FAWPIO-INDIA
REPORT
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Executive summary

This report calls for a major revision of watershed development policy - particularly in relation to the planning of structural interventions.

The need has arisen because over the past ten to fifteen years increased intensification of agriculture has led to much reduced flows of water into tanks. Field levelling, field bund construction, 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 twenty years ago for planning structural interventions within watershed development projects, are not appropriate today.

New planning methodologies are required which take account of these reduced flows. These methodologies also need to ensure that priority is given to basic human needs (e.g. domestic water supplies) and equitable allocation of water so that the poorest people are not disadvantaged and that environmental flows are maintained to support the river system.

Recommendations:

1. Bridging Research and Policy. A gap exists between the knowledge and understanding of specialists and policy makers. Increased efforts need to be made to bridge this gap and raise awareness of the technical issues and constraints involved in watershed management including:

i. Challenging the conventional wisdom that water scarcity can be solved simply by increased tank or soil water conservation interventions. Water retention interventions should be considered only within a broader, integrated approach to land and water management which takes account of downstream externalities (Kerr *et al*., 2006; Calder *et al*., 2005; Calder, 2005).
ii. Promoting awareness that major river basins such as the Krishna and Cauvery are approaching closure (essentially there are now no annual outflows except in high rainfall years).
iii. Raising awareness that, in a closed basin, creating additional water storage capacity or promoting further agricultural intensification or tank rehabilitation and deepening will only provide local water benefits often to a small number of households at the expense of the wider community, downstream users and the environment.

2. Improved framework for watershed management including methodologies to determine water resource impacts of watershed interventions

i. The connection between land use in the catchment and inflows into tanks indicates that traditional methods for estimating tank inflows may now need to be reviewed and revised. Where these empirical methods, which were calibrated at a time when no borehole supplied irrigation was present in the catchment and water tables were high, are applied under present conditions (when there is essentially no groundwater flow to tanks), the methods may overestimate tank inflows.
ii. Assessing the changes in tank inflows that will occur as a result of decreased water tables will also require modifications to process based methods such as the Soil Water Assessment Tool (SWAT) or Hydrological Land Use Change (HYLUC)

model, so that they can then be used to recalibrate more empirical engineering methods.

iii. Minimum flow requirement. Together with the political and socio-economic questions influencing the choice of which tanks should be prioritised for rehabilitation there remains the question of which catchments may already be 'over-engineered' in terms of tanks and soil water conservation measures. The modelling methodologies outlined above will enable users to calculate the number of interventions that could be allowed before any minimum flow requirement from the catchment is breached.

iv. Operational Management Framework. An improved operational framework for planning watershed interventions needs to be developed. It is recommended that this framework is based on a process of stakeholder dialogue that incorporates tools and methodologies that have been derived to assess the water resource and societal impacts of watershed interventions. The JSYS and KWDP projects in Karnataka already provide a platform for participatory planning but this, as in other watershed development projects, needs to be focussed more towards water resource management.

3. Improved assessment methodologies to determine societal impacts of watershed interventions

Allocation Equity. It is recommended that any planned intervention which provides water retention in a closed catchment should be considered in the wider biophysical and socio-economic context. The decision is inevitably as much a political, in the sense that it must address state and national poverty alleviation strategies, as it is an engineering decision. It involves questions as to whether the future effective reallocation of water meets basic human needs and is equitable. For example, provision of greater water retention in headwater areas may be to the advantage of local people (perhaps often previously disadvantaged scheduled castes who are living on the poorer lands in headwater areas) but this gain in water availability would be at the expense of the often richer farmers, lower down the catchment, who would have been benefiting previously from this water.

4. New 'green water' approaches need to be developed and piloted within watershed development projects.

The effective closure of many Indian cactchments requires a major shift in watershed development policy, away from the provision of further supply side measures and towards greater 'green water' demand management. New management systems will need to be developed and piloted that are more integrated and multi-scalar, that take account of

Household-level discussions, Mustoor within the KWDP and JSYS study area.

downstream externalities[1], that involve a process of stakeholder dialogue and are evidence-based. To raise awareness of these issues and to change attitudes will be a major task which will also require the provision of dissemination tools and mechanisms directed at all levels of management – from project management to the village level. Management systems need to encourage both sustainable green water use and improved conjunctive use of surface and groundwaters. Systems where green water use is sustainable (less than the rainfall and allowing some agreed minimum blue water flow from the catchment) and where surface water is the predominant form of irrigation for average to high rainfall years, with groundwater use reserved for supplementary irrigation within the dry season and in low rainfall years should be aimed for. These systems should not only mitigate many of the societal harms associated with present watershed developments, including the competitive 'chasing down' of watertables, but also avoid the high electricity costs of deep groundwater pumping.

[1] An externality arises when the actions of one person affects the livelihood of others who have no control or influence over such activities (Patel P - World Bank, 2004). They may be either positive or negative.

Foreword

The cluster of projects dealing with land and water issues funded under DFID's Forestry Research Programme has established that erroneous views about land and water management are often leading to ineffective or counterproductive outcomes from watershed development projects. In particular, it has been shown that the promotion of forestry, irrigation and soil water conservation measures, without due regard to water resource constraints, can lead to perverse and inequitable outcomes (Calder, 2005)

The Forest, Land and Water Policy, Improving Outcomes (FAWPIO) programme is proposed (Calder, 2004; Calder *et al.*, 2004) as the means for encouraging more evidence based policies for land and water management through Bridging Research and Policy (BRAP) activities and through the development of an improved framework for land and water management. The framework will include modelling methodologies to determine the biophysical and societal impacts of watershed interventions.

This report, including items in the interim report, presents the findings and outputs of the FAWPIO-India component of the programme since the inception workshop, which took place in Bangalore in May 2005.

These outputs include:

- Detailed scenario modelling of a cascade of six tanks at Mustoor, Kolar District, Karnataka, using the HYLUC-Cascade model and Bayesian Networks.
- The development of the Exploratory Climate Land Assessment and Impact Management, EXCLAIM tool. The development includes the incorporation of a new 'slider' which takes account of the impact of different densities of structures on catchment flows (both surface and groundwater) and its application on the Mustoor catchment.
- A summary of stakeholder perceptions regarding the impacts of soil and water interventions on the Mustoor catchment from focus group discussions.
- A list of "points of agreement" that represents the consensus view on the nature and causes of water-related challenges in semi-arid areas of Karnataka. This list was compiled with the active involvement of specialists in the World Bank funded Sujala and JSYS Projects.

LIST OF ACRONYMS AND ABBREVIATIONS

BRAP	Bridging Research and Policy
BIRDS	Bijapur Integrated Rural Development Society, NGO for Inchigeri Area
CGIAR	Consultative Group on International Agriculture Research
CIFOR	Center for International Forestry Research
CLUWRR	Centre for Land Use and Water Resources Research
DFID	Department for International Development
EXCLAIM	EXploratory, Climate, Land, Assessment, Impact, Management
FAWPIO	Forest, Land and Water Policy: Improving Outcomes
FRP	Forestry Research Programme (DFID)
GBI	Green Blue Initiative
GIS	Geographic Information System
HYLUC	Hydrological Land Use Change Model
ILWRM	Integrated Land and Water Resource Management
IWMI	International Water Management Institute
JSYS	Jala Samvardhane Yojana Sangha (JSYS is implementing the Karnataka Community Based Tank Management Project)
KAWAD	Karnataka Watershed Development Society
MRH	Macrocatchment Rainwater Harvesting
NGO	Non Government Organisation
SCS	United States Soil Conservation Service (relates to a runoff estimation technique)
SEI	Stockholm Environment Institute
SHG	Self-Help Group
SIDA	Swedish International Development Cooperation Agency
SIWI	Stockholm International Water Institute
WB	World Bank

1. Background to the FAWPIO Programme

1.1. Problem statement and objectives

The cluster of projects dealing with land and water issues funded under DFID's Forestry Research Programme (R7937, R8171, R8174, ZF0176) has established that misguided views (water related myths) about water management are leading to ineffective or counterproductive outcomes from many watershed development projects.

Water Related Myths

- Planting trees increases local rainfall and runoff
- Water harvesting is a totally benign technology
- Runoff in semi arid areas is 30 – 40% of annual rainfall
- Rainfall has decreased in recent years
- Aquifers once depleted stay depleted
- Watershed development programmes drought – proof villages and protect village water supplies
- Introduction of drip and sprinkler irrigation frees up water for other uses

In particular, it was shown that the excessive promotion of forestry, irrigation and soil-water conservation measures, without due regard to water resource constraints, can lead to many perverse and inequitable outcomes:

- Catchment closure, when no water is released from a catchment except in high rainfall years, causes damage to the environment and downstream users (many river basins in southern India including the Krishna and Cauvery are now approaching closure);
- Reduced availability of 'public' water in communal village reservoirs (known as tanks) but increased availability of 'private' water for farmers with access to deep groundwater through boreholes;
- Excessive deepening of water tables which threatens traditional village water supplies, both through reduced availability and reduced water quality (increased levels of arsenic and fluoride contamination are associated with deep groundwater extraction) (Batchelor *et al.*, 2003);
- Boom and bust cycles in agricultural production, which cause extreme hardship and have been attributed as the cause of many farmer suicides when farmers become indebted in 'chasing down' the water table;
- Huge costs due to electric power generation for pumping groundwater from ever greater depths (some estimates are that ~2/3 of all electricity generated in some southern Indian states is used for pumping groundwater)

The FRP Booklet "From the Mountain to the Tap", (DFID, 2005) summarises the findings of these research projects (see also Calder, 2000, 2005; Batchelor *et al.*, 2003) and calls upon policymakers to design water projects based on scientific evidence of benefits.

The Forest, Land And Water Policy, Improving Outcomes (FAWPIO) programme is proposed as the means for encouraging more evidence based policies through:

1. Mechanisms for Bridging Research and Policy (BRAP) which will involve sharing research knowledge and land and water policy developments between researchers and policymakers and between FAWPIO partner countries;
2. An improved framework for land and water management including:
    - Modelling methodologies and GIS based dissemination tools which can indicate both the water resource and societal impacts of proposed watershed interventions prior to implementation;
    - Poverty reduction assessment methodologies addressing the question: who are the winners and losers arising from watershed interventions?
    - Greater focus on managing the evaporation from a catchment through 'green water' policies. The new proposed 'quadrant' approach to managing catchment vapour (green) and liquid (blue) water flows is outlined below.

1.2. FAWPIO Funding

The inception phase of FAWPIO (March 2005 – January 2006) was funded solely by DFID's Forestry Research Programme. Discussions have been held with the DFID Water Energy and Minerals (WEM) team and with DFID India but no commitments to continued funding of the programme have been given.

FAWPIO is a research partner under the SEI-SIWI Green Blue Initiative (GBI). GBI has received seed funding from SIDA but the inclusion of FAWPIO within GBI will require additional funding which would provide DFID with the opportunity to ensure that the findings from its investments in land and water related research continue to influence other aid donors and national governments, ensuring improved and more evidence-based land and water policies.

1.3. FAWPIO INDIA - Achieving the inception workshop vision

At the inception meeting of FAWPIO India, which took place in Bangalore, 6-7th May, 2005, a vision for the future of watershed development within Karnataka was agreed amongst the participants. This provided the focus for the development of strategies for an improved land and water management framework and for the biophysical and societal modelling tools which would underpin this framework.

FAWPIO's water – related vision is summarised in Figure 1.

FAWPIO Inception Workshop Water-Related Vision:

- By 2015, all households:
  - a) have assured access to 55 lpcd of safe drinking water (incl. sanitation)
  - b) have access to a minimum of 30 litres of water per animal for livestock watering or other small-scale productive uses
- By 2015, water resources are managed to achieve:
  - a) each watershed unit releases 40% of mean annual flows to the downstream watershed without increasing the pollution load
  - b) Annual groundwater extraction is 60-80% of natural (annual) recharge
- By 2015, improved farm-level water management of water contributes to:
  - a) 20-30% increased rainfed agricultural productivity in irrigated and rainfed agriculture with assured fodder availability
- By 2015, improved awareness and planning leads to:
  - a) improved ecological balance, biodiversity (species counts) and aquatic life

Figure 1 FAWPIO's Water – Related Vision

1.4. Strategy Evaluation –Inchigeri, Doddahalla and Mustoor, Kolar District

At the Inception Workshop it was agreed that through knowledge of the biophysical and societal impacts of watershed interventions (forestry, soil-water conservation measures and irrigated area), different possible strategies would be evaluated to see if they have the potential to achieve the FAWPIO Inception Workshop Vision.

