siltation increases from the 'no silt' (Fig. 4) to the present day 'silted' (Fig. 5) scenario; the volume of outflow events is 0.8% of rainfall in 'no silt' and 1.8% of rainfall in the present day 'silted' scenario (Fig. 6).

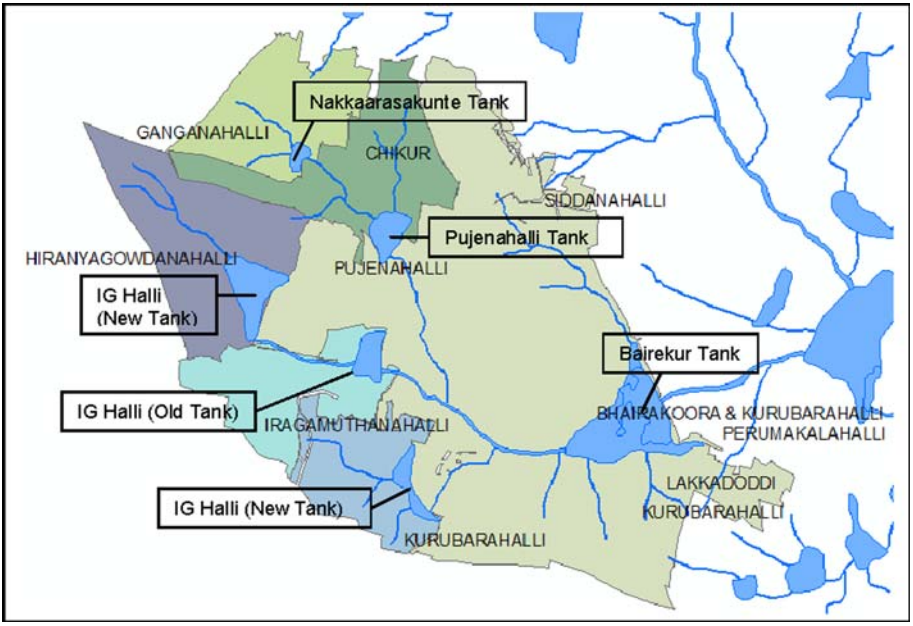

Fig. 3 Mustoor catchments tank cascade system feeding the downstream Bairekur tank

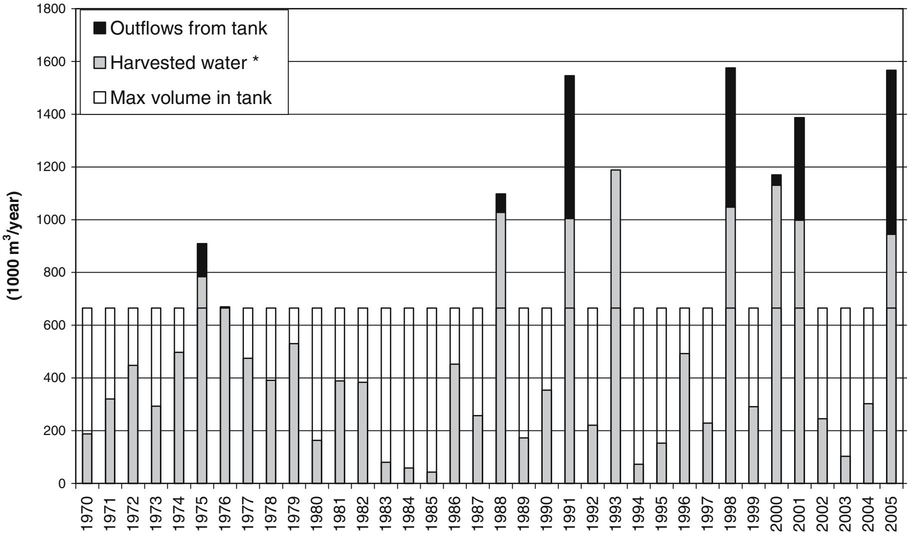

Fig. 4 Mustoor Catchments (Main Tank), Bairekur Tank Scenario 1, No silt. * 'Harvested water' represents the difference between tank inflows and outflows and includes water abstracted for irrigation and water lost through evaporation and seepage from the tank

