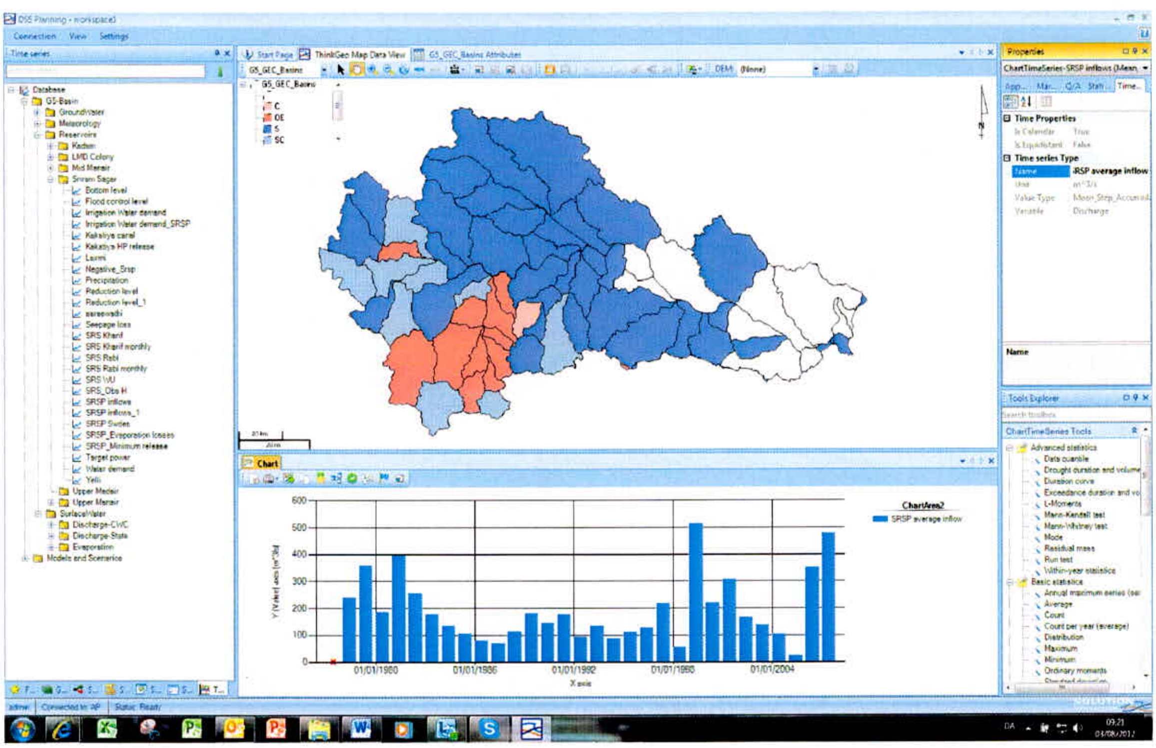
DHI

Development of Decision Support System (Planning) for Integrated Water Resources Development and Management

Final Report



National Institute of Hydrology
Final Report
August 2013

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National Institute of Hydrology

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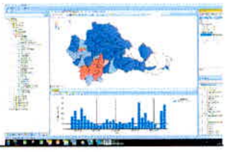

DSS (P) map and chart

Prepared for National Institute of Hydrology

Represented by Director R.D. Singh

Project No	11803440
Classification	Open

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Contents

Figures

Tables

Appendices

Archiving: All standard project files (documents, etc) are archived in DHI project site. Any other project files (set-up files, forcing data, model output, etc) are archived on an external hard drive located in the DHI project archive under Project No 11803440

1 Introduction

The Decision Support System Planning (DSS (P)) project has been implemented by the National Institute of Hydrology in India (NIH) and the Consultant starting December 1st 2008. The project objective was to develop a decision support system, the DSS (P), for integrated water resources development and management, customized to meet the requirements of the implementing agencies, particularly the nine participating states (Table 1-1). The planning elements considered in the project were surface water planning, integrated operation of reservoirs, conjunctive surface water and ground water planning, drought monitoring and management, and water quality. Within each state, one or more basins were chosen to illustrate the capabilities of the DSS (P) and were used in training technical staff in developing its functionality. This report describes the project implementation and its main results as well as provides recommendations for future activities. The contents of the report are as follows:

Chapter 1	Introduction
Chapter 2	Brief description of the developed DSS (P)
Chapter 3	Implementation of the project
Chapter 4	Development of DSS IT Infrastructure
Chapter 5	Application of the DSS (P) in the states
Chapter 6	Conclusions and recommendations

Table 1-1 List of participating states and case study areas

State	Case study area
Andhra Pradesh	Godavari 5 / SRSP
Chhattisgarh	Seonath Basin
Gujarat	Mahi Basin
Karnataka	Palar Basin and Tungabhadra Command Area
Kerala	Bharathapuzha Basin
Madhya Pradesh	Wainganga Basin
Maharashtra	Upper Bhima Basin
Odisha	Lower Mahanadi Basin
Tamil Nadu	Vaippar, Agnyar, Thambiraparani Basins

2 The DSS Planning Software

The DSS (P) has been developed to assist states in developing water management plans given current and future pressures and drivers affecting water quantity and quality within basins. The software includes a range of tools to process and analyse time series and GIS information designed to a greater awareness of current conditions in order to better understand and quantify current water management issues (Figure 2-1).

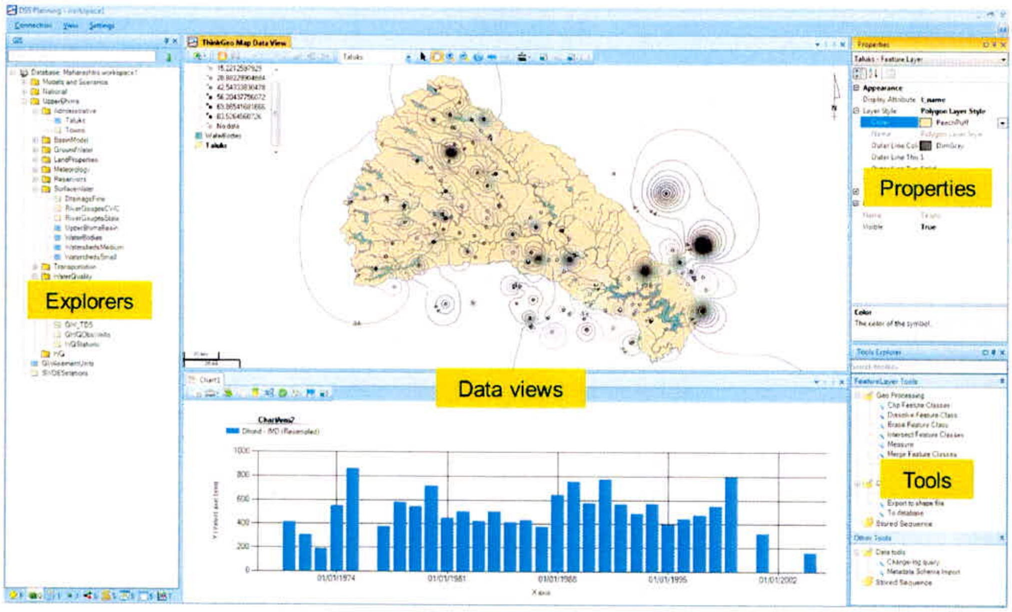


Figure 2-1. DSS (P) Planning Interface including the GIS and Time Series Explorers as well as directories of all the GIS coverages and the properties and tools explorers for editing and operating on the maps and charts.

In addition, a central part of the DSS (P) is the ability to import and apply models, which may be used by water managers for short- and long-term planning. The models simulate the impact of changes in water management (for example water demands) to derive consequences for water users and the environment, both locally and downstream. Examples of model application include:

- *Assessing the potential and impact of extracting additional water from reservoirs.* Using decades of historical inflow, models applied in the DSS (P) are used to test plans for increased water supply and quantify the risk of critically low reservoir storage at the end of the dry season and the likelihood of filling the reservoir in the subsequent wet season.

- *Managing drought.* Surface and groundwater use in drought prone areas is tested for long period of time, in which droughts occur, to assess the impact on the water storages in the drought periods and the sustainability of the water utilization on the longer term.

The DSS (P) also includes other elements to support water management activities:

- *Processing and analysing GIS and time series data.* Tools are available to easily import data to the DSS (P) database and make this data available to all relevant personnel with intranet access to the server. The user organization may thus provide common access to maps and time series data for all relevant personnel. A range of tools are provided to import, analyse, display, and quality assure the data or export it for external use. Links to other GIS provides are incorporated, e.g. Google Maps (Figure 2-2).

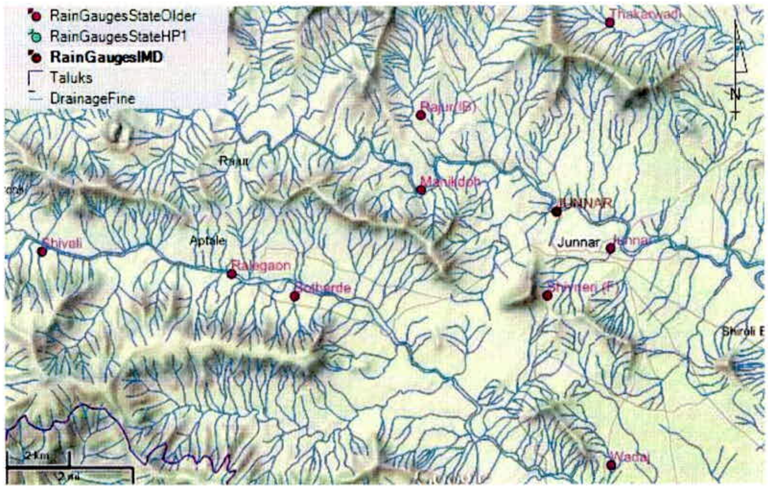


Figure 2-2 DSS (P) map showing streams and rain gauges over a Google Terrain background maps

- *Informing the public on the water resources situation.* While the tools mentioned above can be applied to prepare relevant tables and graphs of data and indicators, the DSS (P) also facilitates setting up web-pages with information to the general public or selected users. The information may include reservoir or groundwater levels compared to the usual levels at the current time of year.

The tools and components of the DSS (P) are all inter-linked and connected to the central database, providing a flexible and powerful DSS. The system may be installed at all relevant offices of the user organisation, from where intranet access to the DSS (P) server can be established, so that that it becomes a central hub for data, maps, models, and other information.

2.1 Prominent features of the DSS (P) software

2.1.1 Time series and GIS

The interlinking of the DSS components makes it possible to associate time series to the GIS layers, which show where the data has been measures, see below.

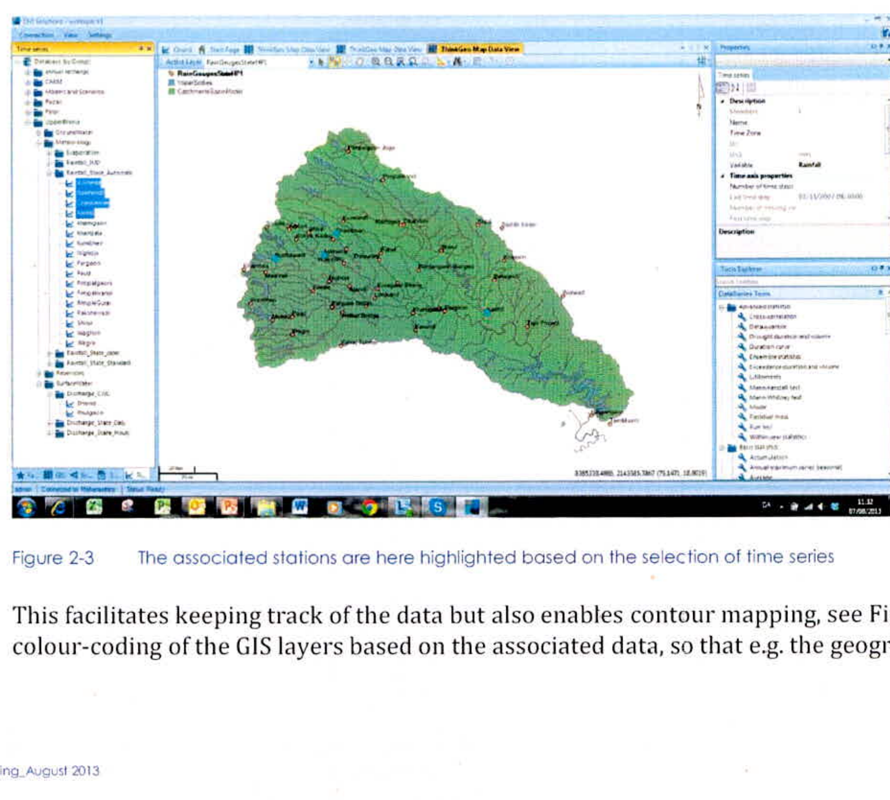


Figure 2-3 The associated stations are here highlighted based on the selection of time series

This facilitates keeping track of the data but also enables contour mapping, see Figure 2-1, or colour-coding of the GIS layers based on the associated data, so that e.g. the geographical distribution of average or maximum values can be illustrated. Tools available for time series and GIS data are listed below.