More specifically it was agreed that the evaluation studies would include:

- water flows and socio-economic impacts associated with soil-water conservation and forestry measures in a two tank cascade at Inchigeri, within the DFID funded KAWAD study area and
- water flows and socio economic impacts associated with tank rehabilitation and proposed soil-water conservation measures and farm ponds at the World Bank funded Mustoor JSYS/Sujala project area.

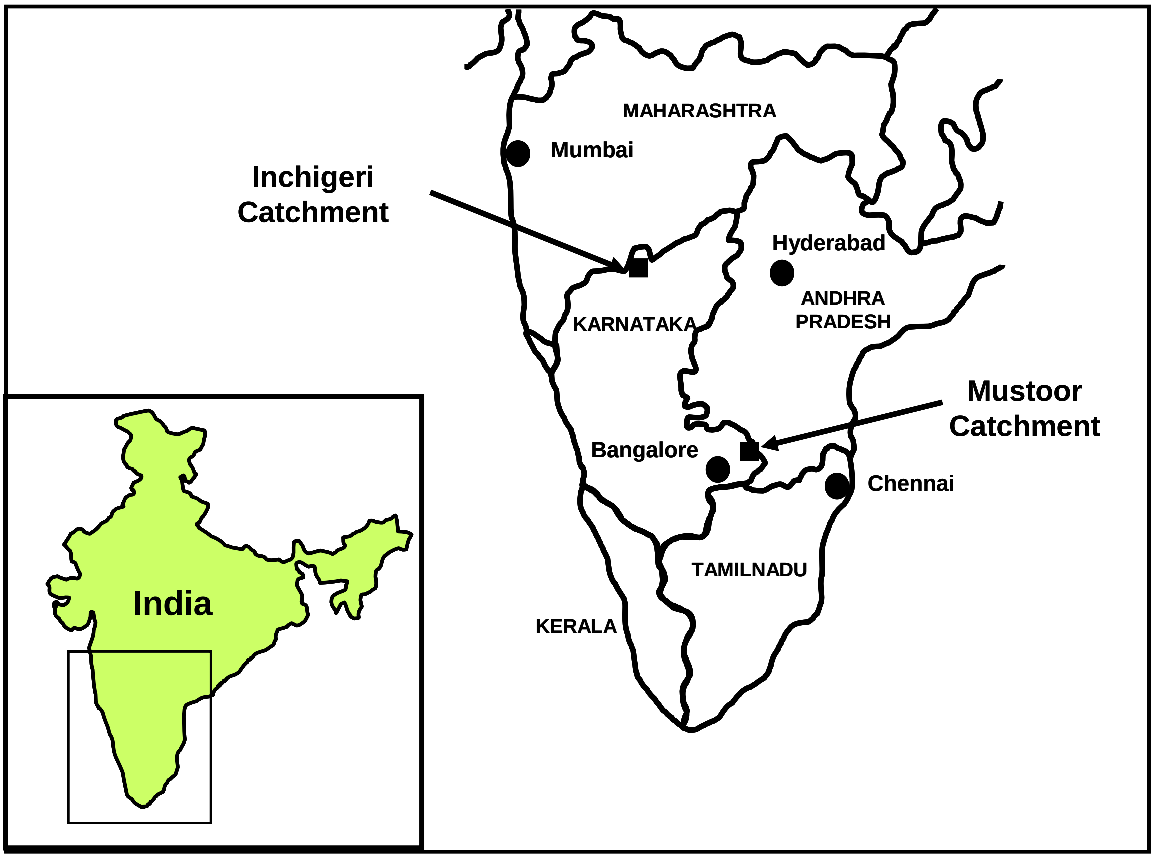

Figure 2 Location of the Inchigeri and Mustoor Catchments

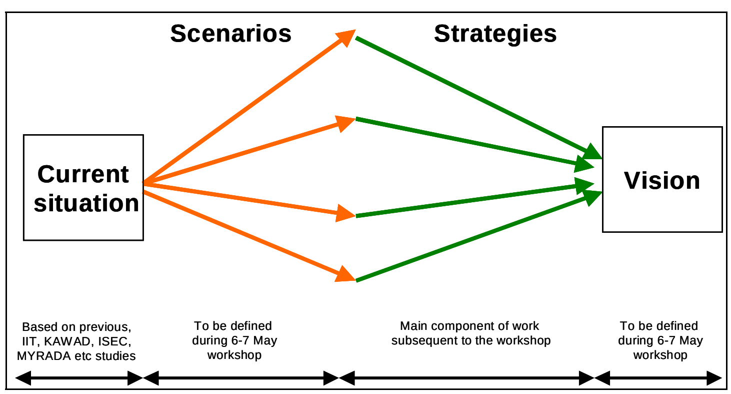

Figure 3 Scenarios and Mustoor catchments, located in strategies required to meet the workshop vision.

2. Improved Framework for Land and Water Management – Biophysical and Societal Modelling Developments

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 soil conservation structures have been shown to improve agricultural yields by providing farmers with additional irrigation water and there are numerous studies that have highlighted localised improvements in agricultural yield or improved soil moisture conditions as a result of these structures.

But concerns have been raised that the excessive use of soil conservation structures can introduce negative impacts, not only on the communities within the watershed area, but also on downstream communities (Batchelor *et al*, 2002 and 2003; Rama Mohan Rao *et al*, 2003; ETC, 2004; Sharma and Scott, 2005, Sakthivadivel and Scott, 2005) .

Similar concerns have been raised (Calder *et al*, 2005) that other interventions involving changes to catchment 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.

Two studies are reported here that have investigated the water flow and societal impacts of watershed interventions in DFID and World Bank funded watershed development projects in southern India. The studies were focussed on the Inchigeri and Mustoor catchments (Figure 2). Some of interventions considered were implemented by the development projects and some occurred or would have occurred without development project implementation. They include the construction of soil water conservation structures, tank rehabilitation, 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 which help to identify better the impacts of the different interventions. The key difference between the two catchments (Inchigeri and Mustoor) with regards to structural interventions is that the Inchigeri catchment has a greater than average concentration (per unit catchment area) of soil conservation structures while the Mustoor catchment has a greater than average concentration of tanks and a high concentration of irrigation boreholes.

It should also be borne in mind that there are also important differences in soil types, Inchigeri is located in an area of vertisols (i.e. black cotton soils) underlain by Deccan basalt and Mustoor is in an area of alfisols underlain by crystalline basement geologies.

2.1. Water flow Impacts

The impacts of watershed interventions on water flows within the study catchments were investigated using a new development of the HYdrological Land Use Change, HYLUC model (Calder, 2003). The 'HYLUC-Cascade' version uses runoff calculated by the HYLUC model for the sub-catchment area of each soil conservation structure in the catchment, and routes this through the cascade of soil water conservation structures and tanks that may exist in the catchment. Within this process the evaporation from, and the infiltration of water retained within structures is accounted for explicitly. The HYLUC-Cascade model can then be calibrated for each catchment such that the surface runoff matches that given by the use of a local (SCS[2]) rainfall to runoff relationship.

2.1.1 *DFID KAWAD watershed study, Inchigeri*

The HYLUC-Cascade model was set up to investigate how changes in the concentration of soil water conservation measures within the Inchigeri catchment have both altered the flows into the Inchigeri tank, and the outflows, sometimes referred to as 'spills' or 'releases', Figure 4. The runoff estimates used in the HYLUC - Cascade model were based on the assumption that the following land use proportions existed in all subcatchments within the Inchigeri catchment: 10% - irrigated agriculture, 3% - natural vegetation, and the remaining area, aside from the water bodies (MRH structures and tank) was assumed to be rainfed agriculture. This assumption is based on discussions with field staff (BIRDS *pers. come.* 2005) and observations from the field.

The outflows provide water to downstream users and the environment. The model shows that even without the interventions introduced by the KAWAD development project the average annual outflows from the Inchigeri tank was only a very small proportion (2.5 %) of the rainfall.

Average annual spills are reduced by a third as a result of the installation of the current concentration of soil conservation structures, as compared with conditions prior to these interventions, Figure 4. The model also shows that if the total capacity of the present structures is doubled, average annual spills would be reduced by two thirds (as compared with present conditions). With regard to spill frequency, the total number of years with tank spills has reduced from 3 spills per decade to 0.7 spills per decade as a result of the current concentration of soil conservation structures.

The results indicate that no further increases in the number of soil conservation structures can be introduced into to a catchment such as the Inchigeri without potentially very serious impacts on surface flows exiting the catchment.

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[2] 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)

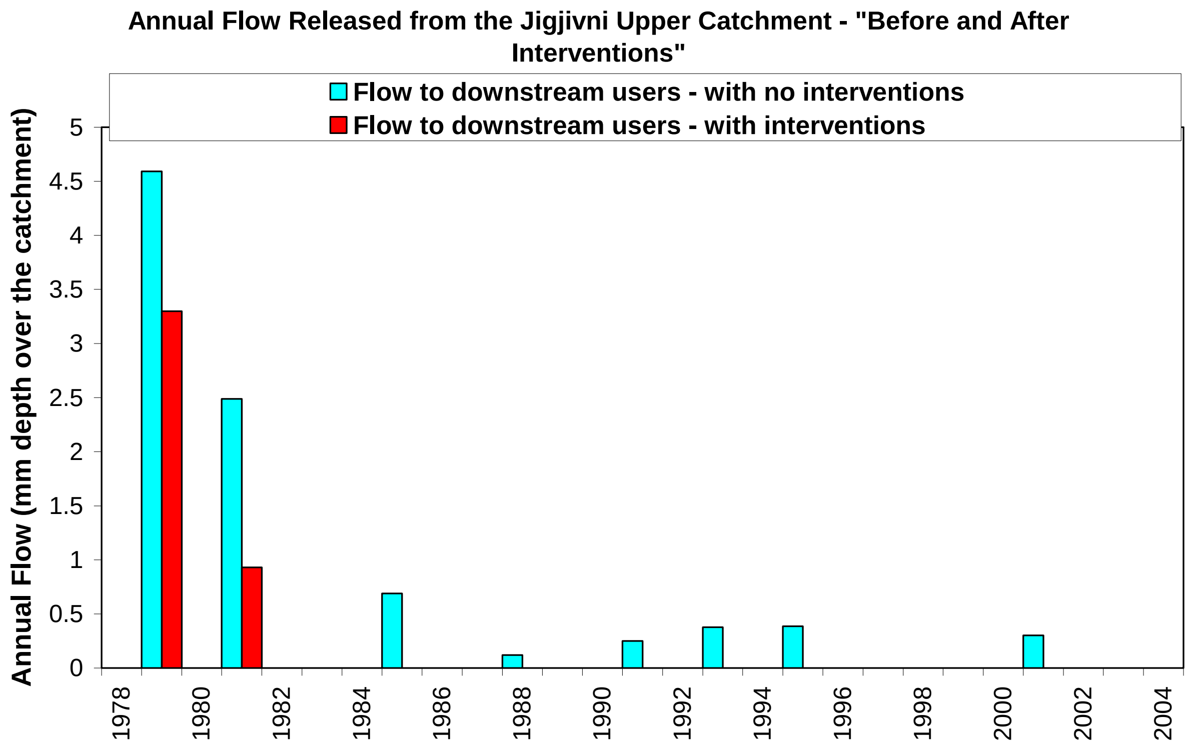

Figure 4 HYLUC-Cascade model predictions showing annual outlflows from the Inchigeri tank, with and without SWC interventions introduced by the KAWAD project

2.1.2 *World Bank Mustoor Catchment Studies*

The HYLUC-Cascade model was also applied to the Mustoor catchment, in the district of Kolar, Karnataka, which drains into the Palar River (Figures 2 and 5) to investigate how watershed interventions might have affected water flows and to determine the possible causes of the much reduced outflows from the Mustoor catchment in recent years.

The model was initially used to investigate how changes in siltation of the tanks within the Mustoor catchment, together with possible changes in rainfall might have affected the water flows and frequency of spills from the Mustoor catchment. (The runoff estimates used in the HYLUC - Cascade model were based on the assumption that land use within the Mustoor catchment is: rainfed areas, 47%; rocky outcrops, 27%; irrigated areas, 14%; tanks, 11%; forest, 1%.

The model was first set to reflect the 'historical' situation when the tanks were originally constructed, for which tank volumes were set to their original maximum capacity, i.e. prior to tank siltation. Assuming tank infiltration rates of 7.2mm / day and annual runoff of approximately 11% annual rainfall, the 'historical' model predicts that the tanks would have spilled only once or twice between 1970 and 1987, Figure 6.