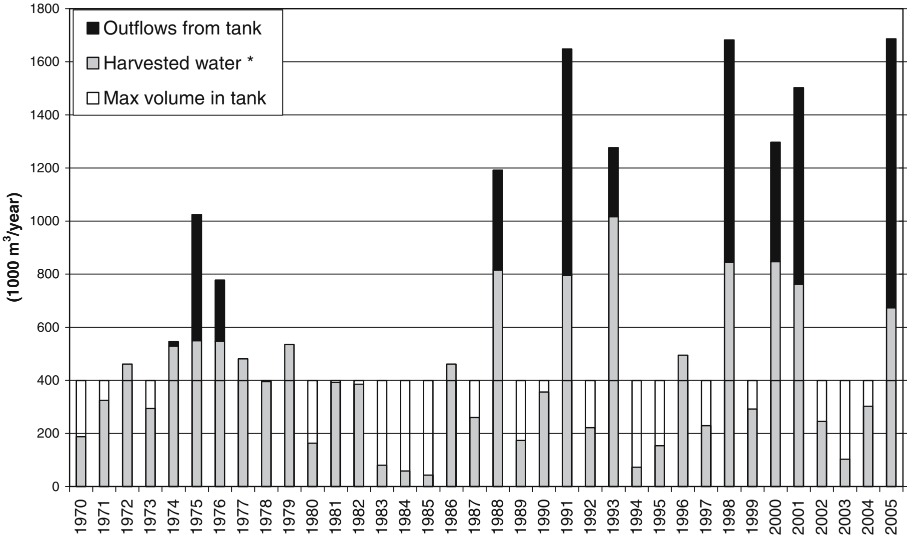

Fig. 5 Mustoor Catchments (Main Tank), Bairekur Tank, Scenario 2, Silted 40% siltation

But the predicated increased frequency of outflows from tanks in modern times as compared with the earliest period of the record are in direct contradiction to the recollections of the local villagers, farmers and local authorities. Local records indicate quite the opposite; they indicate that tank outflows (spills) were much more frequent in the past that they have been in recent years. Whereas for the early period between 1970 and 1987 and assuming the 'no silt' scenario, (1), the model predicts,

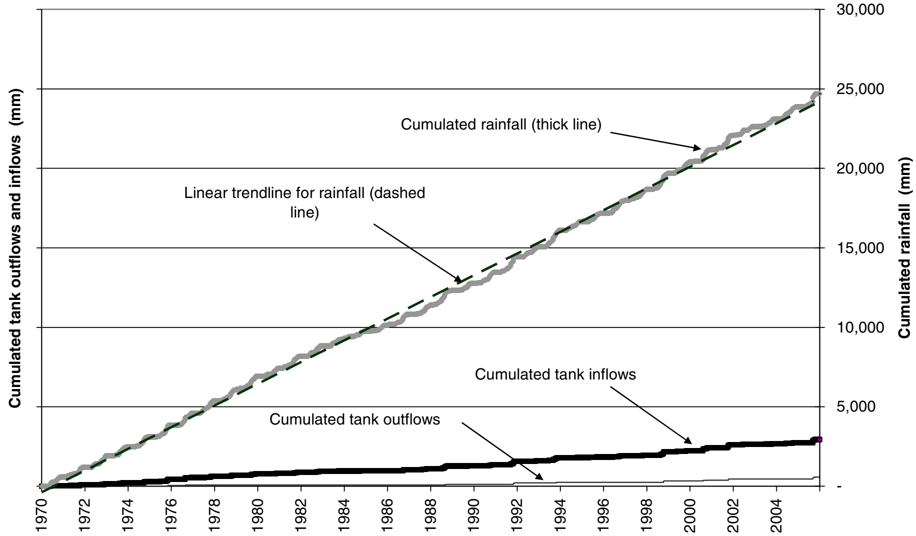

Fig. 6 Cumulative rainfall, and cumulative predicted inflows and outflows from the Bairekur Tank for the 'Silted' scenario assuming 40% siltation of tanks. (Note that predicted outflows are only a small percentage, 1.8%, of the rainfall)

Fig. 4, that the tanks would have spilled only once or twice, local people recall that tanks spilled much more frequently, at least once every 3 years.

For the post 1987 period, and assuming scenario (2), that the tanks are 40% silted, the model predicts that the Bairekur tank outflows would occur once every 2 years, Fig. 5. But village observations for this period indicate that the tanks spilled much less frequently and have not produced any outflows in the last 10 years.

Here we have a situation where the HYLUC-Cascade model, which is accounting for rainfall variation and tank siltation effects on flows, is predicting changes in tank outflows over time which are the opposite to those that have been observed by local people.

The model's underestimation of tank spill frequencies in the early period of the record and overestimation in the more recent period, post 1987, indicates that there may be other factors at work between these two periods which have caused reduced tank inflows in the most recent period and which are not being properly accounted for in the model.

Three possible contributing causes were investigated: (1) incorrect estimation of local rainfall, (2) groundwater abstraction reducing baseflow inputs into tanks, (3) increased upstream water retention measures resulting from agricultural intensification.

