Australian Government

Australian Centre for
International Agricultural Research

Final report

Project	Impacts of meso-scale Watershed Development (WSD) in Andhra Pradesh (India) and their implications for designing and implementing improved WSD policies and programs
project number	LWR/2006/072
date published	30/05/2015
prepared by	Professor Geoff Syme, Edith Cowan University Professor V Ratna Reddy, Livelihoods and Natural Resources Management Institute Dr Shakeel Ahmed, National Geophysical Research Institute Dr K V Rao, Central Research Institute for Dryland Agriculture Dr Paul Pavelic, International Water Management Institute Dr Barry Croke, Australian National University Dr Wendy Merritt, Australian National University Dr Ram Ranjan, Macquarie University Dr Chiranjeevi Tallapragada, Livelihoods and Natural Resources Management Institute
co-authors/ contributors/ collaborators	Dr PD Sreedevi, National Geophysical Research Institute Dr Sarah Sarah, National Geophysical Research Institute Mr Sreedhar Nallan, Edith Cowan University Dr Sanjit Rout, Livelihoods and Natural Resource Management Institute Dr Joseph Guillaume, Australian National University Mr D Bernet, International Water Management Institute
approved by	
final report number	FR2015-05
ISBN	9781 925133714

published by

ACIAR
GPO Box 1571
Canberra ACT 2601
Australia

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Figures and Tables

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ANU	Australian National University
AP	Andhra Pradesh
APFMGS	Andhra Pradesh Farmers' Managed Groundwater System
BIRDS	Bharathiya Integrated Rural Development Society
BN	Bayesian Networks
CPR	Common Property Rights
CRIDA	Central Research Institute for Dryland Agriculture
DDG	Deputy Director General
DEM	Digital Elevation Model
DHAN	Development of Humane Action
DIPA	Development Initiatives for Peoples Action
DPR	Detailed Project Report
DRD	Department of Rural Development
ECU	Edith Cowan University
ERT	Electrical Resistivity Tomography
EWAC	**E**quitable surface and ground **W**ater **A**llocations in **C**atchments
ExCLAIM	Exploratory Climate Land Assessment and Impact Management
FGD	Focus Group Discussion
GIS	Geographical Information System
GO	Government Organization
HUN	Hydrological Unit Network
ICAR	Indian Council of Agricultural Research
IWMI	International Water Management Institute
IWMP	Integrated Watershed Management Programme
LCR	Lithologically Constrained Rainfall
LNRMI	Livelihooods and Natural Resources Management Institute
MU	Macquarie University
NGO	Non Government Organization
NGRI	National Geophysical Research Institute
NRAA	National Rainfed Area Authority
PIA	Project Implementation Agency
PSM	Propensity Score Matching
SL	Sustainable Livelihoods
SRL	Sustainable Rural Livelihoods
STATA	Statistical Software Package
SWAT	Soil and Water Analysis Tool
SYA	Star Youth Association
VES	Vertical Electrical Sounding
WASSAN	Watershed Support Services and Activities Network
WOTR	Watershed Organization Trust
WS	Watershed
WSD	Watershed Development

1 Acknowledgements

The Department of Rural Development (DRD), Government of Andhra Pradesh (AP), has been very supportive from the design stage of the research until the end. As a formal partner in the project DRD, not only supported and participated in the selection of sample sites, but also provided the much needed feedback in helping to make the research policy- relevant. More importantly, DRD agreed to mainstream the results through capacity building of their staff. Adapting the research at the implementation level is one of the major achievements of this research. Our sincere thanks are due to the DRD, Government of AP.

A number of individuals have contributed to the completion of the research and to bring it to its present shape. Given that the project has had five year duration, it has naturally experienced a degree of turnover of team members. The project has gone through the rigorous scrutiny of four ACIAR Programme Managers. Dr. Christian Roth at the initial stages of the project. His successors at the ACIAR, the late Dr. Mirko Stauffacher, Dr. Andrew Nobel and Dr. Evan Christen. Dr. Kuhu Chatterjee and Ms. Simrat Labana, from the ACIAR, India office have provided valuable inputs in terms of feedback and excellent administrative support at various stages of the project.

The project benefited immensely from the inputs from Dr.Tirupathaiah, then Special Commissioner, DRD, who provided constructive feedback in setting the objectives and designing the research at the initial stages and his successor, Dr. C. Suvarna, Special Commissioner DRD. At the national level Dr. Alok K Sikka, DDG (Natural Resource Management), ICAR, and Technical Expert, National Rainfed Area Authority (NRAA), has provided the much needed recognition to the research by assuring his support for spreading the recommendations through capacity building activities to the implementing agencies at the national level.

A number of people have provided valuable inputs to the research at various stages. Our thanks are due to Dr. Mac Kirby, Dr. K. A. S. Mani, Dr. Madar Samad and Mr. Sreedhar Nallan for their respective contributions. The research has benefited from the critical comments from Dr. Jeff Bennett in the initial stages and the external reviewers Dr. Dennis Wichelnsand and Dr. M. Dinesh Kumar. Our thanks go out to them for their constructive feedback.

The time and patience of the rural households in the sample villages in participating in, the field research, which forms the core of this research, is greatly appreciated. The information provided by the sample households and the participants in formal and informal group discussions at the time of data collection and their feedback at the time of validation of the results has been invaluable. We only hope that this research would help in enhancing their conditions a little. The field research was ably supported by two NGOs viz., Development Initiatives for Peoples Action (DIPA) and Star Youth Association (SYA) operating under Bharatiya Integrated Rural Development Society (BIRDS) and field investigators who had gone through hard task of collecting the information from the farmers. We sincerely appreciate and thank their efforts.

2 Executive summary

Introduced as a soil and water conservation intervention aimed to stabilise agricultural productivity in the rainfed regions, the Watershed Development (WSD) program has transformed into a rural development intervention in India over the last three decades. WSD is among the flagship programs of the Government of India with substantial annual budgetary allocations. It has been administered at the micro or village level. Meta analysis of evaluations shows that the success rate is about twenty percent. The productivity impacts look high possibly because most of the studies were not subjected to rigorous statistical analysis. While inadequate or unsustained implementation is often identified as the root cause of the poor performance of the program, a number of other reasons have been flagged. While some of these reasons relate to the ability to deliver such programs at a community level there is also the issue of scale and whether appropriate attention has been applied to this with a knowledge of the realities of hydrology and land use.

This project examined the effectiveness of WSD from the perspective of meso-scale implementation based on the hydrological units at the meso-scale rather than micro-scale. It has examined hydrological, land use and socio-economic variables. The concept of sustainable Livelihoods has been used as an integrating framework for examining farmer resilience. Finally a Bayesian Network approach has been used to link the biophysical, land use and livelihoods analyses. Two hydrological units with contrasting rainfall and a legible hydrological structure were selected for the study with upstream, midstream and downstream villages with WSD programs were sampled for livelihoods analysis. These were in Anantapur/Kurnool (a low rainfall district) and Prakasam (a medium rainfall district) in Andhra Pradesh. Two control villages with no WSD were also sampled.

The project found biophysical aspects such as rainfall, soils and land use, determine the nature and intensity of impacts. Similarly, the hydrogeological features of a watershed determine groundwater storage and development potential and its sustainability in the short and medium terms.

It was also found that household resilience is an important indicator of the socio-economic impacts of WSD, Bayesian Networks proved to be useful for integration and can be developed into a decision-support tool. It found that the effects of WSD, as it had been implemented, were positive but modest. Key variables for success were community participation and ownership. In future equity issues will become more pronounced and will need to be considered.

In short the project has developed a comprehensive approach towards evaluating WSD and supports its implementation at a meso or hydrological unit level. The project also developed a simple macro-catchment level model to assist in identifying priorities for WSD intervention at the meso level.

The overall methodology has been adapted to provide a training module at regional and national levels. Training courses have been delivered at both levels in three tranches. The project, with its recommendations, has been detailed in Reddy, V.R and Syme,G.J. (Eds) 2015 *Integrated Assessment of Scale Impacts of Watershed Development: Assessing Bio-physical Influences on Livelihoods*. Elsevier, Amsterdam.

3 Background

3.1 Watershed Policies in India

Watershed development (WSD) has expanded significantly over the last decade, with the 1994 National Guidelines providing the framework within which this expansion has taken place. The recent Government of India (GoI) Working Group on Rainfed agriculture estimates that the total area covered by watershed programmes was about 45.58 million hectares in 2005, about 40 percent of the total potential area, at an investment of Rs. 170370 crores. Annual expenditure on WSD during Xth plan was about Rs. 2300 crores. Although this represents a substantial achievement, given that this progress has taken over 40 years, the speed of implementation of watershed programmes, the ability to scale up successful experiences is clearly a major policy issue.

In particular, the need for effective on-the-ground implementation capacity is recognised as an important constraint in many areas, both from government agencies and from NGOs who are intended to be the main Project Implementation Agencies (PIAs). This constraint is also reflected in the quality of watershed implementation, which at its best can be a flexible and empowering process that can transform the livelihoods and resource base of poor communities. But historically, the guideline figures for both the size (500 ha) of a watershed and the amount spent per hectare have been rigidly applied in many places regardless of local needs or conditions. In some cases, the actual implementation is far from satisfactory, with insufficient effort to engage local communities or implement appropriate interventions to an adequate quality.

Although there are exceptions, much watershed development has concentrated on physical interventions such as contour bunding and check dams that are intended to improve groundwater recharge and reduce land and soil degradation. These physical interventions are often not balanced against non-structural measures or measures to improve the production process or open up new livelihood opportunities. These measures include policy changes that introduce cropping pattern shifts and changes in livelihood patterns. The need to widen the scope of activities in watershed programmes is reflected in the “watershed plus” approach in which a wider range of interventions is considered. But this is still recognised as limited and there are active strategies to develop the approach yet further. The development of a process to widen the scope of possible interventions and design the choices made to be more effective in local conditions is critical for the further evolution of watershed policy.

Equity is seen as a major policy issue, with past watershed programmes often failing to reach the poorest households and disproportionately benefiting the better off sections of the community. This is clearly reflected, in the pattern of expenditure on different activities in watershed programmes, with an estimated 70 percent of funds used for land and water management interventions that predominantly benefit larger farmers and only 7.5 percent being used to support the livelihoods of poor and landless. There is a need to more effectively target the needs and potential for change of landless and land poor (especially those with rainfed lands on upper slopes at a family level. This is particularly important for women if watershed development is truly to become the catalyst for a wider process of local-level development and poverty reduction.

Several approaches are considered for addressing the equity issues, though these approaches are mainly technical in nature and hence their impact is limited to physical coverage rather than actual benefits received by those most in need. Moreover, the focus of these approaches continues to be on landed households. One such approach to alleviate this is ‘ridge to valley’ treatment of the watershed area. This approach gives preference to small and marginal farmers who are located on the degraded slopes of the higher reaches of the watershed. Another approach is to treat the entire land in the village rather than restricting the focus to 500 hectares. This approach facilitates the coverage of all the sections of the landed households and ensures better participation and cooperation. Additionally, focusing on the landless households in the community through initiating specific programmes for them is crucial for enhanced livelihoods of the poor. These aspects are being incorporated at the national level in the recently initiated Integrated Watershed Management Programme (IWMP) and need to be a key component for designing WSD. One of the key issues in achieving inclusiveness in WSD is its scale of operation.

3.2 WSD and Importance of scale

The WSD approach has emerged to deal with the complex challenges of natural resource management, adopting the watershed as an appropriate unit of implementation. Though a watershed can be defined at different levels, international practice reveals that the micro-watershed has usually been the chosen scale of implementation for WSD. This scale facilitates a program to act in response to human needs and natural resource problems at the local level. Watershed management at micro level has been demonstrated to be both ecologically and institutionally sustainable, and capable under the right conditions of empowering vulnerable segments of the society. The micro-watershed approach enables amicable integration of land, water, and infrastructure development, particularly because of the more homogenous nature of soil, water and overall physical conditions within the micro-watershed. Theory and experience have shown that facilitating collective action in small, village-level watersheds has fewer constraints than at larger scales. Moreover, organising collective action at the micro-watershed level has generally been shown to result in lower costs, and in improved use of financial and human resources, particularly for the management of common resources.

The recent generation of WSD projects has been mostly successful in its integrated and participatory approach to sustainable conservation and development in upstream areas. This has given some impetus to scaling up to larger watersheds. However, micro-watershed approach encounters adversity when it comes to scaling up. Operating at the micro-watershed scale does not necessarily aggregate up or capture upstream-downstream interactions. A mix of upstream interventions would only have a considerable positive impact downstream if prioritized and planned within the larger watershed perspective and with understanding of the spatial and hydrological links between the perceived externalities and their underlying factors (for example, land and water use). This suggests that the next phase of application should be at a wider level. In a sense this has been achieved through a parallel project on climate change and watershed developed impacts on water security in the Krishna basin (ACIAR Project No. LWR/2007/113).

Watershed management projects are generally aimed not only to provide local on-site benefits at the micro-watershed level, but also to offer positive externalities in the form of valuable environmental services downstream as well as to provide a means of correcting downstream negative externalities within the larger watershed. Therefore, investment in upstream cannot be justified by their on-site benefits alone and can only pass economic reasoning when downstream benefits are embodied.

Until now WSD evaluations have usually paid attention only to on-site interventions and their benefits. Whether these actions were of advantage to the downstream location or were the best possible approach to minimizing negative externalities had often not been ascertained. Despite their apparent objective of improving natural resource conditions in a watershed, WSD programs may prove detrimental to downstream areas. Research has revealed that the micro-watershed approach may be producing hydrological problems that would be best addressed by operating at a macro-watershed scale. For example, in India, recent hydrological research cautions that watershed projects may be aggravating precisely the water scarcity they intend to overcome as intervention in the water cycle in some areas is ineffective as well as creating less water in other localities.

Similarly, stakeholder involvement and participation normally covered on-site requirements of local farmers, and the spatial dimension was tackled through community-based planning. The institutional settings also only focused on the micro-watershed, with limited or no cooperation across the watersheds or between upstream and downstream populations. The success of the project was assessed on-site, and the individual level outcomes (income increase, land area treated, yield increase) were in general aggregated across the watershed area. There is hardly any evidence which can prove that the improved conditions in the wider watershed results as a consequence of micro-level activities and institutions at upstream level or even that the activities were optimal or cost-effective ways to improve conditions in the watershed.

Acknowledging the difficulty of unpacking farming practice and livelihoods at a macro level this project addressed the issue of the need to create an integrated evaluation approach for assessing the effectiveness and consequences of adopting WSD programs at the meso level. This integrated approach need to include hydrological, socio-economic, livelihoods and resilience measures.. We have defined "meso" in terms of hydrological units whereby the upstream, midstream and downstream effects of WSD on the surface and groundwater resource can be understood.

4 Objectives

This project aims to contribute to improved rural livelihoods and greater water related equity by researching and mainstreaming options for sustainable water management across rainfed watersheds in Andhra Pradesh, India. To achieve this aim, the project has set itself the following objectives:

Objective 1: To enrich and upgrade an integrated approach (from ACIAR project ASEM/2001/095) for the assessment of the environmental, economic and social impacts of current WSD at a meso-scale in Andhra Pradesh.

Activity 1.1

Inception planning workshop to finalise scope, determine data needs and develop initial framework for integration methodology

Activity 1.2

Adaptive review of integration framework

Activity 1.3

Documentation of the integration framework

Objective 2: To assess the cost effectiveness and water-related resilience and equity outcomes of stakeholder-defined possible future WSD scenarios in Andhra Pradesh.

Activity 2.1

Collection and compilation of socio-economic, hydrological, crop and climate models and data for the two selected sites in India

Activity 2.2

Design and execution of social and economic surveys

Activity 2.3

Development and validation of a linked surface and groundwater model

Activity 2.4

Application of model to explore stakeholder-defined water-harvesting scenarios

Activity2.5

Exploratory application of the model to identify opportunities for improved water use and sustainability outcomes

Activity 2.6

Coupling of economic and social assessments with hydrological model

Activity 2.7

Analysis of the impact of existing WSD scenarios on cost effectiveness and equity of WSD using coupled economic/social assessment and hydrology model

Activity 2.8

Training in use of models by NGO’s and agency partners

Activity 2.9

Engage stakeholders in alternative scenario definitions on an iterative basis for meso-scale water management modeling

Activity 2.10

Training in use of livelihood assessment methods for NGO's and agency partners

Objective 3: To develop an awareness of the potential of the integrated approach and the project findings in the WSD policy at local and state levels.

Activity 3.1

Development of partnerships with end-users and stakeholders to define WSD policy needs and assessment tools

Activity 3.2

Development and implementation of a project monitoring and evaluation strategy

Activity 3.3

Customize information and disseminate policy recommendations in partnership with potential user groups at the central, state government, NGO and community levels

Activity 3.4

Conduct of workshops to compare and contrast appropriate methodologies and findings in Australia and Andhra Pradesh

Activity 3.5

To scope and design project for application of methodology and findings of this project to East India and\or Bangladesh or Nepal

5 Methodology

5.1 Study design and methodology

The study design and methods evolved out of preliminary workshops and consultations with stakeholders and the community which has experienced WSD in rainfed areas. The major goal of the research was to establish what the issues would be if WSD or integrated water resources management was shifted from a micro to a meso level of application. The methods for each component together with their strengths and weaknesses are described in the following sections.

5.1.1 Study locations

Two distinctive hydrological unit networks (HUNs) in Andhra Pradesh were chosen for the study. In general terms, these could be contrasted as low (Kurnool/Anantapur) and medium (Prakasam) rainfall areas. Specific study villages were identified upstream, midstream and downstream for both HUNs (Figure 5.1 & 5.2). Two control villages without WSD were also chosen for comparison.