However villagers, farmers and local authorities report that, during this period, the tanks spilled more frequently, at least once every 3 years.

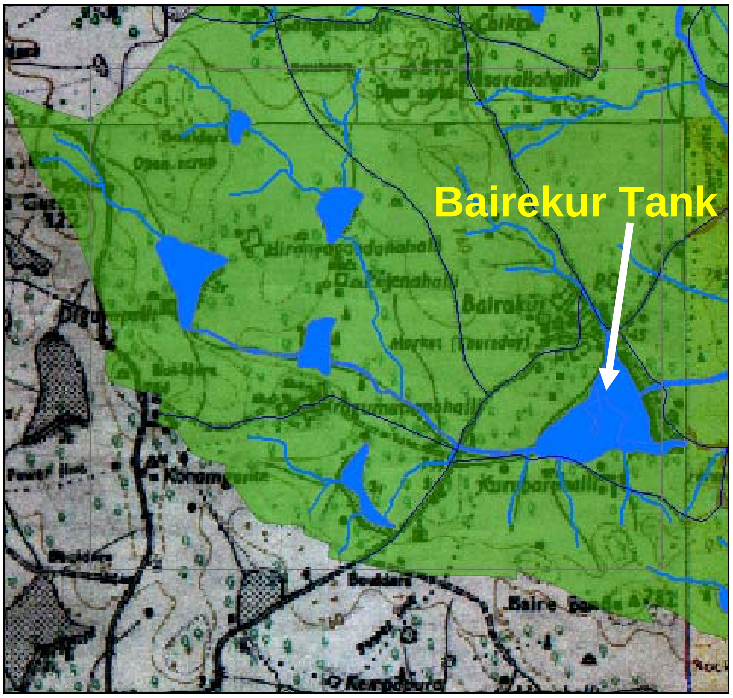

Figure 5 Mustoor Catchment Tank System

With the Mustoor Cascade model set to reflect the ‘present’ situation (past five years) where the tanks are assumed to be 40% silted, the model predicts that the Bairekur tank spills would occur once every two years. Most of the other tanks are predicted to spill with equal or higher frequencies over this ‘present’ period, Figure 7. But village observations for this present period indicate that the tanks spilled less frequently than predicted by the model, Figure 8.

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 opposite to those that have been observed by local people.

Furthermore the HYLUC Cascade model predicted that the Bairekur tank would have spilled in October 2005 whilst observations (made by the field team as well as villagers) indicate that it had filled only to about 1/4 capacity by October 2005.

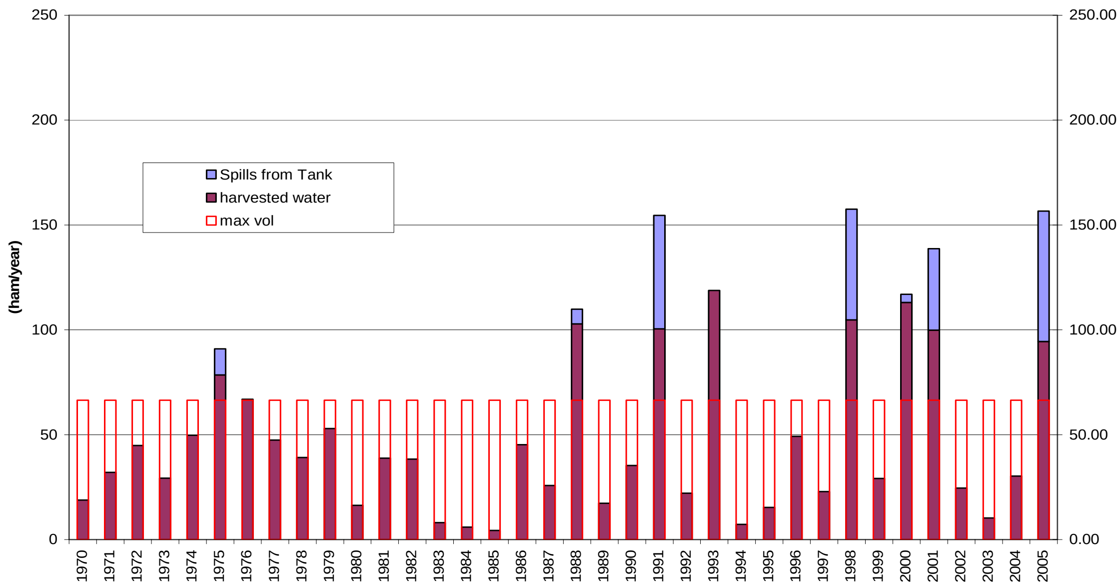

Figure 6 Mustoor Catchment (Main Tank): Bairekur Tank – 'Historic' scenario - No siltation

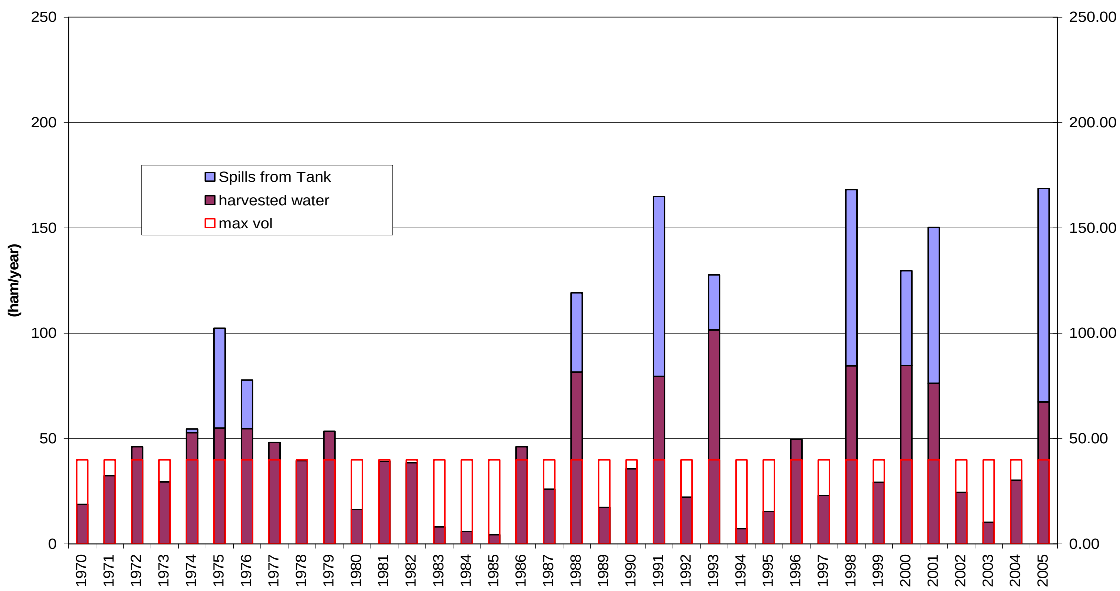

Figure 7 Mustoor Catchment (Main Tank): Bairekur Tank – 'Present' scenario - 40% siltation

A comparison between model outputs and locally observed spills from the Bairekur Tank is shown in Figure 8. The approximate frequency of spills reported by locals (estimated from Table 4) is compared with modelled spill frequencies.

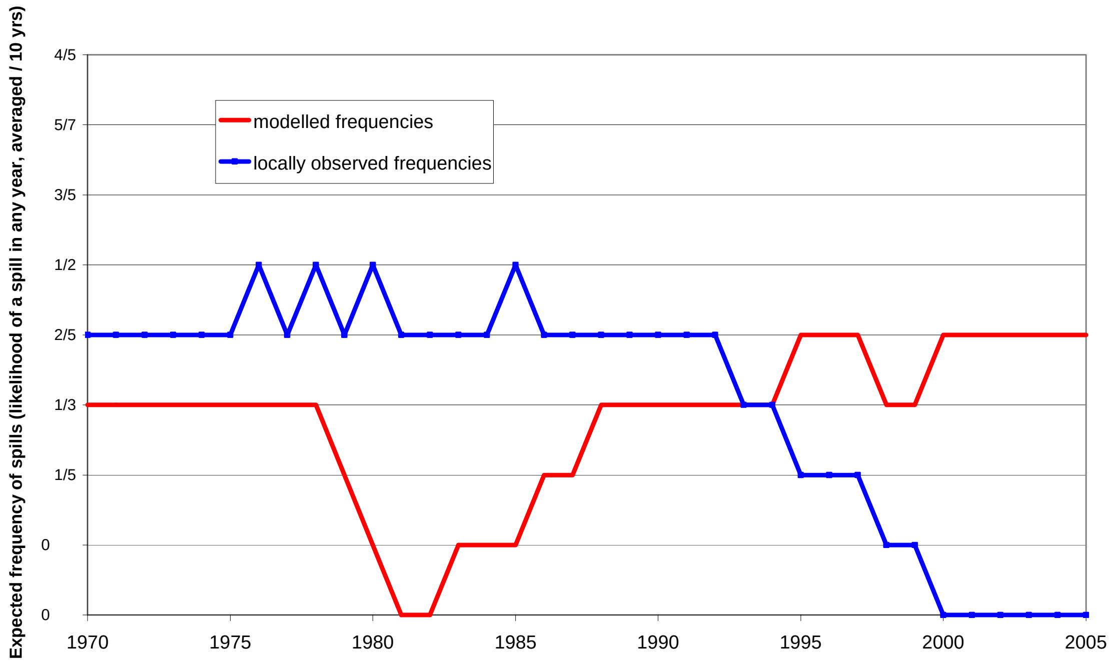

Figure 8 Modelled versus observed Bairekur Tank spill frequencies

('Present' scenario - 40% siltation)

The model's underestimation of tank spill frequencies in the 'historical' period and overestimation in the 'present' period 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 : i) incorrect estimation of local rainfall, ii) groundwater abstraction reducing baseflow inputs into tanks, iii) increased upstream water retention measures resulting from agricultural intensification.

Rainfall Estimation

Rainfall records used in the modelling (Mulbagul and Nangli rainfall stations) and 2 other nearby stations show no reduction in annual rainfall from the 'historical' period compared to the 'present'. Figure 9 displays the variation in Mulbagul annual rainfall from the mean annual rainfall between 1970 and 2004.

A simple comparison of long term annual fluctuations in rainfall at these two sites against other nearby sites suggests that there are no abnormal deviations from the regional annual rainfall trends in this area.

Thus the analysis does not provide any evidence to support the public perception that rainfall has decreased in the 'recent' period and 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.

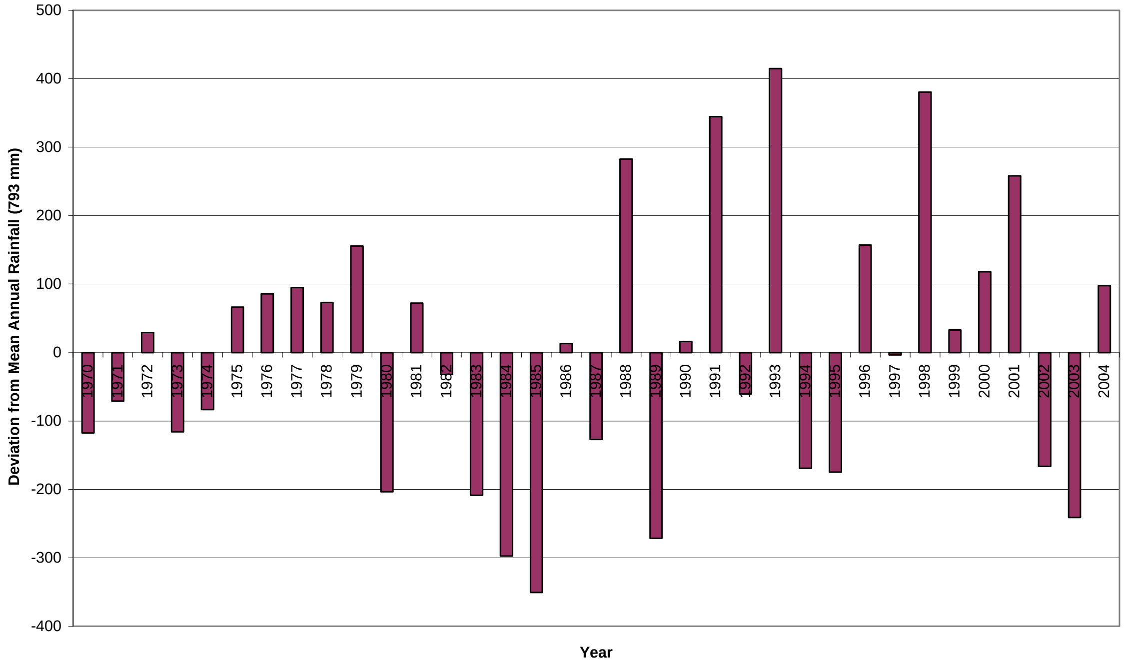

Figure 9 Variation in Mulbagul annual rainfall from mean annual rainfall (between 1970 & 2004)

A direct comparison of trends in rainfall and runoff can be made by plotting accumulated rainfall along side accumulated runoff, Figure 10. Only 11% of the rainfall has been used to allow the two parameters (rainfall and runoff) to be plotted at similar slopes, thus enabling their trends to be compared. The slope of the accumulated rainfall and runoff lines do not decrease over recent years indicating that there is no significant reduction in either rainfall or runoff over the recent period. On the contrary, runoff appears to be higher than the norm over the last 5 years (refer to the rainfall linear trend line), correspondingly spills are also greater.