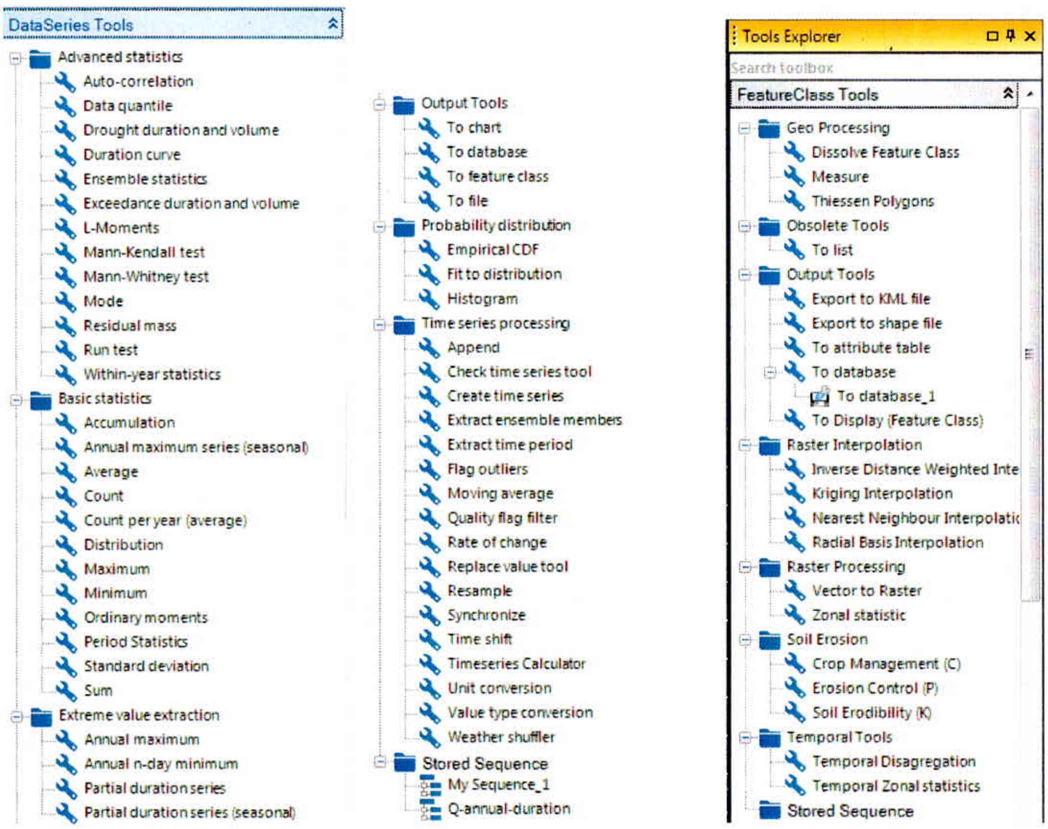


Figure 2-4 Tools for time series (two left columns) and GIS data processing

The GIS manager provides the ability to work with GIS maps within the DSS. It offers a number of visualization options as well as tools for spatial processing.

Time series and GIS data is stored in the database and may be queried and organized in groups using the explorer. The GIS explorer provides access to standard explorer functionality related to organizing groups, feature classes, and rasters.

All GIS vector data exposed in the GIS explorer are denoted "feature classes". If a feature class is added to a map the visualization of a feature class is denoted a "feature layer". Grid and image based data is exposed in the GIS explorer as "rasters". These are added to the map as a "raster layer".

The map data view provides functionality for navigation and layout. All navigations options are available in the toolbar in the top of the GIS data view and layout options are available through the property control.

2.1.2 Spreadsheets

A spreadsheet functionality has been incorporated to provide the users with well-known functionality to analyse and process data and model results. This became quite populate with the DSS Planning users and was therefore extended during the project, so that models could also be modified and executed directly from spreadsheets. The example below enables assessment calculation of crop water requirements for an irrigation scheme in a model based on the hectares for each crop. The compiled requirements are exported directly to the model.

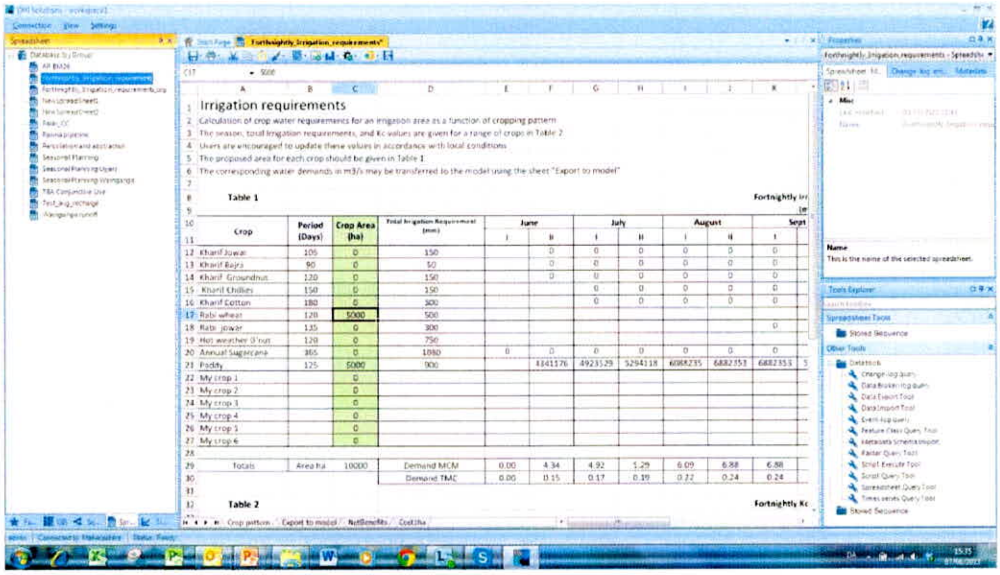


Figure 2-5 DSS Spreadsheet

The spreadsheet in DSS Planning allows users to use the tools related to GIS, time series or general mathematical or statistical tools to process the different data as well as model outputs for planning.

2.1.3 Scenario manager

River basin models may be imported to DSS Planning, applied to data within the DSS database and utilise the available tools to extract key results, which may support decisions.

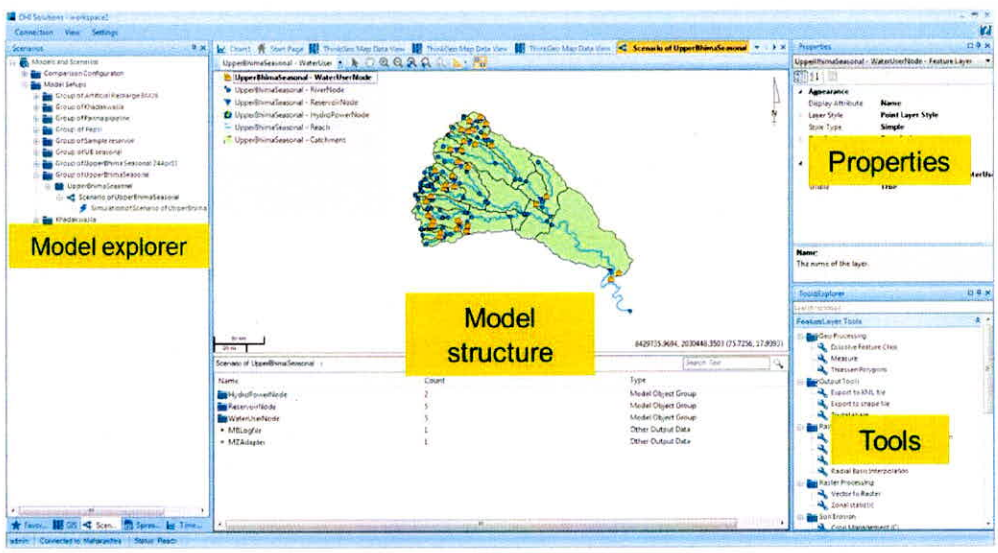


Figure 2-6 DSS Scenario manager

A range of examples of model application are given in section 5and **Error! Reference source not found.**.

2.1.4 Scripting

Scripting is the code written for different tools or applications which gives flexibility to the user for making his own applications or tools in DSS Planning or to customize the different processes to produce the outputs. The scripting is done in Python. Scripting in combination with the DSS spreadsheet forms a powerful user tool to automatize processes and make them more userfriendly for end-users, who are more concerned with the desired outputs than the processes involved. This also helps in analysing different scenarios without repeating the post processing of modelling results.

2.1.5 Dashboard Manager (DBM)

The DBM facilitates generation of web pages, including dynamic pages with content, which depend on time series or other varying information. The definitions may be calculated on-the-fly and stored on the web server. When the web pages are requested by a user in a web browser the definition is retrieved and the web pages is generated and sent to the user. The DBM is a client-server application.

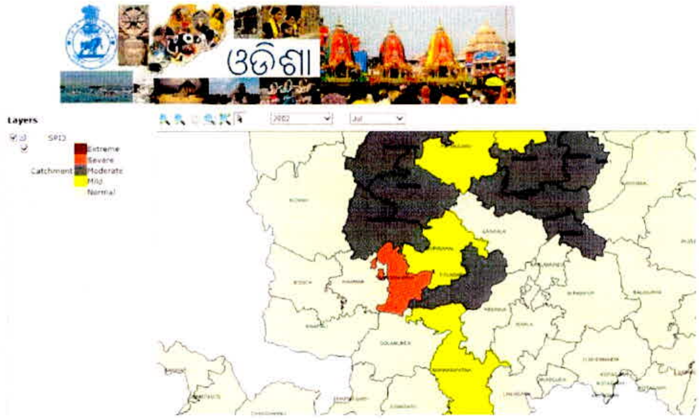


Figure 2-7 Sample applications of the Dashboard Manager showing drought indicators for an area in Odisha.

The DBM allows the users to make the information publically available on World Wide Web. It is also effective way of communication of results to the general public or update the public on day to day basis about the different information related to water resources like reservoir level, water availability, reservoir storages, rainfall etc.

3 Project implementation

The DSS (P) Project was divided in ten tasks that have been implemented as described below.

3.1 Task 1: Needs Assessment

All the nine states participating in the DSS (P) Project were visited during the first six months of 2009 to assess the requirements and limitations for developing a decision support system for water management in each state. Each state visit lasted one week and was conducted by an NIH-DHI team of 5-6 persons. During the visit, the team evaluated the water resources issues of concern in the state, the availability of required GIS and time series data, the modelling requirements to address these issues, the capacity of staff within the state governments to operate the DSS (P) to identify training needs, and assessments of the available IT hardware and software.

Results of the visits were summarised in the *Needs Assessment Report* (DHI, September 2009). Specifically, the report described the overall conditions found in the states, conclusions concerning the selection of pilot basin, capacity building needs, and time schedule of the project. This report was divided in ten volumes, covering the main report and a report for each of the nine participating states:

Volume I	Main Report
Volume II	Andhra Pradesh
Volume III	Chhattisgarh
Volume IV	Gujarat
Volume V	Karnataka
Volume VI	Kerala
Volume VII	Madhya Pradesh
Volume VIII	Maharashtra
Volume IX	Orissa
Volume X	Tamil Nadu

3.2 Task 2: DSS (P) Model Conceptualization

The overall structure of the DSS (P) was then defined considering the requirements of the implementing agencies. The definitions covered the overall structure, the modelling software to be associated with the DSS (P), and the structure and selected methodologies for each component. A range of DSS (P) Use Cases were derived in cooperation between NIH, the Consultant, and state representatives to formulate requirements for the DSS (P) and derive specifications. The *DSS Model Conceptualization Report* of January 2010 describes these Use Cases along with the overall structure of the DSS (P) and lists the main requirements to the software. It also describes the planned DSS (P) components in detail, outlines the required functionalities, and suggests a user interface.

3.3 Task 3: Database Development

The implementing state agencies, supported by NIH and DHI, invested considerable time and efforts in identifying, collecting, formatting, and importing data for their case study areas. This third task of the project was carried out to outline the structure and framework of the database development as well as to collect, format, and populate time series and spatial data into the database.

In a comparison of candidate database systems, it was concluded that the combination of PostgreSQL and PostGIS provides the most mature out-of-the-box GIS solution while being on par with the other solution with respect to DSS (P) requirements. This solution was therefore selected.

The associated requirements for procurements were described in the *Database Development Report* (DHI, April 2010), which also outlined the specifications, formats, and framework for the database, including software for interfacing with the relevant databases applied by the Implementing Agencies (IAs) for storing time series data, particularly the SWDES and GWDES. Overview of the data available at the time within each of the case study areas were also provided in the report.

3.4 Task 4: Generic DSS (P) Development

The DSS (P) Planning project has been implemented in parallel to other DHI projects with similar objectives:

- The NB-DSS (P) project was carried out during 2009-2012 to develop a decision support system for the Nile Basin Initiative, an organization created by the countries sharing the Nile River basin, to support water resources planning and investment decisions in the basin.
- The RT-DSS (P) development for the Bhakra Beas Management Board during 2008-2013
- The RT-DSS (P) for Krishna-Bhima in Maharashtra during 2012-2013

As the scope of these project were overlapping to some extent is has been possible to coordinate the development efforts and obtain mutual benefits for the projects. This has helped enabling development of a comprehensive, generic DSS (P) software package, which covers all the envisaged types of application. Only minor modifications have therefore been required when customizing the software to meet specific user demands.

The generic DSS (P) software was described in the *Generic DSS Development Report* (DHI, January 2011), from the user's point of view and demonstrations, covering issues of surface water, groundwater, water quality etc., were made using data of the pilot basin area, the Upper Bhima in Maharashtra. A description was also provided of how the other participating states may apply the DSS (P) to address the issues identified during Need Assessment. The report also included a detailed technical description of the software architecture.

3.5 Task 5: DSS (P) Customization

The customization of the DSS (P) software to meet the needs of the participating states was divided in three steps, each covering three states. Task 5 also included preparation of the *Interim Report*, which was provided in four separate volumes:

Volume I	A guide to water management in general and to the application of the DSS (P) Planning in particular. The report includes general recommendations as well as specific guidelines.
Volume II	Customization of the DSS (P) in three states: Maharashtra, with the pilot basin, Chhattisgarh, and Gujarat.
Volume III	Customization of the DSS (P) in three additional states: Karnataka, Madhya Pradesh, and Odisha.
Volume IV	Customization of the DSS (P) in the three final states: Andhra Pradesh, Kerala, and Tamil Nadu.

