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ORIGINAL PAPER

Watershed development in India. 2. New approaches for managing externalities and meeting sustainability requirements

Ian Calder · Ashvin Gosain · M. S. Rama Mohan Rao · Charles Batchelor · James Garratt · Emma Bishop

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Abstract This paper recognises the need for a revision of watershed development policy in India in relation to the planning of development interventions involving agricultural intensification and rainwater harvesting and the need for new approaches to assist the planning process. Building on, and using as an example, the results of biophysical and societal impact studies carried out on two watershed development projects in Karnataka three new management/dissemination tools, are suggested. These are (1) the web-based geographical information systems exploratory, climate land assessment and impact management tool dissemination tool for disseminating to policymakers and non-specialist stakeholders the downstream impacts of watershed interventions, (2) the 'quadrant' approach for ensuring that sustainability criteria are met and (3) Bayesian networks to investigate the biophysical and societal impacts of interventions.

Keywords Bayesian networks · Dissemination tool · Externality · Management tools · Rainwater harvesting · Sustainable water resources · Watershed management

Abbreviations

BIRDS	Bijapur integrated rural development society (an NGO for the Inchigeri area)

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I. Calder (✉) · C. Batchelor · J. Garratt · E. Bishop
Centre for Land use and Water Resources Research, University of Newcastle, Newcastle Upon Tyne NE1 7RU, UK
e-mail: i.r.calder@ncl.ac.uk

A. Gosain
Civil Engineering Department, Indian Institute of Technology, Delhi, India

M. S. R. M. Rao
Jala Samvardhane Yojana Sangha, Bangalore, India

CLUWRR	Centre for Land Use and Water Resources Research
DFID	Department for International Development
EXCLAIM	EXploratory, Climate Land Assessment and Impact Management tool
SWAT	Soil Water Assessment Tool
G/B	Green and Blue water
GIS	Geographical Information Systems
HYLUC	HYdrological Land Use Change
JSYS	Jala Samvardhane Yojana Sangha, a World Bank programme responsible for implementing the Karnataka community-based tank management project
KAWAD	Karnataka Watershed Development Society
SCS	Soil Conservation Service
SWC	Soil and Water Conservation

1 Introduction

Concerns have been raised in an earlier paper (I. R. Calder et al., 2007, submitted) that structural water retention interventions within watershed development projects may not always have the intended beneficial impacts on water availability and people's livelihoods (see also: Batchelor, Singh, Rama Mohan Rao, & Butterworth, 2002; Batchelor, Rama Mohan Rao, & Manohare Rao, 2003; Rama Mohan Rao et al., 2003; ETC, 2004; Sakthivadivel & Scott, 2005; Sharma & Scott, 2005).

These concerns are exemplified by two studies that investigated the water flows and societal impacts of watershed interventions in Department for International Development (DFID) and World Bank funded watershed development projects in southern India, at Inchigeri and Mustoor. It was concluded that the general intensification of agricultural activities is the cause of the reduction in catchment flows now observed throughout much of India. The intensification results from the construction of rainwater harvesting structures, tank rehabilitation, increased areas under irrigation using borewell water, increased areas under forestry and other farming activities which might involve field levelling and field bunding, on rainfed as well as irrigated areas, and increased areas under horticulture.

Because of these changes to the environment it is believed that methodologies for planning watershed interventions, which were appropriate perhaps three decades ago are no longer appropriate under present day conditions of much reduced catchment flows.

New planning tools and methodologies are required and this paper describes three new approaches, which have been developed to assist the planning process. These are (1) the web-based geographical information systems (GIS) EXploratory Climate Land Assessment and Impact Management (EXCLAIM) dissemination tool for disseminating to policy makers and non-specialist stakeholders the downstream impacts of watershed interventions, (2) the 'quadrant' approach for ensuring sustainability criteria are met and (3) Bayesian networks to investigate the biophysical and societal impacts of structural interventions.

Traditional engineering methodologies based on the Soil Conservation Service (SCS) method are reviewed and it is suggested that these methods, which have the great advantages of simplicity and robustness, will need to be adapted and recalibrated for present day conditions if their use is to be continued.

2 The geographical information system-based exploratory climate land assessment and impact management tool

The GIS-based EXCLAIM tool has been developed as a means for disseminating knowledge of land and water interactions to policy makers.