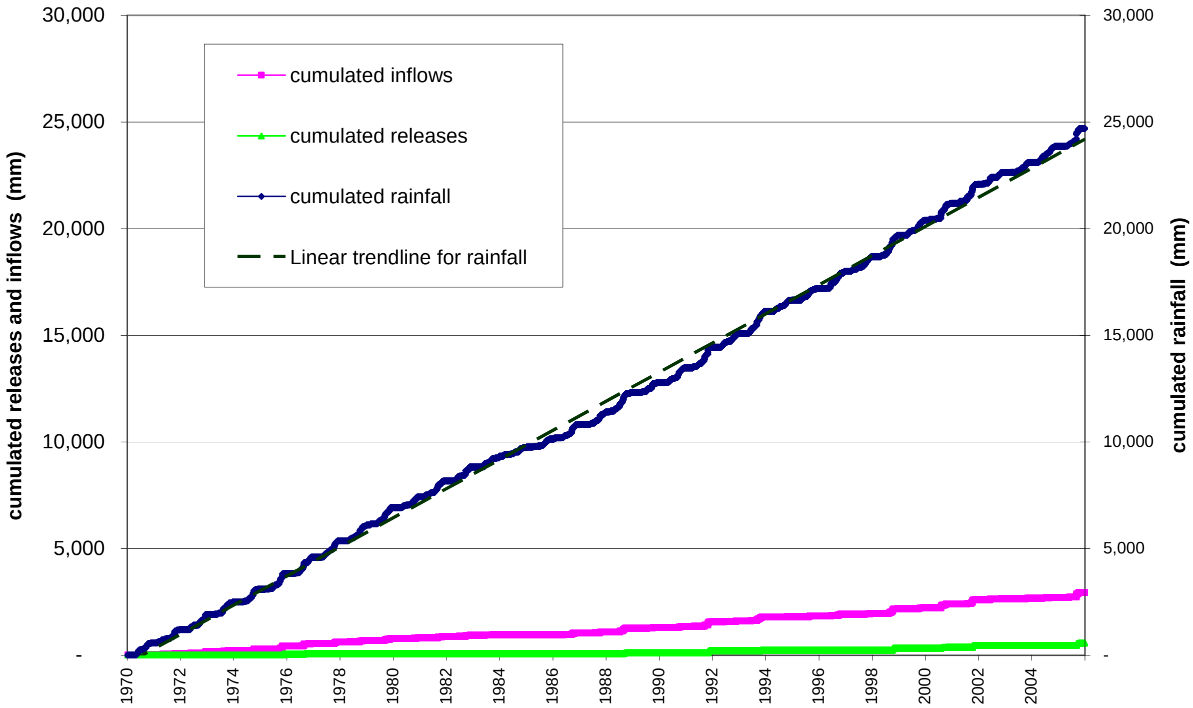

Figure 10 Cumulative rainfall, and cumulative predicted inflows and outflows from the Bairekur Tank for the 'Present' scenario assuming 40% siltation of tanks

Baseflow processes

It is possible that high groundwater levels in the catchment, occurring during the 'historical' period or in very wet periods during the 'recent' period, could augment streamflow volumes via the production of baseflow (also referred to as regenerated groundwater flow). Groundwater related processes may be responsible for tank levels in the 'historic' period being higher and resulting in more tank spills, than if they were receiving only surface runoff. However the HYLUC and Cascade models, in their current format, are unable to account for such process (the only sources of inflow into the tanks are upstream spills or surface runoff produced directly from rainfall).

The large increase in groundwater abstraction over the last 5-10 years, has resulted in greatly reduced groundwater tables across much of the catchment, particularly in the lower areas. It is likely that this lowering of the water table will have led to 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.

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, farm ponds, contouring and field trenching will all contribute to reduced tank inflows.

Further data and modelling developments are needed to properly represent these groundwater related processes and land based engineering intervention impacts in the Mustoor catchment.

2.2. Village-level surveys of biophysical and societal impacts of watershed interventions

2.2.1 *Aim of the village surveys*

The societal component of the FAWPIO (India) study concentrated on socio-economic aspects of priority water-related issues in the Mustoor sub-watershed. These included:

- Access to safe domestic water and sanitation
- Access to water for irrigation, livestock and other productive uses
- Livelihood patterns of different social groups including the migration situation
- 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 Sujala, JSYS and previous government programmes.

2.2.2 *Societal Data collection*

Methods of collecting information included focus group discussions, meetings with key informants and triangulation of primary and secondary information from a wide range of sources. Secondary information included data collected by Prakruthi (Prakruthi is a local NGO) as part of the World Bank-supported Sujala Project and information collected by the World Bank-supported JSYS Project. Although data were collected over a six month period starting in April 2005, there were two periods of intensive fieldwork in July and October 2005.

2.2.3 *Societal Impacts*

General socio-economic information

Table 1 presents the demographic information for villages that have land in the catchment area of Bairekur Tank. The majority of people in these villages belong to 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 these villages, the majority of the family incomes ranged between Rs 10,000-20,000 per annum. A significant number of families have incomes in the range Rs 5,000 to 10,000 and only about 10% of the families have incomes above Rs 40,000 per annum.

Village name	Total number of families	No. of families below the poverty line		Total number of landless families
		Govt. Stats.	PRA 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

Table 1. 2004 demographic details (Source: Sujala Project)

Domestic water

For most villages, domestic water is supplied to standposts via overhead tanks that are connected to borewells fitted with submersible pumps. Water is supplied on average for about one to two hours each day. Table 2 provides a summary of findings from a survey of domestic water use that was carried out during October 2005. The survey showed that, even during the monsoon period, most villagers are accessing and using domestic water at rates that are below the national drinking water norm of 45 lpcd[3]. In general, villagers considered that water quantity is a bigger problem than water quality. However, in Bairekur villagers stated that there are 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, there are also problems with the water sources from borewells whose yields decline during the summer and in periods of drought. Historically, open wells were the main source of domestic water but almost all these wells are now defunct. Some are completely dry whilst others are unusable as the small amount of water they hold is polluted with algae and household waste. Each village has two to three hand pumps but the majority of the hand pumps are non-functional. For example, Bairekur has 10 hand pumps but only four are functional.

[3] lpcd – litres per capita per day

Village water supplies are, in general, insufficient to meet the needs of livestock and, as a result, other sources have to be found. In most cases, tanks are used when they have water in them. If the tanks are dry, irrigation borewells are the main source.

Village name	Domestic water use	Livestock water use	Time taken to collect each pot
	(lpcd)	(lpcd)	(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

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

Groundwater

Table 3 summarises the status of borewells and open wells in the Bairekur catchment area in October 2005. This survey confirmed that by 2005 almost all the open wells were non-functional. However, it was stated in some villages (e.g. IG Halli) that open wells located in command areas below tanks refill when tanks have periods of good inflow. In some cases, these open wells are used as a source of irrigation water.

The first borewells in these villages were constructed in the period 1982 – 85. These first borewells had a depth of 250 – 300 ft but now the depth being drilled is up to 800 ft with more incidences of failure in recent years. There have been high levels of private investment in borewell construction. Many of the borewells that were being used as sources of water for irrigation, are currently non-functional, Table 3. Statistics are not available on the numbers of farmers who have lost money 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 catchment area has gone through a "boom and bust" cycle of groundwater development. Whilst the opinion of villagers is that this is partially true, many believe that the "bust" part of the cycle has been caused by low rainfall rather than an increase in demand. Or, put another

> 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 fourth 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. After the sixth failed well, he had few animals left.

way, they believe that many of the currently non-functional borewells will become functional again after a period of above average rainfall.

Although many farmers have fallen into serious debt as a result of failed investments in borewell construction, farmers are still investing in borewell drilling. This is because the potential returns from irrigation using a successful borewell are such that a farmer can pay off all his or her debts within one or two years and make very good profits if they have a reliable well (See Box 2).

> Box 2. Irrigation profitability
>
> One farmer in IG Halli stated that he had invested almost one lakh rupees in drilling three borewells. One of these was successful and he is now able to irrigate approximately 2 ha. Within one year, he was able to recoup his whole investment as he got bumper crop of tomatoes.

Bairekur catchment is located in an area of crystalline basement. As a consequence, the hydrogeological conditions are extremely variable and highly dependent on the depth of weathering and the degree of fracturing. Hydrogeological conditions in the Bairekur catchment area are such that it is more difficult to construct a successful borewell in the headwater areas than further down the system. This fact is not lost on farmers in upstream villages Pujenahalli and HG Halli. Villagers also feel that farmers in headwater areas tend to have less money to invest in drilling wells. This is due in part to the poorer soils and lower land capability classifications of land in the headwater areas.

Village name	Open wells		Borewells	
	Functional	Defunct/ very unreliable	Functional	Defunct / very unreliable
Iringamattanahalli (IG Halli)	-	60	15	5
Pujenahalli	-	14	6	24
Hiranyagowdanahalli (HG Halli)	1	9	3	3
B. Kurubarahalli	-	-	6	44
Bairekur	-	150	50	150
Peramakanahalli	-	35	17	30

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

	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 250-300 ft	20 - 50 borewells to a depth of 500 ft depth	Around 350 borewells to a depth of around 800 ft. 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 two three showers	Every month two three 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

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

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. !994 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 not 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 5. Inflow and spill timeline for tanks in the Bairekur Catchment

Surface water resources

The Bairekur catchment is located in an area of Karnataka that has a very high density of tanks. Table 5 summarises information on inflows into and spills from tanks in the Bairekur catchment area. The general perception of villagers is that tank inflows have reduced in the last 10-20 years along with the frequency of spill. Reasons that are given for this include: i) Low rainfall; ii) Land use change in the catchment areas and iii) 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. The third reason came from a more detailed discussion of changes that they have observed in recent years. The perception that rainfall has been declining systematically is one that is not supported by 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 catchment 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 the tanks in the Bairekur catchment area spilled during the week before the October 2005 fieldwork. However, there was no spill from the Bairekur Tank, which last spilled in1995. Hence for the last 10 years, the Bairekur catchment has been ‘closed’.

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

Table 6. 2004 irrigation data (Source: Sujala Project)

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 is that the potential net irrigated area has 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 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 minimize risk). As indicated in the water-user typology (see Table 7), 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.

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 Dept. 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 JSYS Project objectives which are directed to rehabilitating tanks so that they can be used as sources of irrigation water. The apparent contradiction is causing concern amongst farmers with land in tank command areas who do not own reliable borewells. If a ban on tank water releases comes into effect, 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. Although not as marked as in some other areas of Kolar District, 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 is not currently very popular in rainfed areas of the Bairekur catchment. Groundnuts intercropped with redgram are a predominate rainfed cropping system.

Increased irrigation and agricultural intensification has 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 households of the relevant famers households rather by landless labourers.

Sanitation

Under a 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 catchment. 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.

Livelihoods and water

Table 7 presents a water user typology for households in the Bairekur catchment. A provisional version of the typology was produced after the initial period of fieldwork in June 2005. This has now been revised to take account of discussions during the October 2005 fieldwork. This typology can be used as a basis for making some generalisations on the winners and losers from development of water resources in the Bairekur catchment in the last 20-25 years.