The reports described the software customization, which had been required to meet user demands. This was, as mentioned earlier, quite limited, as the generic software generally included all required functionalities. The reports therefore mainly described applications of the DSS (P) and provided inspiration to the users for additional types of DSS (P) use.

It was recommended at this time that the DSS (P) should be installed at all relevant offices in each state, from where intranet access to the DSS (P) server can be established, and that it be regularly used as a central hub for data, maps, and other information. It was also recommended that the states should initiate expansion of the DSS (P) application to other fields and other geographical areas.

3.6 Task 6: DSS (P) Testing/Refinement

While the highest number of DSS (P) applications were developed for the Upper Bhima in Maharashtra, DSS (P) testing was performed using data from all states. Tests were made within all the different types of DSS (P) application facilitated by the software. These have been elaborated to actual applications cf. the *DSS Application Report* of October 2012. This report also describes the software refinements, which were made on the basis of these tests.

3.7 Task 7: DSS (P) Application and Demonstration

To illustrate how the DSS (P) software can be used in water management, different types of application have been enabled. This task expanded the IA's technical staff abilities to use the spatial and temporal data along with modelling capabilities to develop applications. Specifically, the activities in the task were used to illustrate:

- The DSS (P) may be used as the central hub for water resources data and information of the state (geographical, meteorological, hydrological data, etc.). State staff may access the DSS (P) from a PC in or near their office via LAN or internet connections from other locations.
- River basin models may be developed and incorporated in the DSS (P) for long-term planning of water resources development and management and help assessing benefits and impacts of potential changes
- Many river basin models may also be applied for short-term planning, over the coming months, so that timely decisions may be taken such as assessing drought or seasonal planning of releases from reservoirs.
- The public and media may be kept informed on drought conditions, reservoir levels and other relevant characteristics through web sites, directly linked to the DSS (P) database.

Selected applications within the five planning elements of the DSS (P) Project are described in section 4 of this report.

3.8 Task 8: DSS (P) Evaluation/Fine Tuning

The DSS (P) Software was installed at the various implementing agencies whenever hardware was available, so that applications could be initiated. The experienced gained from applications of DSS (P) and recommendations from the various users have led to various refinements of the software, particularly the following:

- A range of improvements have been made to strengthen the GIS capabilities of the system. Several geo-processing and import-export tools are now available to work with vector and raster data directly in the DSS.
- The collection of available time series tools in the DSS (P) Software has been expanded and the linking between the GIS and time series data strengthened. While it is recommended that states maintain the data processing procedures introduced under HP-I, it may be beneficial to supplement these procedures using tools available in the DSS (P)

Software. Facilities for direct import of data from SWDES, GWDES, and HYMOS databases have been provided.

- River basin models have been developed for the case study areas and may be imported for application inside the DSS (P). The DSS (P) interface for this has been refined to accommodate user requests.
- The DSS (P) spreadsheet enables processing of historical time series and model data and results in a way, which is familiar to most users and therefore easily learned. Additional functionalities of the spreadsheet component have been introduced to support greater application of the spreadsheets (e.g. buttons to export data or initiate model runs).

Other fine tuning has been made in connection with the parallel project to develop the DSS (P) Software for the *Nile Basin Initiative*, which has led to additional development of facilities that were not required by the participating Indian states. These facilities are, however, built into the DSS (P) Software and are available to the IA's for water management.

3.9 Task 9: Dissemination/Training and Outreach Plan

The use of DSS (P) Software in water resources management is still new to the Indian states and most state employees have little background in IT. A comprehensive training program was initiated as soon as the components of the DSS (P) had been defined. The training focused initially on the modeling components, which are the most complicated elements, requiring considerable knowledge and experience by the users (Table 3-1). Following modeling training, DSS (P) software training was provided as were specialty courses in other elements such as groundwater modeling. The final training courses concentrated on refining the DSS (P) applications in each state and were done in course setting to promote the exchange of ideas between IAs.

Table 3-1 List of training courses conducted

Course	Time	Duration	Location	Participants
Rainfall-runoff and river basin modelling	October 2009	1 week	NIH Roorkee	NIH core group
Rainfall-runoff and river basin modelling	October 2009	2 weeks	NIH Roorkee	4-6 staff from each Southern state
Rainfall-runoff and river basin modelling	November 2009	2 weeks	NIH Roorkee	4-6 staff from each Northern state
Applying RR and RBM models for Upper Bhima	November 2009	2 weeks	NIH Roorkee	6 staff from Maharashtra
RR and RBM course II	January 2010	2 weeks	NWA Pune	6 from each southern state + 2 from CWPRS
RR and RBM course II	February 2010	2 weeks	NIH Roorkee	2-6 from each northern state
DSS (P) in water management	August 2010	6 weeks	DHI Denmark	1 staff from each state and CPCB
Introduction to Groundwater modelling	September 2010	1 week	NIH Roorkee	2-4 GW staff from each state
Introduction to DSS	October 2010	3 weeks	DHI Denmark	NIH core group
The Dashboard Manager	January 2011	1 week	NIH Roorkee	NIH core group
DSS (P) introduction and case study support	January 2011	2 weeks	NIH Roorkee	1-4 staff from each northern state
DSS (P) introduction and case study support	February 2011	2 weeks	NWA Pune	1-6 staff from each southern state
Groundwater modelling	June 2011	1 week	NWA	17 state GW staff

			Pune	
DSS (P) in water resources management	September 2011	3 weeks	DHI Denmark	3 state staff, 4 from NIH, 4 from central agencies
DSS (P) scripting and dashboards	November 2011	1 week	NIH Roorkee	NIH core group
DSS (P) application	January 2012	1 week	NIH Roorkee	2-7 from each northern state
DSS (P) application	January 2012	1 week	NIH Roorkee	3-5 from each southern state
DSS (P) scripting and dashboards	June 2012	1 week	NWA Pune	1-2 from each state.
Training of Trainers	Apr. to Aug. 2013	4 weeks	NIH Roorkee	NIH core group
Total duration of courses		38 weeks		

The courses were generally conducted by DHI in cooperation with NIH, from which core group members occasionally participated as instructors. Some courses were arranged specifically for the NIH scientists to enable their contribution as co-instructors in other courses and thereby strengthen their capabilities as trainers (Table 3-1). In order to ensure the best possible staffing on the project, states were initially asked to provide biographical information of 12 staff members from which the six best qualified were selected. Training material was developed for the various courses and this has been further elaborated and combined to a full Training Manual.

The training courses were followed up by on-the-job training and support by NIH and the Consultant in the states, so that DSS (P) applications could be developed and implemented in accordance with the prioritization of each user organization,

Training-the-Trainers courses were conducted towards the end of the project to facilitate continued training in DSS (P) use after the project completion.

The Consultant and NIH have further interacted with state senior officer at meetings and workshops in the states to create awareness of the technology and its potential to address water management issues. Key information on the DSS (P) Planning project and software has been provided throughout the project in a range of workshops and on the project web site (http://dssplanning.dhigroup.com/).

The multi-media presentations include web, flyers and brochures, and a video-presentation of the DSS (P), which can be seen on You Tube (search for *DSS Planning*).

3.9.1 Established capacity

The developed DSS (P) and associated river basin models have been applied to a range of analyses in the selected case study basins, see section 4. The applications have been made by the trained staff, most of whom have been involved in the project from the beginning and participated in the long range of training courses and on-the-job training activities in their state.

The state staff has been responsible for carrying out the DSS (P) and model applications from the early stages of the project, corresponding to the post-project situation. The capabilities of the participating state staff have improved considerably during the project, but are still limited in many IAs when it comes to applying the advanced elements of the DSS (P).

The number of trained and active DSS Planning users varies from one to four staff per user organisation. All are capable of applying the basic DSS Planning tools and existing model and able to develop new model applications within their case study areas. Some states also have users, who would be – or have already proven to be – capable of developing models outside the case study areas with little or no support.

Further strengthening of the state user groups is generally recommended for all implementing agencies, however, to ensure sustainability of DSS use.

3.9.1.1 Organizational strengthening

The DSS (P) Project has significant potential to support the management of water resources in India, and this is not yet fully utilized. As under HP-I, it is generally the State Data Centres that have provided staff for the DSS (P) Project activities under HP-II. The States' Planning Wings and Irrigation Circles have often not been involved although the developed tools would be particularly beneficial for these organizations. It is expected that more benefits may be derived from the DSS (P) if the organizations responsible for the water resources planning and management are more deeply involved in the applications.

The Consultant has proposed organizational strengthening in the states for continued use of the DSS (P) Software, see Appendix A. The figure below shows recommended organisational changes to strengthen the implementation of the DSS (P) Software. Two organisations may be established: a DSS User Group and a Water Planning Task Force.

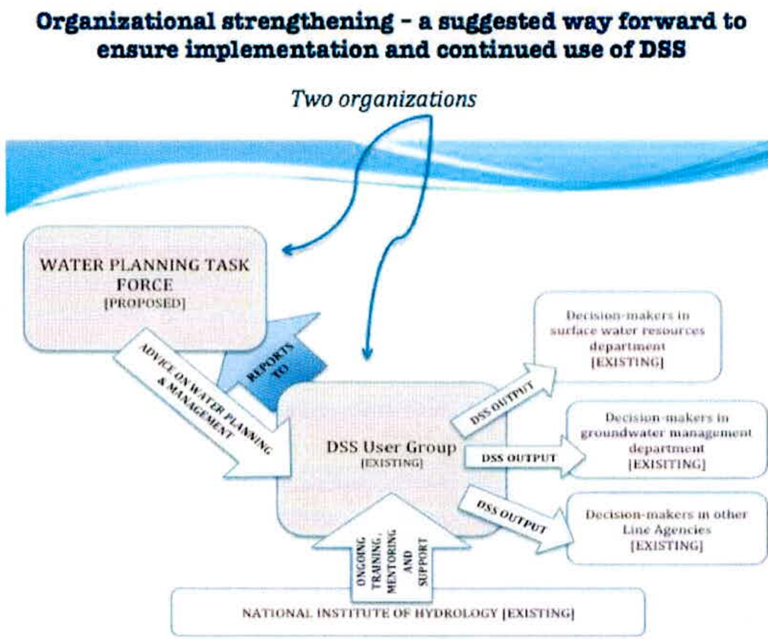


Figure 3-1 Organizational changes to facilitate DSS (P) use

A DSS User Group

The first step is to ensure that the key decision-makers, e.g. operational staff in seasonal water allocation, state agency and basin organisation water planners, are involved in the project through a functioning entity which is endorsed by the secretary of the leading water agency in each state.

The DSS (P) Applications in each state were developed to address specific water resources development, management and planning needs for those states. The way to link these DSS (P) Applications and their outputs more closely to decision-making in each water agency is to ensure the heads of key Line Agencies convene (or reconvene) a DSS User Group from water Line Agencies in their state and which includes the existing DSS (P) Software users from the project.

The DSS User Group can comprise:

- State water agency staff

- Water user associations
- National Institute of Hydrology adviser

The role of the DSS User Group can be to:

- Carry out the DSS (P) Applications including execution of models, review of scenarios and selection of preferred scenarios
- Establish and run a monitoring process on the implementation of the preferred outcome from the DSS (P) Application
- Report learnings gained from implementation of preferred scenario and use of DSS (P) Software to State Water Planning Task Force
- Improve/refine application of the DSS (P) Software in the light of learnings
- Distribute lessons learned from to Line Agencies associated with DSS (P) Project in each state at national workshops and web portals

State-level Water Planning Task Force

There is also a need for an organisation to coordinate action between the DSS User Group and line agencies in each state in the long-term, a Water Planning Task Force (WPTF). This may serve as the core decision support for state level water allocation and management decisions. It is also a good way of making the relevant people in each state aware of the DSS (P) Project and its possibilities.

The WPTF can comprise:

- Cabinet level water, agriculture, industry and other relevant ministers
- Senior advisers from relevant agencies
- Executive member of National Institute of Hydrology

The WPTF will – hopefully – appreciate the DSS (P) Project and help creating interest and regular application by relevant users, also outside the groups' project staff are in contact with now.

These recommendations are further elaborated in Appendix A.

3.10 Task 10: Final Report

This task involved preparation of the present report and conduction of a concluding workshop.

3.11 Project staffing

The staffing on the DSS Planning project has regularly been adjusted to provide the best possible support to the IAs in their on-going activities and fulfil project objectives. Compared to the original estimates it has been necessary to increase staffing in some area to meet IA demands, while a reduction could be justified in other areas.

Some changed occurred in key positions:

Team Leader	Chris Joy resigned in March 2009 and was replaced by Hans C. Ammentorp
Deputy Team Leader	Dr. K.S. Ramasastri was replaced by Dr. C.R. Singh in February 2012
Principle Expert Hy-	Hans C. Ammentorp maintained this position until the approval of Jens K. Lørup in March 2010. Considering the state requirements, Mr. Am-

drology	mentorp continued to provide hydrological support throughout the project as he already had an in-depth knowledge of the hydrological issues in the case study areas. Mr. Lørup has mainly contributed to training courses in Denmark and India.
Principle Expert Groundwater	While Henrik Sørensen participated in project activities in the initial stage of the project it was later found that the need for groundwater expertise was mainly within use of advanced groundwater models (MIKE SHE). Key DHI experts in this were therefore drawn upon, i.e. Douglas Graham and Oluf Z. Jessen.
Principle Expert Surface Water modelling	At the time of writing the proposal for this project it was envisaged that the SWAT model would be applied as part of the DSS. An expert in this software, Professor R. Srinivasan, was therefore proposed for the surface water modelling position. When the choice of modelling software landed on MIKE software it was decided instead to draw upon DHI staff, which has considerable experience in the application of this.
Senior Export Water Quality	Most of the water quality related activities have been carried out in cooperation with CPCB and focused on modelling. While the Senior Expert Anders Malmgren-Hansen supported these activities, most of the expertise has been provided by Flemming Thorbjørn Hansen, who is DHI's main expert in water quality modelling using MIKE BASIN.