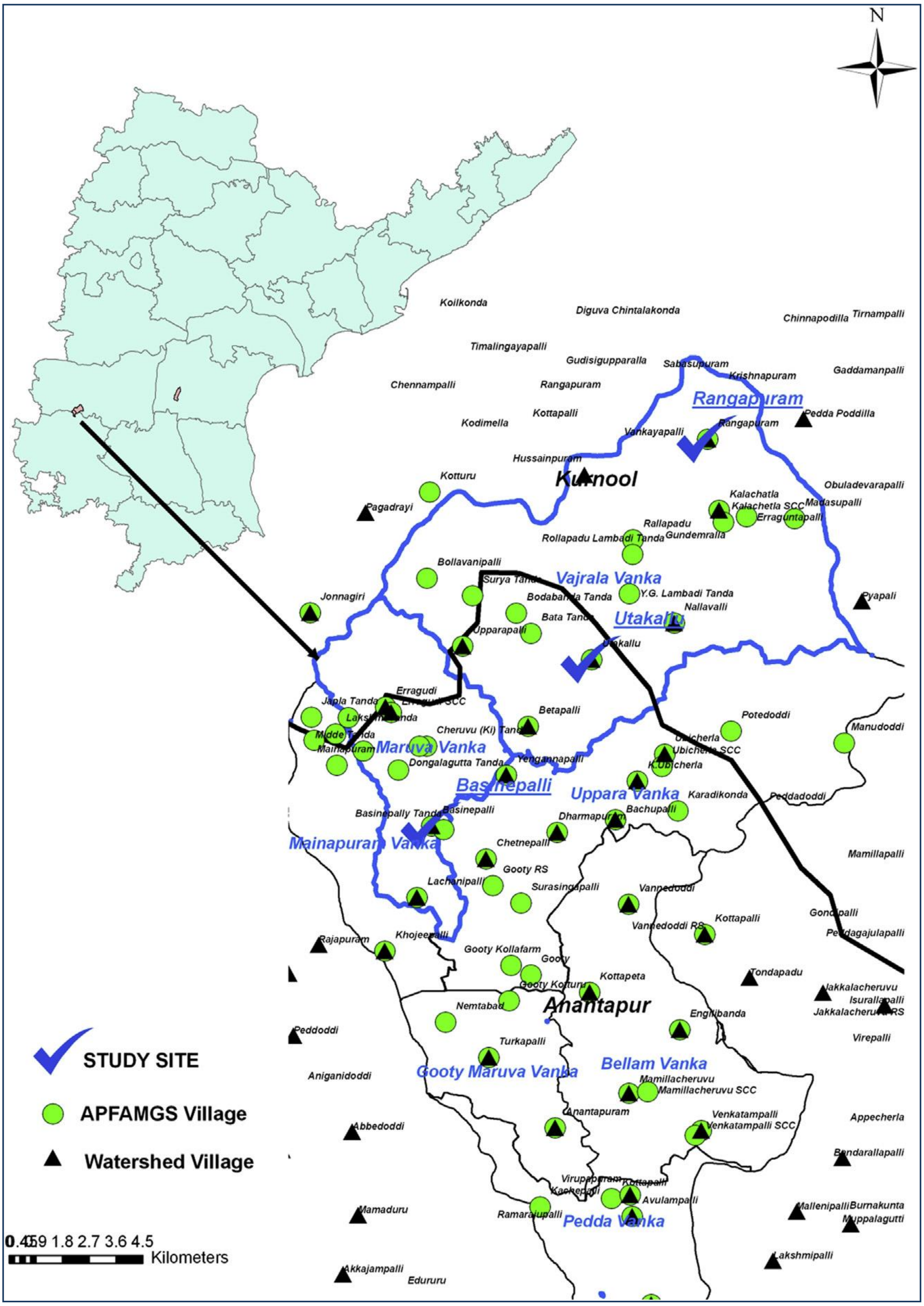

Figure 5.1 Anantapur/Kurnool (Lower Rainfall - HUN1) from Reddy and Syme (2015)

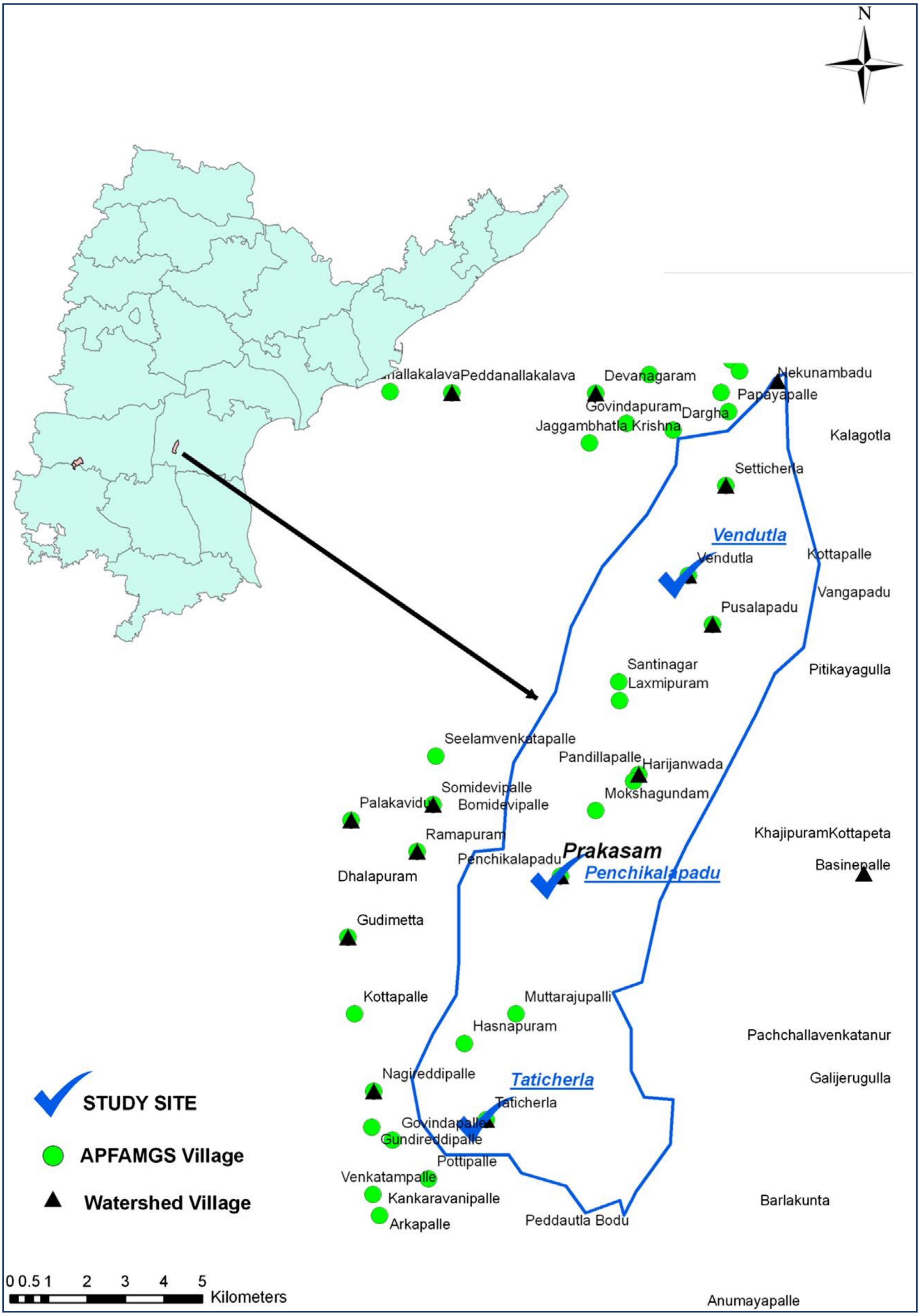

Figure 5.2 Prakasam (Medium Rainfall - HUN2) from Reddy and Syme (2015)

5.1.2 Strategic conceptual and methodological issues

To achieve the above objectives there first had to be an understanding of the basic requirements for effective evaluation at the meso rather than micro level (Syme *et al*, 2012). For the purposes of this research and for the design of meso-scale WSD generally it was considered that hydrological legibility was required. That is WSD application should be modelled in hydrological units in which there is a good possibility for relating ground and surface water flows to land use. If this is the case this enables models targeted at potential users throughout the sub-catchment. It was also concluded that there was a need for relatively simple whole of catchment models to assist decision makers in deciding the most beneficial pattern of meso-scale WSD for the sustainability of water management as a whole. This need for hydrological understanding lead a ultimately to the selection of the two research HUNs and the control villages. The specific hydrological modeling undertaken is described below.

The selection of the HUNs was the basis for the social, economic and survey data collection. It must be noted that this constrained the power of generalisation of the survey data because randomised data from the entire catchment was not collected. Nevertheless, given that WSD evaluation will need to relate to the relevant HUN with its unique hydrology and land use situational circumstances will always have significance for the delivery of WSD whether in hydrological, economic and societal terms.

Having selected two *HUNs* with contrasting rainfall there was a need to select a methodological vehicle for integration and appropriate indicators of socio-economic WSD outcomes.

The first objective also required an integration methodology that could accommodate both quantitative and qualitative data and expert opinion with the capability of application to scenario evaluation analysis. This approach also needed to be able to accommodate biophysical, social and economic data for evaluation of future possible WSD designs and modes of application and explore cause and effect relationships between them. The preferred choice for this tool was the development and application of a Bayesian Network approach.

The holistic concept of Sustainable Livelihoods was chosen as an approach to understanding a range of five "capitals" that constituted overall wellbeing. These included all aspects of factors which are thought to be influential in governing the overall wellbeing of an individual, family or community.

Finally an output criterion was required to provide an overall estimate of whether the WSD was meeting its overall requirement of a socially cohesive and sustainable rainfed agriculture sector. The variable chosen for this purpose was resilience which was defined as the number of drought years a farmer could survive without having to leave cultivation. There are a number of theoretical formulations for the concept of resilience.The reason for using this formulation in this project are discussed in later sections.

5.1.3 Assessing scale impacts of watershed development: An analytical framework

In their discussion on the issues of scale in relation and WSD (Syme *et al.,* 2012) showed that there was scope for applying a top-down, whole-of-catchment approach for strategically assessing the availability of water resources (in the form of surface water, soil water and groundwater), and that already reserved for the various anthropogenic uses so as to identify allocation strategies at the sub-catchment level. As part of that study, a 'checkerboard hydrology' approach was devised to illustrate the types of impacts of alternative levels and distribution of WSD activities on water resources at the broader scale.

The ease of understanding the checkerboard makes it a well-suited tool for facilitating discussions with planners and policy makers on the benefits and tradeoffs of different configurations of WSD. However its gross simplicity makes it unsuitable for science-based planning and therefore an improved approach was sought.

The key criteria that were looked for in the model are summarized by the following points:

Credibility – A process-based approach wins favour with policy makers wishing to promote scientifically-based planning and implementation of WSD projects

Simplicity – Complex models are accessible only to specialist modellers with an interest in scientific research but is highly unlikely to be taken up by practitioners. There is a need to 'bring the model to the users' in a form that is understandable and relevant. What the simple approach gains in terms utility can be lost in terms of absolute accuracy. In the data-scarce conditions where WSD are implemented, where catchments are universally ungauged catchments and with limited or no monitoring wells, the data to support sophisticated approaches is not available.

Accessibility – Models should be available at no cost and be run with the most basic computing requirements by non-specialists.

Our review of the existing models did not meet these criteria. The closest we could identify was the EXploratory Climate Land Assessment and Impact Management (EXCLAIM) tool developed by the Centre for Land Use and Water Resources Research (Newcastle University), as reported by Calder et al (2008). EXCLAIM which is a Java-based tool designed for non-specialists to indicate the range of outcomes and tradeoffs associated with changes in landuse within a catchment by incorporating climate, hydrology, landuse and socio-economic variables. It has been applied to a range of problems such as rainwater harvesting and forestry. Because it does not account explicitly for watershed interventions, surface water – groundwater interactions and groundwater use was not applied in this study.

Thus, the simple integrated hydrologic modeling approach was conceived and developed to do what assess water availability under alternative landuse, climate and WSD scenarios to create more effective and equitable WSD projects. The approach developed to date only addresses water resources availability which is seen as the most important biophysical constraint from the context of the Indian WSD. The need to incorporate other elements into the analysis, such as agricultural production and economic benefits in particular, are recognized limitations in the model, which could be improved upon in future.

5.1.4 Hydrological and Hydrogeological methods

Detailed knowledge of subsurface aquifer geometry and properties are equally important at the watershed scale for implementing the watershed management decisions. Therefore, geophysical and hydrogeological investigations were carried out to decipher the aquifer geometry and its extent to know the groundwater resources and selection of suitable sites for rain water harvesting. Ultimate groundwater availability in space and time is important for the end-user to decide the developments and maintain their socio-economics. In the present study the Electrical Resistivity Tomography (ERT) and Electrical logging were carried out to determine the aquifer geometry based on the geophysical signature along with aquifer resistivity properties.

5.1.5 Surface Electrical Geophysical surveys:

The method is based on the electrical property of the earth's sub-surface. Electrical Resistivity Tomography was carried out at a few points covering whole watershed using the Wenner-Schlumberger configuration with spread length of the survey as 480 meters employing 48 electrodes with 10 m inter-electrode spacing. By injecting an appropriate current (DC) through two electrodes, electrical potential differences were measured using the other two electrodes. Thus using Ohm's law, the resistance and ultimately apparent resistivity was determined in 2D space. The inversion of the electrical measurements provided the distribution of the resistivity along the profiles, from the surface down to a depth of about 92 m. This depth of investigation primarily depends on the electrode spacing, strength of the current injected as well as resistivity of the overburden, the top formation. The resistivity distribution thus obtained in 2D space is constrained by the known values obtained from drilling of the wells and geophysical logging

.

5.1.6 Drilling of new bore-wells for calibrating the Electrical Geophysical survey

Based on a number of geophysical surveys viz., Vertical Electrical Sounding (VES) as well as ERT, electrical resistivity distribution of the geological formations were obtained and depending on the favourable resistivity values for potential aquifers in the given geological environment points for drilling at least one well in up-stream, mid-stream and down-stream were drilled in both the study areas. The interpreted geophysical results matched well with the drilled bore well litho logs. The depth of drilling ranges from 100 to 160 meters. This, of course, at one hand shows the success of geophysical investigation and provide additional data for further studies on the other hand. However, the drilled sites were usually chosen at places where maximum potential of groundwater was expected; thus providing the maximum of the groundwater potential.

5.1.7 Geophysical Electrical Resistivity Logging:

The geophysical survey can be carried out at various scales. The well known electrical survey when carried out using a bore-well such that one or more electrodes are lowered in the bore-well providing mainly the resistivity distribution in one dimension. The most commonly used electrode arrangement is normal or potential sonde in which one current electrode and two potential electrodes are located on the sonde. The other current electrode is kept on the surface. The curves obtained by potential or normal resistivity logs are symmetrical in form in which the maximum indicates the layer with the higher resistivity and the minimum indicates a layer with lower resistivity. The information obtained thus are confined to a well scale only.

Logging provides more continuous data on the vertical and lateral distribution of well section and depends on the sensitivity of the sondes. Most of the resistivity logging surveys was carried out nearby ERT sites for understanding the geologic sequences, different lithological information.

5.1.8 Lithologically Constrained Rainfall (LCR) method:

Quantitative estimates of recharge to aquifer and changes in groundwater storage are important to manage the development of groundwater resources and know the amount of groundwater that can be withdrawn without exceeding recharge. In hard rock areas the most common methods for recharge estimation are groundwater balance, water table fluctuation, soil water balance and chloride mass balance etc. (Sophocleous, 1991; Moon, Woo & Leeb, 2004; Maréchal, et al 2006; Batelaan & Smedt, 2007; Sibanda, Nonner & Uhlenbrook, 2009). These methods require analysis of huge volume of hydrological data such as precipitation, surface runoff, evaporation and change in groundwater storage accumulated over a considerable time span which is generally inadequate or lacking or unreliable in many areas (Sukhija & Rama, 1973).

Apart from these methods Lithologically Constrained Rainfall (LCR) method was adopted to estimate the natural recharge in study area (Chandra, Ahmed & Rangarajan, 2012). This method needs three input parameters i.e., soil resistivity (ρs), vadose zone thickness (H) and precipitation(P). The lithological alterations take place very slowly in the geological time scale, it can be considered almost constant (say for ±50 years). Thus, the rainfall is the only parameter varying with time for such period.

Advantages of this method are; a reasonably good estimate with the input parameters that can be obtained easily in the field with good accuracy, less time frame and cost-effective. Rainfall data were collected from adjacent rain gauge stations in and around the watersheds. Soil resistivity was obtained using geophysical methods and water levels were directly measured in the study area.

5.1.9 Change in groundwater storage (ΔS):

Estimation of ΔS is a basic pre-requisite for efficient groundwater resource management. It is particularly important in regions with large demands for groundwater, where such resources are key to economic development. ΔS here describe the volumetric loss or gain of groundwater from the aquifer system between two time periods. ΔS are assessed by multiplying the difference in groundwater levels for the two corresponding monitoring periods with the specific yield of the formation and the area overlying the groundwater basin. Estimation of aquifer water storage variability is of great importance for the management of water resources.

5.1.10 Depths to water levels:

Ground water levels are monitored in pre and post monsoon seasons (2010 to 2015) and monthly water levels are monitored in 2013 (January to December) and then from May 2014 to May 2015 to understand the ground water fluctuation behaviour and seasonal variations. The groundwater levels data collected for 2005 to 2009 from BIRDS (NGO) for understanding the long term trend of water levels in the study areas. The rise and fall of the water table is a direct reflection of recharge and discharge conditions in the groundwater reservoir.

5.1.11 Modeling the impact of watershed development on water resources

An intensive fieldwork campaign in the Purulia District of West Bengal has resulted in the development of a model designed to represent the impact of watershed development on a 2 km^2 catchment. This model has been adapted to be applied to larger scale catchments (of the order of 100 km^2) in Andhra Pradesh to investigate the upstream/downstream impacts of watershed development.

The model needed to be modified to include large in-stream dams. These large dams are distinct from the ponds used in the model developed for the West Bengal study site. Also a deep aquifer has been added to the model. The climate of Andhra Pradesh in comparison with that of West Bengal is much dryer, with significantly less rainfall. The shallow aquifer is much dryer and therefore the inhabitants are pumping water up from the deep aquifer to irrigate their crops. The structure of the Andhra Pradesh model (Gooty site) is as shown Figure 5.3

5.1.

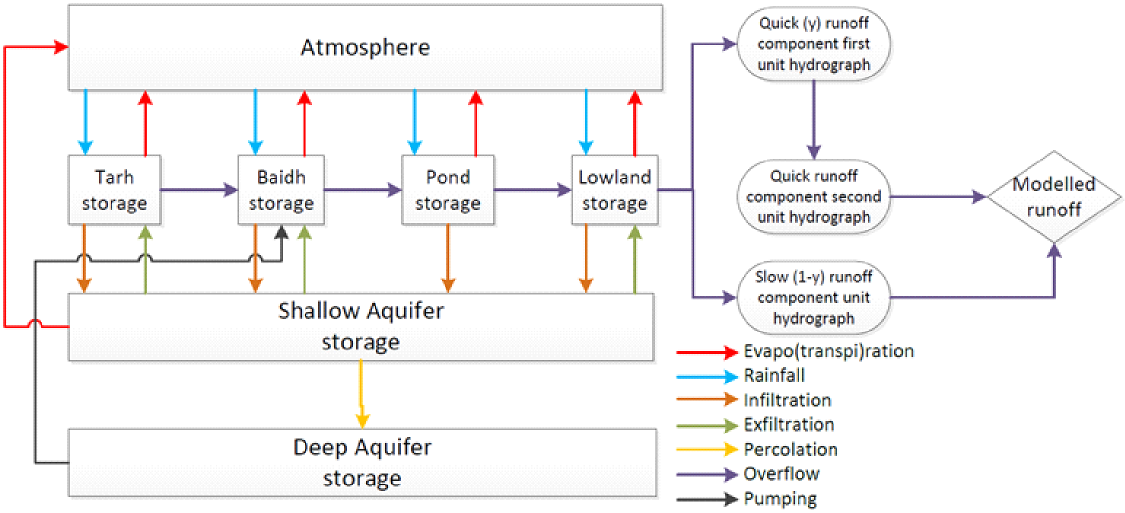

Figure 5.3 Structure of Andhra Pradesh Model

A spatial interpretation of the area resulted in a change of the model structure and the calculation sequence. Also some model processes have been changed because these processes were not included in the original model or were causing problems in the generated output by the model.