2.2.1 *Rainfall estimation*

Rainfall records used in the modelling (Mulbagul and Nangli rainfall stations) and two other nearby stations show no reduction in annual rainfall from the early period of the record as compared to the present, Fig. 6. Furthermore a simple comparison of rainfall at these two sites against other nearby sites indicates no abnormal deviations from the regional rainfall. The analysis therefore provides no evidence to support the public perception that rainfall has decreased in recent years and that this decrease in rainfall is the cause of reduced flows into tanks and the reduced incidences of tank outflows.

2.2.2 Baseflow processes

It is possible that high-groundwater levels in the catchments occurring during the early, pre 1987 period of the record, or in very wet periods during the more recent, post 1987 period could augment streamflow volumes into tanks via the production of baseflow (also referred to in India as regenerated groundwater flow). But the HYLUC—Cascade model in its current format only accounts for surface generated flow as the inflow into rainwater harvesting structures and tanks. The large increase in groundwater abstraction since the widespread adoption of electric submersible borehole pumps in the late 80 has resulted in a rapid depletion of watertable over much of India. In the last 5–10 years groundwater tables at Mustoor have approached 300 m below ground level in some parts of the catchments and it is likely that this lowering of the water table will have led to much reduced baseflow production which would, in turn, have reduced inflows to tanks. This hypothesis is supported by local observations of springs drying and decreased duration of flows in ephemeral streams during recent years.

2.2.3 Water retention through agricultural intensification

Together with the increased groundwater abstraction associated with the general intensification of agricultural practices, other engineering interventions may also be reducing tank inflows. Land based engineering interventions, which increase water retention including field levelling, field bund construction, intercropping and improved rainfed farming systems, farm ponds, contouring and field trenching will all contribute to reduced tank inflows.

2.3 Biophysical modelling conclusions

A number of important conclusions can be drawn from the modelling studies on the Inchigeri and Mustoor catchments:

- The long-term outflows from both catchments are, at present, only a small proportion (<2%) of the rainfall.
- Any further developments involving increased intensification of agriculture and any increase in rainwater harvesting will reduce these already small outflows—impacting on downstream users and the environment and contributing to basin closure.
- The Mustoor study indicates that agricultural intensification is having a major impact in reducing flows into village tanks. Although when constructed the density of village tanks was probably appropriate to the flow conditions at the time the justification for such a high degree, or an increased degree of water retention, under today's conditions of reduced flows is less justifiable.

3 Societal impacts of watershed interventions-village level surveys

3.1 Biophysical modelling conclusions

The societal component of the study on the Mustoor sub-watershed aimed to identify the socio-economic context of the study area together with the socio-economic impacts of watershed interventions in relation to:

- Access to safe domestic water and sanitation.
- Access to water for irrigation, livestock and other productive uses.
- Livelihood patterns of different social groups including migration.
- Functionality of the village institutions.
- Water-related timelines.
- Specific adaptations of people and institutions to increasing competition for water.
- Functionality of village tank systems.
- Level of involvement in ongoing and previous watershed development programmes.

3.2 Societal data collection

Primary data was collected during focus group discussions and meetings with key informants. This was cross referenced with secondary data from a wide range of sources including data collected by Prakruthi (a local Non-Governmental Organisation (NGO)) as part of the World Bank supported Sujala watershed development project and data collected by the World Bank supported Jala Samvardhane Yojana Sangha (JSYS) tank rehabilitation project. The data were collected over a 6 month period starting in April 2005 which included two periods of intensive fieldwork in July and October 2005.

3.3 Societal impacts

Table 1 presents the demographic information for villages that have land in the catchments area of Bairekur tank. The majority of people in these villages belong to

Table 1 2004 demographic details

Village name	Total number of families	No. of families below the poverty line		Total number of landless families
		Govt. Statistics	Participatory Rural Appraisal data	
Iringamattanahalli (IG Halli)	78	27	59	22
Pujenahalli	35	14	11	6
Hiranyagowdanahalli (HG Halli)	57	31	16	4
B. Kurubarahalli	61	42	56	7
Bairekur	418	70	190	231
Peramakanahalli	88	25	51	15

Data form Sujala project

Table 2 Levels of village water supply for domestic and livestock use

Village name	Domestic water use (lpcd)	Livestock water use (lpcd)	Time taken to collect each pot (minutes)
Iringamattanahalli (IG Halli)	32	55	7
Pujenahalli	45	41	4
Hiranyagowdanahalli (HG Halli)	34	33	7
Bairekur	48	44	12
Peramakanahalli	40	33	6

Scheduled Caste (SC) and Scheduled Tribe (ST) families. This is a fairly typical rural area and, as such, agriculture is the main source of income. Most landless households rely heavily on agricultural wage labour or migration. In all the villages the majority of the family incomes ranged between Rs 10,000 and 20,000per annum. A significant number of families had incomes in the range Rs 5,000–10,000 and only about 10% of the families had incomes above Rs 40,000per annum.