The participating staff is listed in the following along with their main project contributions.

Organization / staff	Main project activities
DHI DK	
Hans Chr. Ammentorp	Project management and contribution to most project activities
Jens Kristian Lørup	Training in modelling and DSS (P) Application. Support to states
Henrik Müller	Training in Dashboard Manager and DSS (P) Software installation support
Anders M. Hansen	Water quality modelling in cooperation with CPCB
Børge Storm	Water quality modelling in cooperation with CPCB
Sara M. Lerer	Training in modelling and DSS (P) Application. Support to states
Douglas Graham	Groundwater modelling
Oluf Jessen	Special study on artificial recharge and groundwater modelling
Paul Glennie	Institutional development of DSS (P) Project
Roberta-Serena Blasone	Training activities
Flemming Hansen	Water quality modelling support
Claus Skotner	Overall DSS (P) Software planning and coordination
Lars Ekebjerg	In charge of overall DSS (P) Software development
Jesper Overgaard	In charge of developing DSS (P) Software data management facilities etc.
Anders Klinting	In charge of developing DSS (P) Software scenario management facilities etc.
Sten S. Larsen	Development of import tools
DHI US/AUS	
Carter Borden	Training in modelling and DSS (P) application. Support to states
Bruce Hooper	Institutional development of DSS
DHI India	
Dr. K.S. Ramasastri	Deputy team leader (2008-2012)

Dr. C.R. Singh	Deputy team leader (2012)
Dr. D. Pandit	GIS, Training and support to pilot basin DSS (P) Applications
Amit Garg	IT, training and support
Ram Prasad Yaddanapudi	Training and support to modelling and DSS (P) Project activities
Kavita Patil	Training and support to modelling and DSS (P) Project activities
Sagarika Rath	Training and support to modelling and DSS (P) Project activities
Sangeeta Thokchom	Training and support to modelling and DSS (P) Project activities
Prajnya Nayak	Training and support to modelling and DSS (P) Project activities
Tanmoy Ghorai	Training and support to modelling and DSS (P) Project activities
Yogesh B. Shete	Training and support to modelling and DSS (P) Project activities
Prabhanjan Alankar	Training and support to modelling and DSS (P) Project activities
Hemant Warad	IT, training and support
Dr. Anish Kumar	Modelling and DSS (P) Project activities
Rucha Dakave	Modelling and DSS (P) Project activities
Shivam Rastogi	IT, training and support
Amit Agarwal	IT, training and support

TCS

Prashant Shukla	Developer, TCS team leader
Sunny Mittal	Developer
Parveen Dhingra	Developer
Vipin Raturi	Developer
Vipin Jain	Developer
Ajay Bishnoi	Tester

External Consultant

Chris Joy	Project management

4 Development of DSS IT infrastructure in the states

The DSS Planning Software has been developed to be applicable over internet or intranet, so that user organizations easily can provide access to a central database for staff in other rooms, buildings or towns. This also implies that the software may be updated from a single point. The DSS Planning software has been installed on servers and workstations, and these are connected to the internet in all the nine states except Gujarat and Tamil Nadu, where state policies prevent open connections. A summary of the IT infrastructure developed under the project in the implementing states is given in the table below.

Table 4-1 IT Infrastructure

State	DSS on Server	DSS On-line	No. of Workstations	Database IP Address
Gujarat				
SW (Gandhinagar)	Yes	Yes	4	N/A
GW (Ahmedabad)	Yes	Yes	7	N/A
Kerala				
Thiruvananthapuram	Yes	Yes	>2 + Wireless	202.88.237.9
Trissur	Yes	Yes	1	117.204.127.319
Karnataka				
SW	Yes	Yes	5	117.218.106.124
GW	Yes	No	2	Not Available
Tamil Nadu				
WRE	Yes	Yes	5	
Odisha				
SW	Yes	No	4	117.218.1.57
GW	No	No	1	
Andhra Pradesh				
SW	Yes	Yes	4	117.239.147.65
GW	Yes	Yes	6	
Madhya Pradesh				
Data Centre	Yes	Yes	4	
Chhattisgarh				
Data Centre	Yes	Yes	2	115.249.43.116
Maharashtra				
GW	Yes	Yes	2	203.199.162.240
SW	No	No	2	
NIH				
Roorkee	Yes	Yes	> 9	117.240.104.33

Thirty (30) licenses for MIKE BASIN and MIKE 11 NAM have been supplied. The users have also been given access to a total of 40 additional licenses in the duration of the project to facilitate completion of their model development activities.

The permanent licenses have been distributed as follows:

- each state has received two licenses. The licenses for Tamil Nadu also include MIKE SHE, which is being applied by this state.
- one license has been provided to each of the central agencies, which have participated in the project and received training.
- The remaining licenses have been provided to NIH

A new version of MIKE BASIN has recently been made available under the name of MIKE HYDRO and it is planned to upgrade the DSS (P) installations to use this version during the coming maintenance period and provide training accordingly. To facilitate this, all licenses have already been upgraded to include both the old and the new version.

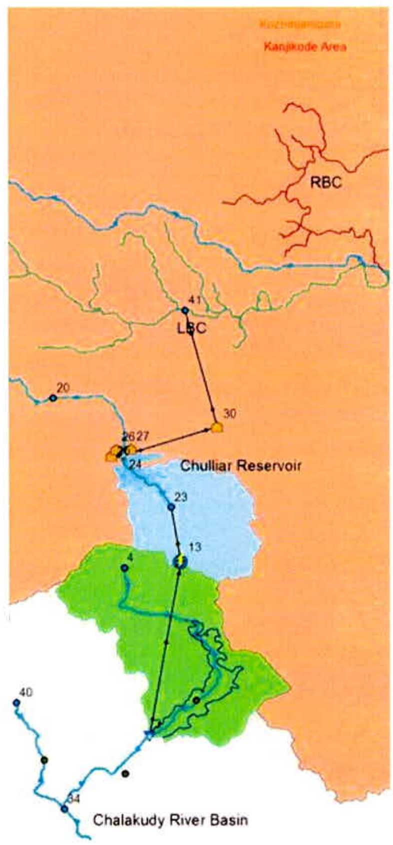
5 DSS Applications

Selected examples of DSS (P) Applications made by the IAs are given below within the fields of surface water planning, integrated operation of reservoirs, conjunctive surface water and ground water planning, drought monitoring and management, and water quality.

For further details and descriptions of additional applications see the DSS (P) Application report.

5.1 Competition for surface water

The Kanjikode Industrial area in Kerala is growing and so is the water demand in the area, which lies within a rain shadow region. The DSS (P) has been applied to assess alternative sources of water to supplement the groundwater, which is being extensively exploited. Different options have been explored:

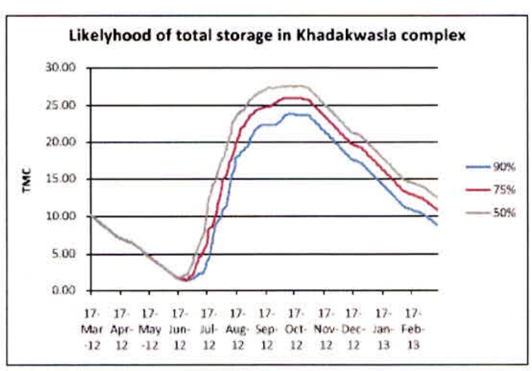


- Augmenting water from the Malampuzha Reservoir. Analysis of the data of this reservoir revealed, however, that excess water is rarely available, so this option is not feasible
- Construction of check dams in the area. These may supply surface water in the wet season and will increase the groundwater recharge and thereby increase groundwater availability in the dry season. There are, however, a number of check dams in this area already so the potential of this option is insufficient
- Extensions of the right bank canal (RBC) of Moolathara Regulator so as to harness the flood water in the perennial Chitturpuzha River and to divert it to the rain shadow area. This was found to be a viable option as water can be diverted during the monsoon season to augment the groundwater table.

A possibility of strengthening the latter option through combined inter-basin transfer and hydropower augmentation has also been analyzed. The tail water after generation of power from the Karappara Reservoir would be led into the reservoir formed by the construction of a weir at Kuriakutty. After generating power, the water is stored in Chulliyar Reservoir and subsequently used for irrigation in the LBC, which often experiences water scarcity.

The analysis indicates a good potential for the hydropower production as well as increasing the water availability for irrigation significantly. This would also permit additional diversion of water to the RBC and thereby to the Kanjikode Industrial Area.

5.2 Integrated reservoir operation



Seasonal planning

A fraction of the water stored in a reservoir is normally reserved to ensure delivery up to the start of the next wet season, even if this is delayed. The minimum storage in a year is therefore often representing a considerable amount of water, which might have been utilized while taking a calculated risk. The DSS

(P) can help assessing this potential through model tests of additional water allocation and evaluation of the associated benefits and risks. Each model includes decades of historical, daily inflow to the reservoirs in the model area as a basis for assessing the likely inflow in the future. Considering the reservoir levels of today and utilizing this historical inflow information, the DSS (P) provides answers to the following questions for given scenarios of planned water allocation:

- What is the risk of reaching critically low levels this dry season?
- What is the likelihood of filling the reservoir in the coming wet season?

This example shows the likely development of the total storage in four reservoirs supplying water to Pune City, industrial areas, and local irrigation schemes in Maharashtra. The storage may be expected to exceed the 50%-curve every second year in average and the 90%-curve in 9 years out of 10. These curves may change over time depending on the actual water allocations and losses, so it is recommended to perform the analysis regularly. Reduction in water allocations was necessary up to the 2012 monsoon in this area, and the DSS (P) helped Maharashtra decide on the timing and magnitude of the required reductions.

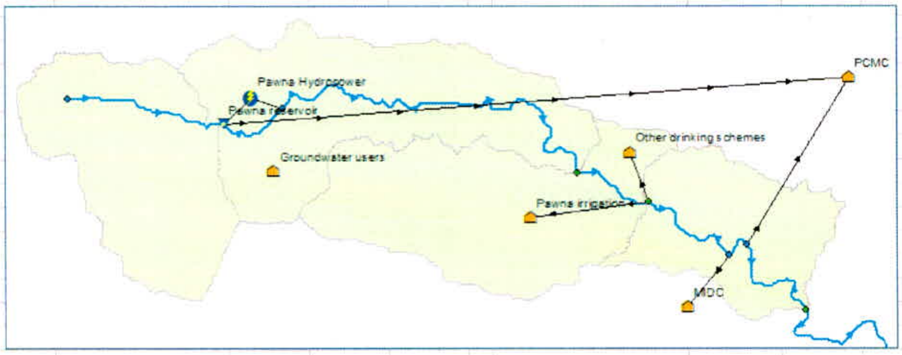
Pawna pipeline

Also in Maharashtra, a riot occurred in August 2011 near Pune as farmers protested against a planned pipeline, which will divert water from the Pawna Reservoir to the PCMC industrial area. This water, around 5 m^3/s, is currently being supplied via the Pawna River, from where it recharges the groundwater to the benefit of these farmers.

Figure 5-1 Three were killed and 25 policemen injured during the August 2011 riot at Pune

The DSS (P) was applied to assess the impact of the proposed pipeline. The DSS (P) spreadsheet was used to summarise the results, as shown below.

Pawna pipeline: concequences of implementation



	MCM/year						
Water supply average	River	Pipeline	Increase	**Power balance**	kWh/year	Rp/kWh	Lakh Rp/year
GW user	34.69	33.88	-0.81	HP Production (pipeline)	6,262,760	2.5	156.57
Pawna irrigation	13.16	13.18	0.03	HP Production (river)	13,832,395	2.5	345.81
Other drinking	16.73	16.76	0.03	Lifting at PCMC (pipeline)	0	3.5	0.00
MIDC	17.33	17.34	0.02	Lifting at PCMC (river)	16,350,000	3.5	572.25
PCMC	157.52	157.84	0.31	Benefit of pipeline	8,780,365		383.01
Water supply deficit	River	Pipeline	Increase	**Other changes**			
GW user	0.00	0.83	0.83	PCMC water treatment costs will reduce			
Pawna irrigation	0.03	0.00	-0.03	Non-monsoon river flow will reduce			
Other drinking	0.03	0.00	-0.03				
MIDC	0.02	0.00	-0.02				
PCMC	0.31	0.00	-0.31				

Figure 5-2 Summary of results for the Pawna pipeline analysis set up in the DSS (P) spreadsheet

The analysis compared simulations of the current and proposed situation with and without the pipeline. It was found that all the official water users would benefit from the pipeline as water supply deficits, which are already rare, would not occur at all during a hydrological period similar to 1970-2009. While the analysis indicated a reduction in the hydropower production at Pawna dam it also showed that the total power balance for the area would be positive when considering the reduction in power consumption at PCMC, where the water is currently lifted 64 meters.

Flood analysis

Flooding occurs from time to time within the Upper Bhima catchment and downstream of the Ujjani Reservoir. This is typically caused by heavy rainfall throughout the catchment area, causing many reservoirs in the upstream area to spill simultaneously and creating high inflow to Ujjani Reservoir.