The assumptions being made during this research are having great influences on the results generated by the model. Especially the simple linear calibrated percolation and exfiltration processes are influencing the modelled runoff significantly. A small change in parameter values will result in largely changed amounts of runoff being generated by the model. Unfortunately, no additional information is available to implement and underpin a more complex approach, or to estimate an order of magnitude. The parameters encapsulating these processes are calibrated during the research, and are the major drivers of uncertainty in the defined model processes. Further investigation during additional research to this catchment is highly recommendable (see section 7.3).

Nevertheless, the simple structure and processes of the model, based on visual interpretations of the catchment and study site using Google Earth, and applying a simple approach of unknown model processes, gave a better representation of the catchments hydrology than the original model.

5.1.13 Watershed development design methodology: Strengths and weakness

The methodology for watershed assessment with interventions and without interventions followed in the project includes detailed rainfall assessment, resource conservation due to interventions (at on stream and off stream), guidelines for proper design of watershed interventions.

The data needed for such type of analysis is a detailed one in terms of daily data on rainfall, temperature, detailed land use information, interventions made at plot level. The data requirements are considered to be medium to high degree of complication.

The methodology used for rainfall is a detailed one which provides information on monthly to annual scale on quantum of rainfall, number of rainy days etc with their variability along with intense storms information and their contribution to the total rainfall in deficit, normal and above normal years. Though the analysis is rigorous one, it is a simple and could be easily done in MS-Excel based and can also be interpreted.

The methodology followed for watershed assessment includes a plot level assessment for each land use and land parcel based on water balance method including runoff estimation based on a soil moisture accounting process at a daily scale. Further, the intervention impacts are also assessed at each plot level with modification of the existing algorithm accounting for the augmentation of water within the plot on a daily scale. Though the algorithm requires daily data, this is considered to be an essential necessity to work on water balances in rainfed areas. This is a compromising methodology between sub daily requirement of rainfall information needed by certain methods to more simpler methods which runoff monthly or 10 day interval.

The remaining data sets used such as a Digital Elevation Model (DEM) or soils information are the publicly available domain datasets. The major idea in using these data sets is to make use of the developed methodology by practitioners with easily available datasets. When high order resolution datasets are made available the same could be used with this methodology. One of the lacunae in the methodology is the assessment of impacts on on-plot versus on-stream. With the net planning approach in implementation in watersheds, every land parcel is addressed for inclusion of watershed treatments and hence thought to be appropriate for inclusion of on plot interventions. Only high rainfall areas, both on-plot and on-stream co-exist requiring an inclusion of on-stream interventions.

The software such as ESRI ArcGIS used in the project is a commercial one, while open source GIS systems are also available with similar functionality.

5.2 The Sustainable Rural Livelihoods framework

Sustainable Rural Livelihood approach[1](SRL) is being used widely as an analytical tool to facilitate poverty alleviation interventions. The recasting of the household as the central focus for analysis helps prioritise interventions, which serve their developmental priorities. There are many different definitions of livelihoods.

In the aptly titled ‘Adaptable Livelihoods’, Davies (1996) provides a detailed understanding of the *dynamics* of the livelihoods of the poor in relation to food, as they respond to highly variable conditions (natural and human) that confront them. Davies’s conceptual framework is based on five key ideas, which can also be expanded to broader issues of sustainable livelihoods: Livelihood systems and security within them, encompassing a broader range of factors than household food systems and security to explain how and why producers pursue particular mixes of strategies to confront food insecurity. *Entitlements:* to explain different sources of food and the range of calls on them within households and livelihood systems. *Vulnerability:* to explain the nature and intensity of food and livelihood insecurity. *Resilience and sensitivity*: useful in analysing changes in levels and intensity of vulnerability to food insecurity within different livelihood systems. *Livelihood: system diversity* to account for variation in the nature and intensity of vulnerability, depending on different ways in which people acquire access to food (Davies, 1996, p. 15).

Rennie, et al., (1996) provide an outline of a SRL approach for field project development. They stress that this should not be an esoteric exercise, but an analytically powerful contribution to policy for improving the position of the poor. They argue that: “*Livelihoods is a more tangible concept than ‘development’, easier to discuss, observe, describe and even quantify”* (p. 16). They stress the importance of going beyond livelihoods at a conceptual level to identify robust research and implementation methodologies for field projects. It is argued that:

“Predominantly the poor of the world depend directly on natural resources, through cultivation, herding, collecting or hunting for their livelihoods. Therefore, for the livelihoods to be sustainable, the natural resources must be sustained” (Rennie et al 1996, p. 16).

This aspect of livelihoods cannot be seen in isolation, however, as access to and the use of natural capital is linked to other aspects of the livelihoods of the poor. Many policies and

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[1] *Mainly draws from Reddy, et.al., 2010.*

measures concerning natural resources do not make these links, focusing on the management of the resources to the exclusion of other issues (much of the same is true for policies concerned with other livelihood assets such as education or credit). The analysis of any one of these issues consequently needs to retain a focus on the scope of the policy, as it exists whilst at the same time making sure that this analysis is placed in a context that allows the links to other aspects of livelihoods to be made. Achieving this balance is one of the central goals of the model adopted here. The model presented here looks at the basic dynamics of livelihoods, something that is inevitably complex given the array of the factors that influence livelihood choices.

People draw on a set of ***capital assets*** as a basis for their livelihoods. Carney (1998) identifies five capitals namely, human, natural, financial, physical and social. These capitals are defined as:

Human Capital: Skills, knowledge, ability to labour and good health and physical capabilities important for pursuing livelihoods. At the formal level these include health education, training, etc.

Natural Capital: Natural resource stocks like soil, water, air, genetic resources, etc and environmental services such as hydrological cycle, pollution sinks, etc., which form the basis for deriving livelihoods.

Financial Capital: The capital base like cash, credit/debit, savings and other economic assets including basic infrastructure.

Physical Capital: The basic and common infrastructure such as roads, connectivity, and other physical assets owned at the community and household level viz., livestock, farm implements, machinery, etc.

Social Capital: Social resources such as networks, social claims, social relations, political relations, administrative relations, affiliations to local groups and associations, etc., which help people to overcome risks, uncertainties, shocks and vulnerabilities, and livelihood pursuits that require coordinated actions.

As such, we can identify the ***access profile*** of households that defines their ability to gain access to capital assets.

5.2.1 The Livelihood model

The conceptual framework presented here traces the inter-connections between the different aspects of people's livelihoods and the factors that influence them (Figure 5.4). Recognising and understanding the dynamics of the livelihoods process is fundamental for any analysis of the factors such as security, vulnerability, resilience and sensitivity as identified above. These all relate to processes of change to the conditions in which people's livelihoods operate and the response of livelihoods to these changes. The structure of people's livelihoods (and in particular the strength and diversity of their livelihood assets) varies greatly, as do the effects of external influences upon them. The key objective of the model is to provide a structure for understanding these dynamics and diversity. (See Figure 5.4)

Livelihoods are also influenced by a wide range of external forces, both within and outside the locality in which a household lives, that are beyond the control of the family. This includes the social, economic, political, legal, environmental and institutional dynamics of their local area, the wider region, their country and, increasingly, the world as a whole. These external factors are critical in defining the basic structure and the operation of livelihood systems. For example, land tenure laws are crucial in determining entitlements, and in consequence access to land for cultivation, which in turn is a critical determinant of the overall structure of livelihoods in rural areas, whilst prices and price variability is critical (for some crops) in determining what will be grown on that land in any particular season.

These external forces are themselves not static. It is their dynamics, the processes of change in the wider economic, social and natural environment, that create the conditions in which livelihoods change. It was noted above that these changes could be longer-term trends (for example changing attitudes to gender roles in a society or the gradual decline in groundwater stocks in a lake) or sudden shocks (the impact of a war, a drought or a collapse of market prices for a key crop). Taken together, the threat of external shocks and trends directly affect the decision-making environment and the outcomes of livelihoods, and provide the *vulnerability context*.

Rennie & Singh (1996) also identified the responses of such threats as either adaptive strategies (where a household consciously adopts a process of change in response to long-term trends) or coping to deploy their different assets to best effect within their often-limited range of choices. This set of choices is again conditioned by the wider context within which they live, and in particular by the extent to which they can control the key decisions that affect their lives. This is (or should be) why participation is widely advocated. This idea of people making conscious choices through deliberate strategies is fundamental to the approach to livelihoods analysis presented here. It is integrated into the model at two stages: as a *livelihoods strategy*, where a set of decisions are made on how to best employ the assets available; and as an '*income' strategy* where choices are made over the use of the products (cash, goods and services) generated by the livelihood activities adopted.

The right hand side of the model (Figure 5.4.) represents the livelihood dynamics of a household. This sub-model starts with the *entitlements* and *access* they possess to the resource base in their locality. These in turn define the *natural capital* available to the household. This natural capital is one form of *livelihood asset*, represented by the pentagon, which can be deployed by the household in their livelihoods.

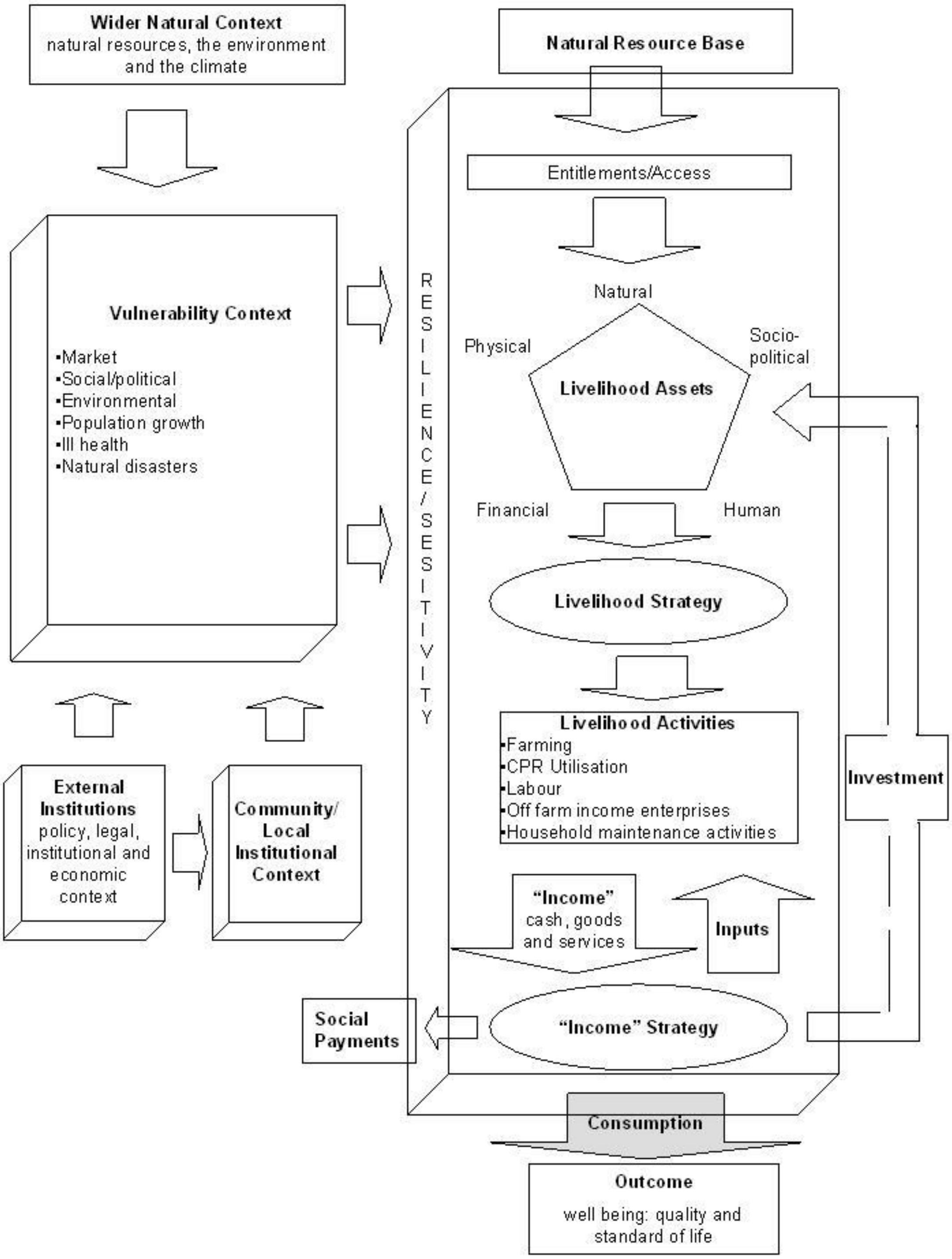

Figure 5.4 The Livelihoods Model

When combined with the others (*financial capital, social capital, physical capital and human capital*), these capital assets represent the capabilities and assets, the 'factors of production' that the household can deploy to make a living. The 'entitlements' box is consequently part of the *access profile* of the household. Similar access factors can be identified for each of the other capitals: for example, the network of social and institutional relationships that a household possesses and the identity of the household in relation to factors such as caste, religion, clan or other determinants of social structure are defining in terms of explaining the social capital that they possess. One key aspect of any livelihoods approach is to understand how the access profile, and consequently the assets available change over time, and in particular how increases or reductions in their values affects the livelihoods of the household.

Taken together, these livelihood assets represent a potential, a set of possibilities for the household to secure a livelihood but they do not automatically define that livelihood, for the extent to which their potential is realised will depend upon the way that they are used. This is reflected in a set of decisions on what assets to utilise when, decisions that together constitute the *livelihood strategy* of the household. There are always difficult choices to be made here, for example, what use of the assets will provide the best returns? What risks are involved in particular decisions? Which and what quantity of assets should be held in reserve for the future? These and many other questions have to be considered in the livelihood strategy and this strategy is at the heart of a livelihoods analysis.

The choices made in the strategy will in turn define the *livelihood activities* of the household: which activities are undertaken by whom and when. Land, labour, material inputs, social networks and all of the other capital assets available are used in different combinations to grow crops, raise livestock, gather common property resources, earn wages, make things, trade, provide services and all of the other multitude of different activities that the different members of the household engage in. These together are their livelihood; the things that people do on a day-to-day basis to make a living. In some cases, there are one or two dominant activities, such as farming, fishing or making pots, but for many households the pattern of livelihood activities is varied and no one activity dominates. Whatever the relative importance of the set of activities, however, the basis for understanding livelihoods is that all need to be included in the analysis.

Households thus earn 'income' (in cash, or kind), which becomes part of the household budget. This income is in turn allocated through a second key set of decisions called the *income strategy*. Income can be allocated to saving or investments, that enhance the value of the assets, to pay for inputs (fertilisers, raw materials, labour) that go into production, to repaying loans or social payments (such as taxes) or, finally, to consumption that is part of *the outcome*, that is, the total set of goods and services that constitute the material fabric of people’s lives. Obviously, the greater the income, the more that is left after other obligations are met (inputs and social payments) for either consumption (meeting the needs of today) or investment (increasing the ability to meet needs tomorrow). Of course, other factors contribute to quality of life, well-being or however one wants to define the goal to which we all strive. This includes the social context within which one lives, a sense of freedom and security and many other non-material factors.

This core of the model reflects the internal dynamics of the process of gaining a livelihood on the part of individuals and the households to which they belong, but it is clear that this process does not operate in isolation from a wide range of influences that condition the flows through the livelihood, the choices available at any stage and the overall outcomes of the livelihood. The first of these is the *local community*: the social groupings, networks and institutions within which the individual household is enmeshed. The social and institutional structures of local communities are locality specific, but reflect differing combinations of place (the locality or neighbourhood) and people (kin, religious, ethnic, occupational grouping or other social and economic characteristics) where an individual household lives.

The second conditioning factor is the *external institutional context*, the legal, political, social, economic and institutional environment: those factors, in others words, that link people and places into regional, national and global systems. This includes the nature and operation of government (which can have both direct effects, such as through agricultural subsidies or health services and indirect impacts, such as through policy and macro-economic frameworks and political climates), the structure and strength of civil society (those non-state institutions and organisations that also regulate social and economic processes), the operation of markets and so on.

The *wider natural environment* is also extremely important in the functioning of livelihoods. This can be through the character and variability of production conditions: the level and timing of rainfall, resource flows within an ecosystem, and its resilience in the face of management strategies, which can cause resource degradation. It can also reflect extreme events such as cyclones, earthquakes or droughts.

These in many ways define the characteristics of the different parts of the livelihood model. For example, entitlements and access to Common Property Rights (CPRs) in a watershed to gather products such as fuel wood and fodder can reflect both the legal and policy framework (which define who owns the CPR and what form of external regulation exists) and local customs and traditions concerning who can gather what. This in turn defines a part of the 'natural' capital in the 'livelihoods assets' pentagon. Similarly, both external monetary policies and financial institutions and local moneylenders define the availability and cost of credit, which is crucial in both determining how much income goes to repay past loans and what credit is available for investments and inputs into production.

These external factors are 'filtered' through the *vulnerability context* that has already been referred to. The vulnerability context describes trends and variability in those factors that affect livelihood processes, and in particular that can materially disrupt different aspects of livelihoods. This can be specific: for example, climate change will directly affect the long-term characteristics of the resource base, with other consequences compounding through the system from there, whilst a devastating cyclone or drought will have massive immediate impacts and can cause structural change to the characteristics of a household's livelihood processes. The nature of vulnerabilities can also vary, depending on form or timing. For example, a sudden collapse in market prices for a dominant commercial crop can affect the assets available by making key assets of land and agricultural implements less valuable. It can affect the livelihood activity through leading to a decision to plant something different or it can affect income if the price collapse happens after planting. Most vulnerabilities are not different to the local and external contexts described above (climate, markets): rather they reflect the dynamics and specific forms that those contexts take.

These forces affect households differentially. Some are more sensitive to the effects of the vulnerability context, others more resilient. This can be represented as resilience *'filter'*, through which the flows of influence from the vulnerability context pass to define the specific impact of external forces on the livelihood system of particular households. The resilience of a household can be higher across the board: for example, secure access to credit or good financial reserves are important in relation to most forms of vulnerability or it can be specific to particular vulnerabilities: owning higher land can be an advantage if there is a flood, but a disadvantage if there is a drought or in relation to erosion.

This model allows one to ‘map’ the consequences of specific changes, including changes brought about through external interventions intended to improve people’s lives. For example, a dominant approach to natural resources management in recent years has been participatory mobilisation to create community-based institutions to manage common property resources as well as private resources. Initiatives such as watershed development or joint forest management in India typify this approach. The points of intervention and impact of such measures can be ‘mapped’ on the livelihoods model.