3.3.1 Domestic water

For most villages, domestic water was supplied to standpipes via overhead tanks that are connected to borewells fitted with submersible pumps. Water was supplied on average for 1–2 h each day. Table 2 provides a summary of findings from a survey of domestic water use, carried out in October 2005. The survey showed that, even during the monsoon period, most villagers were accessing and using less domestic water than the national drinking water norm of 45 litres per capita per day (lpcd). In general, villagers considered water quantity issues to be a bigger problem than water quality issues. However, in Bairekur, villagers stated that there were water quality problems as a result of rusting pipes and contamination with insects and other detritus.

During summer, the reliability of village water supplies declines substantially as a result of the irregular power supply. In Peramakanahalli and Kurubarahalli villages there were also problems associated with borewell yields, which decline during the summer and in periods of drought. Historically, open wells were the main source of domestic water but almost all these wells were defunct in 2005. Some were completely dry whilst others were unusable as the small amount of water they held was polluted with algae and household waste. Each village had two to three hand pumps but the majority of the hand pumps were also non-functional. Bairekur, for example, had ten hand pumps but only four were functional.

Village water supplies were, in general, insufficient to meet the needs of livestock and, as a result, other sources had to be found. In most cases water was taken from tanks and when these were dry water was taken from irrigation borewells.

3.3.2 Groundwater

Table 3 summarises the status of borewells and open wells in the Bairekur catchments area in October 2005. Almost all the open wells were non-functional due to depleted groundwater tables although, in some villages (e.g. IG Halli) open wells located in command areas below tanks refilled when the tanks received

Table 3 2005 status of wells based on focus-group discussions

Village name	Number of open wells		Number of borewells	
	Functional	Defunct or very unreliable	Functional	Defunct or very unreliable
Iringamattanahalli (IG Halli)	0	60	15	5
Pujenahalli	0	14	6	24
Hiranyagowdanahalli (HG Halli)	1	9	3	3
B. Kurubarahalli	0	0	6	44
Bairekur	0	150	50	150
Peramakanahalli	0	35	17	30

significant inflows. In some cases, these open wells were used for irrigation purposes.

The first borewells were constructed between 1982 and 1985 with a depth of 80–100 m. Now the depth drilled is up to 300 m with a higher rate of failure even at these depths. Although many of the earlier constructed borewells are currently non-functional (Table 3) private investment in borewell construction continues undiminished. Statistics are not available on the numbers of farmers who have lost money by drilling 'dry' boreholes but it is believed to be significant (See Box 1 for a typical example). The water-related timeline (Table 4) suggests that the Bairekur catchments area has been going through a 'boom and bust' cycle of groundwater development and is now in the 'bust' phase where the areas under irrigation are now contracting to meet the available irrigation water from a reducing number of functioning borewells. Whilst villagers recognise the decrease in irrigated areas many believe that the 'bust' part of the cycle brought on by depleted water tables has been caused by low rainfall rather than an excessive demand. Or, put another way, they believe that many of the currently non-functional borewells will become functional again after a period of above average rainfall.

Box 1 Dry boreholes

Mr Sheshappa from Pujenahalli village drilled a first dry borehole in 1985, a second in 1994, a third in 2001, a four in 2002 and two more in 2003. At the start of this attempt to become an irrigator farmer, Mr Sheshappa had a relatively large number of livestock. Aftethe six failed well, he had few animals left.

On this mistaken belief, and the allure of the potential returns, which can be gained from irrigating using a successful and reliable borewell, farmers are continuing to invest in borewell drilling, risking serious debt if they fail. The returns are such that if a farmer can achieve a successful well he might pay off all debts within 1 or 2 years and make very good profits (See Box 2).

Box 2 Irrigation profitability

One farmer in IG Halli stated that he had invested almost one lakh rupees (100,000 rupees, equivalent to ~US$ 2,000) in drilling three borewells. One of these was successful and he is now able to irrigate approximately 2 ha. Within 1 year, he was able to recoup his whole investment as he got a good crop of tomatoes.

