Catchment Assessment and Planning for WATERSHED MANAGEMENT

SUMMARY REPORT

JUNE 2015

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This is the Summary of the two-volume report of a Catchment Assessment and Management Planning Study (Main Report and Annexes). The study is a major step by the World Bank toward improving the understanding of hydrology issues in watershed management in India, based on a detailed assessment of the Government of India's Integrated Watershed Management Program. The Report's findings will contribute to the design of new World Bank supported, and government financed watershed programs in India. Further, the lessons learned in this report can guide hydrological assessments in watershed program development in other regions.

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INTRODUCTION

THE ISSUE

Even the latest Common Guidelines for Watershed Development Projects implemented by the Department of Land Resources (DoLR), Ministry of Rural Development (MoRD), Government of India (GoI), do not define a 'watershed' in the hydrological sense. Instead, contiguous plots of land measuring around 1000 to 5000 hectares, are designated a 'watershed' and are intensively treated to control and capture the water in that area. The Guidelines advocate a 'multi-tier ridge to valley sequenced approach' where the uppermost part of the catchment (usually hilly and forested), is treated first followed by the 'middle tier' (intermediate slopes just above agricultural lands) followed by the lowest tier, which are the 'plains and flat areas'. In India, as also in other parts of the world, such an approach however, can have three key water-related consequences:

- **Reduced water flows to the lower parts of the catchment** and more importantly, the larger rivers that flow in the valleys, as a result of greater capture of water and increased evapo-transpiration from expansion in the area irrigated in the upper parts of the catchment.
- **Less water in streams and aquifers,** as a result of increased cultivation, groundwater extraction and evapo-transpiration (from irrigated and rainfed farming systems). In some cases, this can leave villages worse off than prior to the treatment, because most options for augmenting water supply have already been exhausted and that area is barred from benefiting from another government watershed project. This is basically the same impact as the earlier one, but only the scale differs.
- **Over-abstraction of groundwater,** in the absence of effective regulation and decision-making that incorporates water use priorities and improvements to the productivity and sustainability of water use. Farmers benefiting from the additional water captured in new and existing rain water harvesting structures - even in the upper and middle 'tiers' of catchments – invest in more bore wells, deepen bore well depth and increase pumping capacity to expand cultivation into previously un-irrigated areas.
- **Greater focus on rural development rather than watershed management,** with issues like water quality, environmental flows and sustainability often being ignored.

The starting point of the Catchment Assessment and Management Planning study was therefore to derive an improved approach and methodology for catchment assessment that could underpin the planning of watershed management programs, in India and elsewhere, and increase net benefits, reduce externalities, ensure primary needs are met, etc.

STUDY OBJECTIVES AND EXPECTED OUTPUTS

The study had three objectives:

- To derive an improved methodology for catchment management planning in the Indian context.
- To demonstrate this methodology in one sub-catchment (of around 100 square km).
- To create practical tools to apply (relevant parts of this methodology) in government watershed programs such as the Integrated Watershed Management Program (IWMP)[1] of the DoLR in the MoRD, GoI.

The main outputs expected at the end of the study were the following:

- **An improved Catchment Assessment and Management Planning methodology:** This methodology would (1) detail the hydrological foundation of watershed management by laying out clearly all aspects including the selection criteria, the maximum possible area coverage, types of treatments, and (2) how it can be applied, practically, on the ground in planning the management of watersheds.
- **The demonstration of the methodology:** The hydrological assessment would have three key components: (1) selecting and setting up of the hydrological models, (2) building scenarios using the model to simulate the impact of different watershed intervention options in a specific sub-catchment and (3) stakeholder involvement in the discussion and selection of options.
  - *Hydrological modeling:* The various steps include model selection, data collection and checking, verification of assumptions and algorithms, calibration and validation, and checking the results with community perceptions – to ensure that the model is a good fit to the local conditions. It also blended in data from various datasets, starting with freely available but coarse global data sets and replacing these with better-quality national, state and local datasets as they became available.
  - *Scenario building and analysis:* The running of the model with different scenarios of catchment management interventions, and comparing with a base case to illustrate the differential impacts of different watershed interventions on catchment hydrology, was to provide a useful and first-hand understanding of upstream-downstream linkages, water inflows and outflows from the watershed, to inform the selection of treatment options.
  - *Stakeholder interactions:* This is important to not only check the hydrological model outputs against local knowledge and perceptions of catchment behavior, but also to discuss the selection of treatment options and understand how best to incorporate community priorities in such decision-making.
- **Tools and procedures:** Based on the outcomes of the demonstration of the methodology, tools and procedures were to be devised to help the various staff and the local communities responsible for planning and implementing watershed programs such as IWMP to use the insights from the methodology. These tools were to streamline the steps and processes in the methodology so that these can be understood and applied more easily.

The new approach and methodology was to be piloted in selected sites under the proposed Neeranchal Project of the DoLR, co-financed by the World Bank, and after learning lessons from the pilot, fine tune and modify these so that, ultimately, a tried and tested, and flexible methodology would be available for DoLR to use it in watershed programs across the country.

1 The government of India is developing a new national scheme called the Pradhan Mantri Krishi Sinchayee Yojana Program (PMKSY), which would be led by Ministry of Agriculture and integrate ongoing national schemes from Ministries of Water, Rural Development and Agriculture. The IWMP would be rolled into the new scheme, but still be delivered by DoLR.

HYDROLOGY IN WATERSHED MANAGEMENT

HYDROLOGY AND THE INTEGRATED WATERSHED MANAGEMENT PROGRAM

The Evolution of the IWMP: Watershed projects in India have an allocation of nearly Rs. 2200 crore (US$340 million) per year at present and are a central plank in India's poverty alleviation strategy. These programs have a clear emphasis on improving the conditions of large majority of the people living in rain-fed areas who are dependent on land and water for their livelihoods, and the thrust is on implementing activities which can be done by the local communities with minimum outside support on technical matters. The IWMP implemented using the 2008 version of the Common Guidelines (revised in 2011), continues this focus. However, it does not include hydrological assessments as a basis for catchment management (although there is some mention of defining watershed boundaries and creating contour maps for assessing runoff and planning rain water harvesting structures).