The guide curves, which have been defined for each reservoir, limit the reservoir levels in the monsoon so that some flood cushion is available throughout the season of high inflows. The reservoir operators may deviate from the guide curves in a potential flood situation, however, if this can reduce maximum outflow from the reservoir and thereby limit flooding levels downstream.

Reliable forecasts on the reservoir inflow can enable more efficient flood mitigation, as water can be released from the reservoirs before the high inflow starts and additional storage thereby created to retain the flood runoff.

This has been tested for a severe flood event for scenarios of 0-, 1-, and 2-day inflow forecasts.

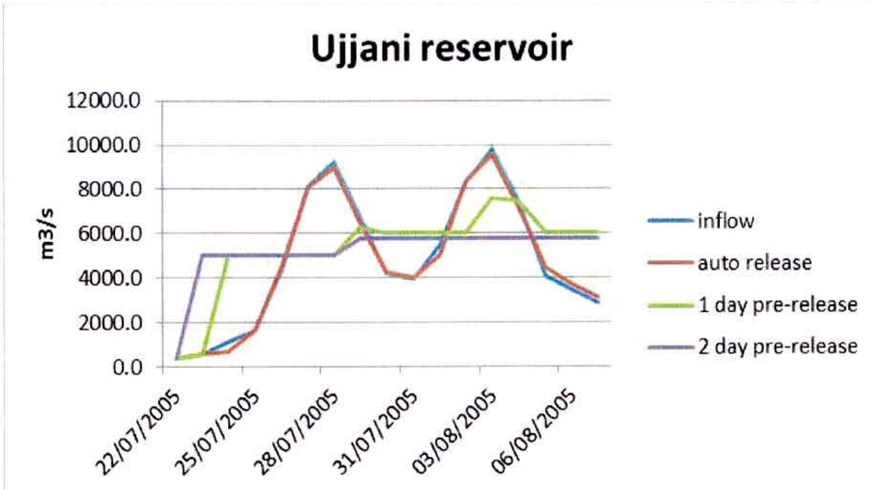


Figure 5-3 Graphical representation of the Ujjani inflow and outflow in the three scenarios.

For the tested event it was found that the forecasts enable a reduction in the flow peaks downstream of the Ujjani Dam from 9550 m^3/s to 7590 or 5800 m^3/s respectively with 24 or 48 hour forecast. Most of this effect is obtained by the operation of Ujjani Reservoir, but the upstream Pawna and Mulchi Reservoirs also contribute. The analysis has shown a significant reduction in the maximum flood values downstream of Ujjani Dam. Flooding of urban areas downstream of the dam commences at a flow of 7800 m^3/s, so this is avoided in both scenarios 2 and 3.

5.3 Conjunctive surface and ground water use

Irrigation water requirements from reservoirs may be reduced if part of the water demands is met from groundwater and this can also help reducing the risk of water logging. Andhra Pradesh has already implemented this successfully in some command areas.

The DSS (P) has been applied to model the impact of conjunctive use along a selected distributary within the Sri Ram Sager project in Andhra Pradesh, see below.

Figure 5-4 The distributary D83 and associated command

The command area is here divided in three separate areas representing the head, middle, and tail end reaches. Natural groundwater recharge has been generated for these areas using a hydrological model. The irrigation water users within each area are divided in groundwater users and surface water users, and the latter will automatically supplement with groundwater whenever the available surface water is insufficient.

Two scenarios have been compared:

I. No restriction is imposed on the surface water use along the distributary. The head and middle end users have unlimited surfaced water available while the tail end users are required to supplement significantly with groundwater.

II. The head and middle section users are limited to take only a fraction of their water requirements from the canal, so that the balance is abstracted from groundwater.

The plots below show the impact on the depth to groundwater in each area over a period of eight years.

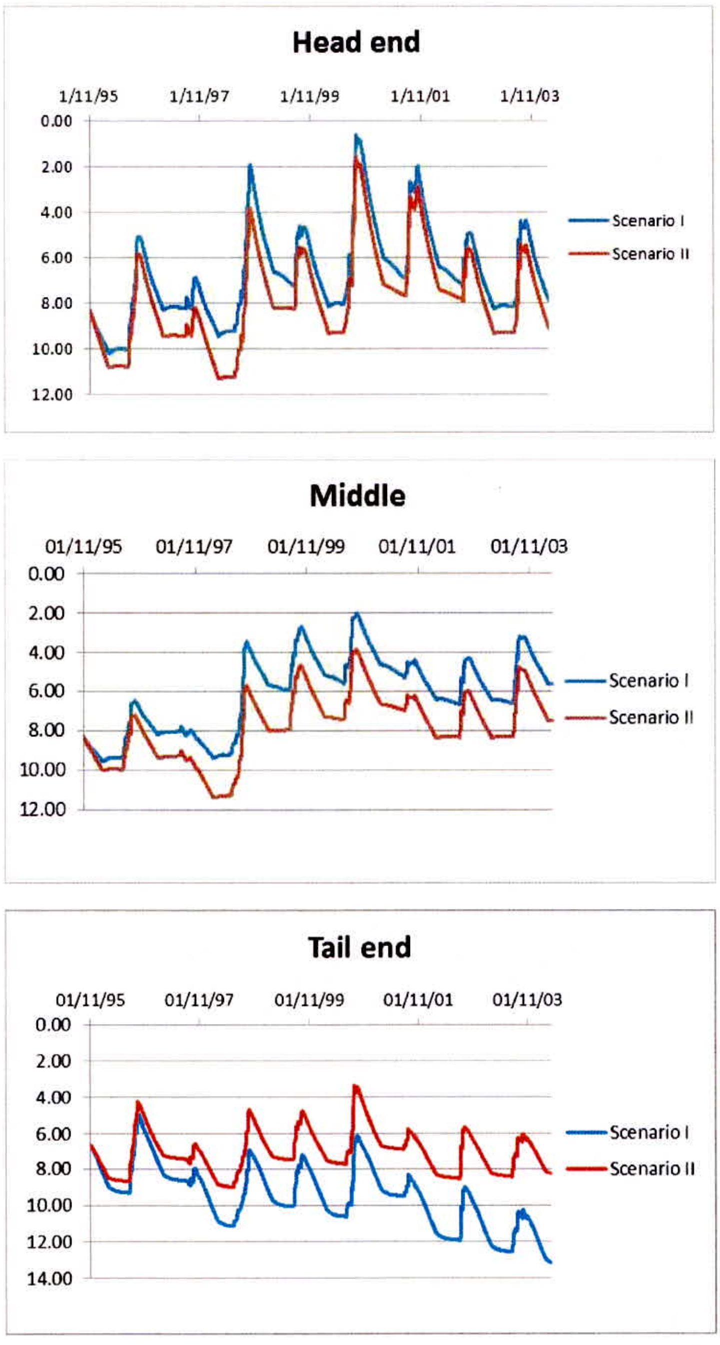


Figure 5-5 The simulated depth to groundwater in metres at head, middle, and tail end of D83

The plots indicate that it is possible to increase groundwater use in the head and middle reaches without introducing a falling trend in the groundwater level here. The corresponding reduction in the abstraction from the canal to these areas allows for more water to continue down to the tail end, where the need for groundwater abstraction thereby is reduced, so that the falling trend in the groundwater level is eliminated.

Artificial Recharge

The potential of increasing groundwater availability through a range of artificial infiltration structures has been tested for a selected watershed. In a scenario of increased water demands from groundwater, the depth to groundwater has been simulated over a 40 year period to indicate the sustainability of this utilization with and without the proposed artificial recharge, see below.

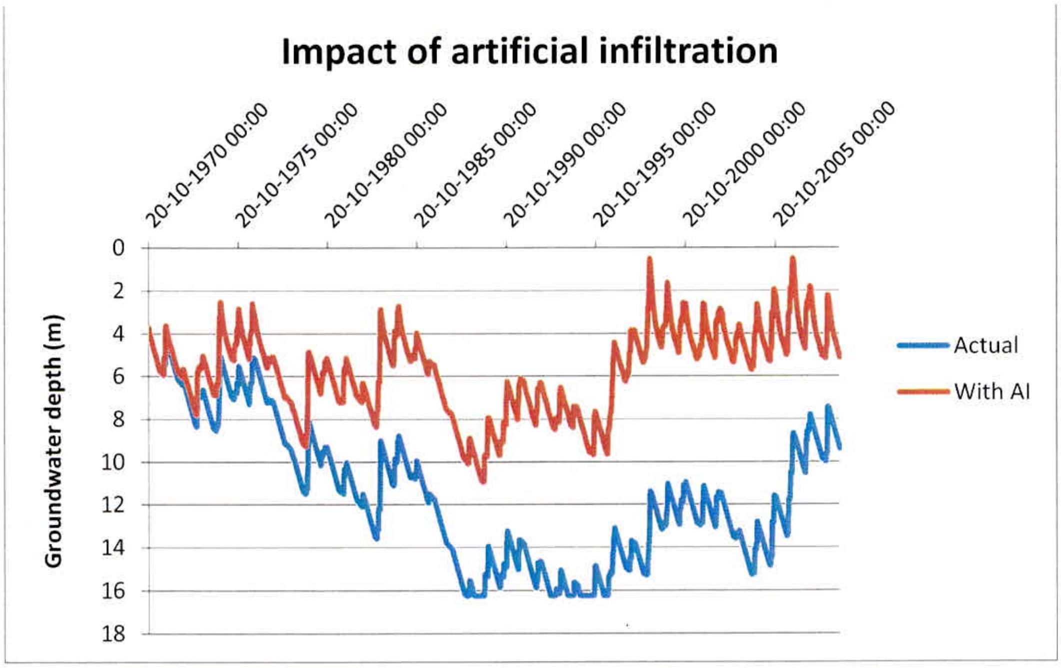


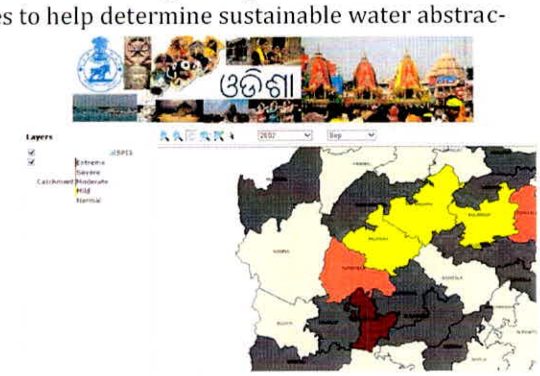
Figure 5-6 Simulated groundwater depth with and without artificial infiltration

The simulations indicate that increased draft will only be sustainable with the artificial recharge in place. Note that an analysis based only on the recent, relatively wet years would have given the false impression that increased groundwater pumping would be possible also without the artificial recharge.

5.4 Drought management

The management of drought is highly prioritised by the participating Indian states. Drought situations are often characterized by low post-monsoon storage in surface water reservoirs and falling groundwater levels, as the utilization of groundwater typically exceeds the recharge. This may be acceptable for a limited period of time provided the groundwater levels may be expected to return to normal levels during subsequent years with average or high rainfall. Different model applications have been made in various states to help determine sustainable water abstraction in these situations.

Tools are also available to generate web-pages, which are linked to the DSS (P) database and built on-the-fly based on database information. These may be used e.g. to indicate the likely severity of future drought, based on recent measurements, and thereby the need for remedial measures in the coming months.



This is illustrated here, where drought conditions are monitored through indicators for each watershed, showing the severity of drought in colour, dark red indicating extreme conditions.

Check dams

It is increasingly common in India to recharge the groundwater during the wet season by local runoff through check dams, abandoned groundwater wells, infiltration tanks or other means. While this has been implemented at many locations, little information is available on the efficiency of the infiltration structures. The efficiency of a recharge pond to increase water availability has been tested for a selected site within the Bharathapuzha basin, Kerala, as shown below.

Figure 5-7 A proposed recharge pond is modelled to assess the increase in groundwater availability

The amount of water which can be infiltrated is assessed on the basis of the estimated infiltration capacity of the pond and the variation of surface runoff, available from the hydrological analysis carried out. Evaporation losses from these facilities are also taken into account.

The dam was assumed to create a small lake with an average depth of 2 meters, a length of 1000 m and an average width of 30 m. The infiltration was set to 1.7 mm/day while evaporation losses varied from 4 to 10 mm/day. With negligible abstraction, water was simulated to remain in the artificial lake all year round. It was found that each recharge pond would infiltrate 0.017 MCM/year while the evaporation losses are 0.061 MCM/year corresponding to 3.6 times the infiltration. The infiltrated water is assumed utilized by the local groundwater users, located within 2 km^2, who could increase their pumping by 10% in this case. The actual increase in groundwater availability depends on the groundwater level and will be relatively low in years with high level as baseflow losses will also be high. This analysis indicates that check dams and recharge ponds are not a very efficient method to increase water availability, and it illustrates the importance of considering downstream water users when planning these structures.

5.5 Water quality

The possibility of utilizing groundwater is limited in many areas due to the high concentrations of e.g. nitrate or fluoride. The DSS (P) includes tools to provide an overview of the water quality situation and illustrates the variation from year to year directly from the data. The example below shows the fluoride concentration in groundwater in colour-code, generated directly from the measure data.