The tool has been applied to demonstrate the impacts of catchment interventions including changes in forest cover, irrigation and soil water conservation structures in a range of countries including India, South Africa and Costa Rica (Calder, 2005). Where the appropriate socio-economic data are available the tool can also demonstrate how spatial changes in land use impact on job opportunities and economic production values.

The tool can also demonstrate the effects of climatic variability. This allows the impacts of different land use change scenarios to be investigated for not only an average rainfall year, but also, through the use of a 'slider', a range of rainfall years. The slider allows anything from the driest to the wettest years in an historical record to be selected by moving the slider over the range of 5–95% rain years.

A 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 of 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 water loss 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 rainwater harvesting and soil-water retention structures will reduce annual flows from a catchment.

The impact of changing the proportion of forest and irrigated areas, through movement of the respective sliders, is indicated by changes in the overall 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 surface, groundwater flows and evaporative flows (as a result of increased evaporation from water retained behind the structures) can be investigated through movement of the 'tank storage' slider. Moving this slider changes the storage from 0% capacity (representing tanks which are entirely silted), to 60% (representing a typical present day scenario), to 100% (representing a 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, including the median rainfall year and ranging from the one in five wettest year to the one in five drought year.

Figure 1 shows the EXCLAIM tool applied to 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 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 Figs. 2 and 3.

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 flows out of the catchment to be restored for an average or medium rainfall year. Figure 4 shows that the extreme scenario of reducing irrigated area to zero will result in positive groundwater recharge and outflow from the catchment.

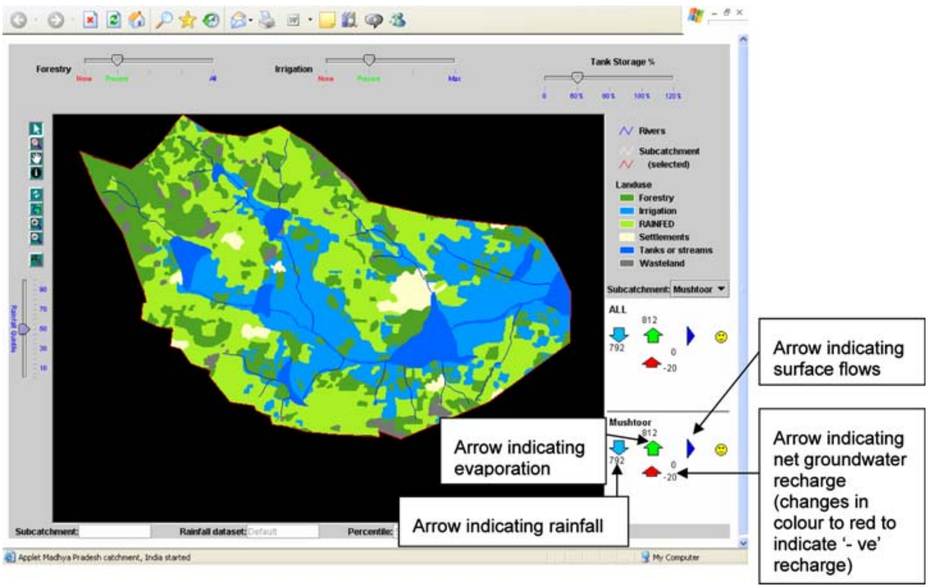

Fig. 1 Current state of development of the EXCLAIM tool for the Mustoor Catchment showing ‘present case’ scenarios of areas under tree crops, irrigation and tank storage for a median rainfall scenario. For this scenario the *tool* indicates that net groundwater recharge is negative and surface flows out of the Bairekur tank (*last tank in cascade*) are zero. Total blue water flows (*Surface plus groundwater*) from the catchment are negative