5.2.2 Evaluating the determinants of perceived drought resilience

We have used a combination of parametric and semi-parametric approaches to analyse determinants of perceived drought survival responses. Ordinary least squares regression is performed to evaluate the factors that lead to drought survival differences across watershed regions as well as across various socio-economic categories. This conventional regression analysis approach provides results based upon correlation between dependent and explanatory variables. One of the drawbacks of such an approach is its inability to establish causality between the independent and dependent variables. Therefore a semi-parametric approach was used, namely the Propensity Score Matching (PSM) method, to assess the effects of watershed intervention on enhancing perceived drought survival. The areas in the study region which have not seen watershed intervention are classified as ‘control’ region and the areas with watershed intervention are classified as ‘treated’ regions. Additionally, a distinction is made between various types of drought survival responses which are associated with different types of capital ownerships of the farmers. The empirical analysis is performed in STATA.

The PSM method has been extensively used in situations where the effect of treatment on a parameter of interest needs to be assessed by separating its influence from any other factors. By matching individuals with similar characteristics within the treated category to those in the control category or region, the PSM method allows for evaluation of the overall difference in the parameter of interest that could be solely ascribed to a particular treatment. The detailed procedure for performing PSM first involves the use of logit or probit methods to generate propensity scores and then a matching algorithm is used to generate the average treatment effect. The obvious advantage PSM offers over conventional regression analysis is that no functional form assumptions are needed. However, PSM can only offer an average or mean estimate of the impact. PSM approach is also prone to hidden biases.

5.2.3 Development of the Bayesian Network

We developed Bayesian Network(BN) sub-models of the five sustainable livelihoods capitals and linked these to a measure of drought resilience. The component BNs have also been implemented within an integrated model that links key hydrological, biophysical and social relationships. This is one of the first examples, to our knowledge, where the sustainable livelihoods framework has been operationalised within a modeling framework to explore the impact of watershed development and other drivers on both household livelihoods and resilience of communities. In a similar study, Kemp-Benedict et al (2009) applied BNs using the sustainable livelihoods framework to explore the links between water-related interventions and livelihood outcomes in northeast Thailand. The BN approach is well suited to implementing the framework as it supports relatively simple representation of cause- and-effect relationships and is flexible in terms of the data and information that can be used to define model relationships.

Description of Bayesian Networks

Bayesian Networks are a probabilistic modeling approach comprising

- Network structure (or influence diagram) which represents cause-and-effect relationships between variables
- Probabilities which describe the strength and nature of relationships between variables

In the field of environmental science or management, BNs have been used for a range of purposes including data analysis, social learning, system understanding and decision making and management (Kelly, et al 2013).

When are BNs useful?

The following decision tree allows us to make a judgment in regard to the selection of the Bayesian Network approach as an integrating mechanism for the various components of the study (Figure 5.5). This Decision Tree was used and it was the teams assessment that the evaluation of WSD was a suitable application for the method.

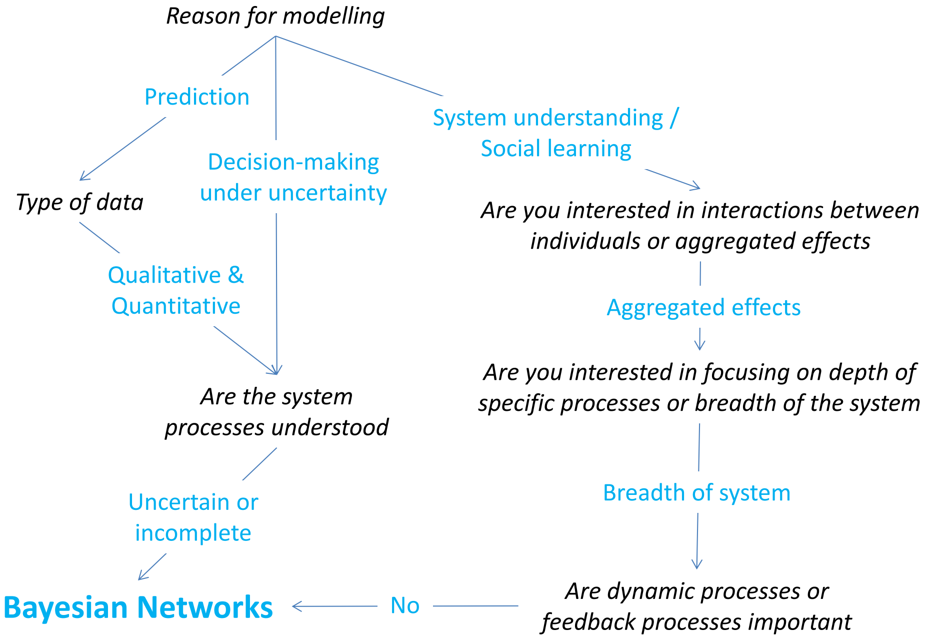

Figure 5.5 Bayesian Network Decision Tree

(adapted from Kelly, et al 2013)

5.2.4 Justice and equity issues

These issues were largely addressed by an extensive literature review on the justice issues inherent in the development of water reform in Australia and India. This review concluded that, given the move to meso-scale implementation of WSD that there should be a concentration on the delivery of communal property rights and institutional arrangements that reflected procedural justice within WSD through appropriate institutional arrangements.

Some data was collected on current perceptions of communal decision making versus through the community surveys and interviews with villagers. These results demonstrated that while there were potential equity or fairness issues that may be of concern in moving from micro to meso-scale WSD these had yet to be fully considered by landholders and other stakeholders. The village level data was supplemented by that from a workshop conducted to assess the similarities and differences between Australian and Indian approaches to WSD and equity which revealed that different approaches may be required in the future for India as opposed to the property rights and market mechanism approaches currently evident in Australia (see Appendix 1 for wider findings from this comparison).

The strengths of this approach is that it has broadly canvassed equity and justice issues but its weakness is that these insights need to be applied during the planning of a new meso-scale WSD so that formative evaluation of desired justice principles and the appropriate institutions can be undertaken.

5.2.5 Village level data collection

A multi-layered approach was adopted for the present study. Focus Group Discussions (FGDs) were used to assess the potential of five capitals in dealing with droughts. This information is complemented with the information generated through quantitative data generated using the questionnaires in two rounds. Besides, case studies were used to understand specific narratives representing different groups. On the whole, three types of instruments were used to generate data. Analysis is carried out from different angles in order to make it analytically robust. Given the complex nature of data that is being generated (qualitative as well as quantitative), one has to be cautious in choosing the analytical tools and instruments. There is need to understand the limitations of each of these tools and methods, especially understanding the investigator / respondent sensitivity of the tools. It is observed that no single tool / method on its own is enough to understand the complexities of the issues at hand. For, each tool / method has its advantages and disadvantages.

Impact assessment is carried out using before-after and with-without approaches. Quantitative data on various indicators of five capitals were collected using a detailed household questionnaire. The questionnaire was canvassed among the sample households in six sample villages that have undergone watershed treatment. All these villages are located within a hydrological (one or interconnected) boundary. Data on various indicators of five capitals are collected for two years i.e., 2010-11 and 2011-12. One of these years is a normal year (2010-11) and the other is a drought year (2011-12). This gives us an opportunity to assess the watershed impacts in drought year vis-a-vis a normal. In other words, the effectiveness of watershed interventions in a drought situation could be assessed. The resilience information from the sample households was collected during the drought year (2011-12), as it helps households to contextualize watershed development in the event of drought. One control village from each hydrological unit is also selected for a detailed comparative assessment. The field work was conducted over a period of 4 months (December to March) in both the years. Qualitative research gained from including focus groups and questionnaires was conducted in different periods over a period of 4 years i.e., between 2009-2013. The results from the analysis are validated with the village communities during the year 2013. Details of the sampling frame are available in Reddy & Syme (2015).

6 Achievements against activities and outputs/milestones

Objective 1. To enrich and upgrade an integrated approach (from ACIAR project ASEM/2001/095) for the assessment of the environmental, economic and social impacts of current WSD at a meso-scale in Andhra Pradesh.

No.	**Activity**	**Outputs/ Milestones**	**Due date of output/ Milestone**	**Risks / Assumptions**	**Applications of outputs**
1.1	Planning workshop to finalize scope, determine data needs and develop initial framework for integration methodology *Syme* *Samad-left project-role taken up by LNRMI*	Inception workshop held and initial framework documented	June Initial Planning September 2009 Conduct of Workshop	Integration is possible. Cancellation of workshops due to unpredictable events.	Integrated methodology providing methodological blueprint for project.
1.2	Development of integration framework *Samad-left project* *Syme* *Croke* *Ranjan* *Reddy*	Six-monthly workshops organized and held; outcomes documented in Annual Reports Presentation of framework and early results to the AP climate and water forum (ACIAR project LWR/2012/035)	March 2010 March 2011 March 2012 October 2012 January 2013 March 2013 May 2013 Presentation to water forum in March/April 2013	Cancellation of workshops due to unpredictable events-these have occurred but the integration approach has changed with the departure of Dr Natasha Herron from ANU which has created the need for more intensive hands on work in 2013 by Australian researchers.	Refined framework being used by project Working Model Version 1 completed Oct 2012.

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks / Assumptions	Applications of outputs
1.3	Documentation of Integration Framework *Syme* *Croke* *Ranjan* *Reddy*	Production of a synthesis report and journal publications	August 2013	Delays in accomplishing project results and finding suitable journal outlets-papers based on experimental design and early model already achieved-more planned. A book contract has been received from Elsevier.	Integration framework being applied by broader scientific community.
		Complete book for Elsevier outlining the integrated approach taken to the project.	June 2014		Book published by Elsevier electronically and hard copy Jan 2015

Objective 2. To assess the cost effectiveness and water-related resilience and equity outcomes of stakeholder-defined possible future WSD scenarios in Andhra Pradesh.

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks/Assumptions	Applications of outputs
2.1	Collection and compilation of socio-economic, hydrological, crop and climate data for selected sites in India *Croke* *Ahmed*	Data sourced and compiled into documented database	December 2011	Unforeseen problems with quality and quantity of data-great difficulties were had in obtaining APFMGS data after the collapse of the organisation. Subsequently this has been covered by NGRI and CRIDA. Data obtained a year later seems to be quite unreliable and this has been communicated to DRD.	Ability to derive improved livelihood assessment
2.2	Design and execution of socio-economic surveys *Croke* *Ahmed* *Reddy* *Ranjan*	Identify areas where new data collection is required, agree on sampling methodological approach. Development and pretesting of	March 2010	We are assuming that we will get consensus on priority data and an agreement on methodology. This may take some time - this activity has been expanded and a quasi	Comprehensive and current data on which to base integrated modeling

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks/Assumptions	Applications of outputs
	Syme	surveys and other methods Data Analysis Integration of survey data into integrated model	December 2010 February 2013 June 2012	experimental and longitudinal approach taken-surveys conducted over two years. Data analysis and publications now advanced. Data being developed into formats suitable for integrated model. Subject to above risks.	This would be used for socio-economic analysis Preliminary Analysis Completed
2.3	Development and validation of linked surface and groundwater models *Croke* *Ahmed* *Rao*	Hydrological modelling platform selected Model set up and calibrated Continued and enhanced monitoring of groundwater levels	December 2009 June 2013 December 2014	None foreseen. None foreseen: but this activity has been highly Delayed due to the lack of and subsequent unreliability of the APFMGS data and the departure of Dr Natasha Herron from the research team. It has now been picked up with data on land use and groundwater levels from CRIDA and NGRI in particular as well as national rainfall data. Dr Corke has now taken responsibility of completion.	This will be used as a basis for activity 2.4 This will be used as a basis for activity 2.4
2.4	Application of Bayesian Network models to explore stakeholder-defined water harvesting scenarios *Mani (no longer in team)* *Dixit* *Reddy* *Rao* *Ramjan* *Syme* *Suvarna* *Merritt*	Detailed analysis of the scenarios defined by stakeholders including interactions to define water harvesting and livelihood (socio-economic/institutional).-A report will be developed from this and initially delivered to members of the AP Water Forum	August 2014	Initial versions of the model may require user-friendly adaptations--could cause delays. Available resources may limit additional data collection. This activity has not progressed at the rate it should have, partially because of the absence of Dr. Mani (of APFMGS) who was to take a lead role in this due to the lack of data from APFMGS Progress in this area will be assisted by	Demonstration of the utility of the model for ongoing planning and evaluation Demonstrated capability to use developed models

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks/Assumptions	Applications of outputs
			December 2014	the socio-economic and decision making data from self reports in the questionnaire which will enable scenario development and DRD staff support. Staff have been made available by Dr. Suvarna Commissioner of DRD. Progress has been improved recently and will be enhanced by ongoing resources available from this variation.	The models used as part of National Training course in New Delhi to which those involved with WSD in different states presented their issues which were interpreted by the BN model and individual components. This feedback to form basis for training courses April/May 2015. This will help increase the versatility of the application of the overall integrated model and enhance ongoing usage.
2.5	Exploratory application of a preferred Bayesian model to explore opportunities to improve water use	Current and potential hydrological baselines modelled and modeling output	September 2013	None foreseen	Application of results for objectives 2.7-2.10

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks/Assumptions	Applications of outputs
	and sustainability outcomes *Reddy* *Ranjan* *Syme* *Dixit* *Rao*	documented for DRD and Water Forum. Also as a journal article Results of model reruns using stakeholder defined scenarios documented for DRD and Water Forum and key officials at mandal level	November 2013 November 2014	Stakeholder scenarios may require dedication of additional resources. This has been delayed for the reasons outlines in 2.4. Improved model of resilience to be included.	Additional scenarios generated
2.6	Coupling of economic/social assessment framework with hydrological model *Croke* *Ahmed* *Rao*	Contribute to coupling of livelihood (socio-economic/institutional) assessment framework with hydrological modelling. Scenarios developed and water balance related to yield and social economic data. Report will be written for DRD, Water Forum and academic journal (s)	August 2012 October 2013	Risks relating to not being able to bring the socio-economic model with the hydrological model under a common denominator (such as scale, units, etc.) can be minimized by advanced planning. These risks appear to be avoided as initial model now operational.	Integrated tool for assessment of alternative policies.
2.7	Analysis of the impacts of WSD scenarios on cost effectiveness and equity of existing WSD policy using coupled economic/social assessment and hydrology model *Ranjan* *Croke*	Impacts of potential scenarios clearly defined in economic and social terms Report will be written for DRD, Water Forum and academic journal (s).	October 2013	None foreseen at this stage although clearly it is behind schedule because of data and modeler change issues. The activities are now progressing on track.	Results used for objective 2.8-2.10

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks/Assumptions	Applications of outputs
	Syme *Reddy* *Merritt (new ANU modeller*				
2.8	Training in use of models both Bayesian but also integrated statistical model. I by NGOS and the AP department of rural development and other relevant AP and GOI(government)departments *Merritt* *Chiranjeevi (LNRMI Communications and Engagement)*	Data base of new scenarios performed by trained users. Contribute to the training in use of the models by NGO's and the AP Department of Rural Development.	December 2013 May 2014 July 2014 November 2014	Lack of sufficient trainees. This could be minimized by ensuring local inputs to the project from the very beginning. The major risk will be engaging more local participants-engagement with AP government sources has been good to this point and input has already been gained on scenarios for this purpose.	Production of skilled personnel who could use the software for future analysis and extension
2.9	Engage stakeholders in alternative scenario definitions on an iterative basis for meso-scale water management modeling *Chiranjeevi* *Merritt* *Reddy* *Syme*	Preliminary scenarios developed with stake holders Iteration of scenarios developed and documented	October 2012 October 2013 May 2014 July 2014	Some stakeholder scenarios may be beyond the scope of the project and may require additional information. This risk could be minimized by establishing contact with stakeholders in the early stages of the project and incorporating their inputs	Generation of stakeholder defined scenarios and their outcomes

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks/Assumptions	Applications of outputs
	Rao		November 2014		
2.10	Training in the use of livelihood assessment methods for NGOs and other agency partners *Chiranjeevi* *Reddy* *Dixit* *Rao*	Ability to use methodology and models	February 2014 May 2014 July 2014 November 2014	Lack of sufficient trainees. This could be minimized by ensuring local inputs to the project from the very beginning given the delay with model development this may have to be taken over by AP government bodies. Opportunities have now been arranged.	Trained Personnel and final software A series of training courses have now been conducted in New Delhi and Andhra Pradesh.

PC = partner country, A = Australia

Objective 3. To develop an awareness of the potential of the integrated approach and the project findings in the WSD policy at local and state levels

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks / Assumptions	Applications of outputs
3.1	Development of partnership with end users and stake holders to defined WSD policy needs and assessment tools *Chiranjeevi* *Reddy* *Suvarna* *Syme* *Ranjan*	Partnerships with end users and stakeholders to define WSD policy needs and assessment tools. Documented agreement for	January 2013 Ongoing	We are assuming sufficient commitment to devote time, attention and data. There is a risk that the livelihoods and fairness approaches will create some debate. The debate about fairness, equity etc has not proven to be divisive and has provided fertile food for thought.	Research priorities that meet partners needs.

No.	Activity	Outputs/ Milestones	Due date of output/ Milestone	Risks / Assumptions	Applications of outputs
		future interactions	December 2014	Overall though this is behind because of the logistics of gaining data have prevented concrete discussions at whole of model level. Discussions are underway however and have been greatly facilitated by the availability of the qualitative data. These discussions have greatly facilitated the development of the 1.0 version of the model	
3.2	Development and implementation of project monitoring and evaluation strategy *Reddy* *Croke* *Ranjan* *Syme* *Chiranjeevi*	Agree on and methodological approach Data collection and analysis Report to ACIAR and DRD and Water Forum as well as Journal article	May 2014 February 2015 May 2015	We are assuming that we will get consensus on priority data and an agreement on methodology. This may take some time. This risk has not eventuated. There is strong support for our approach both within the team and from our regular AP government network. To some extent an ex-ante project evaluation has occurred because of the nature of the integrated model development. This will be enhanced by the implementation of the systematic engagement strategy as outlined above. The quantitative evaluation will however have to be developed and to some degree will be dependent on the satisfactory conclusion of 3,1. It may be that this could be considered as an activity that could be led by DRD and could be quite simple. Available resources may limit data collection if a wider evaluation is to be conducted. It may also be that the model is used as a shell for a future ACIAR or AP or other project and its suitability for general use assessed in this manner.	Ongoing change in design as a result of evaluation.