Bairekur catchments is located in an area of crystalline basement bedrock where the groundwater aquifer is dependent on the depth of weathering and the degree of

Table 4 Water-related timeline analysis (based on focus-group discussions in five villages)

	Before 1975	1975	Around 1985	Around 1995	1999–2005
Open wells	10–20 ft	10–50 ft	Some wells drying up during the summer months	Many openwells failed or defunct as a result of falling groundwater levels	Nearly all openwells are defunct with exception of wells downstream of tanks. These have water when tank is full
Borewells	No borewells	No borewells	First borewells to a depth of around 80–100 m	20–50 borewells to a depth of 180 m	Around 350 borewells to a depth of around 270 m. More than 70% of borewells constructed are non-functional
Tanks	Full every other year and spill every 2–3 years	Full every other year. Prolonged dry period at some stage during 1970s.	Full every other year. Spill every 2/3 years.	Full every other year. Spill every 2/3 years. Last observed spill from Bairekur tank in 1995.	Spill from all tanks but Bairekur in 1999 and 2005. Almost no tank inflow during 2003–2004
Forest	Some forestry	Limited forestry	Limited forestry	Minimal forestry. Small amount of new horticulture	Minimal forestry. Small amount of new horticulture
Rainfall	Every month 2/3 showers	Every month 2/3 showers	Dry spells	Average rainfall	Average to very low rainfall
Livestock	Large number of livestock	Reduced livestock numbers	Reduced livestock numbers	Reduced livestock numbers	Some increase in livestock numbers for dairying. Problem with fodder availability
Crops	Ragi, groundnut, paddy (Byruvadlu)	Ragi, groundnut, paddy	Ragi, groundnut, paddy (byruvadlu)	Ragi, silk, tomato	Ragi, tomato, groundnut and very little silk
Health	Healthier than 2005	Healthier than 2005	Average	Average	Lot of diseases but treatments are available, unlike in previous years

fracturing. The hydrogeological conditions are such that it is more difficult to construct a successful borewell in the headwater areas than further downstream. This fact is not lost on farmers in upstream villages such as Pujenahalli and HG Halli, where the villagers also feel that farmers in headwater areas are further disadvantaged because they tend to have less money to invest in drilling wells due to the reduced agricultural returns from farming land with poor soils and lower land capability classifications.

3.3.3 Surface water resources

The general perception of villagers is that tank inflows have reduced in the last 10–20 years along with the frequency of spills (outflows). Table 5 summarises information on inflows into and spills from tanks in the Bairekur catchments area. Reasons given by villagers for this include: (1) low rainfall; (2) land use change in the catchments areas and (3) groundwater level decline that has led to a drying of springs and seepage zones. It should be noted that villagers gave the first two reasons without any prompting and the third reason came from a more detailed discussion of changes that they have observed in recent years. (As discussed earlier, the perception that rainfall has been declining systematically is one that is not supported by trends in rainfall data from rain gauges in the area.)

Although there are some functional springs and seepage zones in headwater areas (e.g. in the Hiranyagowdanahalli catchments area), most springs and seepage zones have dried up in recent years. As a consequence, villagers have observed a reduction in the flows in the ephemeral streams that feed into tanks. They have also observed that the duration of flow after a rainfall event is much shorter (e.g. a few days rather than a few weeks).

The majority of tanks in the Bairekur catchments were full and had outflows (were spilling) during the week before the October 2005 fieldwork. However, the Bairekur Tank was only approximately one quarter full and consequently had no spills at this time. Local knowledge indicated that the Bairekur Tank had not spilt since 1995 and hence that for the last 10 years, the Bairekur catchments has been effectively ‘closed’.

3.3.4 Irrigation

Table 6 summarises information from a survey of net irrigated area that was carried out in 2004 as part of the Sujala project. The general opinion of villagers was that the potential net irrigated area had increased in the last 10–15 years. This is because some land holdings located outside the tank command areas can now be irrigated using water from boreholes. This said the actual net irrigated area has been well below the potential during the last 5–10 years because tanks have had poor inflows and many borewells have failed. Erratic electricity supplies have also limited extraction from functional borewells.

Construction of borewells has enabled farmers with reliable borewells to double and triple crop all or part of their land holdings and to grow crops that have been selected to maximise profit (rather than minimise risk). A distinction has emerged between farmers with reliable wells who are able to intensify their cropping systems and farmers with unreliable wells who, for a variety of reasons, have a tendency to fall into debt during periods of low rainfall.