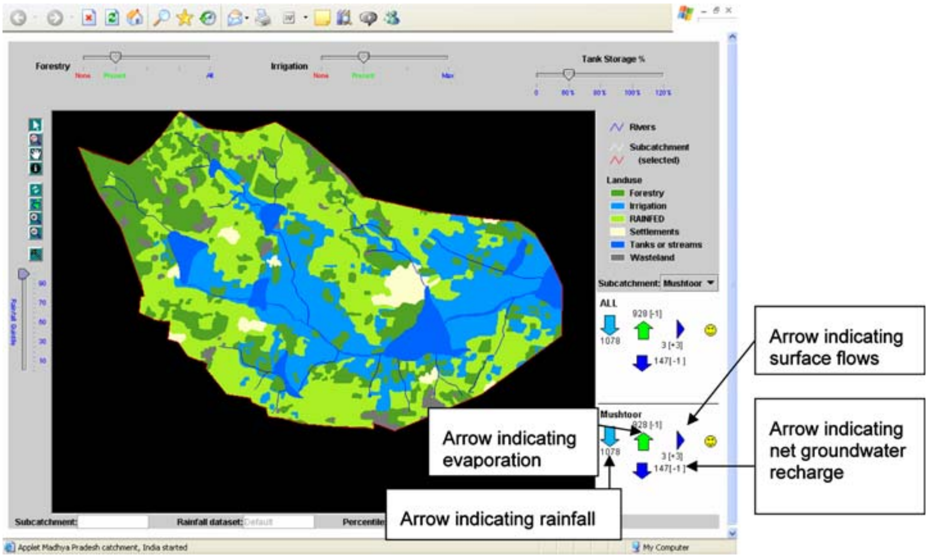

Fig. 2 EXCLAIM visualisation of the Mustoor Catchment showing 'present case' scenarios of areas under tree crops, irrigation and tank storage for a one in five wettest year rainfall scenario. Net groundwater recharge is positive and *positive surface flows* indicate some surface flows from the Bairekur tank. Total blue water flows from the catchment are positive

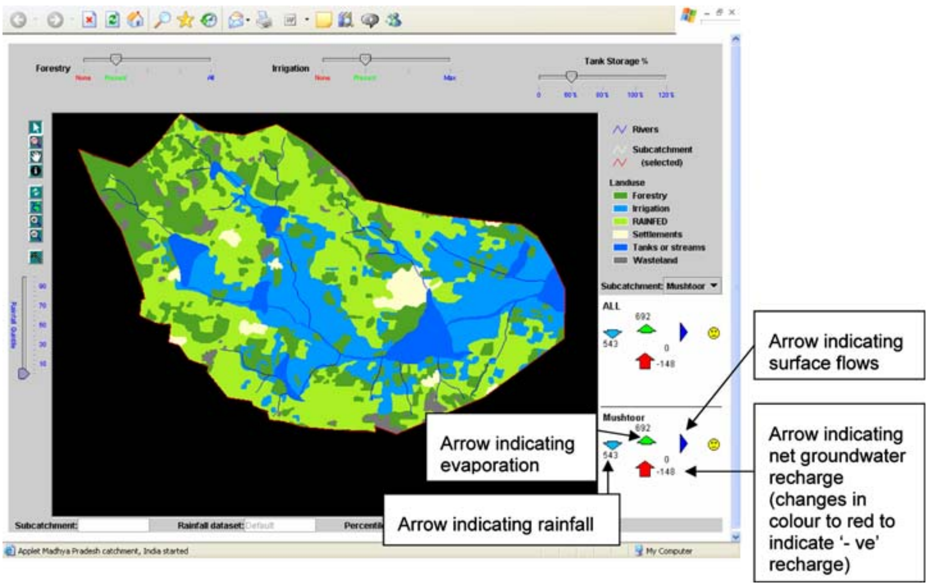

Fig. 3 EXCLAIM visualisation of the Mustoor Catchment showing 'present case' scenarios of areas under tree crops, irrigation and tank storage for a one in five driest year rainfall scenario. Net groundwater recharge is negative and there are zero outflows from the Bairekur tank. Total blue water flows from the catchment are negative