CATCHMENT ASSESSMENT AND MANAGEMENT PLANNING: INTERNATIONAL TRENDS

Watershed development: There has been a shift over the last 10 years in the international perspective on watershed management programs, based on experience so far, to the 'next generation' of projects with significant differences in approach in two main areas as follows:

Integrated Catchment Management (ICM): This is a concept from the 1990s, implemented in some developed countries, that is not only based on sound hydrological information but also capable of addressing the issue of multiple stakeholders with different expectations and requirements. ICM envisages catchment-wide management of water resources, while ensuring sustainable, efficient and equitable water use within the catchment. However, given the legitimate but often different values and interests of communities relating to water within a catchment, tradeoffs are necessary. Considering the variety of uses and users of land and water in the catchments, these tradeoffs ought to be based on multiple objectives and criteria, which cut across social, economic, environmental, and political aspects. A discussion of tradeoffs must follow as clear a scientific understanding of the underlying hydrology. The first step towards ICM, thus, is to develop a sound understanding the hydrology of the watershed and potential impacts of interventions, for which modeling is perhaps the only tool available.

Modeling catchment hydrology: The key findings from the review of ICM internationally are:

- Modeling tools exist for simulating the complex hydrological processes in catchments.
- Catchment management plans should offer a vision for the catchment and its communities for the future.
- Catchments cannot be managed merely on the basis of scientific knowledge of hydrological and ecological processes.

- There is no blueprint for catchment management.
- Rapid advances in cyber technologies and remote sensing can be used to advantage.
- Watershed management programs must be based on an initial large-scale assessment and planning process that can guide lower level watershed planning with communities.
- Hydrological modeling can help catchment management in several ways.
- Modeling is not a panacea and good models require time and effort to set up and run as well as data at appropriate scales and intensity.
- There are benefits to engaging with stakeholders during the modeling process.
- There are ways to mitigate risks and uncertainties in watershed planning and management in water scarce areas.

CATCHMENT ASSESSMENT AND MANAGEMENT PLANNING PILOT

KEY FEATURES OF THE PILOT

An integrated, inclusive and iterative approach: Based on the available international experience with ICM, the approach and methodology to be piloted were:

- A hydrological assessment of a fairly large-sized catchment, based on modeling using a mix of secondary information (remotely-sensed and terrestrial bio-physical and societal) and primary information from communities living in the catchment, that could generate scenarios of potential future impacts (local and downstream).
- Iterative and interactive discussions with local stakeholders, using the modeling scenarios, to understand their priorities and perspectives as well as their reactions to the scenarios.
- Possible revisions to the micro-watershed plans, based on inputs from the model scenarios and stakeholder discussions, focusing on water demand management and livelihood promotion.

The study focus was on testing the approach and methodology, rather than on generating an actual watershed-wide plan for implementation.

Short iterative modeling cycles: The modeling work undertaken in this study was guided by recent global experience as follows:

- The aim of the modeling process is usually to generate evidence and understanding (both biophysical and societal) and also to promote evidence-based social and institutional learning.
- Especially by using data from independent sources (including stakeholders and citizen scientists), the modeling process aims to build (stakeholder) confidence in model outputs.
- Increasingly, modeling involves blending and using information from multiple sources.
- Modeling is best done in a series of iterative steps and/or cycles.

Scenario generation: The potential impacts of various watershed management options were generated based on questions that were locally relevant for upper and lower parts of the (larger) watershed, and discussed with key stakeholders to try and evolve a general plan for water allocation based on local perceptions and perspectives.

Typology of watersheds: Using information from the hydrological assessment, a typology of color-coded watersheds was developed to guide the nature of watershed interventions to be undertaken in each (Table 1).

TABLE 1 TYPOLOGY OF WATERSHEDS AND POSSIBLE MANAGEMENT OPTIONS

Inflows vs. Outflows	Supply vs. Demand	Inflows vs. Supply	Management Strategy and Options
BLUE WATERSHEDS			
Inflows far exceed outflows ($P > ET_a + E$)	Entire demand met from supply ($PE + E = S$)	Inflow far exceeds Supply	*All options to augment water-based livelihoods (e.g., RWH for cropping):* ❖ Increase beneficial ET to meet future consumptive demands (through increased cropping, tree-planting, etc.) ❖ Create RWH structures to increase soil infiltration and groundwater recharge (will reduce downstream flows)
GREEN WATERSHEDS			
Inflows exceed outflows ($P > ET_a + E$)	Demand exceeds Supply ($PE + E > S$)	Inflow exceeds Supply	*Reduce excess of demand over supply* by creating RWH structures (will reduce downstream flows) *Augment downstream flows* by freeing water from agriculture through water productivity improvements (without increases in irrigated area) by: ❖ Reducing non-beneficial evaporation ❖ Reducing beneficial evapo-transpiration ❖ Reducing non-recoverable deep percolation from irrigation
BROWN WATERSHEDS			
Inflows equal outflows ($P = ET_a + E$)	Demand equals supply ($PE + E = S$)	Entire Inflow tapped No more renewable water available	*No RWH structures* (will only re-distribute the same water in the watershed by creating new losers and winners, a zero-sum game) *Augment downstream flows* by freeing water from agriculture through water productivity improvements (without increases in irrigated area), by: ❖ Reducing non-beneficial evaporation ❖ Reducing beneficial evapo-transpiration ❖ Reducing non-recoverable deep percolation from irrigation *Prioritize and protect drinking water sources* *Promote non water-based livelihood options*
ORANGE WATERSHEDS			
Inflows equal outflows ($P = ET_a + E$)	Demand exceeds supply ($PE + E > S$)	Entire Inflow tapped No more renewable water available	*Reduce excess of demand over supply by:* ❖ Reducing non-beneficial evaporation ❖ Reducing beneficial evapo-transpiration ❖ Reducing non-recoverable deep percolation from irrigation *Prioritize and protect drinking water sources* *Promote non water-based livelihood options*
RED WATERSHEDS			
Outflows exceed inflows ($ET_a + E > P$)	Demand met from unsustainable supply ($PE + E = S$)	Entire Inflow Tapped Deficit met through aquifer mining	*Reduce mining of aquifer by* ❖ Reducing non-beneficial evaporation ❖ Reducing beneficial evapo-transpiration ❖ Reducing non-recoverable deep percolation from irrigation *Prioritize and protect drinking water sources* *Promote non water-based livelihood options*

Note: ET_a = Actual evapo-transpiration; E = Evaporation (from water bodies and barren soil); PE = Potential Evapo-transpiration; P = watershed inflow (precipitation); S = Water supplies; RWH = Rain Water Harvesting.