No.	**Activity**	**Outputs/ Milestones**	**Due date of output/ Milestone**	**Risks / Assumptions**	**Applications of outputs**
				Opportunities have now been confirmed.	
3.3	Customize information and disseminate policy implications and partnership with potential user groups at the central,state government, NGO and community levels *All participants*	Focused meetings/ workshops with partners to establish what information is useful and why. Alternative futures will also be discussed Final stakeholder workshop and presentation of results.	February 2014	None Foreseen but perhaps to wide a range of expectations to be accommodated.	Project tools used for assessment of alternative policies by the stakeholders.
3.4	Conduct workshop in Australia to compare and contrast appropriate methodologies and findings in Australia and Andhra Pradesh Three policy-related officers of Aust Water Agency *Croke* *Ranjan* *Syme* *Rao* *Ahmed* *Reddy* *Chiranjeevi*	Report on the cross cultural generality and validity of the integrated WSD analysis in AP and Australia	January 2014 Oct 2013 Now Complete	None Foreseen	Will feed into policy options identified by the overall findings of this projectfor Andhra Pradesh government departments and the two participating Australian CMAs

No.	**Activity**	**Outputs/ Milestones**	**Due date of output/ Milestone**	**Risks / Assumptions**	**Applications of outputs**
3.5	Scoping Application East India or Bangladesh or Nepal *Ranjan* *Syme* *Ahmed* *Rao* *Ahmed* *Reddy* *Chiranjeevi*	Review of reports on WSD needs and applications for potential areas Conduct of interviews/field trips with key Stakeholders Scoped design and analysis for project based on outcomes of this	January 2015 April 2015 May 2015		First Round Project has been approved with Dr Christian Roth as leader :LWR/2014/072 Promoting socially inclusive and sustainable agricultural intensification in West Bengal and Bangladesh Field trip April 11th to 22nd to assist in 2nd round submission
3.6	Project finalisation	Final report to ACIAR	May 2014	Final Project meeting April 22nd -24th	Final Report 31st May 2015.

PC = partner country, A = Australia

7 Key results and discussion

This section discusses the issues surrounding the design and implementation of WSD and describes the key findings that contribute to alleviating current problems. The description is largely in summary terms to provide an outline of the outcomes of the project. More detail is available in Reddy, *et al* (2015). It provides an example of how integration of findings from a variety of perspectives can assist in the evaluation of WSD. Specifically it shows that WSD must be planned with an understanding of the hydrological parameters including the effects of landuse on them before WSD is implemented. It also demonstrates that while WSD is beneficial it is its relationship with a number of livelihood capitals that will govern its influence in the long term. That is the findings here suggest that targeted meso implementation will be a beneficial approach. Implementing WSD at a meso level however will lead to challenges in terms of institutional structures, social organisation for implementation and possibly new equity issues that will need to be planned for.

WSD has become critical in developing rainfed agriculture, which accounts for 60% of the cropped area in India. Over the years, about a quarter of the rainfed areas have been covered under the WSD program. However, the impact of WSD on the productivity or stabilisation of agriculture has been marginal. Earlier evaluation studies have pointed out that people's participation and collective action is a prerequisite for effective implementation and impact of the program. Thus, the implementation process is rather intensive and demands substantial human resources, apart from financial resources. Guided by these studies, implementation guidelines for participatory watershed development were introduced in 1995. Since then, about nine variations of these guidelines were developed in order to improve the implementation of the program. While frequent procedural changes in the implementation guidelines resulted in confusion among implementing authorities at the cutting-edge level, the guidelines could bring about some changes in the social capital indicators such as participation in the program. However, no substantial improvement has been observed in the implementation and impacts of the program over time.

While inadequate implementation is often identified as the root cause of the poor performance of the program, a number of other reasons have been flagged such as unintended hydrological outcomes.

Being a government program, WSD has all the management constraints associated with such programs, including lack of sufficient time, delays in fund releases, and so on. Though these are common to all the developmental programs, the intensive nature of WSD cannot absorb such drawbacks. For instance, though the guidelines provide a 12-month timeframe for organising the communities and ensuring their participation, only three months are allowed for the implementing agencies for carrying out the process on the ground. In fact, engaging communities like non-governmental organisations (NGOs) that have built rapport with the local communities much prior to the program, or who could spare more time (by allocating more human resources), has proved to be more effective in showing the WSD impacts compared to the involvement of the government departments. On the contrary, the responsible departments for implementing watersheds are often constrained by limited available human resources coupled with the demands of their other mainstream responsibilities that impede progress. Given this, it is often concluded that NGO-implemented watersheds perform better when compared to government-implemented watersheds. Thus, given the fact that 80% of the watersheds are being implemented by the government departments, the overall performance of the program has remained low.

The concentration of effort in identifying the factors important in developing new guidelines has resulted in the sidelining of the original purpose of watershed interventions. While WSD is a technology meant for soil and water conservation that would strengthen the natural resource base for the farming systems and improving its resilience, the focus has been on improving crop yields and agricultural incomes. More importantly, the inter-linkages between different and dependent natural systems such as biophysical and hydrogeological systems have been totally neglected. This project was an interdisciplinary one developed to reintroduce the concept of sustainable management of natural resources with a view towards providing greater resilience for communities involved with WSD programs. Specifically the concept of the benefits of scaling implementation of WSD to the realities of the behaviour of water in the catchment has been examined in an interdisciplinary context.

Biophysical aspects such as rainfall, soils, and landuse, determine the nature and intensity of impacts. Similarly, the hydrogeological features of a watershed determine groundwater storage potential and its sustainability in the short and medium terms. However, these aspects are hardly taken into account while designing or assessing the impacts of the WSD programs. In the absence of information on these aspects, WSD interventions (type as well as intensity) have been uniform across locations.

Similarly, common indicators of impact assessments such as irrigation, crop yields, and income, have been used irrespective of the variations in biophysical and hydrogeological attributes of the watershed or location. This results in: i) interventions that may not be effective as they are not in line with the hydrogeology and biophysical requirements; ii) impact assessments that are not comprehensive as they do not take the externalities associated with hydrogeology (groundwater) into account leading to under- or over-estimation of the cost-benefit ratios; iii) variations in the impacts of WSD at different locations (upstream and downstream) not being captured in the context of meso-scale WSD (about 5000 ha); and iv) the impact of WSD on the resilience of the households not getting assessed, although it is the main impact expected in any situation.

This project therefore examined watersheds located within a hydrological unit. Technical data have been generated on biophysical and hydrogeological aspects through monitoring the wells, collecting long-term rainfall data, geo-referencing the water bodies, and watershed interventions. Modelling was used to capture the rainfall-recharge and groundwater-surface water linkages, and the socio-economic data were collected using scientific and representative sampling methods complemented by qualitative research. The Sustainable Rural Livelihoods (SRL) framework (five capitals) was adopted to assess the watershed impacts, along with a separate resilience survey to assess the resilience of the farming households.

Household resilience was used as an indicator for WSD impact. Resilience has been explained with the help the five capitals of the households and modelled to identify the factors influencing resilience. All these aspects (hydrogeology, biophysical attributes, five capitals, and resilience) have been integrated to assess the linkages using Bayesian networks (BNs). A consistent stakeholder engagement process was adopted to communicate the findings at the policy, implementation and community levels. Stakeholder engagement was used to influence the policy (state and national-level policy makers), implementation (implementing agencies), and validation of the findings (farmer level).

This section pulls together and synthesises the analyses from all the research components and provides an overview of the impacts of WSD in the context of hydrogeology and biophysical aspects. Details of each of the project components and their findings are available in Reddy *et al* (2015).

7.1 Hydrogeology

The rainfed regions of the Indian Peninsula are hard rock aquifers that can be characterised as shallow, deep, fractured, and non-fractured weathered zones. The characteristics of the aquifers vary widely across and within (especially meso-scale) the watersheds. Such wide variations result in variations in the potential and availability of groundwater resources in the region. Groundwater systems in these regions mostly depend on rainfall, which occurs during limited periods of the year. Of late, the yearly rainfall variations have gone up due to climate variability, adding to the temporal dimension to groundwater variation. Given the fact that these regions depend extensively on groundwater for drinking as well as irrigation purposes, variations in the availability of groundwater becomes an important determinant of agriculture and related livelihoods. Thus, the supply side of groundwater is associated with high variability due to the nature of the aquifer system and the changing rainfall pattern.

The supply side variations would not have been a serious concern had the demand remained constant. As long as the demand for groundwater remained within the limits of recharge from rainfall, the supply constraints are hardly noticed. However, the demand for groundwater during the last two decades has outstripped the supply; i.e., beyond the rainfall recharge. This has caused severe constraints on the availability of water, even for drinking, in these regions. Often this has resulted in the over-exploitation of the resource and deterioration of groundwater quality. The first victims of this resource degradation have been the communities that are located on shallow aquifers. On the other hand, communities located on deep aquifers have resorted to capital-intensive deep bore wells. As a result, access to groundwater has been privy to capital-rich large and medium farmers in these regions. Thus, depletion of aquifers has aggravated inter- as well as intra-regional inequities.

Watershed interventions are expected to enhance groundwater recharge artificially. Given the huge demand for groundwater in these regions, communities as well as the watershed implementing agencies have given priority to on-stream interventions (mainly check dams) without understanding the aquifer geometry, water level trends, groundwater recharge and changes in groundwater storage. The watershed interventions have been based on surface drainage pattern and hence do not improve the recharge in an optimal way. Therefore, a more rigorous assessment of the hydrogeology is required in order to optimise watershed interventions. The geophysical investigations coupled with rainfall-recharge estimates carried out in the study sites have helped in assessing the groundwater availability at various space and time scales. .

Given the geometry of the aquifer system, i.e., soil cover, weathering thickness, etc., differential watershed interventions are required across the locations. For instance, areas tapping the first fracture can be treated with water-spreading methods (e.g., check dams) and areas tapping deep fractures should have injection wells. Thus, a complete knowledge of the system with details on the varying weathered thickness and presence of fractures as well as the groundwater storage capacity helps in judiciously planning the watershed interventions

Further, the integrated surface water – groundwater modeling simulation tool has provided assessments of the availability of surface water and groundwater resources on a monthly basis for a range of watershed interventions, land use, and climate-related scenarios. This model clearly indicates that there is scope for a pragmatic broad-scale approach for developing more robust and equitable WSD interventions as against the presently-followed uniform interventions. This tool is simple in formulation, aims to be as generic as possible, and requires limited amounts of data for climate, topography, soils, land use, hydrogeology, and watershed interventions that can usually be met from secondary sources. The model can help in shedding light on designing and implementing improved watershed development strategies that can be taken up by the relevant government and non-government agencies to support planning and decision making. .

Another model of rainfall-recharge linkages that was developed for the West Bengal study site was tested on an ungauged study site as well as a gauged catchment adjacent to the ungauged study site in Andhra Pradesh. The modified model in the ungauged study sites resulted in a decreased modelled runoff (and a lower rainfall-runoff coefficient). The watershed interventions resulting in higher storage created in the upstream of the watershed has reduced the runoff and hence more rainfall is needed to cause the same amount of runoff. The calibrated values of the gauged catchment mainly influence the exfiltration, infiltration and percolation of the area. The small difference (increase) in rainfall-runoff coefficients of the gauged catchment and the non-gauged study site could mostly be related to a change in rainfall, while the more intensive rainfall events have increased the modelled runoff. This model has the capability and can be used for estimating the effects of watershed developments in this region. A very complex model structure and model processes including spatial variability could have been chosen but for the data constraints. Therefore, a model structure and the processes defined in a manner as simple as possible were chosen for performing this research. Improved data availability could help in arriving at more precise assessments in future research and planning .

As is the case with surface and sub-surface hydrology other biophysical aspects such as climate, soils, and land use not only vary within and between watersheds but also influence watershed interventions. With uniform technological interventions under low and medium rainfall zones, the interventions may create new problems especially in the case of meso-scale watershed development programs. Interventions on every land parcel, namely “net planning” for water conservation intervention mainly through farm bunding and water absorption trenches for land use patterns such as scrub lands not only render the investments unproductive in the immediate term but also raise new hydrological issues such as reduced flows into the existing water bodies. This can create conflicts within communities.

In order to overcome these problems, it is necessary to estimate the water availability under different scenarios such as with and without watershed interventions. Water conservation efforts through a certain quantum of water harvesting under a modelling framework would provide valuable insights into water availability. Based on the available water after conservation efforts at the farm level, additional storage could be planned on streams as ex-situ conservation interventions after accounting for the existing storage capacities through tanks. Modern tools such geographical information system (GIS) coupled with the high computing power available and publicly available datasets enhance the capabilities of project Implementing Agencies (PIAs) in visualising the watershed features and key parameters representing erosion status and runoff potential. This helps in making informed decisions in prioritising the sub-watersheds within the meso-scale hydrological units.

7.1.1 Groundwater quality analyses and bore-well drilling in Prakasam and Anantapur study areas under meso-scale ACIAR project

The project has initially has been designed to assess the impact of WSD and hence the quality of groundwater was not planned to be analyzed. However, during the conduct of the project, it was realized that groundwater quality often affect the management issues and it was decided to test groundwater quality by analyzing at least twice a year. Hydro-geochemical study of ground waters was thus carried out in both the watersheds. The analytical results of physio-chemical parameters of groundwaters were compared with the standards as recommended by the ISI and WHO (2004). The result shows that most of the parameters like Electrical conductivity (EC), Total Dissolved salts (TDS), Sodium (Na), Magnesium (Mg), Nitrate (NO3) and Fluoride (F) are beyond the desirable limits and maximum allowable limits of the ISI and WHO drinking water guide lines particularly in Maruva vanka and Vajrala vanka watershed.

EC is a relevant measurement of salinity hazard to crop when using groundwater for irrigation. Classification of groundwater based on salinity hazard was also made according to the recommendation of Wilcox (1955). According to Wilcox (1955) classification 62.5% and 37.5% samples show unsuitable category in pre-monsoon season and 66.7% and 33.3% have unsuitable category in post-monsoon season in Maruva vanka and Vajrala vanka watershed. In Peethuruvagu watershed only 15%, 75% and 10% of sample fall in good, doubtful and unsuitable category respectively in pre monsoon season and in post monsoon season these figures are 20%, 65% and 15% respectively. None of the samples fall under excellent category in both the watersheds and in both the seasons.

Na concentration plays an important role in evaluating irrigational quality of groundwater. A high concentration of Na is undesirable as Na is adsorbed on the exchange sites causing soil aggregates to disperse, reducing its permeability. The Na in irrigation waters is also expressed as percent sodium or soluble sodium percentage (Na %). According to Wilcox (1955) 33.33%, 45.83%, 12.50% and 8.33% of samples have good, permissible, doubtful and unsuitable irrigation water quality category in pre monsoon season. In post monsoon season 25%, 33.33%, 20.83% and 20.83% of samples have good, permissible, doubtful and unsuitable irrigation water quality category. In both the seasons none of the sample fall under excellent category in Maruva vanka and Vajrala vanka watershed. In Peethuruvagu watershed 5%, 70% and 25% have good, permissible and doubtful irrigation water quality in pre monsoon season and 35%, 10%, 20% and 15% have Excellent, good, permissible and doubtful irrigation water quality in post monsoon season.

In addition, fluoride that is an important parameter in defining the groundwater quality and the analyses show that groundwater has higher Fluoride content that the permissible limits in the Anantapur areas whereas the values of Fluoride are within the permissible limit in Prakasam dist for both the seasons.

Thus such study could very clearly demonstrate the suitability of the groundwater for various purposes so that suitable remedial measures could be planned. The study also shows the importance of groundwater quality in any watershed projects.

In a similar attempt, the subsurface was investigated using advanced geophysical techniques of Electrical imaging and sounding. This information has provided better knowledge on the sub-surface geological formation and it was proved that the knowledge using advanced technique has provided better result after drilling the borewells. The potential aquifer were found where the local farmers could not get any groundwater. The drilling results are provided in the table. Drilling were made in upstream, downstream and midstream in both the study areas.

Table 1 Details of drilled bore wells in both the watersheds

Well No	Village (Location)	Long/Lat	Elevation in m amsl	Total depth drilled in 'm'	Water struck in m bgl	Discharge in litre/sec	Remarks
Maruva & Vajrala vanka							
MV1	Rollapadu Thanda (Upstream)	77.670E 15.260N	472	91.4	49.37	2.08	Bore wells are rare in this area. Local people's opinion was there is no water in this surrounding site. Only one bore well was observed nearby this site.
MV2	Uttakalu (Midstream)	77.650E 15.210N	404	137.16	18.89 & 107.59	1.73	Local peoples were not interested in this site. Because many failed bore wells are nearby this site. Total drilled depths of failed wells are around 186 m.
MV3	Medhi Tanda (Downstream)	77.590E 15.190N	395	121.92	94.48 & 117.34	2.48	The yield of this well is very good. Low yield and failed bore wells are observed nearby this site.
Peethuruvagu							
PV1	Pottipalli (Upstream)	79.030E 15.370N	246	101.49	63.39	0.69	Local peoples were not interested in this site. Because many failed bore wells are nearby this site. Total drilled depths of failed wells are around 183 m.
PV2	Mokshagundam (Midstream)	79.070E 15.460N	216	163.27	102.10 &106.98	0.25	Local peoples were not interested in this site. Because many failed bore wells are nearby this site. Total drilled depths of failed wells are around 183 m.

PV3	Near Setticherla (Downstream)	79.090E 15.520N	204	90.22	--	--	Drilling was stopped at 90.22 m bgl because very thick compact zone was observed from 57 m bgl to 90.22 m bgl.

7.2 Socio-economic implications

In the absence of appropriate or optimum design and implementation of watershed interventions, the expected positive socio-economic impacts may not be evident. Moreover, they would vary across locations depending on the aquifer geometry, type and nature of aquifer, rainfall-runoff and recharge, surface-groundwater recharge, extent of surface water storage, and land use pattern. The externalities of hydrogeology could be captured in the upstream-downstream context at the meso-scale, when watersheds are placed within a hydrological unit. Besides, the lag between the implementation and impact assessment could influence the impacts, as measured from the experience of the households—the greater the lag the higher the risk of households missing the linkages between the interventions and their impacts. Unlike the earlier impact assessment studies, the sample watersheds here are purposively selected from a hydrological unit by the hydrogeology and biophysical scientists.

Technically, watershed interventions are expected to strengthen the natural resource base and improve the resilience of the farming system. Hence, the resilience of the household is included as an indicator of watershed impact. In addition to the standard approach of measuring the impacts on various socio-economic indicators, the SRL framework of five capitals has been adopted to provide a holistic assessment.

As expected, the standard approach of impact assessment failed to provide any clear evidence due to the time lag. In the case of the five capitals, the impacts are observed to be subdued though statistically significant. On the other hand, reported resilience has provided clear evidence of impact when compared to the five capitals approach. Resilience, measured in terms of household capacity to withstand a number of droughts, is positively associated with the rainfall (Hydrological unit-HUN), location (downstream), and watershed (treated area). That is, the unit (HUN2) with better rainfall is more resilient than the one with lower rainfall (HUN1); downstream locations are more resilient than upstream and midstream locations; and villages treated with watershed interventions are more resilient than untreated (control) villages. These findings support the formulated hypotheses.

However, there are deviations to this logical pattern: the extremely poor performance of the upstream village in the low rainfall zone (HUN1) despite being a model watershed (acclaimed as a best-implemented watershed) and the unexpected poor performance of a watershed in the relatively better rainfall zone (midstream village in HUN2) despite the shifts to high value horticultural crops, defy standard explanations.