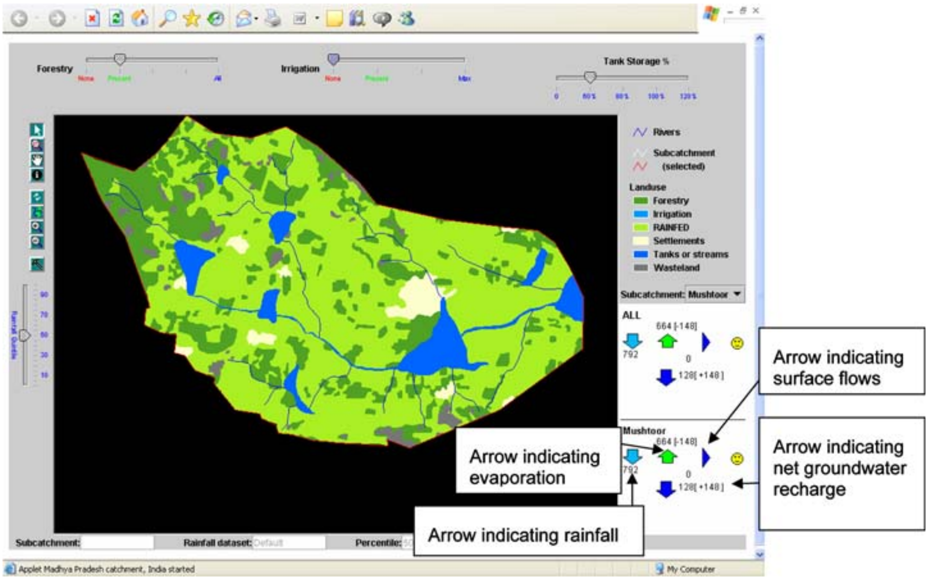

Fig. 4 EXCLAIM visualisation of the Mustoor Catchment showing a 'present case' scenario of areas under tree crops and tank storage but for zero area under irrigation and a median rainfall scenario. Total blue water flows from the catchment are positive

3 A proposed 'quadrant' approach to managing green water (evaporation) and blue water (liquid) flows from a catchment

Many watershed development programmes have produced significant benefits for some social groups through the promotion of rainwater harvesting, forestry and groundwater-based irrigation. But these interventions all tend to increase evaporation and reduce water yields from catchments. Thus the questions arise:

- Under what circumstances might these interventions result in beneficial or untoward outcomes?
- How can a balance between high and low water using land uses be achieved to achieve long-term sustainability of water use and the maintenance of downstream and environmental flows.

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 any bulk transfers of water into the watershed) the long-term precipitation (P) exceeds the total long-term evaporation (E) from the different land uses, 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 a 1 year, or a more severe criterion of say, 5 years. The (Qs-Qm) criteria could then be regarded as positive, if the return period for flows was less than 1 or 5 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 5 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 (G/B) terminology derived by Falkenmark (1995), these could be referred to as the G/B 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 soil and water conservation (SWC) measures and water retention structures. Consider increasing density of structures, rehabilitate structures.

(2) $P < E$, Qs > 0.

Green water management: Reduce areas of land uses with increased evaporation, e.g. reduce irrigation and forestry. Consider increasing 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 SWC measures and water retention structures. Consider increasing efficiency of existing structures through measures such as deepening (reduces evaporative losses by 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. Consider increasing 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 expanding areas of land uses associated with high 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 Fig. 5.

This approach, shown in the 'quadrant' diagram, Fig. 5, 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 G/B 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.

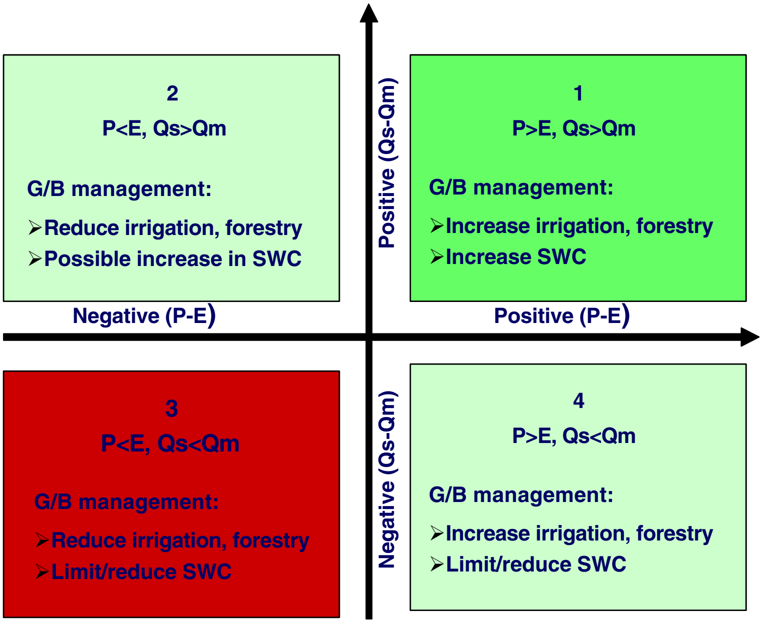

Fig. 5 Catchment conditions, which can be used to identify green and blue water management options and whether benefits would be derived from further soil water conservation measures and water retention structures

4 Bayesian networks

4.1 Relevance of Bayesian networks

Many biophysical and societal factors have to be considered when developing and implementing watershed management strategies. Some of these factors are distinct and relatively easy to monitor and analyse, such as rainfall and population, whereas others, whilst being equally important, are much more difficult to define and quantify such as awareness, resistance to change and social cohesion. Bayesian networks, also known as Belief networks, provide a methodology for 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 have been piloted under the Jala Samvardhane Yojana Sangha and Sujala watershed development projects to:

- Reach a common understanding amongst stakeholders on the nature and causal linkages between biophysical and societal factors central to the success of the projects.
- Investigate the potential 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.