Using catchment types: Classifying catchments can help determine the management strategy and guide intervention planning. Three points to note concerning these classifications of catchments are:

- *Classification requires inputs from several sources,* including hydrological modeling, from stakeholder discussions and from discussions with other government departments, to understand interventions planned by these agencies.
- *Classifications can apply to smaller units within a catchment,* such as sub-watersheds and hence a single, large catchmen can have a patchwork of color-coded types within it.
- *Classifications can change based on changes within the catchment* brought about by other government programs or departments.

Changes in catchment type: A catchment can move from Green to Brown if the consumptive water demand increases to touch the inflows and there is a proportional increase in supplies (by developing all water resources in the catchment) to meet this demand. If further increases in demand for water are not met (due to the lack of water stocks), then the catchment would become an Orange catchment (as in some parts of hard rock peninsular India), and, if the excess demand is met through mining of groundwater, it would become a Red catchment (as in some parts of the Luni basin in Rajasthan).

Watershed management options: This was not directly part of the pilot since the objective was to derive and test the approach and methodology and not create an actual management plan for the watershed. However, this was part of the iterative process of stakeholder engagement and hence was addressed, albeit partially. Based on international experience, and given the constraints of resources and time, however, it was decided to focus on a decentralized village-level planning process, followed by a multi-stakeholder meeting. The implications of these plans on local and downstream water resources were to be included into the modeling as a distinct scenario to assess potential impacts. If these were found to have 'unacceptable' consequences for downstream communities (based on criteria that can be political, social, economic or environmental in nature), the plans were to be revised till they were found to be acceptable. The approach, thus, called for iterating between village-planning and checking the downstream impacts using the hydrological model.

HYDROLOGICAL ASSESSMENT

Choice of state: The pilot was located in a watershed in the western Indian state of Gujarat.

Choice of catchment: The 393 km^2 Upper Sukhi catchment that was chosen lies within the Orsang sub basin of the Narmada basin, and most of catchment (79%) is in Chhota Udeypur district. Land use is mostly agriculture and forest (a significant part falls within the Ratanmahal wildlife sanctuary) and it contains the Sukhi dam and reservoir. Most importantly, around 50 villages in the part of the catchment lying in Chhota Udeypur district had been selected as IWMP project sites.

Locating individual IWMP watersheds: Five IWMP Batch 1 (started in 2009-10) project villages (Kevdi, Dholisimel, Dungarblint, Kundal & Ghata) that formed an upstream-downstream continuum within one 21.5 km^2 sub-watershed were selected for detailed study.

Choice of model: The Soil and Water Assessment Tool (SWAT) was identified as a suitable model for a number of reasons, including a large number of applications in India, being open-source and additional software and online support.

DATA COLLECTION

Secondary data: Although a team member was dedicated solely to secondary data collection it took two months (from mid September to mid November), to collect all the required information, as the information had to be procured from different government agencies. The modeling, however, had started by using global data sets, the strategy being to replace these rather coarse data sets with more accurate data sets from Indian sources as and when they became available.

Primary data: Five different questionnaires were prepared to collect information on wells, RHW structures, agricultural practices, socio-economic and irrigation details and a timeline on resource changes. Another field team member was dedicated fully to this task and data collection was completed in two months. The primary data was greatly facilitated by the fact that the IWMP projects were still ongoing in these villages – which not only gave access to the information collected by the IWMP baseline survey but also facilitated entry-point discussion and rapport-building with villagers.

BROAD PICTURE

The hilly and rocky *Upper Sukhi* catchment has relatively high rainfall, occurring in a few months in a year resulting in high velocity flows that do not allow water harvesting structures to remain intact and functional along the main streams. More wells and Rain Water Harvesting (RWH) structures built in the last decade have supported a growth in irrigated agriculture in catchment villages.

Although the local community is tribal and poor, mostly farming small and marginal land holdings during the single crop monsoon season, some farmers have wells with year-round water to support irrigated agriculture. Cropped and irrigated areas have increased in the last decade, with a preference for longer-duration cotton, a cash crop. All the area under winter crops (mostly maize) and the small area under the summer groundnut crop are irrigated.

Wells also provide water for drinking and livestock although there is a shortage in summer months even in normal rainfall years, which affects the last irrigations for the winter (*Rabi*) crop. Low rainfall years and droughts worsen the situation considerably. Many in this agriculture-dependent community migrate for work after the monsoon *Kharif* crop to supplement their livelihood.

Watershed management in this catchment has to take account of the following:

- The relative lack of treatment of the uppermost parts of the catchment, which are forested, uninhabited, and directly under the control of the state Forest Department.
- A large number of structures already built on the (smaller) drainage lines, implying that there are few suitable sites left to build more large RWH structures, such as check dams.
- Most structures built on the upper reaches of the main streams flowing into the reservoir have been broken by the monsoon rainwater carrying branches and boulders, and there is not much space in villages to build additional RWH structures.
- There are large variations in rainfall, evapo-transpiration and runoff across dry and wet years which affect inflows into the reservoir which, in turn, affect canal releases to downstream communities.

This basic understanding of the characteristics of the catchment, the impact of watershed interventions on the water resources in the local villages and in downstream villages is an essential first step to modeling the catchment.

CATCHMENT MODELING

Three key issues from additional analysis informed the setting up of the SWAT model:

- **The Rainfall-Runoff relationship in the *Sukhi* Catchment:** The estimated relationship between total annual rainfall and estimated total annual virgin flows (runoff) best fitted a power function, which suggests that if rainfall increased by 1 unit, runoff would increase exponentially, i.e., by much more than 1 unit.
- **Estimation of Evapo-transpiration:** This is the amount of water lost to the atmosphere due to evaporation and transpiration through flora such as grasses, crops, shrubs and trees, and is another key input into a simulation model. The greater the water lost through evaporation from water bodies and through the transpiration from biomass (grass, shrubs and trees) the lower the runoff, generally, and in this case, the inflows into the *Sukhi* reservoir.
- **Groundwater flows in the catchment:** The way in which the SWAT model handles groundwater is simplistic and the catchment selected was too small to get sufficient secondary data to run a supplementary groundwater model such as MODFLOW. Additional analysis provided some insights that could be used to improve the simulation modeling using SWAT:

- There is significant inter-annual variability in water levels.
- Water level fluctuation is greater for very low rainfall than for abnormally high rainfall.
- Following years of drought, a good monsoon results in excessively high groundwater recharge.
- The post-monsoon depth to water level in a high rainfall year is lower than in very low rainfall years.
- There is neither long term decline nor long term rise in water levels overall.