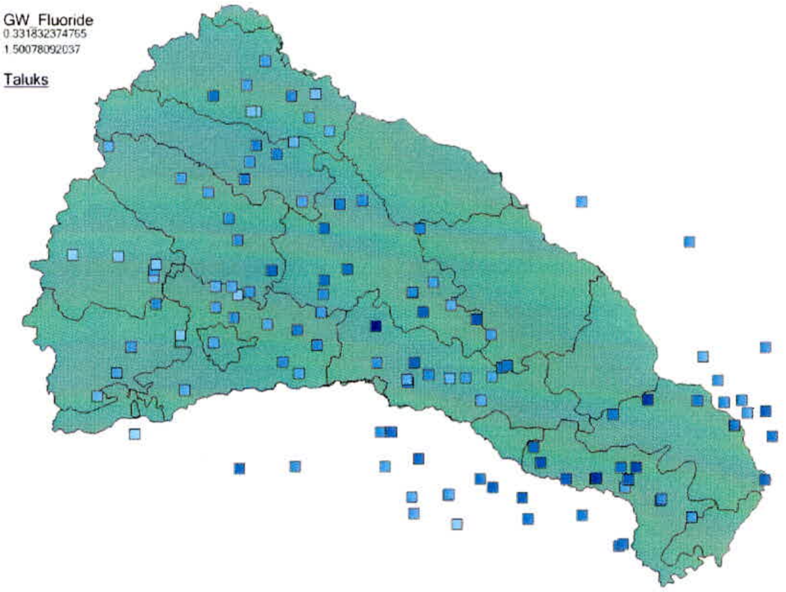
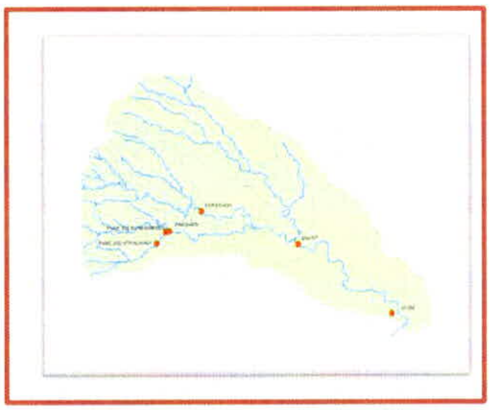


Figure 5-8 Fluoride concentration in groundwater

Maps of this type are useful in the planning of groundwater utilization and mitigation measures.

Water Quality Modelling of Upper Bhima Pilot Project Area



The water quality of the Upper Bhima has been analysed in a model prepared by Central Pollution Control Board (CPCB) and DHI with support from the Government of Maharashtra.

MIKE BASIN has been applied as a screening tool to identify the relative impacts of the analysed scenarios. The model applications include an assessment of pollution loads from urban, industrial, and agricultural sources and their impact on the river water quality. Based on the calibrated model, analyses were performed to identify the relative contribution from waste water treatment plants (WWTP) and diffuse sources, and scenarios of the impact of future population growth and climate change were analysed.

5.6 Climate Change

Concern for the effects of climate change has started rising in India. Several years of late arrival of the monsoon and severe droughts are deeply affecting the agricultural sector in many states. Developing strategies to adjust to predicted climatic changes will be important for water managers in developing comprehensive, adaptive water plans. The DSS (P) can be used by water managers to predict how future climate conditions will affect the availability of water resources given the variety of climate scenarios, e.g. as reported by the Intergovernmental Panel on Climate Change.

A climate change analysis has been made for the drought prone Palar basin, Karnataka, where groundwater levels dropped dramatically in recent years.

Meteorological time series for the future were generated using the *delta change approach*, in which the expected change in precipitation, temperature, and evaporation is assessed from a range of global or regional climate models in terms of monthly scaling factors. The climate change scenario was chosen as emission scenario SRA1B and the driving meteorological series altered accordingly, so that the impact on groundwater could be simulated

The analysis made for catchment C2 within the Palar basin shows a net increase in the groundwater level with a quicker recovery following the drought years (2002-2004). The conditions in dry years are basically unchanged, but increases in the wet season rainfall cause increased recharge and thereby high groundwater levels. The results indicate that in future conditions, groundwater availability will increase and thus can support additional water use for drinking water or irrigation or be used to recuperate dropped groundwater levels.

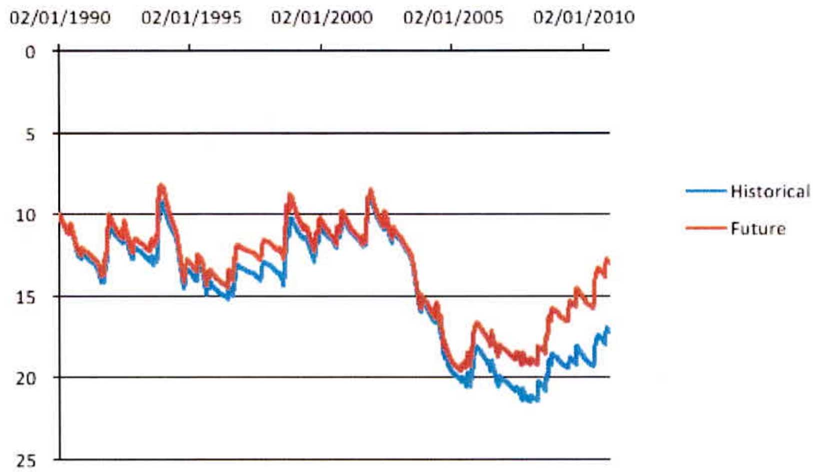


Figure 5-9 Average depth to groundwater for the C2 Catchment as predicted from the Palar RBM for the Historic (blue line) and Future Scenarios (red line). Units are in m^3/s.

The Palar model also indicates greater surface runoff with higher peak discharges as well as baseflow. The net result is a 20.8% increase in surface water runoff under new climate conditions and same abstraction rate.

5.7 Status of DSS Application in the States

At the time of planning the DSS, in 2009, different applications of the future DSS were suggested by each state, as described in the Needs Assessment report. Most of these have subsequently been carried out although some states chose to address other issues of higher priority by the time that the DSS was ready to be used.

The table below lists the status of DSS application in the Implementing States

Overview of state applications

	CHHATTISGARH		
	Activities	**Status**	**Comments**
1	Support decision on reservoir/ tank operation in dry years	Completed - Seasonal planning for Tandula Complex	-
2	Conjunctive use in command areas	Completed	-
3	Demonstrate benefit of change in cropping pattern	Completed for Tandula Command Area	-
4	Canal lining	Completed	-

5	Inter basin Transfer (Transfer of water from RSP to Tandula Tank)	Completed	** Additional Application
6	Update DSS (P) server and Online connection	Completed	-
7	Generalized Interface	Seasonal Planning for Reservoir ; Conjunctive Use of SW & GW	-
8	Additional Interface	Tandula complex seasonal planning Completed	**Additional Application
	MADHYA PRADESH		
	Activities	**status**	**Comments**
1	Assessment of surface and ground Water Availability in Wainganga basin	Completed	-
2	Crop selection and corresponding water requirement	Completed - Seasonal Planning of Sanjay Sarovar Reservoir.	-
		Completed - Impacts of Changes in cropping pattern, particularly in dry years	-
3	To assess the impact of rehabilitating the infrastructure	Completed - Maintenance of irrigation canals and impact on water use efficiency and availability.	-
4	Identification of efficient use of water by the projects, which are existing and under construction	Completed - for Rajiv Sagar Project	-
5	Update DSS (P) server and Online connection	Completed	- ADSL BSNL connection has been procured with Static IP address, which needs to be configured to the server (directly or through the router). - The service provider needs to set up the Static IP address. - Once IP address is configured, it just need to replace the local IP address by the Static IP address and connect to the server from outside the local network.
6	Generalized Interface	Seasonal Planning for Reservoir ; Conjunctive Use of SW & GW Completed	-

7	Additional Interface	Seasonal Planning for Reservoir and crop selection Completed	-
	ODISHA		
	Activities	**Status**	**Comments**
	Hirakud		
1	Conjunctive use	Completed	-
2	Mitigating water logging through increase GW pumping	Completed	
3	Changing cropping patterns to increase benefits for the farmers without increasing water abstraction	Completed	-
	Upper Tel		
4	Demonstrate benefits of changed cropping patterns	Completed	-
5	Drought Management in Upper Tel Basin	Completed - Artificial recharging	**Additional Application
6	Dashboard for drought monitoring	Completed	**Additional Application
7	Update DSS (P) server and Online connection	Completed	-
8	Additional Interface	Completed	-
9	Generalized Interface	Seasonal Planning for Reservoir ; Conjunctive Use of SW & GW	
	KARNATAKA		
	Activities	**Status**	**Comments**
	Palar		
1	Drought management in the basin	Completed	
2	Identifying recharge areas	Not feasible	** Instead additional application was taken up
3	Impact of cropping pattern change	Completed	
4	Artificial recharge	Completed	
5	Climate change application for one of the sub-catchment	Completed	**Additional Application
	Tungabhadara		
1	Water logging at head end	Completed - Conjunctive use model for Tungabhadhara command area (distributary-wise)	

2	Water scarcity at tail end user	Completed - Conjunctive use model for Tunga-bhadhara command area (distributary-wise)	
3	Increase in soil salinity	Not feasible	** Instead additional application was taken up
4	Seasonal planning for Tunga-bhadhara	Completed	** Additional Application
5	Generalized Interface	Seasonal Planning for Reservoir ; Conjunctive Use of SW & GW	-
6	Additional Interface	Seasonal Planning for Tungabhadhara completed	-
7	Dashboard	Groundwater scarcity completed	-
8	Update DSS (P) server and Online connection	SW DIVISION: Completed	-
		GW DIVISION: Completed	-
	KERALA		
	Activities	**Status**	**Comments**
1	Evaluate and compare scenario for water management in basin	Completed - Bharatapuzha basin	
2	Water Management for dry year	Completed - Bharatapuzha basin	
3	Hydropower	Completed - Karappara	
4	Groundwater - (a) Impact of sand mining (b) measure to increase GW infiltration	Completed -(2) Artificial recharging	- Impact of sand mining not feasible
5	Sustainable environmental flows and ensuring acceptable WQ in lower reach	Completed - WQ model in Bharatpuzha	-
6	Industrial demand v/s groundwater use	Completed	** Additional Application
7	Inter-basin transfer for conjunctive use	Completed	** Additional Application
8	Impact of change in cropping pattern	Completed	** Additional Application
9	Update DSS (P) server and Online connection	Completed	-
10	Generalized Interface	Seasonal Planning for Reservoir ; Conjunctive Use of SW & GW completed	-
11	Dashboard	Bharatapuzha Basin	** Additional Application
	GUJARAT		
	Activities	**Status**	**Comments**
1	Increase efficiency of water management	Completed	-

2	Improving conditions in drought prone areas	Completed	-
3	Reduced periods of inundation in low-sloping command areas through conjunctive use, weather forecasts, or improved drainage.	Completed	-
4	Assessment and monitoring of surface and GW quality	Completed	-
5	Update DSS (P) server	Completed	-
		Completed	-
6	Generalized Interface	Seasonal Planning for Reservoir ; Conjunctive Use of SW & GW completed	
7	Interface	Seasonal planning for Patadungri; Dependable year estimation completed	**Additional application
	ANDHRA PRADESH		
	Activities	**Status**	**Comments**
1	Combined management of reservoirs and water transfers within the Sriramsager project area including its Stage II extension	Completed for SRSP	-
2	Providing water for all sectors considering the increased demands	Completed for SRSP	-
3	Crop selection and corresponding water requirement of command area	Completed for SRSP	-
4	Balancing head end and tail end abstractions	Conjunctive use for SRSP completed	-
5	Groundwater seasonal planning and artificial recharge	Completed for Gandlapet	** Additional Application
6	Update DSS (P) server and Online connection	Surface Water: Completed	-
		Ground Water: Completed	-
7	Generalized Interface	Seasonal Planning for Reservoir ; Conjunctive Use of SW & GW	-
8	Additional Interface	Seasonal planning for SRSP; Conjunctive use in SRSP command area	
	TAMIL NADU		
	Basin	**Activities**	**Comments**
1	Vaippar	• Severe water shortage and competing sectors • Inter-basin transfer • Integrated operations of reservoirs • Conjunctive use of	The state decided to go for advanced hydrological modelling and has been sup-

		ground and surface water in command areas • Assessment and monitoring of surface and ground water quality	ported according by NIH and the consultant.
2	Agniyar	• Severe water shortage and competing sectors • Inter-basin transfer of water to Agniyar basin • Determining impacts of over exploitation of GW • Drought monitoring assessment and management	The state decided to go for advanced hydrological modelling and has been supported according by NIH and the consultant.
3	Tamirparani	• Multipurpose multi-reservoir operation • River pollution • Drought management in northern areas • Conjunctive use of ground and surface water in command areas • Assessment and monitoring of surface and ground water quality.	The state decided to go for advanced hydrological modelling and has been supported according by NIH and the consultant.
	MAHARASHTRA		
	Activities	**Status**	**Comments**
1	The project area is severely drought prone and groundwater over-exploited	Completed	-
2	Increasing competition between domestic, industrial and agricultural water demands	Completed	-
3	Evaluating integrated reservoir operation to minimize the effects of drought and flooding	Completed	-
4	Conjunctive use	Completed	-
5	Assessing the water pollution on Ujjani from upstream irrigation, municipal, and industrial waste.	Completed	-

6 Conclusions and recommendations

The main conclusions from the project implementation are given below along with recommendations for continued DSS (P) use.

(1) The objective of the DSS (P) Planning project was to develop a Decision Support System (Planning) for Integrated Water Resources Development and Management. This has been fully achieved, resulting in a unique DSS, which includes a long range of inter-related tools with the following functionalities:

- Import, manage and analyse hydrological and meteorological time series data
- Import, manage, and analyse geographical information
- Import and apply models for short-term and long-term planning
- Perform additional analyses using the incorporated spreadsheet
- Add tools through scripting
- Publish water resources information on the internet

The DSS (P) has been developed so that data, information and results may be accessed by all these components and easily transferred between them. The developed system is thereby highly flexible and enables a wide range of applications.