- **The 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 that have resulted from agricultural intensification. However, competition for water resources resulting from agricultural intensification has led to problems with the reliability of domestic water supplies in some villages. With the exception of families with private supplies (e.g. some families in IG Halli), every household suffers to some extent when there are problems with the domestic water supply.
- **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 either 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 members have lost out because of reduced access to grazing land and reduced tank inflows which have made watering livestock more diificult. Groundwater drought along with the failure of rainfed cropping in recent years 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.
- **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 has been the group that has been at most risk of spiraling into poverty as a result of failed investments in borewell construction or horticulture. Regionally, farmer suicides have been relatively common in this group. Box 3 lists some of the mechanisms by which members of this group slip into debt.
- **Land owners and resource rich all the time.** Arguably this relatively small social group is the one that has benefited most from agricultural intensification and water resource development in the catchment area. 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 activities such as being a moneylender or getting involved in the panchayat. Diversification has the added benefit of reduced dependency on access to water and to good markets

Box 3. Mechanisms that link poverty to overexploitation and competition for groundwater resources in crystalline basement areas (After Batchelor et al, 2003)

Failed borewell investments. Investment in well construction is a gamble with high risks, particularly in ridge areas and other areas with low recharge potential. Farmers who take loans to construct borewells but are unable to find groundwater, will not be able to make repayments and, in many cases, will quickly spiral into debt.

Higher borewell costs of latecomers. Latecomers to borewell construction often have to make larger investments than firstcomers. This is because groundwater levels have already fallen and siting a successful borewell involves drilling to greater depths. Also latecomers often have smaller land holdings and, as a result, the scope for siting a successful well is more limited. The net result is latecomers have to take larger loans and, consequently, are more likely to default.

Competitive well deepening. Wells owned by richer farmers tend to be more productive and/or generate more income. If groundwater overexploitation takes place and water levels decline, richer farmers are more able to finance competitive well deepening. Also, as wealthy farmers tend to have established their wells before competitive deepening starts, they are in a much better position to take new loans. As latecomers are often unable to finance competitive well deepening, their wells fail and they are unable to repay loans and often have to sell their land to moneylenders, who are in many cases the richer farmers.

Impacts on domestic water supplies. Overexploitation of groundwater for irrigation has lowered water tables in aquifers that are also sources of urban water supply. This has led to a reduction in supply, particularly in peak summer and periods of drought. Collecting water takes more time and involves carrying water longer distances. In some extreme cases, competition between agricultural and urban users is leading to complete failure of the village water supply. In these cases, villagers sometimes have to use water sources that are not safe and suffer illness as a result. Illness usually represents both a loss of income and expenditure on medical treatment.

Crop failure or low market prices. If crops should fail for any reason (e.g. major interruption in electricity supply, wells running dry) or if there should be a steep fall in market prices of produce, farmers with large loans for borewell construction are extremely vulnerable. If they should fail to make repayments on loans, which typically have interest rates of 2% per month in the informal money market, they can easily spiral into indebtedness with little hope of recovery.

Falling groundwater levels. Falling groundwater levels in many areas have increased the risk of wells failing during periods of drought as there is no longer a groundwater reserve or buffer to maintain supply during dry seasons and droughts. It is often poor and marginal farmers that have borewells that are most likely to fail, albeit temporarily, during such periods.

Impact of intensive drainage line treatment. Intensive drainage line treatment as part of watershed development and other programmes can impact on the pattern of recharge. The net result is that, in semi-arid areas, some borewell owners can see the yields of their borewells increase but others (usually located downstream) see their borewells become less productive.

Reduction in informal water vending. Informal markets for groundwater have emerged in recent years in these parts of semi-arid India, as farmers with access to surplus supplies sell water to adjacent farmers who either lacked the financial resources to dig their own wells or had insufficient supplies in the wells they did own. Now as well yields decline, water markets are becoming less common as well owners keep all available supplies for their own

Village Institutions

Self-help Groups (SHGs) have been formed in almost all the villages as part of the Sujala Project. In general, these SHGs are conducting regular meetings and are 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, is facilitating the groups' activities through continuous capacity building. The general view of villagers is that small-scale income-generating opportunities are very limited with the exception of dairying. However to sustain this activity, women are currently travelling long distances to obtain fodder. Assuring drinking water for the livestock especially during the summer is also a major challenge. On the positive side, there is a high local demand for milk and, as a result, marketing is not a problem.

User groups promoted by Sujala and the JSYS projects are also functioning well with regular meetings and records. In contrast, Water and Sanitation committees promoted by DANIDA are almost non functional. However, one person in each village is still responsible for operating the domestic water supply system.

All these villages have their representatives in Bairekur panchayat. The general perception is that the activities of the panchayat are mainly focused or limited to Bairekur village.

Community management practices are very limited in these villages.

Group	Characteristics
1. Whole village	Problems common to majority of households that require "whole-village" solutions. These include: Drinking water shortages during summer months and, in some cases, drinking water quality problems; Lack of drainage; Limited and unreliable electricity supplies; Agricultural intensification has led to increased production at least during good rainfall years. This has resulted in an injection of cash into the economy of most villages.
2. Landless and resource poor households	Low income and a need to migrate for want of work. Often "distress" migration in low rainfall years. Less likely to be distress migration in high rainfall years because of improved local employment opportunities and possibly better returns from livestock and small land holdings; In case of landowners, low levels of income from agricultural activities as a result of small and/or poor land capability holdings and lack of access to reliable water supplies even in good rainfall years; High levels of indebtedness. Large proportion of income used to pay off debt during good rainfall years; Unlikely to be able to invest in borewell construction

Group	Characteristics
3. Landowners and resource rich during periods of good rainfall	Good returns from agricultural activities during periods of high rainfall as a result of good land resources; Have borewells but the yields of these wells dwindle during summer months and fail completely during dry years; Tendency to slip into debt during periods of poor rainfall and to have to repay debts using a large proportion of income during periods of good rainfall; Will be tempted to borrow and/or invest additional money in drilling additional borewells in hope of constructing a high yielding well; Unlikely to have sufficient income to be able to diversify out of agriculture.
4. Land owners and resource rich all the time. Diversified sources of income	Good returns from agricultural activities even during low rainfall years; Have had the luck of constructing a reliable high-yielding borewell; Unlikely to be in debt and probably a moneylender. As a result, likely to have a high level of status and power in the village; Able to use cropping systems that are geared towards marketing opportunities and maximising profits; Able to diversify from agriculture; Will invest in additional borewell construction out of choice rather than distress.

Table 7. Water-related typology for Bairekur catchment area

2.2.4 *Incorporating biophysical and societal impacts within decision support tools*

The results of the cascade modelling, from both the Inchigeri and Mustoor catchments have been incorporated into two decision support and interpretive tools: EXCLAIM and Bayesian Networks, where:

- Relationships between tank inflows and outflows (where outflows from tanks through spillways are termed “spills” or “surpluses”) and the evaporation from water retained behind structures with different densities of structures have been incorporated into the EXCLAIM model, and
- Relationships between annual rainfall and the volumes captured by the structures as well as annual spills have been used to populate Bayesian Networks.

2.3. Development of the GIS based Exploratory Climate Land Assessment and Impact Management, EXCLAIM tool.

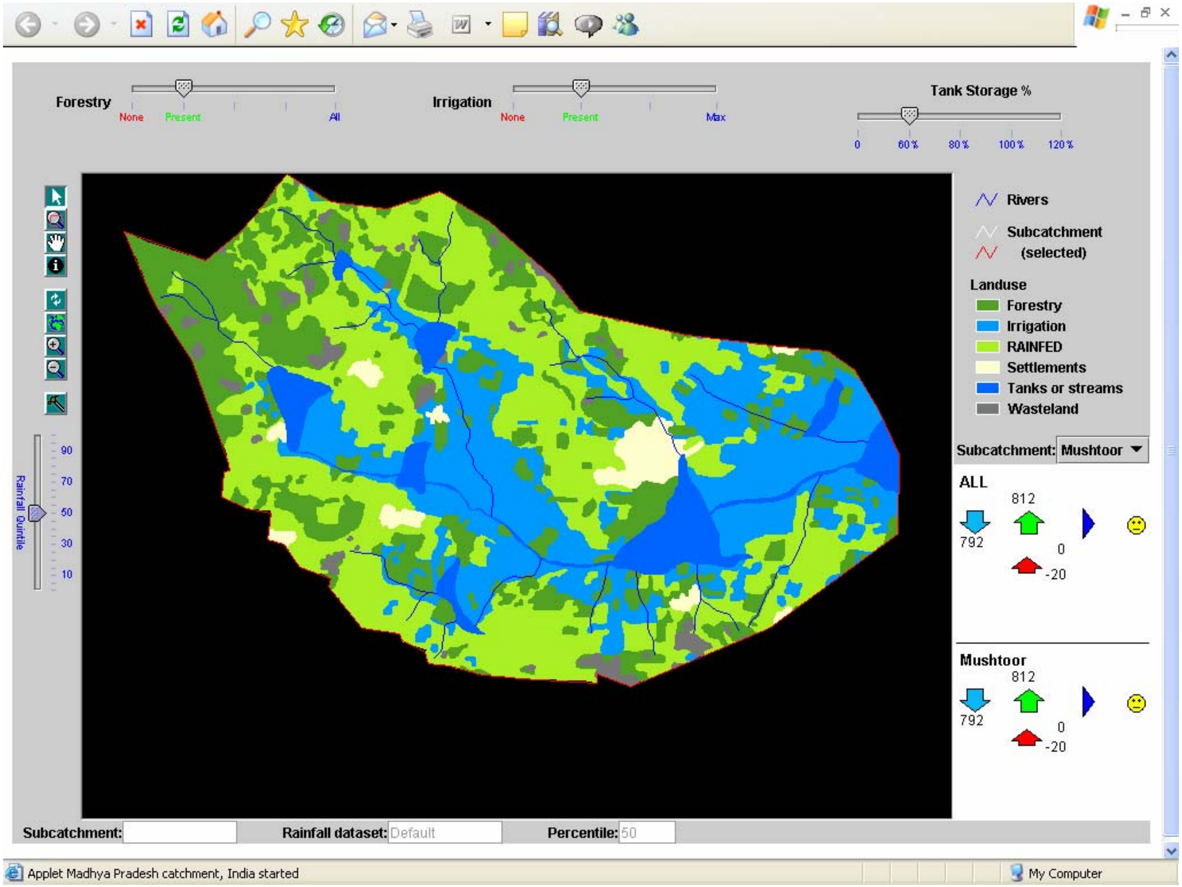

Figure 11 Current state of development of the EXCLAIM tool for the Mustoor Catchment showing "present case" scenarios of areas under tree crops, irrigation and tank storage for a median rainfall scenario. For this scenario the tool indicates that net groundwater recharge is negative (red arrow) and surface flows out of the Bairekur tank (last tank in cascade) are zero. Total blue water flows (Surface plus groundwater) from the catchment are negative.

The new development of the EXCLAIM tool involves the joint incorporation of "sliders" which determine the extent of irrigation and forested areas within a catchment, and of a "slider" which controls the extent tank storage and soil-water conservation measures within a catchment. Together these sliders show:

- How different land uses determine the sustainability of the catchment with respect to evaporative use and how large areas under irrigation or combinations of areas under irrigation and forestry can lead to unsustainable rates of evaporation that exceed the precipitation input;
- That increasing tank storage and densities of soil-water retention structures will reduce annual flows from a catchment.

Recent development of the tool has involved the incorporation of "arrows" which show how the management of land use which determines evaporation (green water management) and the management of surface water through water retention structures (blue water management) affect liquid flows out of the catchment (blue water flows).

The impact of changing forest and irrigation area, through movement of the respective sliders, is indicated by changes in the evaporation from the catchment (changes in the green up arrow), with corresponding changes in the blue water flow (blue horizontal and vertical arrows indicating surface and groundwater flows respectively). The arrow representing net groundwater recharge is shown as a blue down pointing arrow when the recharge is positive and a red upward pointing arrow when net recharge is negative, i.e. when the net abstraction due to groundwater abstraction for irrigation exceeds the groundwater recharge taking place over the catchment. (Note that a negative net recharge indicates a depleting groundwater table)

The impact of different densities of water retention structures or tank capacities on both surface and groundwater flows and green water flows (as a result of increased evaporation from water retained behind the structures) can be investigated through movement of the "tank storage" arrow. Moving this arrow changes the storage from 0 capacity (representing total siltation), to 60% (representing the often the present scenario), to 100% (representing desilted tank) to 120% (representing desilted and deepened tanks).

All the above combinations of land use and tank storage scenarios can be investigated under different climate scenarios through the use of the "climate" slider which allows selection of various climate scenarios, ranging from the one in five wettest year to the one in five drought year, including the median year.

Figure 11 shows the EXCLAIM tool for the Mustoor Catchment showing "present case" scenarios of areas under tree crops, irrigation, and tank storage for a median rainfall scenario. For this scenario the tool indicates that net groundwater recharge is negative (red arrow) and surface flows out of the Bairekur tank (last tank in cascade) are zero.