SWAT MODELING

Compared to actual inflows into the *Sukhi* Reservoir, the SWAT run with global data was a reasonable but not very good fit to the data, either for monthly or annual inflows into the reservoir. With the inclusion of national and state data, the SWAT model performed better and the final results showed that the simulation of monthly inflows into the *Sukhi* reservoir matched the actual data well. This is an important result because it shows that high quality data are available in India to support effective modeling.

STAKEHOLDER INTERACTIONS

After stakeholder interactions in each of the five surveyed villages, a multi-stakeholder meeting was held, which discussed four key areas:

- *Community planning and co-management of water resources:* The basic idea was an ambitious one of *co-management of local water resources* by the village communities and the government. Instead of the current practice of government departments asking villagers to participate in various government development schemes by attending meetings, finding suitable locations for interventions and contributing labor, material and cash towards construction and maintenance, the co-management approach focuses on facilitating villagers to form their own plan for water resource development and management to address the multiple-use water requirements (domestic water for humans and livestock and irrigation) of the village and asking government departments which of their schemes could help create the planned infrastructure. It was admittedly ambitious but worth exploring.
- *Creating decentralized and flexible water storage in each village:* Given that the villagers had identified summer water shortages and problems during droughts, another issue discussed was ways to provide supplementary water for drinking, livestock and for *Rabi* irrigation (e.g., last two irrigations) in summer. An option discussed was to build flexible and decentralized storage (e.g., large or small traditional tanks like *Talabs* and *Tankhas*) in different parts of the village.
- *Minimal intervention on drainage lines:* Since most structures built in the past on the main streams had been broken by the high velocity of the monsoon streams, these were no longer considered useful investments. Instead, the idea given was to create supplementary storage *off the drainage line* but fed by diverting waters from the main stream during high rainfall years and periods. Such structures would also minimize the reductions in flows downstream into the *Sukhi* reservoir.
- *Water use productivity improvements:* An important intervention suggested was to improve water productivity (i.e., agricultural output or profit per unit of water), to counter potential reduction in water availability. The idea was that farmers may be more willing to accept some reduction in water availability if profits remained the same.

Local villagers were in general agreement with these ideas, pointing out that their older generations had wanted to build large *Talabs* (traditional ponds) in the upstream areas to capture rainwater and recharge village wells, but pointed out two key constraints: (1) Upstream areas are often under the control of the Forest Department, and villagers were unable to get the required permission to build these RWH structures in the upper catchment; and (2) land for creating decentralized storage was a problem, since the majority of the land holdings were small (less than two hectares) and few farmers could afford to spare the land required to build a *Talab* on their lands. Nevertheless, the Chief Executive Officer of the Gujarat State Watershed Management Agency, requested the villagers to prepare village water plans and promised help from his team to support their efforts.

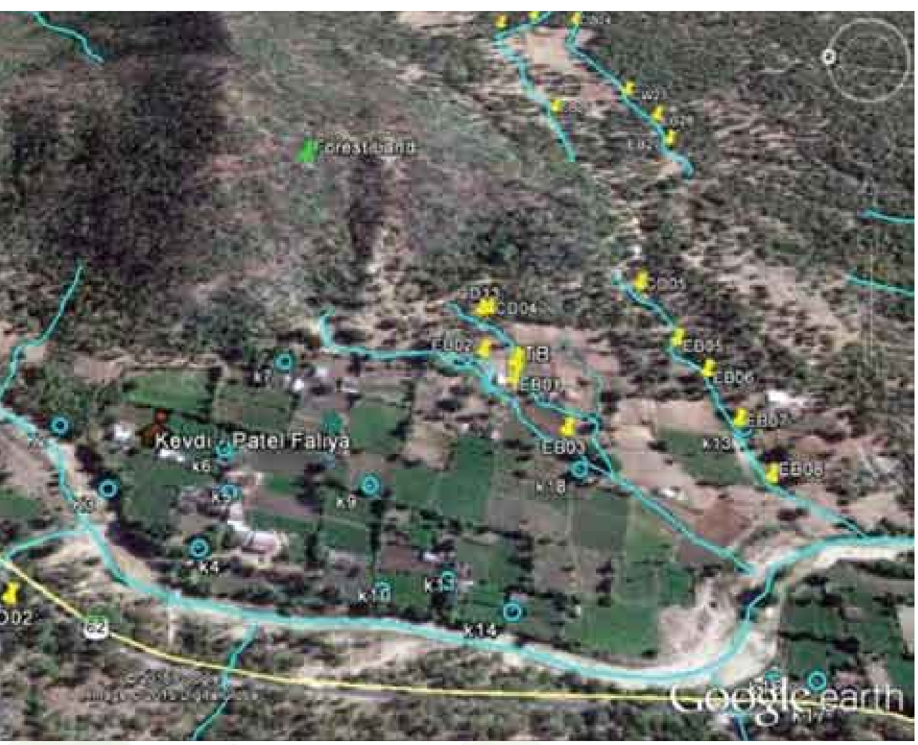
VILLAGE-LEVEL PLANNING

Concept: The idea of co-management with a decentralized village-level planning process was the central concept. The implications of these plans on local and downstream water resources were to be included into the modeling as a distinct scenario to assess potential impacts. If these were found to have 'unacceptable' consequences for downstream communities (based on criteria that can political, social, economic or environmental in nature), the plans were to be revised till they were found to be acceptable. The approach, thus, called for iterating between village-planning and checking the downstream impacts using the simulation model.

Expected outputs: Although the preliminary modeling results showed that the catchment was 'water-surplus', the fact that the catchment is located within a 'closed' river basin meant that reductions in downstream flows had to be minimized (at least to maintain environmental flows). Given this, key outcomes expected from the facilitated village-planning process were:

- *Improved capacity of the local community to create plans to manage local water resources* especially storage to overcome summer scarcities and droughts, tap available government funding and create the required water infrastructure.
- *Creation of local storage with minimal intervention on drainage lines:* Supplementary off-drainage line water storage to provide protective and/or supplementary irrigation (e.g., last two irrigations of the *Rabi* season) through flexible and decentralized storage options, including large or small *Talabs* (traditional tanks), *tankhas*, etc., through a multi-annual Village Water Plan, to capture and store water during high rainfall periods for use in the low rainfall periods – with minimal reduction of downstream flows.
- *Better drinking water security* by creating household-wise storage (i.e., *tankhas*) to store 15 months of drinking water for a six-member family.
- *Improved water productivity and land productivity:* Technical and economic options to raise the profit per unit of water to offset any future reductions in water availability, especially downstream, due to a variety of possible reasons including increasing climate variability.