Table 5 Inflow and outflow timeline for tanks in the Bairekur Catchment

Tank name:	Before 1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Pujenahalli		Crops cut for fodder	Spill every 2/3 years. 1994 was a bumper year					Spill	No spill. Almost no tank inflow during 2003–2004					3 days spill.
HG Halli	Spill every 2/3 years	Spill almost every year						Spill. Bumper year.	No spill					Spill. Bumper year.
IG Halli (New Tank)	Tank regarded as being a mess, unreliable and in a poor location. High level of siltation with trees and scrub growing in tank bed. Consensus that tank may have spilled once in 60 years but no recollection of when this might have been													
IG Halli (Old Tank)	Spill every 2/3 years							Spill for one night only	No spill					Spill for 3 days
Bairekur		Tank filled every year but no spill		Last observed spill	No spill			Almost full but no spill	No spill					No spill less than 50% full

Table 6 2004 irrigation data

Village name	Total land area (ha)	Land under agriculture (ha)	Net irrigated area (ha)
Iringamattanahalli (IG Halli)	239	117	42
Pujenahalli	118	54	25
Hiranyagowdanahalli (HG Halli)	202	64	21
B. Kurubarahalli	109	54	10
Bairekur	713	334	84
Peramakanahalli	363	177	93

Data from Sujala Project

Although borewells have been constructed by many farmers with land in tank command areas, releases from some tanks are still being used as a source of irrigation water (e.g. IG Halli New Tank). However, the situation relating to tank releases has been complicated by a Revenue Department order requiring all tanks to be converted into recharge structures (i.e. sluices to remain closed at all times). This is in potential conflict with the JSYS project objectives, which are directed to rehabilitating tanks so that they can be used again as sources of irrigation water. The apparent contradiction was causing concern amongst farmers with land in tank command areas who do not own reliable borewells. If a ban on tank water releases is continued, these farmers will lose their access to irrigation water.

Farmers intent on minimizing risk tend to plant ragi as the main staple crop whereas farmers who are able to take risks plant paddy and commercial crops. Tomatoes are a popular commercial crop because there is a high demand from the traders who buy tomatoes in local markets and then transport them to Bangalore, Chennai and other urban areas. There has been an increase in the area under horticulture (e.g. mangoes). These areas are receiving supplemental irrigation if and when the landowners have a reliable borewell. Although there are a few small plots, cultivation of eucalypts on arable lands was not widely practised; groundnuts intercropped with redgram was the predominant rainfed cropping system.

Increased irrigation and agricultural intensification have led to a higher labour requirement per unit area. However, the general view is that most of this additional work is being carried out by members of the relevant farmers' households rather than by landless labourers.

3.3.5 Sanitation

Under a Danish International Development Agency (DANIDA)-supported scheme, latrines were constructed in almost every house (except in HG Halli and Kurubarahalli). However, these are not being used and most have been converted into bathrooms or livestock storage units. Environmental sanitation is poor throughout most of the villages in Bairekur catchments; there are no community initiatives to keep villages clean and the general view is that the maintenance of drainage is the responsibility of the panchayat.

3.4 Livelihoods and water

A water user typology for households in the Bairekur catchments was carried out to provide the basis for making generalisations in relation to which groups have benefited, and which groups may have been disadvantaged, from water related developments in the last 20–25 years.

3.4.1 Whole village

Taking the village as one social unit, it can be argued that most households have benefited to some extent from the injection of cash into village economies as a result of agricultural intensification. However, competition for water resources resulting from agricultural intensification has led to problems relating to the reliability of domestic water supply (with the exception of families with private supplies, e.g. some families in IG Halli).

3.4.2 Landless and resource poor households

This social group has benefited from wage labour that has been available when watershed development-type work is taking place. However, in most other respects this group has not benefited from agricultural intensification because members do not own land, have poor quality land or are not able to borrow to invest in borewell construction. As a group that relies heavily on livestock, it can be argued that members have been disadvantaged because of reduced access to grazing land and reduced tank inflows, which have made watering livestock more difficult. Groundwater drought together with failure in rainfed cropping has increased the pressure on this group to migrate, or rather for some members of each household to migrate, leaving behind the old and young family members and livestock.

3.4.3 Landowners and resource rich during periods of good rainfall

This group benefited from agricultural intensification at least during the ‘boom’ years before groundwater levels started to fall. In recent years, this group that been at most risk of falling into poverty as a result of failed investments in borewell construction. Regionally, farmer suicides have been relatively common in this group.

3.4.4 Land owners and resource rich at all times

Arguably this relatively small social group is the one that has benefited most from agricultural intensification and water resource developments. In part from making timely investments and in part as a result of being lucky in constructing a reliable well, members of this group have been able to consolidate their wealth and power in the village by diversifying out of agriculture and by engaging in activities such as being a moneylender or getting involved in the panchayat. Diversification has had the added benefit of reduced dependency on access to water.

3.5 Village institutions

Self-help Groups (SHGs) have been formed in almost all the villages coming under the Sujala Project. In general, these SHGs were conducting regular meetings and were keeping good records. Their regular thrift and credit activities have resulted in banks providing loans for income-generating activities especially dairying. The local

NGO, Prakruthi, was facilitating the groups' activities through continuous capacity building. However, the general view of villagers was that small-scale income-generating opportunities were very limited, with the exception of dairying, and to sustain this activity women were having to travel long distances to obtain fodder. Assuring drinking water for the livestock especially during the summer was also a major challenge. On the positive side, there was a high-local demand for milk and, as a result, marketing was not a problem.