The explanation for these deviations lies in the hydrogeology of the locations. The hydrogeology of the upstream village in the low rainfall zone (HUN1) is very shallow (basin) and does not support any on-stream interventions for groundwater recharge. As a result, despite well-constructed and maintained check dams, this village could not benefit from groundwater recharge. Hence, this village continues to depend on shallow wells and the situation worsens during years with less than normal rainfall.

On the other hand, the case of the midstream village in the better rainfall zone (HUN2) is that the land use pattern is not in line with the groundwater potential. This village is characterised by a moderately shallow basin with limited groundwater potential. Due to the nature of the aquifer, groundwater swells and depletes faster during good as well as bad rainfall years. Due to the absence this hydrological information, horticultural crops were promoted, and when the demand for water surpassed supply the potential wells started failing and the crops started drying up. This was because groundwater was exploited beyond its potential (sustainable yields or rainfall-recharge coefficient). Therefore, as long as there is balance between demand and supply, cultivation of water-intensive crops such as the horticultural crops is sustainable, as observed in parts of the low rainfall zone (HUN1).

These two cases clearly demonstrate the role and importance of hydrogeology and land use practices in explaining and understanding the watershed impacts. In the absence of such information the impacts are often attributed to the quality of watershed implementation or at the most to rainfall variations (if any). This clearly indicates the need for considering the biophysical aspects while designing and implementing the watersheds. With such integration of designing, implementation and assessment becomes convenient and comprehensive when watersheds are placed in the context of a hydrological unit.

Parametric and semi-parametric analyses of farmers' perceived drought survival responses were performed to assess the role of the five capitals as well as the households' characteristics in making farmers resilient to repeated droughts. Drought resilience with and without WSD intervention as well as the identified variables that influenced farmers' non-agricultural incomes such as employment programs, dependence on common pool resources, and migration incomes were tested. It was found that households with a significant source of non-agricultural income could either come from vulnerable or resilient categories. Further, it is observed that the role of human capital such as health and education in influencing drought resilience becomes very crucial. Healthy individuals are not only found to show higher participation in labour force and employment programs, they also have higher income from common pool resources as they can put in more effort. However, all the healthy households are not necessarily drought resilient. Similarly, a larger number of educated members in the household also made the household more resilient. However, households that spend more on education indicate a marginally lower drought survival. This highlights the tradeoffs between accumulating higher human capital (which could provide long-term resilience) at the cost of reducing current or short-term resilience.

Equity has been the most difficult objective to achieve in any developmental intervention. This is more so in the case of WSD, as the technology is land-based; i.e., landless households automatically fall outside the set of beneficiaries. In order to overcome this bias, other interventions targeting the landless such as supporting non-agricultural activities, self-help groups, and so on, have been introduced under the livelihoods support component. Apart from this, the inequity within the landed households is the most controversial as it tends to increase with the interventions due to structural anomalies like access to groundwater. Addressing the structural issues will require major policy changes, apart from proper planning of WSD interventions. This is not only observed in India but also in Australia. That is, long-term management of WSD requires consideration of how collective decision making and action can be maintained at an appropriate hydrological scale in both Australia and India. Crase, Gandhi and Clement, (2013) has provided valuable insights as to the criteria that any new institutions at the meso level would have to meet to enhance the possibilities of success. These can be used at the outset in combination with the initial application of WSD or integrated water management at a whole of catchment level.

While property rights and markets can assist, there is no natural "evolution" to sustainability through these vehicles. Although both can be helpful, there is a need for them to be underpinned by concerted community action that needs to be based on distributive and procedural justice. It is clear that landholders are motivated by individual profit needs and rely largely on their own judgment or follow lead farmers when choosing the crop type. In the long term, this will lead to the ongoing deterioration of the resource in quantity as well as quality terms.

It is observed that communal approaches to groundwater management do exist, but are not currently of great priority to the community in Andhra Pradesh. However, the move to meso-scale WSD will require careful attention to how justice principles can be used to promote sustained community action and appropriate property rights. In this regard, four "rationalities" or criteria for the successful delivery of the WSD identified by Crase et al 2013, will provide a very useful evaluative tool. These rationalities include social rationality, political rationality, organizational rationality, and government rationality all of which are highly pertinent to the achievement of justice and cooperation at the local level and crucial if meso-institutions are required to be designed and created .

7.3 The approach to integration

Integrated modelling methodologies have a greater potential compared to purely disciplinary approaches to support comprehensive assessment of social, economic and biophysical aspects of a complex natural resource management such as the WSD. Climate and recharge estimates drive predictions and assessment of the availability of surface and groundwater resources as impacted by WSD, climate, and landuse (i.e., water extractions). Water availability and land use together influence crop productivity for households that have access to the available water resources, depending on how they use these resources, and consequently, their decisions and resilience.

The critical aspect of research is to integrate the various technical aspects of WSD interventions and their impact on the socio-economic fabric and livelihoods of the communities. The Bayesian Network (BN) methodology has been used to achieve this. The BNs have been applied within the meso-scale project to relate the stocks of the livelihood capitals to the capacity of the households in order to survive consecutive droughts. The utility of the BN models in analysing social data sets and how scenario analyses can be implemented using the approach has already been demonstrated (Ticehurst, Curtis, & Merritt, 2011). Hence, the BN models form the basis for the integrated model described and are used to link the biophysical and livelihood outcomes to alternative policy scenarios.

Thus, the increased scale of watersheds brings in advantages and disadvantages as far as the effectiveness of the programme. As discussed previously, the IWMP at 5000 hectare scale should help internalise the externalities associated with hydro-geology and bio-physical aspects. On the other hand, it could hinder institutional aspects pertaining to collective strategies. It is necessary to assess the impacts of watershed interventions using an integrated approach. Here the integration is achieved through loose-coupling of bio-physical and socioeconomic models (Figure 7.1) of the watersheds at a scale of 5000 ha. and above. The bio-physical model consists of hydro-geology, rainfall, soil type, land use, etc., while the socio-economic model incorporates household resilience in relation to its livelihood capitals. The integrated model is primarily driven by the socioeconomic model. Within the socio-economic model watershed impacts are assessed in terms of household resilience to changes in climate *viz*., mainly droughts. Level or degree of resilience (number of droughts a household can withstand) varies across households. The degree of household resilience is linked to the household's assets and capabilities. Sustainable livelihoods (five capitals) framework is used to assess the household assets and capabilities. Outputs from the bio-physical model and supporting analyses were linked to household assets and capabilities in the socio-economic model through variables representing natural capital, especially the quantity and quality of water and land quality. Bio-physical attributes like hydro-geology, rainfall, soil type, etc., are exogenous or given to the household. These attributes need to be taken in to account while assessing the watershed impacts. These attributes are critical in determining the extent of impacts, the designing of interventions should consider these aspects for optimising the impacts. Of these hydro-geology and soil type are highly variable and instrumental in creating inequity in access to resources, assets and capability. However, some households could substitute the lacuna in these attributes with other capabilities (capitals) like human capital or social capital to enhance their resilience.

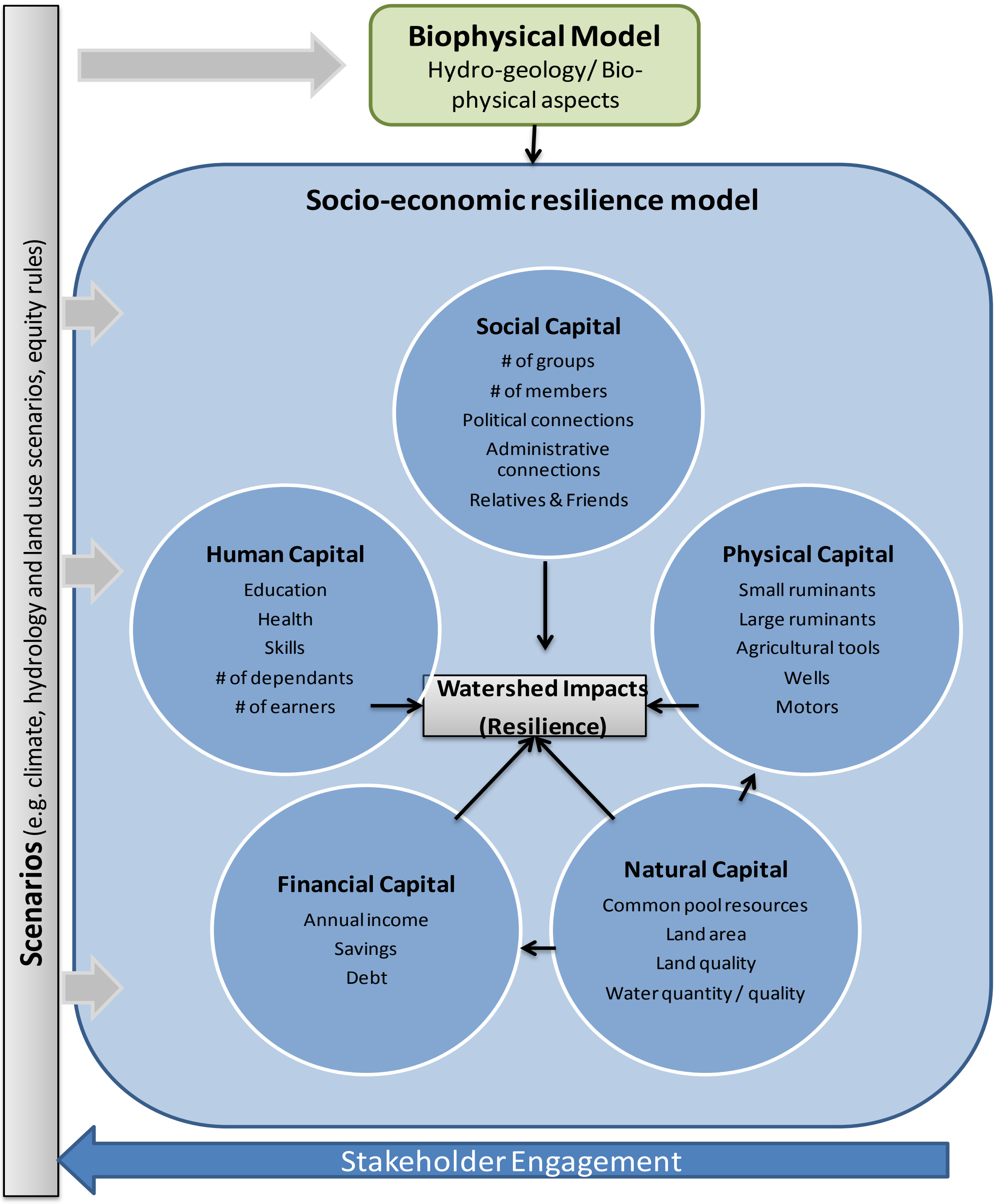

Figure 7.1 Integration Framework

The integrated model is based on the research that has adopted a clear analytical framework and scientific approach for assessing the watershed impacts. The aim of the integrated approach is to provide design inputs for sustainable watershed interventions that enhance livelihoods outcomes. The bio-physical model uses appropriate modelling techniques that include groundwater, surface-sub-surface water modeling; landuse modeling; etc. These models are used to arrive at appropriate watershed intervention designs that are location specific. The nature and density of interventions are determined by the exogenous factors like rainfall, soil quality; slope, aquifer structure; land use (forests, waste lands, etc), etc. Crop patterns would be sustainable when crops are grown according to these bio-physical attributes. For cropping pattern in a specific area influences the groundwater use and balance. When crops are chosen according to the soils and sustainable groundwater yields, it could be termed as sustainable crop pattern.

Community livelihoods are determined by the bio-physical potential of the region that can support farm systems with high potential to enhance livelihoods. While agricultural or farm systems could enhance livelihoods in terms of financial capital, there are other forms of household assets and capabilities (human, physical, social) that could potentially enhance livelihoods. And watershed interventions might directly or indirectly influence these capitals.

Hence, watershed impact assessments should look beyond natural and financial capital on which watershed has a direct bearing. The socio-economic model adopted here looks in to five capitals and capabilities of the household. Number of indicators of these five capitals along with the bio-physical aspects are used to explain the variations in watershed impacts (resilience) between upstream / downstream and control situations.

Equity is evaluated in terms of horizontal and vertical distribution of benefits. Horizontal equity is assessed by comparing upstream / downstream impacts. Vertical equity is assessed in terms of distribution of benefits with in upstream / downstream. The integrated model helps in assessing whether the distribution of benefits is optimum given the bio-physical attributes of the specific location. The model helps in arriving at alternative and appropriate design interventions that could optimise the benefits. Equity would be optimum when benefits are optimised across locations. Optimum equity is not necessarily the absolute equity, which is ideal and desirable. Appropriate policies (compensation, subsidies, incentives, payments for environmental services, etc) could help converting optimum equity to absolute equity to a large extent. This is true even in the case of vertical equity though the different types of policy interventions are required to improve absolute equity.

While the integrated model is built using the actual data generated at different levels viz., village, household; etc., it is capable of developing alternative scenarios. These scenarios pertain to climate change predications; groundwater (hydrology), land use changes; etc. In fact, these scenarios are generated based on the perceptions of various stakeholders and implementing agencies through stakeholder engagement process.

7.4 Model structure and development process

BN sub-models have been developed for each of the five capitals based on the resilience survey data. These sub-models are linked to a measure of resilience which is defined in this study as the capacity of a household to survive consecutive drought years (Figure 7.2). Stocks of each capital during 2010-2011 are related to household class variables and, if applicable, additional explanatory variables. Levels of each capital stock are linked to the resilience of that stock. The resilience variables are linked to a final outcome variable which describes the strength of each household's capital summarises the technical steps involved in the model development process (Figure 7.2).

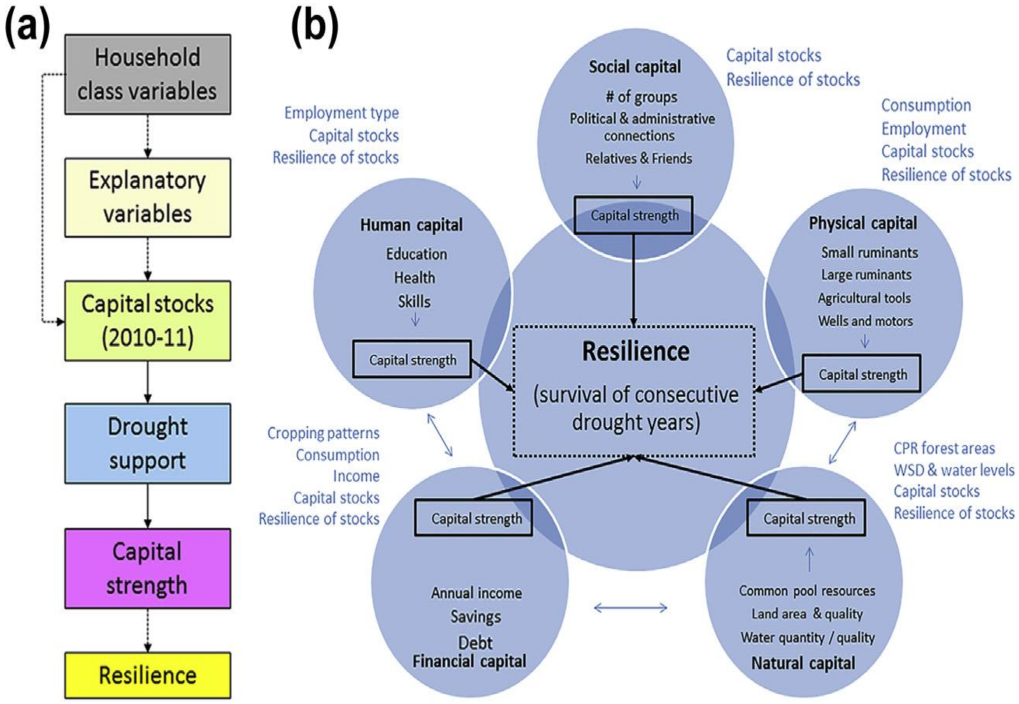

Figure 7.2 Capital strength and resilience BNs:

(a) sub model BNs for each type of capital are linked to resilience or the capacity of households to survive consecutive drought years. (b) Structure of the BN model

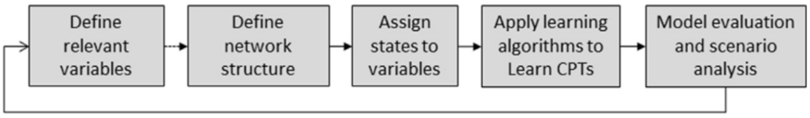

Figure 7.3 Model Development Process

7.5 Livelihood capital sub-models

The BN sub-models have been developed to demonstrate the impacts of WSD on livelihood capitals and household resilience to drought, both within and between the study villages. Household class variables reflect treatment (*Watershed Development*), geographic (*Hydrological Unit* and *Location*) and socio-economic categories (*Economic Category* [farm size] and *Social Category* [caste]). In this report we present one of these models relating to human capital. An overview of all five capitals are shown in Reddy & Syme (2015) as are various examples of how social data can be interpreted using BNs. The natural capital model is discussed in detail in Reddy & Syme (2015).

The human capital stocks represented in Figure 7.4 are skills, education, and health. The *Skills* variable is the child node of the *Economic category*, *Social category*, *Hydrological unit* and *Watershed development* variables. Education resilience is related to both *Literate household members* (which is determined by *Economic category*, *Watershed development* and *Hydrological unit*) and *Education expenditure* which is linked to the *Economic category* and *Location*. Health resilience is linked to the *Health* and *Health expenditure*. These variables are, in turn, linked to the *Economic category*, *Watershed development* and *Hydrological unit*. *Health* is also linked to *Social category* and is a parent of *Health expenditure*.