The village planning process, focused on the first three of the outputs expected.



VILLAGE PLANNING IN KEVDI

Time and resources did not permit a watershed-wide consultation, as suggested strongly by international experience, with iterative and well-facilitated discussions with multiple stakeholders, including the government, within an institutional and regulatory framework set by the government, respecting agreed priorities for water allocation. The exercise was limited, instead, to the five selected villages (IWMP micro-watersheds) and to assessing the impact of these plans on model outputs.

The village planning exercise was carried out in Kevdi village with an innovative approach using Google Earth and hand held GPS sets. This approach had the following key advantages: (1) it makes planning more inclusive for the community; (2) it is the only option when maps and land records are difficult to procure; (3) it is useful where maps may be available, but detailed planning requires identifying water bodies and problem areas; (4) it creates maps that can be used for implementation and monitoring; and (5) it uses existing methods: e.g., primary data collection and transects.

The main options for improved water infrastructure were sub-surface dykes on the main streams and, for inland areas, farm ponds (lined and unlined) and repair of earthen bunds (sometimes deliberately breached by farmers so as to cultivate in the moist soil upstream of these bunds). The total capacity of the proposed structures was around 25,600 cubic meters.

SCENARIOS OF IMPACT

Creating scenarios

Model scenarios enable an analysis of the potential impacts that investments in water infrastructure and other factors (e.g., changes in climatic variables) may have on the hydrology and water resources of the broader catchment. Such analysis makes it possible to explore trade-offs involved in decision-making, for example, at what level of watershed developed does the reduction in downstream flows starts affecting downstream benefits such as irrigation and drinking water supplies – and become politically, economically, socially or environmentally unacceptable? Scenario development is a stage at which all stakeholders can provide their input based on their vision of the future of the watershed. The development of scenarios for the *Sukhi* catchment focused on two main factors:

- *Changes in the levels of* in situ and ex situ RWH in the catchment.
- *Changes in cropping intensity,* in particular, the expansion in double-cropped area.

Two versions of the scenarios are presented, one for the catchment as a whole and the second for the five villages where detailed analysis was undertaken.

Catchment scenarios

Scenario description: Two main scenarios were developed to look at the impacts of land use change and watershed development on the hydrology of the Sukhi catchment:

- *Scenario 1:* Models the catchment in the absence of the watershed development and the intensification of agriculture that has occurred over the last two decades.
- *Scenario 2:* Models the opposite situation and represents a significant intensification of agriculture and watershed development from current levels (the most plausible future for the watershed given the investment by IWMP and other watershed development activities and the increasing demand placed on agriculture to improve local livelihoods).

Both scenarios 1 and 2 are disaggregated into 3 parts: Part (a) models the combined impacts of changes in RWH and land use; Part (b) models the impacts of changes in RWH alone and Part (c) models the impacts of changes in land use alone. The best simulation from the model calibration was used as the Baseline. Then, scenarios were evaluated for the period 2007 to 2012. The overall impacts of the scenarios were as would be expected:

- Scenarios 1a, 1b and 1c, result in increases in inflow into the *Sukhi* reservoir while Scenarios 2a, 2b and 2c result in decreases.
- The combined impact of the two factors in Scenario 1a results in the largest increase in reservoir inflows.
- The combined influence of the two factors for Scenario 2a results in the largest decrease in inflows.
- The impact on watershed development on downstream flows is greatest in dry years – as the relative impacts of the scenarios are greatest in 2009, the driest year (inflows increase by 24% for Scenario 1a and decrease by 19% for Scenario 2a).

Detailed scenario results: Whether it is a dry year or a wet year also affects various water balance components–evapo-transpiration (ET), percolation, artificial recharge from RWH structures and reservoir inflows. The changes in these components for the Baseline and other Scenarios, as a percentage of rainfall, show the following for 2009, the driest year, and 2011, the wettest year:

- **The driest year, 2009:** Changes in the double cropped area have the largest impact on the amount of water lost as ET from the catchment.
- **The wettest year, 2011:** The impact of the scenarios on ET is far less as a percentage of rainfall, although the absolute difference is similar.
- **Percolation rates:** Differences in percolation rates between the scenarios are mainly a result of recharge from RWH structures, which more than doubles for the baseline to Scenario 1a. This is in line with the increase in RWH structure capacity from 15 m^3/ha to 40 m^3/ha for scenario 1a and an expansion of structures into the mainly forested sub-watersheds. Recharge from RWH structures in 2009 is double the average recharge as a percentage of rainfall.

VILLAGE SCENARIOS

Extracting village areas: Since it is the impacts of interventions in the five villages that are of direct interest, SWAT was used to extract model outputs for these areas within the larger catchment. The detailed water infrastructure plan for Kevdi village was extrapolated to the other survey villages by calculating the amount of extra capacity needed for each hectare of agricultural land.

Scenario description: The 40 m^3/ha figure applied in Scenario 2a earlier (to represent intensification of RWH) is slightly lower than the average of 42 m^3/ha capacity of RWH structures calculated as a function of village area. These revised figures for additional RWH structures were used to generate three village-level scenarios:

- **V1:** models the villages in the catchment as if no watershed development or increase in the area of double cropped agriculture had occurred.
- **V2:** represents an increase in RWH capacity based on the plan developed for Kevdi village.
- **V3:** represents a 25% increase in double cropped area within each sub-watersheds and an associated increase in RWH capacity, calculated using the per hectare figure from the Kevdi village plan.

Scenario Results: Water Balance Components: Extracting data on the water balance components for the nine sub-watersheds reveals:

- **ET** is lower for the five villages than for the catchment as a whole, due to the large areas of forest and degraded forest in these five villages.
- **Reservoir inflows** for the five villages are similar to those of the whole catchment for the baseline (as an average over the period). However the variations in inflows in 2009 and 2011, the driest and wettest years, are more significant.
- **Percolation and (artificial) recharge from RWH** are similar to the figures for the whole catchment.
- **Scenario v1**, denoting a removal of RWH structures and the decrease in double cropped area, sees only small increase in average reservoir inflows, highlighting the fact that the study villages are located in an area of the catchment that so far has seen relatively less intensive agricultural and hydrological development.
- **Scenarios v2 and v3,** as expected, result in decreases in reservoir inflows but the decrease is larger for scenario v3 due to increase in double cropped area and the larger increase in RWH capacity.