User groups promoted by Sujala and the JSYS projects were also functioning well with regular meetings and records. In contrast, water and sanitation committees promoted by DANIDA were almost non-functional

All the villages are represented in Bairekur panchayat although the general perception of villagers was that the activities of the panchayat are mainly focused or limited to Bairekur village.

4 Summary of main findings

The studies carried out on the Inchigeri (KAWAD) and Mustoor (World Bank) watershed development catchments have highlighted some of the water resource and societal problems, which may arise when a process of ongoing agricultural intensification is combined with engineering interventions which increase water retention.

At the Inchigeri site the modelling study has shown that rainwater harvesting structures and high levels of groundwater extraction upstream of the Inchigeri tank have significantly reduced inflows to the tank. The study shows that, by using a 30 year rainfall record, the tank would have spilled and provided water flows to downstream users almost every fourth year if the rainwater harvesting had not been in place. With the structures in place spills, which provide water for downstream users as well as for environmental flows, would have occurred in only 2 years of the 30 years record. The rainwater harvesting structures combined with high levels of groundwater extraction have contributed to the closure of this catchments and of the wider Krishna Basin within which it is located.

The model shows that the incorporation of rainwater harvesting structures within the catchments increases the water harvested within the catchments by 14% but at the expense of an increased evaporation loss from waterbodies, over and above that from the Inchigeri tank, of 18%. The 'efficiency' of the structures can therefore be considered to be on a par, but somewhat less efficient than that of the tanks within the catchments. This result is not unexpected as the rainwater harvesting structures have a similar area to volume relationship as the tanks and the same infiltration rates were assumed for both rainwater harvesting structures and tanks in the model.

The perception that rainwater harvesting structures should be in some way more 'efficient' in retaining water than large tanks or reservoirs, by reducing evaporation losses, is not borne out by the model results.

It appears that the good intentions for using these structures to 'capture' more water overall are, in an environment such as Inchigeri, misguided. Most of the water retained by the rainwater harvesting structures would otherwise have been retained in the tanks (except in the very wettest years) and the general outcome of installing rainwater harvesting structures is that runoff is captured, no more 'efficiently' than in the tanks and the overall impact is towards increasing total catchments evaporation and moving the catchments closer to 'closure'.

By contrast to the Inchigeri catchments the Mustoor catchments, although not having at present a high density of rainwater harvesting structures, does have a very high density of tanks and a high concentration of irrigation boreholes. The unsustainable nature of groundwater abstraction at this site is evidenced by the failure of many borewells with groundwater tables exceeding 300 m in some areas—which in turn are causing economic hardship to farmers ‘chasing down’ water tables and problems to domestic water supplies in some of the villages.

The societal studies indicate that the process of agricultural intensification and the introduction of engineering interventions over the last 20 or so years has created both winners and losers and significant changes to the social structure in the villages. Often it appears that the richer groups have been the overall winners whilst the poorest groups have either been unaffected or, in more extreme cases, the losers.

The preliminary outputs of the modelling studies (which have been obtained during the 9 month duration of the project) are in good agreement with what limited observations exist on the historical flows and spills from the Inchigeri catchments.

For the Mustoor catchments the present models are underestimating the frequency of spills from the Bairekur tank in the pre 1987 period and over estimating the frequency of spills in more recent years (post 1987). Three possible contributing causes were investigated: (1) incorrect estimation of the local rainfall, (2) groundwater abstraction reducing baseflow inputs into tanks and (3) increased upstream water retention measures resulting from agricultural intensification. The rainfall analysis does not provide any evidence to support the public perception that rainfall has decreased in the more recent period. There is therefore no reason to believe that the reduced flows into tanks and the reduced frequency of spills are related to temporal changes in rainfall. Baseflow processes and upstream water retention measures, both the result of the ongoing agricultural intensification and groundwater depletion which has been taking place in the catchments (neither of which has been adequately accounted for in the present models) are identified as the likely causes.