(2) The structure and required functionalities of the DSS (P) was defined in cooperation with the Implementing Agencies through interaction at workshops, meetings, and state visits. It was originally envisaged to develop a generic DSS (P) for common issues and later customize the software in accordance with specific user requirements. However, it was possible to develop a comprehensive, generic DSS (P) from the start, so that only minor adjustments were required to meet all demands. This was to some extent facilitated by coordinating the development activities with the parallel DHI project on the Nile River Basin for which the objectives were quite similar.

(3) A long range of applications has been made during the project to test, evaluate and fine tune the DSS. The applications were made within each of the five components, i.e.

(i) Surface water planning

(ii) Integrated reservoir operations

(iii) Conjunctive surface water and groundwater planning

(iv) Drought monitoring, assessment and management

(v) Management of both surface and groundwater quality.

The applications made by the different states have mainly aimed at addressing the issues defined during the Needs Assessment phase. Some states have changed their priorities in the course of the project, however, to address other important issues.

(4) A considerable number of applications were made to the Upper Bhima basin in Maharashtra, which was selected as pilot basin for the project. While some of these have assisted Maharashtra in deciding the actual management of the scarce resources during the 2012 dry season, other application were made to serve as inspiration to all states and to illustrate the applicability of the system.

(5) Application of DSS (P) Planning in India is still in its initial stage. A considerable potential exists for the IAs to apply the DSS (P) to other types of water management issues and to other river basins.

(6) It is important for the sustainability of DSS (P) use that applications continue and that these are defined to address issues, which are prioritized by the states. It is therefore recommended that the user organizations establish or maintain a Water Planning Task Force and strengthen the DSS User Group, as discussed in section 3.9.1.1. The local planning wings or similar departments should play an active role in defining and implementing DSS (P) applications.

(7) Continued technical support to the DSS (P) applications should be ensured during and beyond HP-II including quality control of the DSS (P) work carried out by the different agencies.

APPENDICES

APPENDIX A

Discussion note:
Implementation Pathways for DSS

Bruce Hooper & Associates, Brisbane, Australia

Development of Decision Support System for Integrated Water Resources Development and Management

Hydrology Project-II

Loan No. 4749. IN. Invitation No. NIH/HP-II/DSS-PLNG/01

Discussion note: Implementation Pathways for DSS

November 10, 2011

Contents

Introduction

Under the World Bank funded Hydrology Project-II, DHI is preparing a DSS (P) to support integrated water resources management and planning (IWRM) for implementation in various Indian states. The DSS (P) Planning tool will facilitate significant improvements in the ability of users to promote IWRM practices in order to lift the quality of life for the general public and sustain national and regional economic development. This Discussion Note was prepared as part of that DSS (P) project.

Aim and structure of this Discussion Note

The aim of this Discussion Note is to outline implementation pathways which will support and facilitate the use of DSS (P) within the States. The note drew information from several sources:

- Previous studies on the use of DSS (P) in water resources planning in India and elsewhere,
- Needs Assessment Reports of DSS (P) use in nine Indian States undertaken in 2009 by DHI,
- Policy directions from the Indian National Water Policy and Asian Development Bank Policy papers and recent ADB project experience in Orissa,
- Initial trialling of a DSS (P) in Maharashtra, Chhattisgarh and Gujarat by DHI, including outputs of workshops with DSS (P) users in those three states in 2011, and
- Discussions with staff of the National Institute of Hydrology, DHI and the Central Water Commission in 2011.

This Discussion Note was prepared to provide:

- Background understanding to IWRM, and the use of DSS (P) in water planning and management and
- Implementation pathways to enhance use of DSS.

The target audiences of this Discussion Note are DSS (P) Project clients and participants whose views and commitment are sought regarding implementation of the actions recommended herein.

The Generic DSS

The initial work in the DSS (P) project by DHI included the development of generic DSS (P) software and its applications to a pilot model area, the Upper Bhima catchment in Maharashtra. The DHI consultants reported the initial software development and application in 2010, describing the software from the users' point of view. DHI also provided details on the software architecture. The software design was described in an earlier DSS (P) Model Conceptualization Report. The functional components of the DSS (P) for IWRM are shown in Figure 1.

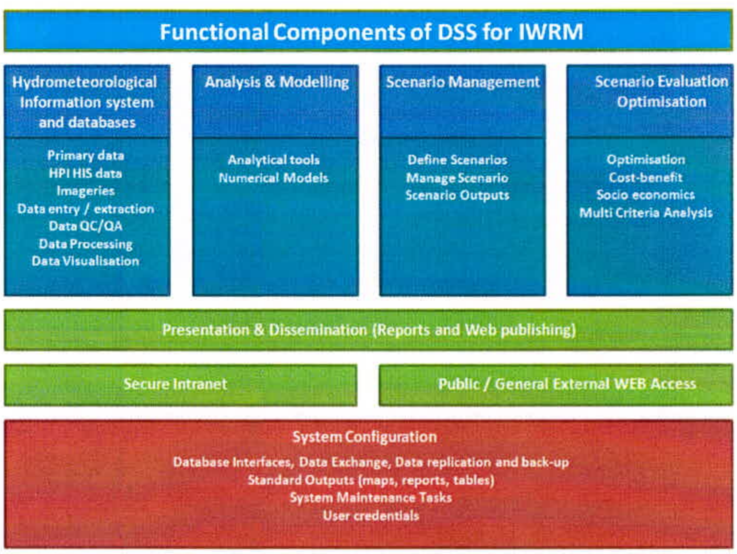


Figure 6-1. Functional components of DSS (P) for IWRM (DHI, 2009)

Approach

The approach used to outline institutional development pathways to support DSS (P) is to provide a process template. Each State water agency has an opportunity for capacity building using this template and can modify it according to its respective needs and situation.

This template involves a partnership approach by establishing and maintaining a change in organisational culture: to move away from an approach in which 'Central Government or State Government is the driver' to one in which 'government and water users are joint partners': all see benefits of using DSS (P) with databases and GIS; all recognise the intrinsic value of cooperation with another – win-win benefits, identifying priority safeguards and finding opportunities for sustainable water resources development while recognising constraints.

The way forward is to create **a new culture for DSS (P) use** – an organisational culture in which:

- Benefits of cooperation are articulated
- Staff in the respective water agencies and water user associations are energised to use the DSS (P) and its results
- DSS (P) applicability is understood
- There is political support to implement the preferred scenario(s), and
- There is a straightforward way to implement the preferred scenario(s).

The way to bring about this cultural change is to make relatively small organisational reforms supported by leadership and financial commitment.

This involves establishing a **DSS (P) User Group** of practitioners in each State and a **Water Planning Task Force** lead by senior government personnel in each State. These two entities will require:

- Key decision-makers, identified and acknowledged in their role
- Skilled executive leadership in the water ministry and departments who own the process of implementing the DSS (P) in their agencies and are willing to cooperate with other water stakeholders (other government agencies, water user groups, industry groups, civil society organisations with a water interest, funding organizations such as the World Bank)
- Key decision-makers with the skills, willingness and enthusiasm to work together as a cohesive group
- The decision-making process linked closely to the head of the lead water agency, and
- Ongoing financial commitment beyond the end of this World Bank funded Hydrology II project.

These are discussed in more detail below, but first, this report provides a conceptual framework to facilitate DSS (P) implementation with comments relevant to DSS (P) implementation in Indian States. This conceptual framework includes:

- Use of IWRM, and
- Heeding Indian National Water Policy directives on information management.

DSS (P) and water resources management and planning

Water resources management issues and the need for an integrated approach

The management and planning of water resources in India has been and remains a challenge, as it is in other BRIC[1] countries. Key issues in Indian water management,[2] including those related to DSS (P) implementation include:

[1] BRIC = Brazil, Russia, India and China; some definitions include Indonesia (BRIIC). Defined by Goldman Sachs in 2001, a BRIC country refers to countries with rapidly developing economies, and the biggest and fastest growing economies. They could become among the four most dominant economies by the year 2050, encompass over 25% of the world's land coverage, 40% of the world's population and hold a combined GDP PPP of 15. 435 trillion dollars. Their Yr 2000 combined water abstraction was ~ 954 km^3 per annum ~ 45% global annual withdrawal. On almost every scale, they would be the largest entities on the global stage by 2050.

[2] Asian Development Bank, undated, (2007?) Water Resources Development in India: Critical Issues and Strategic options.

1. Access to and adequacy of safe water - declining per capita water availability, deteriorating water quality, seasonal water shortages, little role of women (who fetch water in rural areas) in water planning, critical urban water shortages.
2. Institutional challenges – management of existing infrastructure and the water resource itself
3. Service provision – limited innovation and reform in the water sector, a shortage of appropriate skills and the need to strengthen the capacity of water administration
4. Over-extraction of groundwater and quality problems
5. A growing financial crunch in the administration of the water sector, including service delivery
6. Expanding water conflicts – between users and between states
7. Absence of affected peoples' involvement
8. Inadequate transparency and accountability to stakeholders water resources decision-making.

It is not an overstatement to suggest such issues tend to overwhelm the capacity of Indian water administrations to deliver sustainable water resources management in some states[3], to different degrees in different states. The imperative and the challenge are to progress a coordinated approach which ensures participation at the very least. IWRM provides a way to address these issues and challenges.

Various definitions of IWRM exist and include:

> *It is much more than water resources development, seeking to integrate three interrelated, but separately evolved concepts: (a) multi-purpose development; (b) an integrative role for the drainage basin unit; (c) the acceptance of intervention to promote development (typically seen to be improvement of social welfare or regional conditions)*[4]
>
> *Coordinated and conjunctive use of all water - by location (surface, ground), by users (rural, urban, peri-urban), or by use (domestic, irrigation, industrial and institutional) - is a working definition of integrated water resource management (... in India)*[5]
>
> *The co-ordinated management of land and water resources within a river basin, with the objectives of controlling and/or conserving the water resource, ensuring biodiversity, minimising land degradation, and achieving specified and agreed land and water management, and social objectives*[6]

while the most internationally promoted definition is:

> *A process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*[7].

Sectoral and sub-sectoral coordination is commonly associated with IWRM (Figure 2[8]). It refers to the planning and management of water resources which takes into account the competition and conflicts for water among irrigated agriculture, hydropower, domestic water supply and sanitation, industry, mining and other users. Integrated planning in this sense leads to such facilities and institutional arrangements as ensuring priorities for drinking water are met as well as water allocations for irrigation for food and environmental purposes, multi-purpose storage reservoirs, licensing sys-

[3] As evidenced, for example, in experience in implementing water resources management in the 2004 Andhra Pradesh Water Vision; the ADB TA 4814-IND WALMI and DoWR Change Management Status Report; the 2004 GoI Twelfth Finance Commission (2005-10); the 2009 Thirteenth Finance Commission (2010-15), the ADB TA-4815-IND: Orissa Integrated Irrigated Agriculture And Water Management Project Public Expenditure review; the 2011 ADB TA-7131 IWRM Roadmap for Orissa.

[4] Barrow, C. J. 1998, River basin development planning and management: a critical review. World Development 26[1], 171-186.

[5] Asian Development Bank, undated, (2007?) Water Resources Development in India: Critical Issues and Strategic options.

[6] Hooper, B. P. 1997, Improving watershed management using an innovative integrated resources management approach in Australia. Journal of Professional Issues in Engineering Education and Practice 123[2], 57-61.

[7] Global Water Partnership, 2000. *Integrated Water Resources Management*. TAC Paper #4. GWP, Stockholm.

[8] Global Water Partnership, 2000. *Op.cit.*

tems, owner-driven local water management and river operations which provide for navigation and other non-consumptive uses.

Stakeholder participation is also commonly associated with IWRM. Like sectoral coordination, it requires an effective enabling environment of water laws, policies and financing to be effective. The enabling environment refers to what constitutes the "rules of the game". The enabling environment:

- Is determined by national, provincial and local policies, legislation and financing and incentives,
- Makes it easy for stakeholders (people who have a say) to participate in water resources planning and management., and
- Includes the forums and mechanisms, information and capacity-building created to establish these "rules of the game" and to facilitate and exercise stakeholder participation.

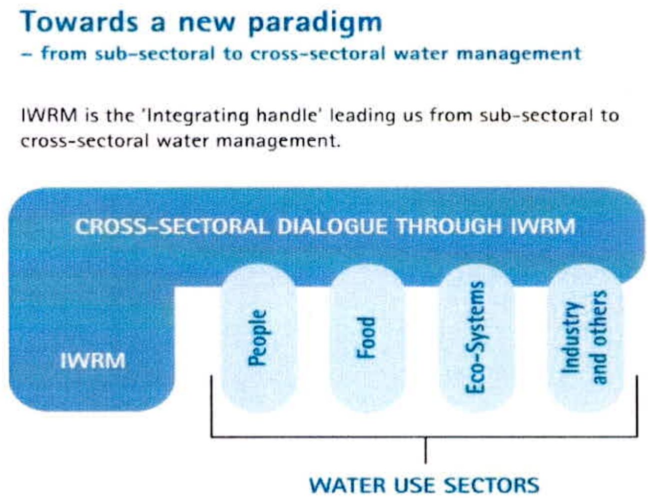


Figure 2. Cross-sectoral dialogue in IWRM

Stakeholder participation ensures that other sectors beyond the water sector are involved in planning and management of natural resources. For example:

- the construction of dams for hydropower must consider mitigation of negative impacts on fishing for livelihoods both downstream and in the reservoir upstream of a HEP plant, and relocation impacts of people affected by the impoundment of the dam;
- industrial development and its associated water demands must consider impacts on local drinking water supplies and irrigation water supplies, both in terms of quantity and quality.