Concluding observations: Overall, the model helps to put numbers on hydrological phenomena such as evaporation, transpiration, groundwater recharge and percolation, and thus explain the observed inflows into the Sukhi reservoir downstream of the catchment. Such information is vital in planning for watershed management in the catchment and also in the prioritization of watersheds to be taken up for treatment. Supplemented by multi-stakeholder interactions, the main observations made possible by the use of this approach are the following:

- *Catchment inflows exceed outflows:* 'Catchment inflows' (rainfall falling over the catchment) are greater than 'outflows' (the water that reaches the *Sukhi* reservoir) – since there were inflows into the *Sukhi* reservoir even in very low rainfall years.
- *Water demand exceeds supply:* The demand for water for domestic uses, livestock and irrigation is

more or less met in the five villages studied in detail, although villagers reported summer scarcities and problems even in a single low-rainfall year.

- *Need alternative rain water harvesting options:* The substantial rainwater harvesting prior to the IWMP projects of 2009-10 had resulted in check dams and gully plugs being built in the best possible locations, leaving few options for such interventions in the IWMP. Options for decentralized storage and recharge structures (e.g., sub-surface dykes and lined farm ponds) could provide the farmers the extra rabi irrigation water that they mentioned as a major issue.
- *Need increased water productivity:* A shift to crops and practices that use the available water but give higher profits per unit of water could improve agricultural livelihoods – but should avoid the observed pitfalls of increased water use following increased productivity.
- *Search for non-water based livelihoods:* Providing support for feasible non-water-based livelihoods that are at least as profitable as migration could help to stem such stress migration.

LIMITATIONS OF THE IWMP

IWMP projects are clearly only one of many factors causing changes in the hydrology of the catchment, which include both government and private investment. The major limitation of the IWMP, however, is a much larger issue of convergence between different government departments and programs. The biggest constraint to catchment management in India and possibly other developing countries is the lack of regulatory frameworks and institutional platforms wherein different stakeholders can come together to discuss their various water requirements and reach agreements – even on 'caps' that dictate how much water is to be let down the main stream or river to the next set of communities in the catchment. International experiences with ICM suggest that, at the very least, success depends on finding locally-effective policy and institutional frameworks.

LESSONS FOR HYDROLOGY-BASED WATERSHED MANAGEMENT

The basic lesson from both the international experiences with ICM and the approach described in the previous section in the context of the IWMP is the fundamental need for sound hydrological analysis and sustained and well-facilitated stakeholder consultations to underpin decisions on watershed management strategies. This has, however, to be undertaken within an integrated policy and institutional framework based on (economic, environmental, social and cultural) development priorities for water allocation across large watersheds. As experienced in countries like Australia, adopting this kind of approach in India will require political cohesion and broad agreements but frameworks for action will have to be context-specific.

The six key steps in the methodology developed for the hydrological assessment are the following:

- Field visits, stakeholder dialogue, transect walks and model selection.
- Model set up and modeling using data from open-access global datasets.
- Acquiring, quality controlling and using secondary data from (non-open access) national, state and other databases.
- Participatory collection of biophysical primary data (e.g., well and RWH structure surveys).
- Participatory collection of societal primary data (e.g., development timelines of water and other natural resources).
- Modeling and scenario analysis to assess and map the scale of current and future watershed management benefits and externalities.

The more innovative aspects of the methodology piloted in this study include the following:

- **Using data from global and regional databases as a starting point:** Being readily available and free, this could enable the setting up the model very quickly – which is very different to normal modeling practice.
- **Iterative incorporation of official and primary data over a period of time:** Refining the model as better-quality (official) data became available.
- **Using only open source software:** While projects and organizations are still willing to spend on software, this is not really necessary currently – and thus the use of GIS and modeling software should no longer be constrained by the cost of licenses.
- **Savings in the cost of modeling work:** This is due not only to the availability of freely-available open source software, but also because models can be set up fairly quickly with available global data and refined as better data is made available.

Planning watershed management interventions, however, requires a longer process of sustained and well-facilitated engagement with key stakeholders, within clear policy and institutional frameworks of water allocation and water use.

SINGLE WATERSHED MANAGEMENT PROJECTS

Key steps for applying the methodology in a stand-alone watershed management project are:

Selection of project area

- *The ridge-to-valley approach is a good starting point,* as in the case of the IWMP, but multi-scalar bio-physical analysis can now be used to decide the starting point.
- *The size of the catchment for the hydrological simulation modeling depends more on the need for accuracy of model findings.* Freely available global data sets and improved 'open source' software means that modeling can be done at any convenient scale, but generally, the larger the catchment, the easier it is to find stream gauging points or reservoirs, and thus, better modeling to simulate catchment hydrology. Outputs for a smaller project area can be extracted from within the larger catchment selected for modeling.
- *Hydrological unit versus administrative boundary is an 'old chestnut'*. Although most projects prefer administrative boundaries for ease of planning and implementation, it is possible to model a larger hydrologically-defined area and extract outputs for the project area.
- *Overall, the best starting point depends on the context.* It is best to start in the upper reaches of the catchment in the project area, even if the entire catchment is not being treated.