Throughout the studies it has been increasingly recognised by all the concerned parties that misguided views on watershed management are contributing to disjointed watershed policy. Beliefs that soil water conservation measures and other engineering watershed interventions involving water retention are necessarily benign technologies permeates present policy. The field studies associated with the JSYS and Sujala projects highlight some of the competitive and sometimes counterproductive actions and conflicts that can arise from these policies:

- Conflicts arise when both upstream soil water conservation measures and tank rehabilitation activities are taking place in catchments which are already ‘over-engineered’, have been subject to agricultural intensification, and are approaching ‘closure’.
- The Revenue Department order requiring all tanks to be converted into recharge structures conflicts with the objective and field actions of the JSYS project which is rehabilitating tanks and associated downstream irrigation channels to provide surface water for irrigation.
- The findings from the societal studies are in conflict with the belief that watershed engineering interventions are necessarily pro-poor. Often the unintended effective ‘privatisation’ of water that occurs as a consequence of water availability being shifted from communal tank schemes to groundwater schemes has been detrimental to the interests of the poor.

5 Discussion and policy implications

Findings presented here indicate that intensification of water retention and use within watershed areas can lead to downstream water shortages. Similar findings have been presented and discussed by other authors (e.g. Batchelor et al., 2002, 2003; Rama Mohan Rao et al., 2003; ETC, 2004; Sakthivadivel and Scott, 2005; Sharma and Scott, 2005).

Despite increasing research evidence to the contrary, water harvesting programmes continue to be planned on the basis that, even in semi-arid areas, there are large volumes of unutilised runoff. The rationale is that water harvesting is a win–win option that has no negative tradeoffs and that runoff is 30–40% of mean annual rainfall. Although localised runoff and runoff from individual storms can be high, annual runoff in semi-arid areas at the micro-watershed scale (or greater) tends to be less than 10% of annual rainfall (Batchelor et al., 2002). In the studies reported here it was found that, in all but the wettest years, there was no annual runoff or surface water outflow from the macro-watersheds. Or, expressed another way, runoff as a percentage of annual rainfall was 0% in average rainfall years, representing ‘closure’ for all but the wettest years.

Svendsen and Wester (2005) argue that, in the absence of leadership and direction, countries may ‘sleepwalk’ into potential disaster as basin closure progresses but without appropriate institutional responses. The indications are that, in recent years, catchments closure has been progressing at an alarming rate in many semi-arid areas of southern India and that awareness and acceptance of this fact has been lagging behind the evidence from field studies. There is still a widespread belief that watershed development will solve problems of catchments closure rather than, as shown here, acting as a contributory factor.

There is also a widely held belief that harvesting rainwater using a large number of small structures, in usually small headwater catchments areas, is more efficient and more socially acceptable than harvesting water in larger tanks or reservoirs in larger catchments. Shah, Makin, and Sakthivadivel (2005) promotes this belief by referring to evidence from studies in Israel in 1960s (cited earlier by Agrawal, 2000). These studies showed that a small 1 ha watershed yielded as much as 95 m^3 water per ha per year whilst a larger 345 ha watershed yielded only 24 m^3/ha/year. The conclusion drawn by Shah et al. (2005) and others is that as much as 75% of the water that could have been collected from the large watershed was lost. But it is likely that the differences in the observed yields are as much to do with scale issues and the biophysical differences in the properties of small headwater catchments, as compared with larger more lowland catchments, as to the effects of different water retention measures.

We might expect:

- Infiltration rates will be greater on lowland soils as compared with often rocky upland soils.
- Water collected over a larger area will generally suffer higher evaporation and infiltration due to longer ‘overland’ travel times.
- Depending upon the shape of structures and their (siltation dependent) infiltration rates, small structures may or may not be more ‘efficient’ in reducing evaporation and infiltration.

A pertinent issue, often forgotten, is that infiltration, occurring either beneath water retention structures or across the catchments as a whole, should not be regarded as a 'loss'; in most situations it provides valuable recharge water to aquifers.

Shah et al. (2005) also suggest that the main beneficiaries of large reservoirs are irrigator farmers. Again this is true in some but not in all cases. India's urban water demands are escalating rapidly and cities such as Chennai are struggling to meet demand, in part, because of lack of sufficient reservoir storage capacity and reduced runoff into existing reservoirs. Attempts to convey water to Chennai from the Cauvery and Krishna rivers have proved to be hugely expensive and ineffective. In the case of Chennai, it is clear that water harvesting and agricultural intensification in reservoir catchments areas is benefiting the few at the expense of the many in the cities. So what can be done to address these externality issues? It is proposed that planning must be based less on 'thumb rules' and much more on the analysis of the biophysical characteristics of an area and the spatial and temporal patterns of demand. Developing appropriate strategies and determining acceptable levels of tradeoffs and externalities must also be regarded as part of the political process. New tools and approaches are required for assisting with the evaluation of externalities, for raising awareness of the complex tradeoffs associated with watershed development and for meeting sustainability requirements. In the companion paper (Calder et al., 2007, Submitted) three new approaches are proposed to assist the watershed development planning process.

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