The surface and groundwater flows that would result under different climate scenarios representing the one in five wettest and one in five driest years are shown in Figures 12 and 13.

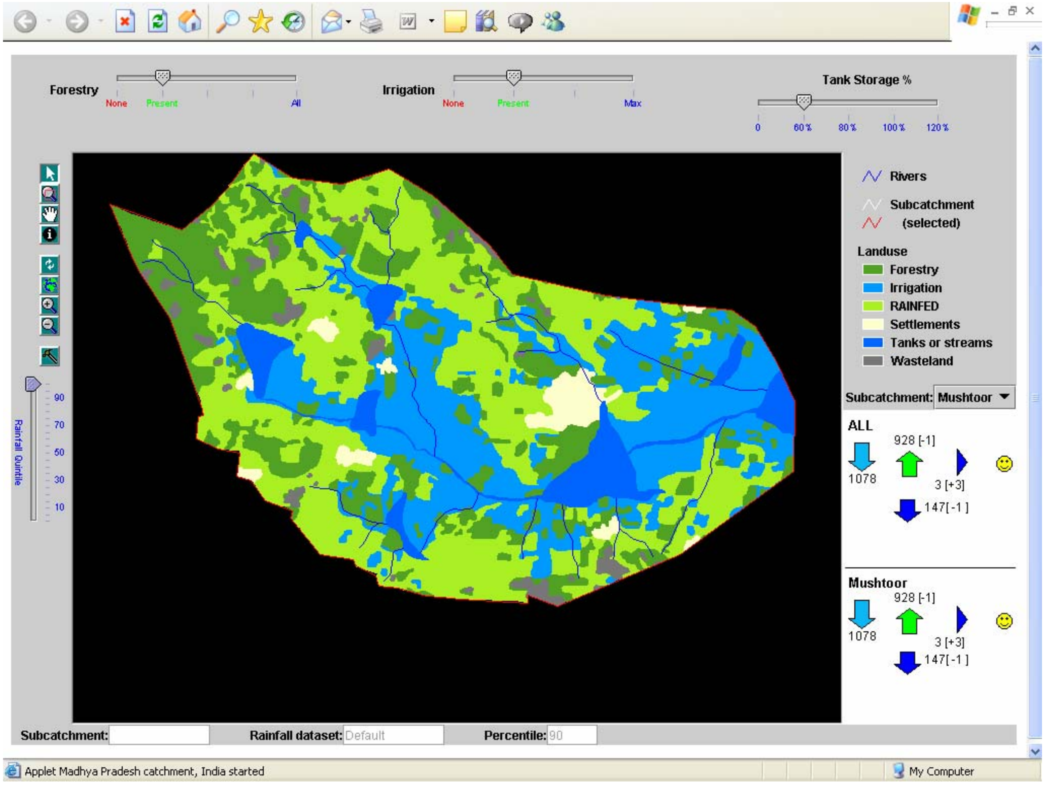

Figure 12 EXCLAIM visualisation of the Mustoor Catchment showing "present case" scenarios of areas under tree crops, irrigation, and tank storage for a one in five wettest year rainfall scenario. Net groundwater recharge is positive and positive surface flows indicate some surface flows from the Bairekur tank. Total blue water flows from the catchment are positive.

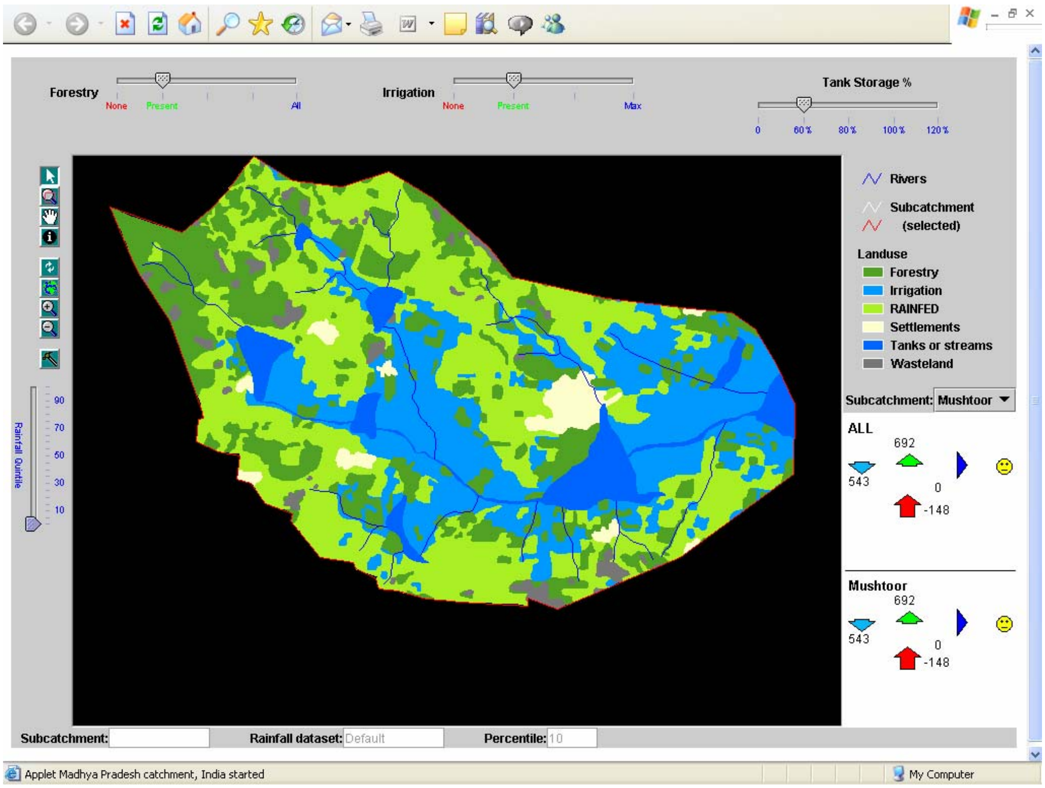

Figure 13 EXCLAIM visualisation of the Mustoor Catchment showing "present case" scenarios of areas under tree crops, irrigation, and tank storage for a one in five driest year rainfall

scenario. Net groundwater recharge is negative and there are zero outflows from the Bairekur tank. Total blue water flows from the catchment are positive.

These visualisations demonstrate that the Mustoor tanks, under present land use scenarios, even in the silted state, have sufficient storage to capture all flows except in the wettest years.

Changes in land use would be required for catchment flows to be restored for an average or medium rainfall year. Figure 14 shows that the extreme scenario of reducing irrigated area to zero will result in positive groundwater recharge and outflow from the catchment.

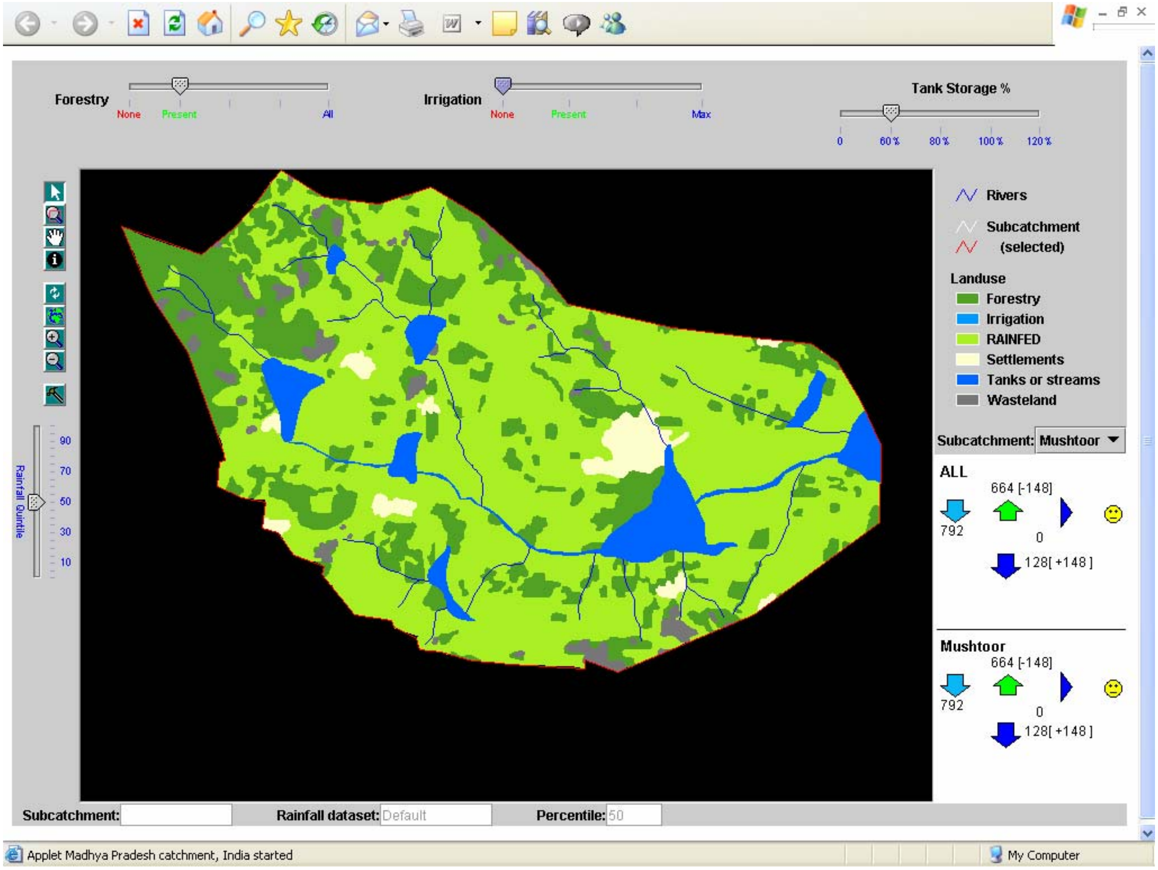

Figure 14 EXCLAIM visualisation of the Mustoor Catchment showing a "present case" scenario of areas under tree crops and tank storage but for zero area under irrigation and a median rainfall scenario. Total blue water flows from the catchment are positive.

2.4. A proposed 'Quadrant' approach to managing green water (evaporation) and blue water (liquid) flows from a catchment[4]

Many watershed development programmes have produced significant benefits for some social groups through the promotion of soil-water conservation measures,

[4] The following text is loosely based on the FAWPIO presentation given by Ian Calder at the SEI-SIWI Green Blue Initiative meeting in Stockholm in June 2005

forestry and groundwater-based irrigation. The question is: under what circumstances might these interventions result in beneficial or untoward outcomes?

It is suggested that to resolve this question consideration should be given to two issues:

1. The sustainability of land uses within the watershed with respect to evaporative use. It is important to determine if, in the absence of bulk transfers of water into the watershed, the long-term precipitation (P) still exceeds the total long-term evaporation (E) from the present land uses, comprising for example dryland agriculture, rangelands, forestry and irrigated areas, i.e., to determine if P > E;

2. Whether surface flows, (Qs), exceed an agreed minimum flow, (Qm). Minimum flow criteria could be defined variously. Conventionally this would be defined in terms of an agreed seasonal or annual minimum volume flow. Alternatively, for reservoired catchments, criteria could be defined in terms of return periods of surface flow exiting the catchment, for example one year, or more severe criteria of say, 5 years. The (Qs-Qm) criteria could then be regarded as positive, if the return period for flows was less than one year or five years. This definition would then approximate conditions, if there are reservoirs in the watershed, of whether or not the final reservoir (or tank using Indian terminology) has spilt within the last year or has spilt within the last five years. The four combinations resulting from this analysis indicate preferred options for the management of evaporation from land uses and for the management of surface flows. Using the green and blue water terminology derived by M. Falkenmark , these could be referred to as the green water and blue water management options:

   1) P > E, Qs > 0

   Green Water Management: Opportunities for enlarged areas of land uses with increased evaporation, e.g. Irrigated areas and forestry.

   Blue Water Management: Benefits may be gained from further SWC measures and water retention structures. Increase density of structures, rehabilitate structures.

   2) P < E, Qs > 0

   Green Water Management: Reduce areas of land uses with increased evaporation, eg reduce irrigation and forestry. Increase areas of ‘water providing’ land uses such as dryland agriculture.

   Blue Water Management: Only local benefits (at the expense of downstream users) will be gained from further soil and water conservation (SWC) measures and water retention structures. Consider increasing efficiency of existing structures through measures such as deepening (to reduce evaporative losses through reducing the surface to volume ratio).