Hydrological assessment

- *A review of earlier hydrological assessments is a necessary first step to a new or updated hydrological assessment.* Collecting secondary information, mining the internet, and undertaking a transect through the catchment are useful parts of this activity, and can be undertaken in any order that is convenient, but informal discussions with local stakeholders are a must in order to add details of interest and to assimilate local information.
- *The choice of model is a key step in the hydrological assessment.* There are a large number of suitable models and the final choice has to be based on a number of issues including the skills and experience of the modeler, the availability of suitable data and the time and resources budgeted for the modeling exercise: SWAT was a good choice for the Indian context.
- *Model set up involves deciding values for a large number of technical parameters in these simulation models,* using available data, the literature, and expert opinion and will have to be adjusted as better information emerges.
- *Collecting primary and secondary data depend on the model chosen.* After listing model data requirements and identifying potential sources of each dataset, global, country-specific or local, primary and secondary surveys can start simultaneously, not only to reduce time but also to ensure that the primary information is available to input into the model.
- *Model calibration and validation are essential to checking how well the model is able to represent catchment hydrology.* Not only is the 'goodness of fit' to be checked but also the extent of uncertainty inherent in the model predictions. Also, the assumptions and data need to be reviewed and revised till the 'goodness of fit' is as close to ideal as possible and uncertainty is minimized. It would therefore be helpful to have an expert or group of experts review the modeling process at regular intervals during the modeling process.
- *Main model outputs are the basic water balance components of the catchment* including key features such as evapo-transpiration, groundwater percolation, recharge of aquifers and runoff outside the catchment), which can be used to classify the watersheds along with information from stakeholder interactions about demand and supply.
- *Understanding future catchment behavior requires the creation of a baseline and other scenarios that work in relation to the baseline.* Interpreting the scenarios in relation to the baseline produces more reliable results than the absolute value of the scenario outputs. While catchment-wide baselines and scenarios are useful and necessary,

the model can also be used to create scenarios for the project area in detail.

Iterative management planning: The hydrological assessment and management planning are part of the same mutually-supportive, synchronous and iterative process. Building cohesion and trust among the key stakeholders is vital, however, as is the creation of an appropriate institutional platform and conducive conditions for effective multi-stakeholder discussions.

- *Management planning can be initiated as a part of the process of stakeholder consultations.* Using information from the earlier stakeholder interactions and field visits and supplemented with model scenarios, needs to be viewed as an iterative and adaptive process.. While Google Earth is a relatively cheap and simple tool to create such interactive map-based discussions, it can also be done with more sophisticated maps and .tools based on remote sensing, which is the case in India with IWMP. One key advantage of using Google Earth and associated software, is that an interactive approach can be used in the field without an internet connection. Detailed planning will involve visiting each farmer's field to discuss specific options to improve water productivity, visiting village water bodies to assess what can be done to augment, protect and prioritize drinking water for humans and livestock, blending traditional knowledge and skills with modern techniques.
- *Assessing plan implications using the model is an iterative next step.* This will introduce the key features of the plan, including the total additional capacity of wells and RWH structures planned and options to reduce water demand and improve water productivity into the model. This can help create a separate scenario to assess potential hydrological impacts in terms of the water balance components.
- *Addressing downstream impacts will become important as planned interventions are likely to reduce surface or groundwater flows.* Discussions will have to be held with communities downstream to see how adverse downstream impacts can be minimized. But this is complicated if there are inter-basin transfers, dams, urban areas and ecological requirements which will then require locally-relevant and effective socio-political institutions and mechanisms to resolve the inevitable trade-offs when downstream flows reduce.
- *Finalizing the management plan will require additional considerations:* These include information to plan for the capacity building of individuals and groups, the strengthening of local institutions, the participation and contribution of local villagers to construction, implementation, monitoring and management of these planned interventions.

WATERSHED MANAGEMENT PROGRAMS

Scaling up from a single (pilot) watershed management project to a watershed management program at a national or sub-national scale or implementing such a management program at scale can also benefit from the lessons of applying this approach and methodology.

Selection and prioritization of watersheds

- *Use hydrological boundaries to define watersheds.* In India, the watershed atlas defines macro-watersheds, which can be a good basis for the selection of the catchment for modeling given that the chances of getting reliable data improves significantly at this scale. Alternatively, a program like SWAT could define these boundaries.
- *Select larger watersheds:* Apart from better data availability at larger scales, a distinct advantage of assessing a larger watershed is the opportunity to involve new stakeholders such as fishing communities, drinking water users, urban water users, lake and tank users and users of water in the downstream watersheds; their needs can and should be integrated into the planning process. More importantly, using larger hydrological units would enable integration of the potential impacts of micro watershed interventions on catchment hydrology into planning and monitoring. Planning for such large-scale catchment could enable tapping the expertise of agricultural scientists, hydrologists and water resource engineers.
- *Prioritizing watersheds is best done from upper reaches of catchments:* As currently being practiced

by the IWMP, starting with watersheds in the upper reaches is a good approach, as interventions to slow down fast moving streams can address soil erosion and help infiltration to groundwater, but this needs to be done using hydrologically-defined boundaries, unlike current practice.

Hydrological assessment

- *Modeling requires a cadre of trained hydrologists to service all project locations.* Available hydrologists should be put through a training program so that the approach taken to the modeling is similar and comparable. Modeling should be overseen by an institution with expertise in modeling, which should standardize the approach and methodology.
- *It would be better to use the same basic model across the program:* Although modifications can (and should) always be made based on local conditions (e.g., the addition of a groundwater model if groundwater aspects are critical).
- *Model set up will depend critically on the skill and experience of the modeler:* Institutionalizing hand-holding support from a centralized agency contracted to do so would help in the initial rounds of modeling to check quality of modeling outputs.
- *Data collection should be standardized, in terms of data requirements and the sources and quality of datasets.* A national government watershed management program should be able to provide modelers with access to the best possible country-specific data sets, which will significantly reduce data collection time but there will still be a need to collect local information through primary surveys (which can be standardized).
- *Model calibration and validation is best quality checked by experts.* How well the model is able to simulate catchment hydrology is best assessed by experts, preferably through an agency contracted to oversee the modeling process. Experts should be technically-qualified modelers with a background in both theoretical and applied aspects, who can be supported in the field by 'barefoot' hydrologists, ranging from villagers to college students with smart phones, trained to carry out certain basic measurements and data collection.
- *Model outputs should also be quality checked by experts.* Basic outputs such as the basic water balance of the catchment will also have to be checked by experts to ensure that they are in consonance with prior modeling results and expert opinion. Along with information from stakeholder interactions about water demand and supply (from the primary village surveys), these model outputs can be used to classify the catchment as per the types discussed earlier.
- *Creating future scenarios can also be standardized.* Certain basic scenarios can be standard across projects but the expert agency could also create additional scenarios as per need at both catchment-scale and also for specific project areas.

Iterative management planning: Both the hydrological assessment and the village planning are to be undertaken synchronously and iteratively.