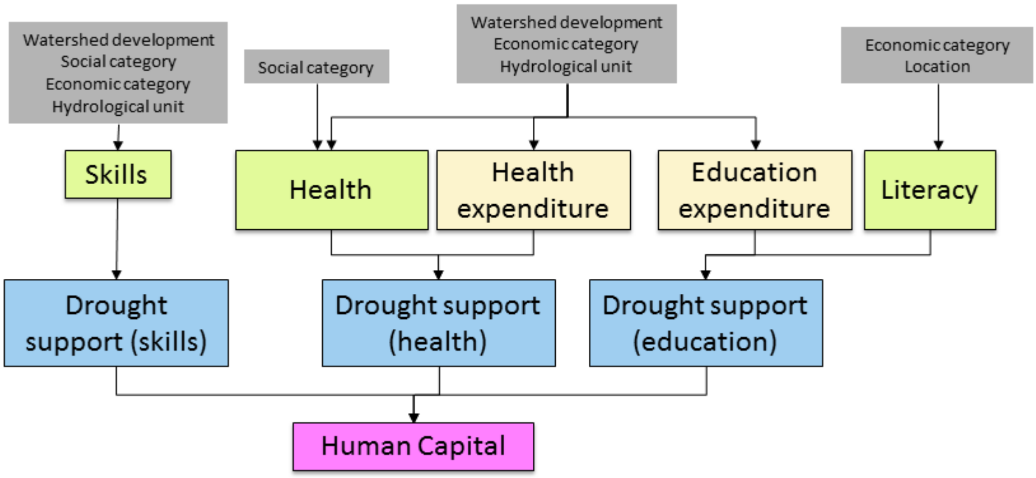

Figure 7.4 Structure of the human capital component BN

7.6 Putting science to practice

Converting good science into practice is critical for achieving the stated objectives for any developmental intervention, especially when technical aspects are involved. Currently engaging with the stakeholders is gaining importance in research programs. Stakeholder engagement needs to be an integral part of a research program from the beginning; but often, researchers interact or share with the stakeholders only when they have something substantial to convey or share. Such an approach, however, does not appeal to the stakeholders, especially policy makers, who often treat the interactions as a formality. This is more so in the context of integrated research where transdisciplinarity makes it complex to convey. Moreover, achieving integration among the team members often takes a considerable amount of time and effort. The experience from this project is not very different, though the Department of Rural Development (Andhra Pradesh), which is the nodal agency for implementing the WSD program, has been a formal partner in the project from the beginning. The real challenge was to differentiate between integrated framework and approach. The project could achieve the shift from the framework to approach quite effectively; it took a focused and concerted effort from the project team to get the right messages to the policy makers at the state (Department of Rural Development) and national levels (National Rainfed Area Authority).

The stakeholder engagement was targeted at three levels, *viz*., policy makers (state and national level), implementing agencies at the field level (government and non-governmental agencies), and the farming communities in the sample villages. The intention was to integrate the priorities of policy makers and the farming communities into the research and enable the middle-level implementing agencies to understand and adopt this integrated approach. Understanding the hydrogeology and managing groundwater accordingly has been the main concern at the policy level while optimising groundwater use in a sustainable manner has been the priority of the communities. At the community level, the hydrogeology along with soils and land use in their villages and its linkages with the existing groundwater conditions and watershed interventions were presented and discussed. This awareness was expected to change their obsession with on-stream interventions (check dams) as against on-farm interventions. Besides, it was also expected to help in improving the acceptability of the new design and implementation of watershed interventions. Similarly, at the policy level, though the policy makers are aware of the importance of hydrogeology in watershed design and implementation, they were not clear on how to take it to the implementation level. The simplified and practical approach adopted in the project has attracted the interest of the policy makers at the state as well as national level, which translated into the demand for customised training for their implementing agencies. Most importantly, the team was requested to help them in preparing the detailed project reports (DPRs) that form the basis for watershed implementation. The first pilot training provided by the team to the district-level implementing agencies was well received and there were requests for more such training with enhanced focus on hydrogeology as was the national program in New Delhi in December 2014. This is a clear sign of the benefit of stakeholder engagement and putting science into practice.

7.7 Research Communications

As outlined above the project team developed a systematic communications approach (Figure 7.5) to enable a considered approach to the incorporation of stakeholder viewpoints into the development of the research, possible scenarios in relation to the future development of WSD and the development and of training modules. At the end of each activity feedback has been received from the participants and used to design the next course. Further, training requirements have also been identified and will form the basis of future training programs. Specific activities aligned to this approach are described in Section 7.8.

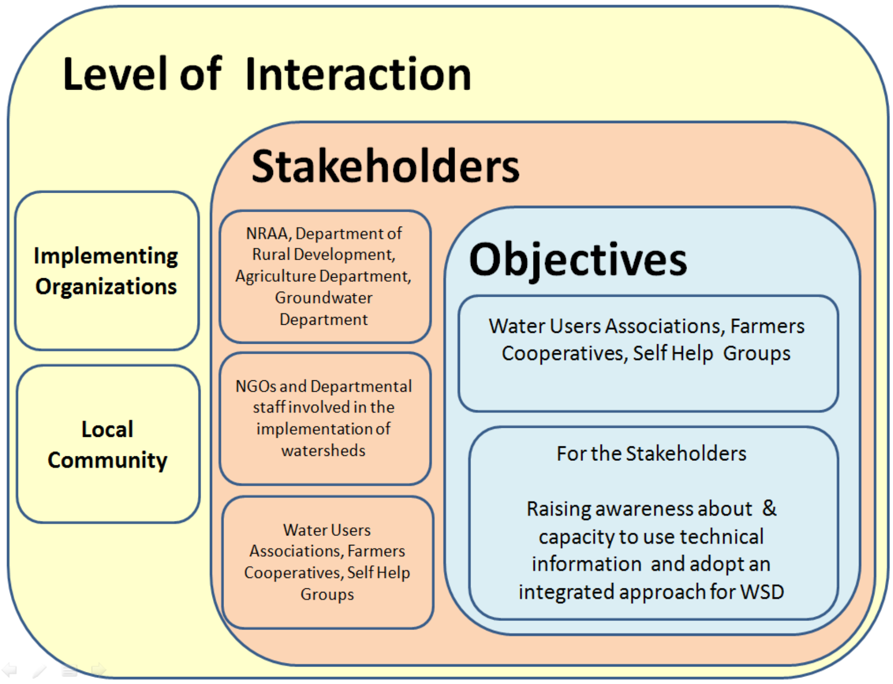

Figure 7.5 The design of the communication strategy

8 Impacts

8.1 Scientific impacts – now and in 5 years

This project provides a practical example of an integrated approach to the evaluation of WSD and other formulations of integrated water management. The Bayesian Network approach demonstrates the need to derive an integrated approach from the beginning which can interact with the specific component studies and can affect their conduct and vice versa. While each of the components of the research have been used before often in other situations the combination of them all provide an example that can be developed and improved by others. For this reason it was decided that a major component of the project would be to present the work in one place as a book which explains both the advantages and disadvantages of each component and sets challenges for future groups to follow. It is hoped that the book will be used as a template for evaluation studies now and in the future and in an-ex ante way for new policies.

Each of the component activities has also provided advances to approaching WSD evaluation.From the socioeconomic and environmental impact point of view the research has paved the way for a systematic and evidence based approach. The research has provided ample evidence that the existing approach to assessing socioeconomic and environmental impacts of WS interventions are not scientific enough. Impact studies thus far have not taken rigorous note of the scientific aspects of the linkages between bio-physical and hydro-geology on one hand and socioeconomic system on the other. This research clearly shows that socioeconomic and environmental impacts are not only due to the quantity and quality of WS interventions per se but also due to the biophysical and hydro-geological attributes of the location. The designing of watersheds so far have not taken the bio-physical and hydrogeology (sub-surface) aspects into consideration, as the design is mainly tuned to surface hydrology (mainly stream flows). The nature and density of interventions would be different if the design is in accordance with sub-surface hydrogeology and bio-physical aspects. More importantly, the type of interventions that are appropriated will vary from location to location. Such a design not only ensures efficient allocation of resources but also ensures effective and sustainable impacts.

This is the first study in India to examine the impacts of watershed development (WSD) programmes at the meso level in an integrated manner that is inclusive of the hydrologic, socioeconomic and livelihood dimensions. As part of that integrated assessment we have developed a surface water– ground water modeling simulation tool that can provide information on the spatially distributed availability of surface water and groundwater resources (expressed in terms evapotranspiration, groundwater recharge and surface runoff), on a monthly basis for a range of watershed intervention, landuse and climate related scenarios. The tool is applicable to assessing hydrologic impacts of farm level land use changes and watershed treatment activities at the micro and meso-scales.

The model has been named EWAC, or “***E**quitable surface and ground **W**ater **A**llocations in **C**atchments”* in full. EWAC was first developed in the MATLAB programming language, tested and verified at the Kothapally micro-scale watershed and then applied at one of the meso-scale watershed study sites at Prakasam. The performance at Kothapally was tested against the SWAT model and found to be acceptable. At Prakasam, where SWAT modeling was not carried out, the results are good in terms of the goodness-of-fit measures of the groundwater component which can be most easily verified are reasonable given the assumptions made. The surface runoff and evapotranspiration can be simulated well. The tool was subsequently refined to make it available for use via Excel. Being “simple” in nature and formulation, the tool is intended to be as generic as possible and requires minimal data that can usually be met from secondary sources. The spreadsheet interface makes EWAC accessible to non-specialist users with responsibility in planning and implementing new projects in a better way than the largely ad-hoc manner currently employed.

The research has also provided new insights into the impact assessment of WSD interventions. The conventional short term indicators of impact such as annual production or seasonal groundwater levels are found to be less suitable when there is a lag between implementation and impact assessment. In such cases, the research has provided new evidence that household resilience (defined as drought withstanding capacity) is a more comprehensive indicator to assess WSD impact. Though resilience appears to be the right indicator, in retrospect, given the nature and purpose of WSD interventions, resilience has never been an indicator of WSD impacts.

On the whole the scientific impacts (socioeconomic context) of the research can be summarised as:

a) Integrating and understanding the hydrogeological and bio-physical aspects is necessary for understanding and assessing the socioeconomic impacts.

b) Planning and designing of WSD interventions in accordance with site specific hydrogeology and bio-physical attributes ensure not only efficient allocation of resources but also effective and sustainable impacts.

c) There is a need for a change in how watershed impacts are measured in terms of the development of long term biophysical and socio-economic indicators..

The project has also demonstrated the utility of the BN methodology to evaluations and analysis of WSD impacts. Linking the survey data to the SL framework using the BN methodology allowed us to explore interactions, influence and causality in the data has not often been successfully attempted.

The outputs of the project will be influential in the design and, if funded, implementation of the ACIAR project promoting socially inclusive and sustainable agricultural intensification in West Bengal or Bangladesh (LWR/2014/072). The findings have also been useful for assisting the current World Bank project on catchment management which is a forerunner to the national Neearanchal project.

8.2 Capacity impacts – now and in 5 years

i) The research has immensely impacted the capacities of the research team. Now the team thinks and believes in integrated approach to WSD assessments.

ii) There has been a lot of cross learning across disciplines- the team now can understand and feels comfortable discussing hydrogeology, biophysical and socioeconomic aspects with a range of audiences.

iii) As social scientists we are now able to understand language and relevance of hydrogeology and bio-physical aspects in WSD and its importance in , Natural Resource Management in general.

Beyond the research team- the implementing agencies (Government and NGO) are more aware of the importance of an integrated approach to WS planning, designing and implementation. The research, in fact, created demand for capacity building at the state and central level. The state and central nodal agencies responsible for WS implementation have requested training for their officers. Even the NGO leads have requested for training in the integrated approach.

The research has also provided the basis for two successful PhD theses in two very different topics: geospatial data analysis for impact assessment (Sreedhar Nallan) and scale issues in social justice in water allocation (Patrick). The first was supported by an ECU Scholarship and the latter by a CSIRO Scholarship.

Training modules have been prepared from the study and training sessions given to government and non-government participants responsible for planning and implementing watershed development projects in Andhra Pradesh and other states where such interventions are commonly used.

At the WSD implementation level a series of three training programs at national and state level have provided an opportunity to use the major findings in WSD implementation. Over 100 people have been involved in the courses. It is envisaged that the skills gained will widen through this group over the near future.

There has been some interest in the Bayesian Network approach from attendees at Delhi workshop (including WOTR), and planning is underway to provide training for key individuals (e.g. Dr . Sanjit Rout). BNs are a potentially useful tool for planning phase of new intervention programs. The network structure can be elicited through participatory modelling processes such as focus group discussions and used to conceptualise how stakeholders (including community members, NGO’s, GO’s and/or researchers) think the system works. This process could help to identify critical indicators to measure prior to, during and post-implementation(see Section 7.9).

The EWAC model helps to fill an important gap in terms of how to implement the Government of India’s Integrated Watershed Management Program in a way that addresses the water resource constraints and the mismatch between hydrogeology and the watershed interventions proposed. Being relatively generic in nature, its application is not necessarily limited to WSD related issues in India and could potentially be used for broader agricultural water management issues.

EWAC has been used to evaluate WSD from an ecosystem approach that seeks to make the most of the natural resource base to improve the livelihoods of rural communities on a sustainable basis. We have examined these aspects and generated data and tools that have helped to raise awareness and stimulate discussion amongst the responsible agencies within the government of India and NGOs implementing projects.

The project has reached out to stakeholders on a regular basis from even before the beginning of the project to create awareness among some of the key policy makers at the state and central levels in India. The National Rainfed Authority (NRAA) is a key stakeholder at the national level and the Department of Rural Development (DRD) in Andhra Pradesh at the state level as well. There is a need for more ongoing concern about the convincing arguments presented regarding the unintended impacts of watershed treatment activities, including reduced stream flows, rampant well drilling and associated over-exploitation of groundwater.

An invited presentation based on the meso project will be given at the UNESCO meeting of DWADI in Tehran in July 2015.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The investment in WSD is now very significant (e.g. almost $US400 million in funding released to all states by Ministry of Rural Development under IWMP), and this study provides an integrated tool for evaluating outcomes and thus maximising the sustainable economic benefit. The analysis of financial capital through the BN could also enable an understanding of the micro-economics involved when WSD is implemented.

Specifically the water productivity analysis showed that

- Both groundnut and cotton are irrigated-dry crops
- Upstream farmers are likely to benefit if more water is harvested to irrigate groundnut and downstream farmers benefit more by allocating more water to cotton crop
- Such a shift in water use between the streams would enhance overall productivity within a hydrological unit

8.3.2 Social impacts

Community impacts are long term in nature. Attempts are made to inform communities regarding the importance of Hydrogeology and landuse in impacting groundwater levels in the context of watershed. Unless the scientific and technical variables are integrated into planning and designing their ultimate impacts are not realised at the community level.

The lithographs obtained through the geophysical work have been effective in at least one village of identifying appropriate places for bores to access water supply. In villages where older techniques have not been able to find such sources the techniques developed for this project can provide a significant long term advantage in terms of access to water.

8.3.3 Environmental impacts

The research has shown how WSD can be systematically developed using sustainable groundwater use given the specific hydrogeology of the macro and meso catchments. It highlights that more than just blanket administration of standard interventions. Given that decline in groundwater tables is currently a major issue both with and without WSD intervention, this project has provided a significant impetus to sustainable water management. Sustainable groundwater water use also translates to the maintenance of enhanced ecosystem services in rainfed landscapes.

8.4 Communication and dissemination activities

A stakeholder engagement plan was prepared and implemented. The AP Department of Rural Development (DRD) has been a key stakeholder all along from the previous Special Commissioner to the current. They have attended all meetings, provided their perspectives and sought our advice and support. There has also been engagement and awareness raising with key implementing NGOs (e.g. WASSAN, WOTR, DHAN Foundation), and at the national level with the NRAA.

A 2-day training course was conducted for government officials of the DRD from 10 districts in February 2014 in Hyderabad. The objective was to incorporate project learnings and the knowledge of the project team into the implementation of the ‘Integrated Watershed Management Program’ specifically via the Detailed Project Reports (DPRs) process. The course was well-received by the team members and feedback provided by the Special Commissioner of DRD.

As a follow-up to the training “Assessing Scale Impacts of Watershed Development: An Integrated Approach” was held in New Delhi in November 2014. Key NGOs in WSD implementation along with government officers and eminent guests discussed the challenges in implementing the Indian WSD guidelines and the benefits that have emerged from the research project.

These training initiatives will be developed and continued in other states over the next year and hopefully beyond.

9 Conclusions and recommendations

9.1 Conclusions

During project formulation it seemed that this research would largely confirm that meso-scale intervention was the best compromise between a larger scale of watershed intervention (which should help avoid inappropriate interventions and would be more likely to result in a more sustainable outcome) and micro-scale interventions which are more easily implemented but where the espoused social goals can only be met if benefits accruing at micro-level did not occur at the expense of water availability or livelihoods at other locations. However, the question of appropriate scale was not simple and the team had to clarify what scale meant in the context of the project goals (Syme, Ratna Reddy, Pavelic, Croke, & Ranjan, 2012). This process highlighted the need for a legible hydrological context before meso-scale WSD can be designed and implemented. This can be achieved by some simple macro scale modelling to establish where interventions were likely to succeed and inform selection of sites in the overall catchment.

There is a clear need to define what you are trying to achieve with WSD and simple indicator(s) and frameworks that can measure and show impact. In this case we chose the concepts of resilience (the number of years the person could survive in drought circumstances). The socio-economic and land use outcomes need an integrated framework for analysis. Linking livelihood and resilience to surface and groundwater models helped demonstrate the effectiveness of WSD. The research indicated some modest, although unequally distributed, benefits of WSD at meso level. New institutions will be needed at regional level to ensure effective and equitable implementation. Ignoring these issues raises the likelihood that debate around equity issues it will increase and uptake of the program may decline.

Lastly, WSD must be considered in tandem with other social programs which affect the livelihoods to adequately assess its effectiveness and how synergies can be created with them to ensure holistic social policy in rainfed areas.

9.2 Recommendations

In a way this research is futuristic, at least when it was initiated in the year 2009 and designed as per the priorities of the Department of Rural Development, Government of Andhra Pradesh. At that stage, the concept of meso-scale watershed was just being introduced and the implementation was about to start. The priority of the department was to understand the major concerns and the likely livelihood impacts of the WSD program. In order to achieve this objective, the research team had to find a prototype meso-scale watershed in a hydrological context. Thus, the study is not typically an impact assessment of the meso-scale WSD program, though it provides all the necessary insights into the likely impacts and concerns. On the whole, the assessment of the impacts validates the hypotheses that meso-scale watersheds could generate differential benefits at scale (upstream/downstream). Given the lag between implementation and assessment, the impacts are most conspicuous in terms of perceived household resilience.

However, it is clear that there is some mismatch of perceptions of the outcome of WSD in terms of the benefits and costs to other parties that relate to hydrogeology and the biophysical characteristics of the location. These (typically ignored) aspects need to be directly addressed in order to improve as well as sustain the watershed impacts. Important concerns and challenges that need policy attention include:

- A hydrology-based approach of selecting IWMP watersheds would help in understanding and accounting for potential upstream– downstream linkages
- Technical inputs need to be used for assessing surface and groundwater hydrology and their linkages in the context of biophysical attributes, while designing the watersheds. This project has demonstrated that models and tools, with limited data demands, can be used at the implementation level with appropriate training
- Based on the hydrogeology and biophysical aspects of the location, WSD interventions can be rationalised in terms of the type and density of interventions—it is not necessary for the entire area to be treated. In fact, some portion of the watershed could be left untreated as a buffer (donor) for the rest of the watershed
- The present blanket, fixed per hectare allocation of funds is not appropriate. Rather, allocation needs to be location-specific with funds divided, within and between watersheds depending on agro-climatic and hydrogeological factors
- Household resilience is an important indicator of the socio-economic impacts of WSD and needs to be explicitly considered
- Achieving equity remains a difficult issue to be resolved and demands judicious planning of interventions with justice principles in mind
- Bayesian Networks (BNs) have the potential to support IWMP design and evaluation
- Stakeholder engagement is an integral part of any research project aiming forpolicy changes. However translating it into effective policy is a time-consuming and difficult process and thus stakeholder engagement remains a big challenge in the post-project phase. Funding agencies should identify and support follow-up activities that may add substantial value
- The project has helped to improve the Detailed Project Report (DPR) process - the vehicle by which the IWMP is implemented while there has been some progress in institutional terms understanding process evaluation is still in its early stages
- Similarly, continued efforts are needed to build capacity within the GOs and NGOs in the implementation of the DPR
- In terms of the hydrological and biophysical research it is necessary that the impact of these factors is examined in the context of different landscapes, particularly in alluvial river basins such as the Ganges

10 References

10.1 References cited in report

Batelaan, O., and Smedt, F., (2007). GIS-based recharge estimation by coupling surface–subsurface water balances. Jour. Hydrol. 337 (3/4), 337–355

Bharati Integrated Rural Development Society (NGO). Nandyal, Kurnool (Dist).