   3) P < E, Qs = 0

   Green Water Management: Reduce areas of land uses with increased evaporation, e.g. reduce irrigation and forestry. Increase areas of ‘water providing’ land uses such as dryland agriculture.

Blue Water Management: No overall benefits from further SWC measures and water retention structures. Consider reducing density of structures and/or increasing efficiency of existing structures through measures such as deepening.

4) P > E, Qs = 0

Green Water Management: Opportunities for enlarged areas of land uses with increased evaporation, e.g. Irrigated areas and forestry.

Blue Water Management: No overall benefits from further SWC measures and water retention structures. Consider reducing density of structures and/or increasing efficiency of existing structures through measures such as deepening.

These outcomes can be illustrated with a quadrant diagram, as shown in Figure 15.

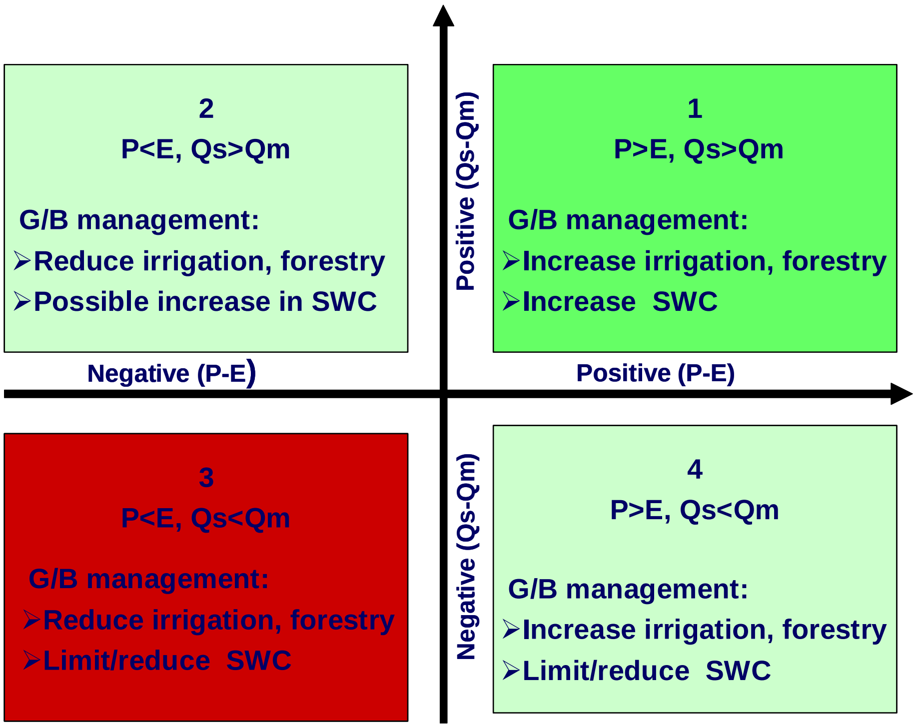

Figure 15 Catchment conditions which can be used to identify green and blue water management options and whether benefits would be derived from further soil water conservation measures and water retention structures.

This approach, shown in the 'quadrant' diagram, Figure 15, may help to direct development funds to those situations where further structural measures are likely to have an overall benefit (quadrant 1) and to scale back investments in catchments which are approaching conditions of catchment closure (quadrants 3 and 4). The approach also makes clear the interconnecting management options regarding green and blue water management and shows that in quadrants 2 and 3 development efforts would be much better directed at green water management, by reducing catchment evaporation losses, than by managing blue water through further water retention measures.

2.5. Bayesian Networks

2.5.1 *Introduction to Bayesian Networks*

Discussions during the FAWPIO (India) inception workshop, held in Bangalore in May 2005, highlighted the many biophysical and societal factors which have to be considered when developing and implementing water management strategies. Some of these factors are distinct and relatively easy to monitor and analyse (e.g. rainfall, population etc) whereas others, whilst being equally important, are much more difficult to define and quantify (e.g. awareness, resistance to change, social cohesion etc). Bayesian Networks (also known as Belief Networks) provide a relatively simple method of representing and analysing relationships between variables. The methodology is particularly relevant to water management and the understanding of societal impacts because it works well even if these relationships involve uncertainty, unpredictability or imprecision.

Bayesian Networks are being used by FAWPIO to:

- Reach a common understanding amongst stakeholders on the nature and causal linkages between biophysical and societal factors central to the success of the JSYS and Sujala Projects;
- Investigate the potential of JSYS and Sujala to improve strategic and tactical land and water management decision-making at a range of spatial and temporal scales. Both projects routinely collect large amounts of information and first indications are that Bayesian Network analysis can help the projects make much better use of this information.

2.5.2 *Prototype Bayesian Networks*

Figures 16 and 17 are examples of prototype Bayesian Networks that have been developed to support decision-making that is central to the JSYS and Sujala projects. More specifically, the networks have been designed to support decisions such as:

- What is the appropriate level of desiltation from tanks that are part of a cascade system?
- What is the potential impact of agricultural intensification (including drainage-line and in-field water harvesting) on the inflows into individual tanks and tanks in a cascade system?
- What are the combined impacts of JSYS and Sujala interventions on the utility of individual tanks and on the utility of tanks down a cascade system?

The main design criteria for the prototype networks have been:

- The nodes should be characterised to represent the disaggregated impacts of the Sujala and JSYS interventions.
- The nodes should be populated with data that are routinely collected by the Sujala and JSYS.
- The networks should be sufficiently simple that a numerate graduate could start using them after 2-3 hours training.

Prototype Bayesian Network (developed using data from Inchigeri Tank)

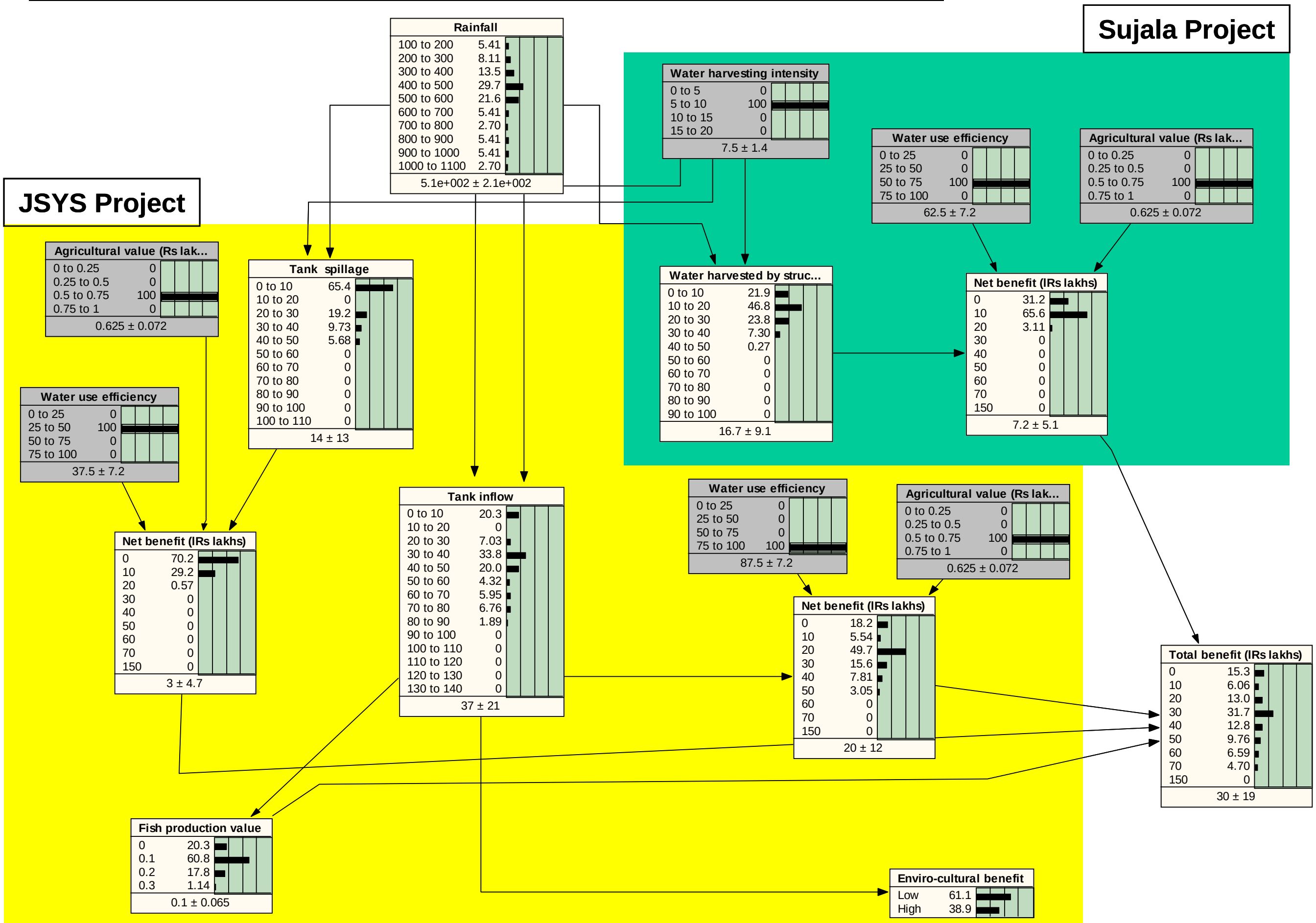

Figure 16. Prototype decision support network for assessing the net financial benefits of different Sujala and JSYS interventions

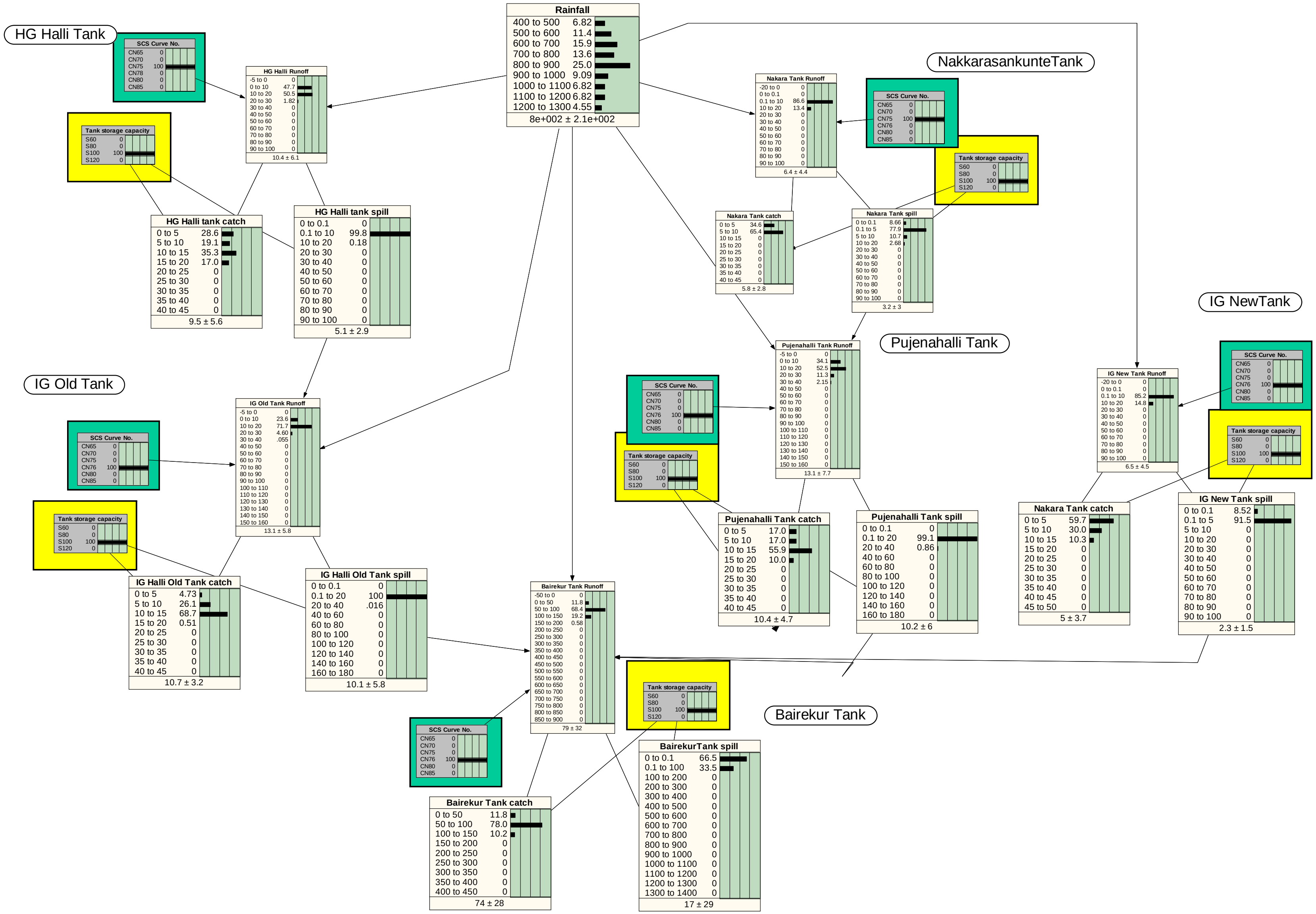

Figure 17. Prototype decision support network for assessing the biophysical impacts of JSYS and Sujala interventions.