4.2 Prototype Bayesian networks

Figures 6 and 7 are examples of prototype Bayesian networks that have been developed to support decision-making in relation to:

- The appropriate level of desiltation from tanks that are part of a cascade system.
- 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.
- The combined impacts of project 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 are that:

- The nodes should be characterised to represent the disaggregated impacts of the project interventions.
- The nodes should be populated with data that are routinely collected by watershed development projects.
- The networks should be sufficiently simple that a numerate graduate could start using them after 2–3 h training.

Figures 6 and 7 shows the layout of the prototype networks with nodes (or factors) that represent project 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 the Norsys website (1995–2006 copyright). A discussion of the potential benefits of using Bayesian networks to improve water management can be found in Batchelor and Cain (1999) and Cain, Batchelor, and Waughray (1999).

5 Water resource assessment and the soil conservation service method

A deficiency in the design of many current watershed development projects in India is that often no water resource assessments are made prior to the installation of water harvesting structures. Ideally assessments should be carried out to take account of the volumes of water retained in existing structures in relation to available water resources and minimum flow requirements before further structures are installed. Where available water resources have decreased through agricultural intensification, catchments, which might in the past have been considered as having optimal design in terms of the density of rainwater harvesting structures, may now be 'over engineered'.

Where assessments are carried out one of the common methods for calculating inflows of water to rainwater harvesting structures is the (SCS) method. The method was developed in the USA and has been adapted, based on soil type, to various regions in India. In India, surface runoff is generally calculated using a specific Indian curve number derived from locally determined rainfall runoff relationships (Tideman, 1999). The method is simple and robust and works well under regimes for which it has been calibrated. However earlier calibration of the method in India will