- *Clear policy and institutional context is necessary for planning.* Multi-stakeholder discussions leading to agreements on a watershed plan will benefit greatly from rigorously-analyzed scientific information – although facilitated discussions will be necessary to ensure that there is cohesion and agreement among the stakeholders. These however, have to be carried out within a certain policy and institutional framework that sets out priorities for development in general and supportive regulation. In the Indian context (and possibly in some other countries) a mixture of government directives (based on economic, environmental, social and cultural factors) on say downstream releases at pre-determined points and timing (given rainfall) may be necessary as a context for further decentralized planning within the boundaries of these directives.
- *Management planning to be done with inputs from the hydrological model.* Field staff will have to be trained in carrying out village planning beyond what is normally done in IWMP at present, as a part of the process of stakeholder consultations, supplemented with model scenarios mapping tools. This will mean involving villagers interactively in discussions of local catchment characteristics and problems, using maps based

on remotely-sensed data. Detailed planning will involve visiting each farmer's field and jointly assessing village water bodies.

- *Assessing plan implications using the model is an iterative next step.* With special training and oversight from the expert group, at least in the initial stages, the key features of the Village Plans will have to be introduced into the model to create a separate scenario to assess potential hydrological impacts in terms of the water balance components.

- *Addressing downstream impacts will be a critical part of the watershed management program.* Most watershed interventions are likely to reduce surface or groundwater flows downstream and hence well-facilitated stakeholder consultations are necessary to see how to address these potential impacts. Sufficient time and resources should be made available for the planning process as communities will participate and invest in these discussions only if they feel the benefits outweigh the costs. Sustaining community involvement, however, will be a challenge and need further investigation and piloting.

LESSONS FOR IWMP

The hydrology-based approach and methodology for watershed management has several significant differences with the current approach (Table 2).

TABLE 2 DIFFERENCES WITH THE IWMP APPROACH AND METHODOLOGY

Issue	Current IWMP Approach	Suggested Revised Approach
Selection and prioritization of watersheds	Selection based on 13 criteria. Ridge to valley approach to prioritize selected watersheds, but without reference to hydrological boundaries. Size of watersheds selected (5000 ha) but not based on hydrological units.	Selection based on a hydrological assessment of a large watershed (macro-watershed as classified in the Watershed Atlas) and prioritized according to key development priorities set by the government as a major stakeholder. Within this macro-watershed, priority accorded on the basis of multi-scalar bio-physical and societal parameters, including protecting drinking water supplies, promoting livelihoods that can be only be addressed by improved water use and natural resource degradation (e.g., soil erosion caused by unchecked drainage lines). Sequence of hydrology-defined watersheds selected from upstream to downstream till the outlets of sub-watersheds within the watershed.
Hydrological assessment	Not done	Perceptual and simulation modeling at large watershed scale (e.g., 40,000 – 70,000 hectares), using information from secondary sources and stakeholder interactions
Village planning	Primary data collected using questionnaires and Focus Group Discussions, as part of a Participatory Rural Appraisal exercise, but only on existing RWH structures (but not geo-referenced). Planning usually finalized by technical experts with villagers asked to help with site selection. Limited discussion of alternative options and strategy to either raise water productivity or limit water demand (although micro-irrigation is promoted). Limited revisiting of village plans Little or no discussions with downstream communities on approaches to tackle possible reductions in downstream flows.	Primary data collected using questionnaires and FGDs, as part of a PRA exercise, directly aimed to collect (additional) information on hydrological aspects (e.g., geo-referenced information on wells and RWH structures and information on cropping patterns, crop durations, irrigation frequency, etc.) Village discussions informed by model outputs and scenarios. Detailed planning of water supply augmenting options (including for different farmer fields and for water bodies) and water demand management options (including micro-irrigation, mulching and switching to less-water intensive crops) aimed at improving water productivity (i.e., profit per unit of water). Iteration of village plans using model scenarios to minimize downstream impacts. Discussions for joint planning with all major stakeholder groups in the watershed on a range of issues including objectives of watershed management, sharing of benefits, water allocations and distributions of roles and responsibilities – which will also tackle, as one of the issues, possible reductions in downstream water flows.

Nonetheless, strategies to manage rising water demand from agriculture requires supportive policy and program actions, such as price support policies (to promote less water-using crops – or at least to *not* promote more water-using crops), electricity pricing (which is a major driver of groundwater exploitation) and policies and laws to regulate groundwater use, all of which have to be based on evidence-based research on potential impact, rather than just on expert opinion. Agricultural marketing remains a major concern (with production not translating into profits for many small and medium farmers), as are access to cheap institutional credit and better agricultural extension services. The responsibility for these, however, largely lies in Ministries and agencies outside the MoRD, which is responsible for implementing the IWMP. Convergence and coordination, thus, becomes a major issue.

Even for issues directly under the control of the MoRD, the responsibility for implementation lies with state governments, which can also pose limits to the effectiveness of policies. As the performance of national and state-level policies in India on a nationally-vital issue such as protecting drinking water needs has shown, it is not sufficient just to have central-government policies mandating the primacy of drinking water needs over other uses: their implementation is just as important. This is where coordinated action across different state government departments can play a vital role. A good example has been set by the World Bank supported Irrigated Agriculture Modernization and Waterbodies Restoration and Management (IAMWARM) project of Tamil Nadu, where staff from seven government departments and an agricultural university formed local teams to work in project villages. A major factor in developing this cohesion was the innovative 'behavioral change' experiment carried out to raise the motivation and commitment of government staff.

In many national schemes in India, including the IWMP, such policy changes are not within the control of implementing departments, and inter-agency coordination (or 'convergence') is confined to IWMP staff facilitating farmers in project areas to access schemes from other departments (e.g., for drips and new varieties of seeds). As a result, It is challenging for IWMP field staff and state level officials to facilitate better access to agricultural markets, credit, and non water-based livelihoods, all of which are critical to improved watershed management.

The establishment of policy and institutional frameworks to manage water and other natural resources within the (larger) watershed sustainably, supported by effective regulation and program support, is the need of the hour. This will require effective coordination between the various central Ministries and state government departments and a possible opportunity for such collaborative action is the new scheme recently announced, called the PMKSY program (which translates broadly to the Prime Minister's Small Farmer Irrigation Scheme), where the objective is to provide all small farmers with irrigation facilities. That said, however, the hydrology-based approach and methodology discussed here may not progress far if the IWMP is unable to invest time, effort and resources to raise (and use) the capacity of its staff for modeling and for facilitating stakeholder interactions, bring in (modeling) expertise and re-orient its activities to focus on improved watershed management outcomes.

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