Figures 16 and 17 present snapshots of the prototype networks with nodes (or factors) that represent JSYS and Sujala interventions highlighted in yellow and green respectively. When the networks are used operationally on a computer, different intervention strategies can be evaluated by simply altering values or probability distributions. Most importantly, different intervention strategies can be evaluated for a range of climatic conditions or for extreme conditions (e.g. flood and drought years). More information on the use of Bayesian Network software can be found on www.norsys.com. A discussion of the potential benefits of using Bayesian Networks to improve water management can be found in Batchelor and Cain (1999) and Cain *et al* (1999).

The design of the prototype networks have been discussed in meetings with Mr Boregowda (E.D. JSYSY Project), Mr Muniyappa (Commissioner, Water Development) and others. These meetings resulted in many excellent suggestions being made for potential improvements to the network designs. Discussions have also taken place on piloting the use of Bayesian Network analysis.

3. Conclusions

The studies carried out so far 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 soil and water conservation (SWC) structures and highlevels of groundwater extraction upstream of the Inchigeri tank have significantly reduced inflows to the tank. The study shows that, by using a thirty year rainfall record, the tank would have spilled and provided water flows to downstream users almost every fourth year if the SWC structures 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 thirty year record. The SWC structures combined with high levels of groundwater extraction have contributed to the *closure* of this catchment and of the wider Krishna Basin within which it is located, as downstream flows are not provided, except during the wettest years.

By contrast, the Mustoor catchment, although not having at present a high density of SWC structural engineering interventions 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 groundwater tables approaching 800-1000 ft 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 twenty 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 catchment.

The agreement between model predictions and observations of the frequency of tank spills is less for the Mustoor catchment. The present models are underestimating the frequency of spills from the Bairekur tank in the historical period (20 -30 years ago) and over estimating the frequency of spills in recent years (last 5 years). Three possible contributing causes were investigated: i) incorrect estimation of the local rainfall, ii) groundwater abstraction reducing baseflow inputs into tanks, iii) 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 '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 which has been taking place in the catchment (neither of which has been adequately accounted for in the present models) are identified as the likely causes.

Further developments to the cascade model will be required to take account of these effects if (as requested by the JSYS project) the study is extended from the present 6 to a total of 26 tanks.

Specialists from the Sujala and JSYS projects, the University of Agricultural Sciences, the Drought Monitoring Cell, the Institute for Social and Economic Change, the International Water Management Institute and the KAWAD project participated in the FAWPIO (India) inception workshop in May 2005. Discussions and ideas generated during this workshop formed the basis for the FAWPIO-India field studies. As the primary partners, the findings from the field studies have been discussed with Sujala and JSYS specialists on a regular basis since the inception workshop. Box 4 lists the main ‘points of agreement’ from informal and semi-formal discussions that have taken place, particularly those during the October 2005 field visit. (It is important to note that this list includes opinions and views that were held by many Sujala and JSYS specialists before the FAWPIO – India studies; in these cases, the FAWPIO - India studies in Inchigeri and Mustoor have helped to provide a focus for discussion on these important issues)

Box 4. Points of agreement (amongst FAWPIO team members)

The following points were discussed in some detail during the FAWIPO (India) inception workshop. These points have been reinforced by the collaborative studies that have been carried out in Karnataka in collaboration with the World Bank JSYS and Sujala Projects.

1. **Groundwater resources.** Throughout the region, there has been a large increase in groundwater extraction for irrigation during the last 15 years. Demand is outstripping supply and, consequently, groundwater levels are falling and competitive well deepening is taking place.
2. **Surface water resources.** Throughout the region, many large watersheds are approaching closure during years with average or below average rainfall (i.e. all the water resources are allocated in all but the wettest years). Hence, scope for developing additional surface water resources is quite limited. Inter-catchment disputes over water conservation are becoming increasingly serious.
3. **Tank inflows.** Intensive water harvesting coupled with high levels of groundwater extraction is having a negative impact on the inflow into many tanks and is adversely affecting their overall utility. This impact is greatest during years with low rainfall. Other activities that increase water use and extraction in tank areas (e.g. increased areas of forest plantation or horticultural crops, improved rainfed farming) are also reducing tank inflows.
4. **Private investment.** GoK-supported watershed development and tank rehabilitation programmes should be considered within the context of high levels of private investment in agricultural intensification. The net impact of these activities has been to change the hydrological characteristics of a large part of semi-arid Karnataka.
5. **Climate Change.** There is no substantive evidence of a systematic reduction in annual rainfall in Karnataka, however, there may be some variations in spatial and temporal distribution.

6. **Water-related policy.** Decision-making is often based on intuition and erroneous wisdom (e.g. myths relating to forest plantation crops, water harvesting) rather than on specialist knowledge. In addition to this, many important policy decisions are based on estimates and / or average values that do not sufficiently represent real temporal and spatial variation in water supply and demand.
7. **Official statistics.** Many important water-related statistics are either out of date or under-reported (e.g. areas under irrigated land use, well numbers, fluoride in drinking water etc.)
8. **Livelihood gains and tradeoffs.** Groundwater development and watershed development have improved the productivity of rainfed areas and the access of many landowners to water for irrigation. However, the potential negative tradeoffs associated with watershed development are being ignored in planning processes. In particular, potential impacts on downstream water users or on domestic water supplies are rarely considered.
9. **Groundwater depletion and poverty.** Overexploitation of groundwater and failed investments in borewell construction have become important causes of poverty. In some areas, groundwater depletion is also associated with increased fluoride in domestic water supplies.
10. **Community perception.** The perception of most communities in the region is that available water resources are becoming scarcer and the reasons given for this include low rainfall, land use change and groundwater level decline. The general consensus is that conservation is needed to improve equity and to protect access and entitlements to water for both domestic and productive purposes.
11. **Privatisation of water.** The shift from tank irrigation to groundwater-based irrigation represents a privatization of water ownership and management.
12. **Power consumption.** There has been a large increase in power consumption in rural areas for pumping groundwater.
13. **Ever-increasing demand for water.** Many interventions aimed at reducing water shortages have the unintended consequence of stimulating water demand (e.g. introduction of horticulture). Similarly, with policies in and outside the water sector.
14. **Awareness.** Although the water resource situation in many areas of Karnataka is extremely serious and arguably at crisis point for many villages, there is much that can be done. A critical step, however, is to raise awareness at all levels of the true causes of water scarcity.
15. **Planning processes.** Finally, approaches to water resource planning do not adequately take account of issues of temporal and spatial scale and the potential impacts (beneficial or otherwise) of different strategies for managing water supply and demand. Hence, the focus of FAWPIO (India) on planning processes.

Throughout the FAWPIO – India study period 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.

4. Recommendations for Improved Watershed Management

Studies conducted by the FAWPIO-India project in conjunction with World Bank and DFID watershed development projects in Karnataka indicate that a major revision of watershed management policy may be required by government - particularly in relation to the planning of structural interventions. This need has arisen because over the past ten to fifteen years increased intensification of agriculture has led to much reduced flows of water into water reservoirs (known as tanks in India). Field levelling, field bund construction, 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 twenty years ago, are not appropriate today.

New planning methodologies are required which take account of these reduced flows. These methodologies also need to ensure that basic human needs are given priority (e.g. domestic water supplies) and equitable allocation of water so that the poorest people are not disadvantaged and that environmental flows are maintained to support the river system.

Recommendations:

1. Bridging Research and Policy. A gap exists between the knowledge and understanding of specialists and policy makers. Increased efforts need to be made to bridge this gap and raise awareness of the technical issues and constraints involved in watershed management including:

i. Challenging the conventional wisdom that water scarcity can be solved simply by increased tank or soil water conservation interventions. Water retention interventions should be considered only within a broader, integrated approach to land and water management which takes account of downstream externalities (Kerr *et al*., 2006; Calder *et al*., 2005; Calder, 2005).

ii. Promoting awareness that major river basins such as the Krishna and Cauvery are approaching closure (essentially there are now no annual outflows except in high rainfall years).

iii. Raising awareness that, in a closed basin, creating additional water storage capacity or promoting further agricultural intensification or tank rehabilitation and deepening will only provide local water benefits often to a small number of households at the expense of the wider community, downstream users and the environment.

2. Improved framework for watershed management including methodologies to determine water resource impacts of watershed interventions

i. The connection between land use in the catchment and inflows into tanks indicates that traditional methods for estimating tank inflows may now need to be reviewed and revised. Where these empirical methods, which were calibrated at a time when no borehole supplied irrigation was present in the catchment and water tables were high, are applied under present conditions (when there is essentially no groundwater flow to tanks), the methods may overestimate tank inflows.

ii. Assessing the changes in tank inflows that will occur as a result of decreased water tables will also require modifications to process based methods such as the Soil Water Assessment Tool (SWAT) or Hydrological Land Use Change (HYLUC) model, so that they can then be used to recalibrate more empirical engineering methods.

iii. Minimum flow requirement. Together with the political and socio-economic questions influencing the choice of which tanks should be prioritised for rehabilitation there remains the question of which catchments may already be 'over-engineered' in terms of tanks and soil water conservation measures. The modelling methodologies outlined above will enable users to calculate the number of interventions that could be allowed before any minimum flow requirement from the catchment is breached.

iv. Operational Management Framework. An improved operational framework for planning watershed interventions needs to be developed. It is recommended that this framework is based on a process of stakeholder dialogue that incorporates tools and methodologies that have been derived to assess the water resource and societal impacts of watershed interventions. The JSYS and KWDP projects in Karnataka already provide a platform for participatory planning but this, as in other watershed development projects, needs to be focussed more towards water resource management.

3. Improved assessment methodologies to determine societal impacts of watershed interventions

Allocation Equity. It is recommended that any planned intervention which provides water retention in a closed catchment should be considered in the wider biophysical and socio-economic context. The decision is inevitably as much a political, in the sense that it must address state and national poverty alleviation strategies, as it is an engineering decision. It involves questions as to whether the future effective reallocation of water meets basic human needs and is equitable. For example, provision of greater water retention in headwater areas may be to the advantage of local people (perhaps often previously disadvantaged scheduled castes who are living on the poorer lands in headwater areas) but this gain in water availability would be at the expense of the often richer farmers, lower down the catchment, who would have been benefiting previously from this water.

4. New 'green water' approaches need to be developed and piloted within watershed development projects.

Household-level discussions, Mustoor within the KWDP and JSYS studv area.

The effective closure of many Indian cactchments requires a major shift in watershed development policy, away from the provision of further supply side measures and towards greater 'green water' demand management. New management systems will need to be developed and piloted that are more integrated and multi-scalar, that take account of downstream externalities, that involve a process of stakeholder dialogue and are evidence-based. To raise awareness of these issues and to change attitudes will be a major task which will also require the provision of dissemination tools and mechanisms directed at all levels of management – from project management to the village level. Management systems need to encourage both sustainable green water use and improved conjunctive use of surface and groundwaters. Systems where green water use is sustainable (less than the rainfall and allowing some agreed minimum blue water flow from the catchment) and where surface water is the predominant form of irrigation for average to high rainfall years, with groundwater use reserved for supplementary irrigation within the dry season and in low rainfall years should be aimed for. These systems should not only mitigate many of the societal harms associated with present watershed developments, including the competitive 'chasing down' of watertables, but also avoid the high electricity costs of deep groundwater pumping.

5. Acknowledgements

The FAWPIO team wishes to acknowledge the excellent support and assistance that they have received from the senior officers, specialist staff and field teams involved in the implementation of the Sujala and JSYS Projects. Staff from the DFID-supported KAWAD Project, KAWAD IAs and NGOs and Prakruthi (a NGO based in Kolar District) have also provided invaluable assistance.

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