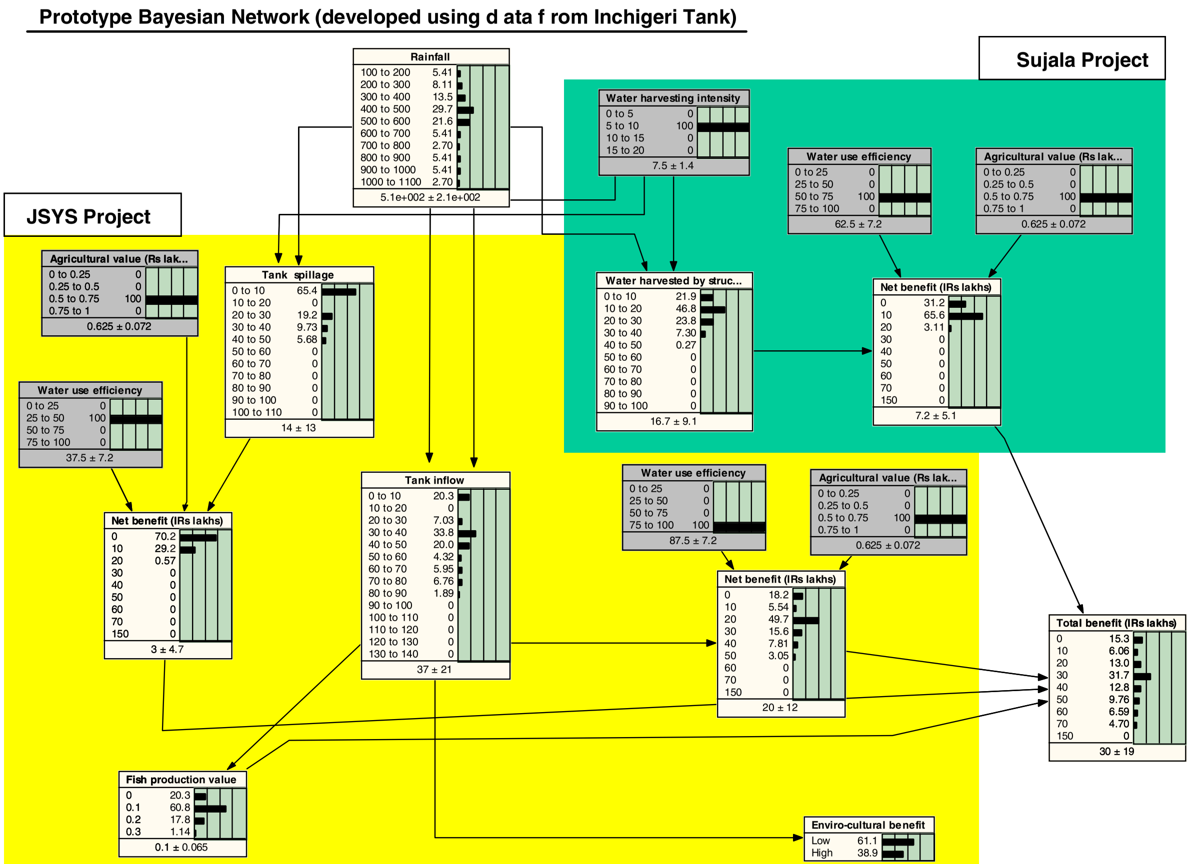

Fig. 6 Prototype decision support network for assessing the net financial benefits of different Sujala and JSYS interventions