Calder, I., Garratt, J., James, P. and Nash, E. (2008). Models, myths and maps: Development of the EXploratory Climate Land Assessment and Impact Management (EXCLAIM) tool. *Environmental Modeling & Software*, 23:650-659

Carney, D. (ED.1998): Sustainable Rural Livelihoods, DFID, London.

Crase, L, Gandhi, V. and Clement, F. (2013) Enhancing institutional performance in watershed management in Andhra Pradesh, India. FR 2013-10 AACIAR, Canberra.

Davies, S (1996) Adaptable Livelihoods, Macmillan, London.

Kelly *et al* (2013). Selecting among five common modeling approaches for integrated environmental assessment and management. *Environmental Modeling & Software,*47, 159-181.

Kemp-Benedict, E., Bharwani, S., de la Rosa, E., Krittasudthacheewa, C., & Matin, N. (2009). Assessing water-related poverty using the sustainable livelihoods framework. (pp. 25pp): Stockholm Environment Institute.

Maréchal, J.C., Dewandel, B., Ahmed, S., Galeazzi, L., and Zaidi, F.K., (2006). Combined estimation of specific yield and natural recharge in a semi-arid groundwater basin with irrigated agriculture. Jour. Hydrol. 329 (1–2), 281–293.

Moon, S.K., Woo, N.C., and Leeb, K.S., (2004). Statistical analysis of hydrographs and water-table fluctuation to estimate groundwater recharge. Jour. Hydrol. 292, 198–209.

Rennie, J.K.and Singh, N. (1996) Participatory Research for Sustainable Livelihoods, International Institute for Sustainable Development, Winnipeg.

Reddy V, Ratna Gopinath Reddy M, Soussan John (2010). Political Economy of Watershed management: Policies, Institutions, Implementation and Livelihoods, Jaipur: Rawat Publishers;

Reddy, V.R. and Syme, G.J. (2015) Integrated Assessment of Scale Impacts of Watershed Intervention: Assessing hydrogeological and Bio-physical Influences on Livelihoods. Elsevier. Amsterdam (Details of Chapters in Appendix 2).

Sibanda, T., Nonner, J.C., and Uhlenbrook, S., (2009). Comparison of groundwater recharge estimation methods for the semi-arid Nyamandhlovu area, Zimbabwe. Hydrogeol. Jour. 17, 1427–1441.

Sophocleous, M.A., (1991). Combining the soilwater 664 balance and water-level fluctuation methods to estimate natural ground water recharge: practical aspects. Jour. Hydrol. 124, 229–241.

Sukhija, B.S., and Rama, F.A.Sc., (1973). Evaluation of groundwater recharge in semi-arid region of India using environmental tritium. In “ Indian Acad. Sci. LXXVII” Sec. ‘A’, Vol.VI, pp.279–292.

Syme, G.J., Ratna Reddy, V., Pavelic, P., Croke, B. and Ranjan, R. (2012). Confronting scale in watershed development in India. *Hydrogeology Journal*, 20(5): 985-993.

Ticehurst, J. L., Curtis, A., & Merritt, W. S. (2011). Using Bayesian Networks to complement conventional analyses to explore landholder management of native vegetation. Environmental Modelling and Software, 26, 52-65.

10.2 List of publications produced by project

Bernet, D. (2011). Simple surface and groundwater balance model to assess watershed interventions at different scales - model development and application at a micro-scale watershed in Andhra Pradesh, India. Masters Thesis, Swiss Federal Institute for Technology (ETH), Züric, Switzerland

Chandrappagari, S. Drought vulnerability and institution building for effective watershed management in arid and semi-arid regions of Andhra Pradesh, India. Paper presented to the 13th Waternet South Africa Symposium

Croke, B., Herron, N., Pavelic, P., Ahmed, S., Reddy, V.R., Ranjan, R., Syme, G. Samad M. and Rao, K.V. (2012) Impacts of meso-scale watershed development in Andhra Pradesh (India) and their implication for designing and implementing improved WSD policies and programs. Water Practice and Technology doi:10.2166/wpt.2012.025

Merritt, W.S., Reddy, V.R., Rao, K.V., Pavelic, P., Ahmed, S., Ranjan, R., Croke, B.F.W. and Syme, G.J.(2011) Integrated modelling for understanding watershed development impacts on social and biophysical systems Proceedings of the 19th International Congress on Modelling and Simulation, Perth Australia (Eds Chan, F., Marinova, D. and Anderssen, R.S. p. 2887-2893.

W.S. Merritt, V.R. Reddy, C. Tallapragada, S. Rout and G. Syme, Modelling social and environmental impacts of watershed development in Andhra Pradesh, India. International Environmental Modelling and Software Society (iEMSs) 2012 International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.) http://www.iemss.org/society/index.php/iemss-2012-proceedings

Merritt, W.S, Patch, B., Reddy,V.R. and Syme, G.J. (2015) Modelling livelihoods and household resilience to drought using Bayesian Networks. *Environment, Development and Sustainability*, DOI 10 1007/s 10668-015-9650-1.

Patch, B., Merritt, W., Reddy, V.R and Rout, S. (2013) Evaluating watershed development impacts on physical capital using household surveys and Bayesian networks, 20th International Congress on Modelling and Simulation, Adelaide, Australia, 1–6 December 2013, www.mssanz.org.au/modsim2013

Pradhan, D. and Ranjan, R. (2013) Empirical Assessment of Crop Technology Adoption for Drought Survival In Rural India Paper presented at AARES Conference Sydney

Ranjan, R (2012) Social norms, social capital and the sustainability of small economies. Journal of Natural Resources Policy and Research, In Press

Ranjan, R.(2012) Natural resource sustainability versus livelihood resilience: A model of groundwater exploitation strategies in developing regions. *Journal of Water Resources Planning and Management* In Press

Ranjan, R. (2013) Mathematical modeling of drought resilience in agriculture. Natural Resource Management Modelling In Press

Ranjan, R. (2013) Climate change and human capital accumulation: Educational decisions under resource uncertainty. Journal of Natural Resources and Research In Press.

Reddy V.R. (2012) Climate change and Food Security: The role of watershed development in India. Paper Presented at the Stockholm Water Week.

Reddy,V.R., Syme,G., Ranjan, R., Pavelic, P., Reddy, M.R., Rout, S.K. and Acharya, N.S. (2011) Scale issues in Meso-Watershed Development: Farmers' Perceptions: Designing and Implementing Common Guidelines. LNRMI Working Paper No2.

Reddy. V.R. and Syme, G.J. (Eds) (2015) *Integrated Assessment of Scale Impacts of Watershed Intervention: Assessing Hydrogeological and Biophysical Influences on Livelihoods* Elsevier, Amsterdam ***(Please note: Description of Chapters by Project Members in Appendix 2.)***

Syme, G.J., Reddy, V. Ratna, Pavelic, P., Croke, B. and Ranjan, R. (2012) Confronting scale in watershed development in India. Hydrogeology Journal, 20 (5), 985-993.

11 Appendixes

Appendix 1: Comparison of WA, SA and Andhra Pradesh

Notes from Workshop

Compiled by: Joseph Guillaume

Differences

- Differences tend to be related to current situation with more similarities in objectives and principles
- “Environment” is a user in Australia (or is becoming so)
- Greater level of emphasis placed on ecosystems and environments
- Models will not be trusted, and model results may be selectively interpreted. It is better to use a model instrumentally as a strawman to trigger discussion and debate rather than as a deterministic predictive tool. Focussing on how to handle what *could* happen can be more effective than trying to determine what *will* happen.
    - Culturally different.
    - Need to still be stochastic
    - Different views of professional in the two countries
    - Model development and use is still at infancy stage by departments.
    - Often used at basin scale to sort the issues of interstate disputes for judiciary purpose rather than using them for WRM in a practical way
    - Model development for determining sustainable yield is mainstream but the use of the models still in infancy. Not clear that models play an essential role yet, compared to just basic science. Many models not really used.
    - Differing function and role of existing NGOs
    - Historically NGOs had greater role in Australia but have been sidelined
    - E.g. landcare
    - Friends of the Earth and Friends of Willunga Basin lobbying for protection of Washpool
    - Landcare funding for ‘Regreen the range’. Revegetation of grazing land on the range
- Policy is limited in its ability to respond to local and temporary variations because it does not directly control pumping, and policy processes take time, resulting in delayed responses.
    - In India, policy is not related to pumping. Pumping is controlled by access to electricity
    - The control is the electricity supply
    - In McLaren Vale, pumping ends up being determined by winery requirements for quality, given the climate conditions
    - Crop water needs vary

    - Cost of pumping is not the main limiting factor, possibly because grapes are high $/ML
- In revising a plan, it is easy (for both users and planner) to keep the same rather than raise new issues and introduce innovation, to avoid resistance to change, and especially under time and resource constraints. This causes tension with adaptive management.
    - In India and Australia existing users don't want to lose the existing rights
    - India just starting to move into adaptive management process, e.g. small scale WSD changing to meso-scale WSD
- Social goals e.g. livelihood more evident in Indian documentation
    - Australia emphasis at most on economic viability
    - Preference for economic efficiency. Changing crops and land use tends to be possible and expected – considered to be a normal part of business, not something to be avoided. E.g. almonds to grapes. Loss of food crops for lifestyle instead
    - Gender
        - Women more likely to be on WAPAC
        - Importance in India
- Nature of support for farmers
    - Economic/financial (drought support payments during/after crisis, e.g. fire drought
    - Access to water
    - Access to services
    - Organisation – SHG, landcare
    - NGOs
    - Farmers do have support in McLaren Vale. E.g. mains to recycled water – financial, public goods – easement for pipeline, provision of recycled water at low cost, services – monitoring, facilitation of management debate
- Better understanding of pumping zones of influence at a policy-usable scale. Pumping tests tend to be too local and analysis at larger scales has difficulty separating effects. The result is a tendency towards very simple, heuristic policy rules, rather than being able to define more defensible triggers.
    - In Australia, based on water allocation not number of bores (buffer rules in McLaren Vale)
    - Similar ideas but different approaches to understanding pumping zones of influence
    - In India, rules for distance between wells (70m) – differs between irrigation bores and drinking bores
    - McLaren Vale has buffer distance from ecosystems and existing wells. Trigger to prevent buying water based on falls in annual water level and rise in salinity. Ineffective in fixing concentration of pumping in one area

Planning and community involvement

- 1st priority: Sustainable groundwater resource management can only be achieved if planning processes understand and address the basic dynamics of the groundwater system. All pumping has an effect, there is no magic 'sustainable' yield. Impacts vary spatially and temporally, and are driven by uncertain factors. Acceptable yield therefore also varies, and management needs to allow pumping to vary and needs to account for local and temporary impacts.

- 2nd priority: Focusing on building stakeholder capacity to engage with planning processes by understanding dynamic consequences of management, including how each group's activities interact - iterative dialogue about management options, objectives and knowledge
    - Discussion across extraction zones (learnings)
    - Episodic planning processes and churn mean that local expertise of agency staff tends to be lost, whereas locals may remember past processes and have continuity of experience
    - Evaluation of community based institutions for inputting into community based institutions
- Priority 3rd. Special effort is required to consider marginalised issues. Values of highly modified ecosystems are unclear and contested. Minority groups can be difficult to engage and have their voice heard, e.g. indigenous
    - Farmers without bores/access to GW availability
    - Role of landless / farmers who cannot afford
    - Tribal
    - Ways to provide water to everybody for their critical irrigation
- 4th priority: Change in crops, irrigation practices and water storage innovation happens easily when economic and policy goals are aligned. Willunga Basin is a special case where lowering water use and sourcing recycled water made economic sense.
    - E.g. In Willunga. Premium grapes needs tighter control of water, reclaimed water is already treated, so only distribution cost
- 5th priority: Direct involvement of water users in monitoring and determining management rules opens new options for adaptive management of the resource, but also increased responsibility that some may be unwilling to take on (even if they are happy to consider themselves custodians of the land)
    - Water budgeting exercise to various groups etc
- Irrigators value someone else taking responsibility for shared resource and do not like the issue of management being reopened
    - Fear of loss of allocation
    - Need for certainty of regulatory context
    - Willunga basin critical issue
    - Providing for crops
    - Piped water supply
    - Systems provided by the government and management and rule setting by community themselves
- Decision makers and stakeholders are not well equipped to deal with the long-term dynamics of a groundwater management system. There is high demand for assessing economic and system-wide impacts. However, researchers have a steep learning curve to understand the local system. Research needs to be approached as a social learning process rather than a straight-forward application of tools.
    - Highly desirable which needs to be driven through a formal mechanism
- Focussing on building stakeholder capacity to engage with planning processes by understanding dynamic consequences of management, including how each group's activities interact - iterative dialogue about management options, objectives and knowledge

    - Need to address the issues between contiguous watersheds considering that importance of large numbers of farmers
- Policy is limited in its ability to respond to local and temporary variations because it does not directly control pumping, and policy processes take time, resulting in delayed responses.
    - There is an expectation of the community that management will solve the problem, but in reality WAP simply acts as an institution to help community manage themselves and the institution is always imperfect
- 6th priority: Extraction limits cannot be separated from how the water is distributed, and each part of the policy cycle needs to be given fair attention. However, broadening the scope in this way provides the opportunity for a positive-sum win-win rather than a zero-sum win-lose allocation situation. E.g. location of pumping has differential impacts and there is opportunity for more explicit linking of monitoring to management.

Individual perspective

- Change in crops, irrigation practices and water storage innovation happens easily when economic and policy goals are aligned. Willunga Basin is a special case where lowering water use and sourcing recycled water made economic sense.
    - Need to understand issues such as perceptions of uncertainty, farmer typology etc.
    - Though info on groundwater resource availability is in the place, the same is not actively used for policy
    - Restrictions are made in terms of policy when the areas are overexploited
    - Groundwater recharge in command areas (serviced with surface water) are treated separately
    - Restriction on new bores / no bores
    - Surface water use only
    - Market demands etc
- There is a need to evaluate how individuals experience management in their everyday activities. How irrigators take policy into account in their decision making influences compliance, adoption of incentives and effectiveness of the overall result. How government officials put policy into practice affects the extent to which irrigators are willing to comply and adopt new practices.
    - E.g. delays in approving buying water adds uncertainty, preventing trade.
    - E.g. policies that are not completely administered due to resources, lack of data, impracticability, i.e. failure to understand administrator's requirements
    - Changes in government agencies create confusion about what's required
    - MAR requires EPA and WAP approval -> barrier to adoption

Science / Research about resource

- Better understanding of preferred pathways within an aquifer. These are particularly crucial to managing water quality risks in managed aquifer recharge, but also
    - Most interesting
    - Understanding of aquifer recharge different zones or within watershed
    - Understanding of aquifer recharge within the watershed scale
- The effect of pumping tends to be confounded by influence of climatic variation, particularly given pumping demand tends to increase in dry years. This makes it

difficult to determine whether a yield is sustainable in a mass balance sense in the longer term.

  - *E.g. McLaren Vale fall in groundwater levels and salinity during drought*
  - Not novel but essential
- Better understanding of seasonal flow directions across different zones. Pumping patterns potentially change direction of aquifer flows during the year, with significant implications for mobilisation of salts, contaminant flow and zone of influence of pumping.
- Key ecological indicators for management of groundwater-based ecosystems
- Where is the MAR possible desirably in landscape. Potential benefits, risks of MAR (e.g. social, economic, water quality, ecological tradeoffs)
- Impact of community (shared) bores on control of management
- What are the important components/processes of the system (rank them)
  - Are processes needed or just behavioural characteristics? (burden on showing processes are needed – i.e. answer cannot be obtained by considering the overall behaviour only)
- Better understanding of pumping zones of influence at a policy-usable scale. Pumping tests tend to be too local and analysis at larger scales has difficulty separating effects. The result is a tendency towards very simple, heuristic policy rules, rather than being able to define more defensible triggers.
  - Information availability at watershed scale becomes increasingly important
  - Need for watershed development
  - Also indicates the restrictions on WSD

Use of science / Need to rethink role of models and modellers

- Stakeholders need training to use models. It is better to start simple and build complexity than to present them with a fully integrated model that even the contributing modelers do not fully understand
  - Hard work
  - Getting balance of amount of information to provide
  - Creation of decision support tools -> capacity building/training with key stakeholders
- Decision makers and stakeholders are not well equipped to deal with the long-term dynamics of a (poorly observed) groundwater management system. There is high demand for assessing economic and system-wide impacts. However, researchers have a steep learning curve to understand the local system. Research needs to be approached as a social learning process rather than a straight-forward application of tools.
- Models will not be trusted, and model results may be selectively interpreted. It is better to use a model instrumentally as a straw man to trigger discussion and debate rather than as a predictive tool. Focusing on how to handle what *could* happen can be more effective than trying to determine what *will* happen.
  - Depends on whether results support their view or not
  - Similar: Should use models to facilitate negotiation of discussion
- Use of science – how can trust in science be improved?
  - How can we improve the ability of decision makers and stakeholders to make use of science?

Appendix 2: Book Contents

Integrated Assessment of Scale Impacts of Watershed Intervention

Assessing Hydrogeological and Bio-physical Influences on Livelihoods

Edited by

V. Ratna Reddy

Livelihoods and Natural Resource Management Institute, Hyderabad, India

Geoffrey J. Syme

Edith Cowan University, Perth, Australia

Elsevier

Radarweg 29, PO Box 211, 1000 AE Amsterdam, The Netherlands

The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK

225 Wyman Street, Waltham, MA 02451, USA

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ISBN: 978-0-12-800067-0

Library of Congress Cataloging-in-Publication Data

Integrated assessment of scale impacts of watershed intervention: assessing hydrogeological and bio-physical influences on livelihoods / edited by V. Ratna Reddy, Geoffrey J. Syme.

pages cm Includes index.

ISBN 978-0-12-800067-0

1. Watershed management. 2. Watershed management–Economic aspects. 3. Soil conservation.

I. Reddy, V. Ratna, editor. II. Syme, Geoffrey J., editor.

TC413.I58 2015 333.73–dc23 2014026080

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

For information on all Elsevier publications visit our web site at http://store.elsevier.com/

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