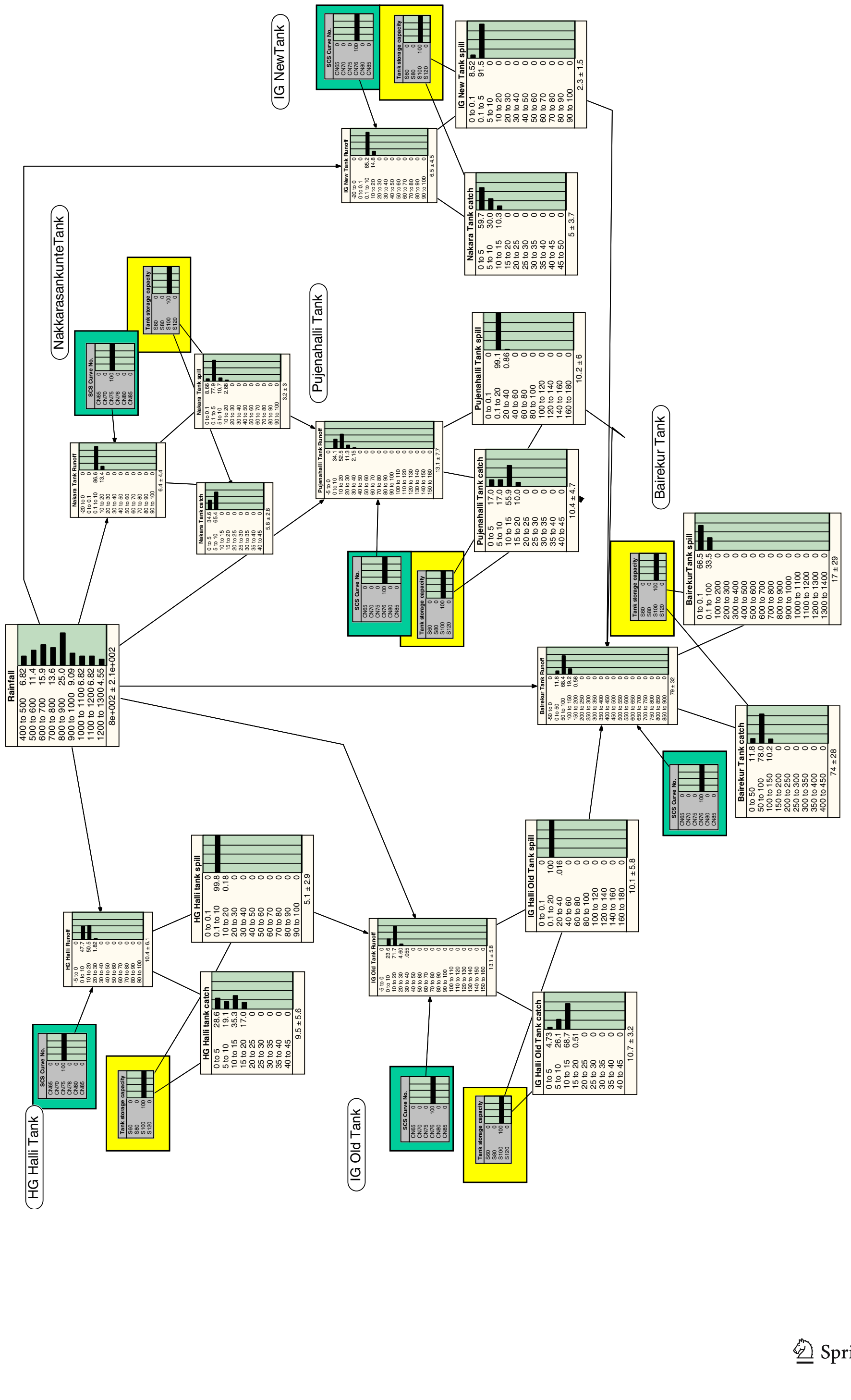

Fig. 7 Prototype decision support network for assessing the biophysical impacts of JSYS and Sujala interventions

have implicitly included contributions of groundwater flow which are not present in many catchments today due to depleted groundwater tables. Application under modern conditions may therefore result in an overestimate of surface flows.

In conditions where there are now no longer any contributions from groundwater flow it is recommended that extreme care should be used in the application of this method using historically derived curves. Ideally, new curves should be derived for present day catchment conditions (of low groundwater tables) or use should be made of modelling methods which can take explicit account of surface/groundwater flow interactions [e.g. hydrological land use change (HYLUC)-EXCLAIM and the soil water assessment tool (SWAT) developed by the US Department of Agriculture (Arnold, Srinivasan, & Engel, 1994)]. It might also be possible to correct the historical curves for modern conditions through the generation of synthetic flows from SWAT and HYLUC-EXCLAIM modelling approaches.

Table 1 Summary of methods for assisting the planning of interventions and managing externalities and meeting sustainability requirements

Methodologies/ planning tools	Main purposes	Limitations and requirements for future developments
New		
Hydrological models: HYLUC-cascade, SWAT, etc.	Provide an understanding of the bio physical processes Provide a means of improving and calibrating empirical methodologies/tools Always likely to used by researchers or specialists	Models are potentially able to describe surface—groundwater interactions but more calibration is needed in field conditions
EXCLAIM	A dissemination and decision support tool that has a strong visual impact	Improved linkage of HYLUC-cascade to EXCLAIM required to ease set up of EXCLAIM applications
	Raising awareness amongst non-technical stakeholders of the societal and biophysical effects of watershed interventions which alter groundwater and surface flows	Coupling of societal impact modelling through the use of Bayesian networks is possible
Bayesian networks	A decision-support tool that is strong on its ability to handle uncertainty and information from a wide range of sources As it is commercially available and documented, it can be used 'routinely' by specialists	Further piloting of the networks for real world situations is required
Traditional		
SCS	Estimation of runoff using a calculator or a PC Easy to use and hence used extensively by engineers and field workers Simple and robust within its realm of calibration. SCS is always likely to be the method of choice for engineering purposes	SCS method does not take account of groundwater flows A major revision of SCS curves and/or input parameters would be needed to deal with all the impacts of agricultural intensification and the effects of changes to groundwater flows

6 Summary of methods and tools

The main purposes, limitations and development requirements of the proposed watershed planning tools are shown in Table 1.

7 Conclusions

Studies conducted in conjunction with World Bank and DFID watershed development projects in Karnataka indicate that a 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 10–15 years increased intensification of agriculture has led to much reduced flows of water into water reservoirs. Field levelling, field bund construction, expansion of horticultural and forested areas and increased abstraction and use of groundwater for irrigation are all contributing factors to reduced flows. Planning methodologies and approaches, which may have been appropriate 30 years ago, are no longer appropriate today.

New planning methodologies are required which are able to take account of these reduced flows. The three approaches that have been discussed in this paper: the web-based GIS EXCLAIM dissemination tool for disseminating to non-specialist stakeholders the downstream impacts of watershed interventions, the 'quadrant' approach for ensuring sustainability criteria are met, and Bayesian networks for determining both the biophysical and societal impacts of structural interventions, provide new mechanisms for assisting the planning process. Further development, testing and piloting of these approaches within watershed development projects will be required to develop fully operational systems.

These approaches, even in their prototype forms, expose the deficiencies and dangers inherent in current watershed development planning—where often little consideration is given to the externalities associated with structural watershed interventions.

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