IWRM has received various levels of acceptance in India while in some places, outright rejection. Overall, there has been limited effective use of IWRM in India. There are many reasons for this including:

- IWRM seen as an attempt to foster the opinions of others outside of India
- Institutional, organisational and human resource constraints
- Financial constraints and lack of motivation for reform
- Lack of technology to support effective coordinated decision-making
- Unwillingness to consider other stakeholders' involvement in water resources management and planning
- Lack of education and professional development in IWRM
- Rejection of the adaptive planning and management approach embedded in IWRM.

However, IWRM can bring benefits, including:

- Implementation of State and National Water Policies
- Improved efficiencies resulting from existing fragmented, sectoral approaches.
- Ability to manage complexity in the water sector - address poverty, sanitation and agricultural water supply together
- Use of the hydrological basin (river, aquifer, lake and their catchments) as the basis for management and so coordinate water management naturally
- Overcoming the lack of transparency and consultation in decision making by insisting on stakeholder involvement, and
- Ensuring that all water stakeholders' rights are recognised.

IWRM is best used when:

- A coordinated approach is needed to handle problems across different sectors - cooperation and consensus normally require respect, trust and goodwill, and a willingness to voluntarily participate in a process
- A serious problem exists which requires a more than one agency to solve, and
- Upstream versus downstream benefits and disbenefits occur amongst water stakeholders.

The implementation of IWRM in India is different to that of highly developed countries. India is an emerging, BRIC[9] country, with a very large population and with unique democratic traditions. Highly developed countries generally have fully developed water resources systems and water infrastructure while there are still development opportunities in some emerging, BRIC countries. The emphasis is less on water quality management, water use efficiency and allocating water for recreational and environmental purposes (environmental flows) in emerging, BRIC countries than developed countries.

In both developing and BRIC countries, there are pressing needs to reduce poverty, improve access to potable water, maximise economic development while minimising environmental impacts, and acquire more water resources for abstraction and use water as a tool for increasing wellbeing through improved sanitation and use of irrigated agriculture. Other differences are listed in the following table - differences in hydrology, administrative capacity, definition of water rights, the size of the informal water sector, stakeholders numbers and transaction costs.

To implement IWRM in India, IWRM must address key livelihood issues and systems of governance which work with very large populations who are dependent on variable monsoon hydrology. The key to implement IWRM in India is to do it the Indian Way, defined by Indians and appropriate to the systems of established water user associations and National Water Policy in place today. The State of Maharashtra has shown some moves towards adopting an IWRM approach using Water User associations well connected with government.

There has been a significant move towards subsidiarity – moving governance of water to the local level and empowering local communities to manage water themselves. In this context, the role of government changes, from being the central manager to the state water resources manager, regulator and service provider, working in partnership with local water users associations and district administrations. The service provider role has been taken on in Indian cities by some private sector entities. This change in roles and responsibilities requires the state water agency to upgrade its skills base, to provide a range of services to very large communities whose governance is becoming more and more localised. The new skills include skills in amongst other things, engagement, partnership building, conflict management.

Table 1. Differences in basin realities between developed and developing/emerging BRIC countries[10]

Emerging/BRIC and Developing Countries	Developed Countries
Rainfall low, climate extreme, higher mean temperatures, lower stream density, water scarcity an emerging constraint	Temperate climates, humid, higher river-stream density
Densely populated in both valleys and catchment areas; population high both upstream and downstream of dams	Population concentrated in the valleys, downstream
Water rights based on rights to rainfall or ground-water; people's notions of ownership relate more easily to rain than to large-scale public diversions	Water rights based on riparian doctrine and prior appropriation
Focus on green water: water stored in the soil profile or blue water	Focus on blue surface water: water found in rivers, and lakes

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[9] BRIC = Brazil, Russia, India and China some definitions include Indonesia BRIIC. Defined by Goldman Sachs in 2001, a BRIC country refers to countries with rapidly developing economies, and the biggest and fastest growing economies. They could become among the four most dominant economies by the year 2050, encompass over 25% of the world's land coverage, 40% of the world's population and hold a combined GDP PPP of 15. 435 trillion dollars. Their Yr 2000 combined water abstraction was ~ 954 km^3 per annum ~ 45% global annual withdrawal. On almost every scale, they will be the largest sovereign entities on the global stage by 2050.

[10] Source: Modified from Shah, Makin, and Sakthivadivel 2004[10] and http://www.iwmi.cgiar.org/home/integrated_river_basin.htm, accessed November 2004; as reproduced in Hooper 2005.

Emerging/BRIC and Developing Countries	Developed Countries
stored in aquifers	
Most water users get their water directly from rain and from private or community storage without any significant mediation from public agencies or organized service providers. Because the bulk of water provision takes place in the informal sector, it is difficult to pass enforceable water legislation	Most water users get water from 'service providers'; most water provision is in the formal sector-making water resources governance feasible
Vast numbers of small-scale stakeholders	Small numbers of large-scale stakeholders
High transaction costs for monitoring water use and collecting water charges	Low transaction costs for monitoring water use and collecting water charges

Regarding DSS (P) and information systems, IWRM in India requires information prepared in such a way that it shows the **benefits and disbenefits to all water stakeholders at the local level of the preferred courses of action** while being **presented on a whole of basin basis**. The basin context for even local courses of action will reveal the interconnections between water users that exist within a hydrological planning unit, the river and/or groundwater basin. The basin context will also allow local water user associations to appreciate and understand local hydrological processes within a basin hydrological behaviour (in terms of river and groundwater flows, extreme events).

This means that users will need to see the benefits and disbenefits of different DSS (P) scenarios across and within a basin. Ideally, there needs to be representation of various water stakeholders in formulating and selecting the preferred management options identified in DSS.

- **Policy imperatives**

The Indian National Water Policy[11] was adopted in 2002 (updating the first version of 1987) and gives broad support to an integrated approach through support for participation. The policy also contains elements strongly related to IWRM. It refers to "multi-sectoral" and "multi-disciplinary" water management. This approach is recognised not just in India but in BRIC and other countries in which there are strong and competing demands for water in emerging, developing or developed economies.

Far more prescriptive to DSS (P) implementation, though, are the policy directives regarding 'Information System', 'Water Planning' and 'Participation'. Comments on these items are shown in Table 2

Table 2. Comments on relevant items of Indian National Water Policy, 2002

Item in Indian National Water Policy, 2002	Consultant's response with respect to DSS (P) implementation
Information System	
2.1 A well developed information system for water related data in its entirety at the national / state level is a prime requisite for resource planning. A standardised national information system should be es-	The objective is commendable but the reality is a long way off without a concerted effort by both national and state governments in the HP-II project case study areas. DSS (P) Planning has progressed since HP-

[11] The broad goals of the 2002 Indian National Water Policy are: 1) establish a well-developed information system for water related data at national/state level to ensure appropriate resource planning; 2) effective water resources planning by encouraging non-conventional methods of water use such as in inter-basin water transfers, artificial recharge of aquifers and desalinization of brackish water, as well as traditional water conservation practices like rainwater harvesting and incorporating quantity and quality aspects as well as environmental considerations; 3) develop and manage water resources by reorienting existing institutions and creating new ones wherever necessary; 4) establishing water allocation priorities as: first drinking water, second irrigation, third hydropower, fourth ecology, fifth industries, sixth navigation and then other uses; 5) preserving quality of environment and ecological balance implementing and operating a water resource project; 6) groundwater development; 7) Fixing water charges in such a way that they cover at least the maintenance and operation costs of providing the service initially, and a part of the capital costs subsequently; 7) ensuring treatment of effluents before discharging into natural streams; 8) promoting water conservation consciousness through education, regulation, incentives and disincentives.

Item in Indian National Water Policy, 2002	Consultant's response with respect to DSS (P) implementation
tablished with a network of data banks and data bases integrating and strengthening the existing Central and State level agencies and improving the quality of data and the processing capabilities.	1. All states are using common databases for surface (SWDES) and groundwater data (GWDES) and have similar procedures for data collection and processing. The quality of data worked with in HP-2 is relatively good after year 2000 which reflects the potential of the DSS (P) as part of the information system and also recognizes the work done under HP-I. The DSS (P) can easily import data from these databases as well as from other sources, and being web-based it can easily be applied to ensure easy access to GIS and time series data for state employees at all levels. Read-only access may be given to a wider audience, either through the DSS (P) interface or on the web. State water agencies can generate modelling outcomes with existing data sets, specifying the limitations of data as currently exist.
2.2 Standards for coding classification processing of data and methods / procedures for its collection should be adopted. Advances in information technology must be introduced to create a modern information system promoting free exchange of data among various agencies. Special efforts should be made to develop and continuously upgrade technological capability to collect process and disseminate reliable data in the desired time frame.	While there are many 'musts' in this statement, existing poor data quality will more than likely continue. In Orissa, for example, data quality is correlated with and dependent on the existence of World Bank funding. This situation is non-sustainable. One option is to establish affordable case study small-scale basin case studies and incrementally increase fiscal appropriations from State-collected water charges to upgrade state datasets. It is important to acknowledge this is a very long term solution but a realistic one.
2.3 Apart from the data regarding water availability and actual water use the system should also include comprehensive and reliable projections of future demands of water for diverse purposes.	These can be developed using demand trajectories with accurate error estimates. Extrapolations from known existing demands are a useful option, related to sector demand projections and realistic, potential improvements in water supply efficiencies if they exist and information from experiences in demand management using water pricing (as exist in Maharashtra).
Water planning	
3.1 Water resources available to the country should be brought within the category of utilisable resources to the maximum possible extent.	This requires consensus on what is meant by 'safe yield', including the identification of where problems with water supply inefficiencies can be feasibly addressed. The DSS (P) applications made so far have all included improved assessments of water availability in the selected basins and development of river basin models to test changes in water use.
3.2 Non-conventional methods for utilisation of water such as through inter-basin transfers, artificial recharge of ground water and desalination of brackish or sea water as well as traditional water conservation practices like rainwater harvesting, including roof-top rainwater harvesting, need to be practiced to further increase the utilisable water resources. Promotion of frontier research and development, in a focused manner, for these techniques is necessary.	There is a need to ensure the output of 'frontier research' in non-conventional methods is linked closely to DSS (P) scenario development; it is more than likely that faster gains could be realised in 3.1 (improving water supply and use efficiencies).
3.3 Water resources development and management will have to be planned for a hydrological unit such as drainage basin as a whole or for a sub-basin, multi-sectorally, taking into account surface and ground water for sustainable use incorporating quantity and quality aspects as well as environmental considerations. All individual developmental projects and proposals should be formulated and considered within the framework of such an overall plan keeping in view the existing agreements / awards for a basin or a sub- basin so that the best possible combination of options can be selected and sustained.	Basin-scale management requires: • Specifying DSS (P) scenarios on a whole of basin basis, including model runs across catchments and sub-catchments • The existence of a functioning river basin organisation and a state water resources management agency which have financial and skills capacities to implement the scenarios in a water management plan • That interbasin transfers be considered as secondary options against a first imperative of improving intra-basin water supply and use efficiency; and including these options in scenario development in DSS
3.5 Water should be made available to water short areas by transfer from other areas including transfers from one river basin to another, based on a national perspective, after taking into account the re-	As for 3.3

Item in Indian National Water Policy, 2002	Consultant's response with respect to DSS (P) implementation
quirements of the areas / basins.	
Participatory Approach to water management	
12. Management of the water resources for diverse uses should incorporate a participatory approach; by involving not only the various governmental agencies but also the users and other stakeholders, in an effective and decisive manner, in various aspects of planning, design, development and management of the water resources schemes. Necessary legal and institutional changes should be made at various levels for the purpose, duly ensuring appropriate role for women. Water Users' Associations and the local bodies such as municipalities and gram panchayats should particularly be involved in the operation, maintenance and management of water infrastructures / facilities at appropriate levels progressively, with a view to eventually transfer the management of such facilities to the user groups / local bodies.	Include stakeholders in a DSS (P) User Group and a State Water Planning Task Force

• Implementation pathways for DSS (P) in IWRM

The above discussion highlighted how IWRM and the Indian National Water Policy form the basis for sound water and information management. The work to date on this project has resulted in considerable development of technical applications of the DSS (P) to the participating states. The June 2011 Interim Report recommends applications in three of the states (Maharashtra, Gujarat and Chhattisgarh) and further development of those applications to meet the clients' needs. This Interim Report, the previous (2009) Needs Assessments Reports for several States, and the results of a rapid survey of DSS (P) users in Line Agencies in Maharashtra by the author in 2011 suggest that the DSS (P) applications will struggle to gain traction unless they are more closely embedded in the water development, planning and management procedures of each State's water agencies. The challenge is to address the lack of traction.

This Discussion Note outlines pathways to address this lack of traction. The pathways are presented to the DSS (P) project team and Line Agencies and other stakeholders for their consideration and adoption.

• Attributes crucial for effective water resources development and management

Traction to lift implementation of both water resources management and development and its associated DSS (P) can be achieved by using good practices in water management. Developed by the World Bank, six attributes crucial for effective State and interstate IWRM include[12]:

Clear and strong institutional arrangements (the 'enabling environment'), supported by clear regulations, decrees, or agreements and with well-defined implementing procedures in each state and in each river and groundwater basin,

Good quality water-related data, information systems and models readily available to each State (including their agencies and bureaus) and river basin organisation, and available at the basin scale that is meaningful and useful for decision-making,

A complete and clear suite or package of basin-wide policies, procedures, and strategies at the national and state level to guide water and natural resource planning, management and administration in each state (as water resources management is a state matter in India),

An appropriate form of communication to increase awareness and improve coordination and participation for relevant basin stakeholders and partners within each state and between states and the Union Government for transboundary Indian basins,

[12] Source: These attributes are modified from those found in World Bank, undated. Integrated River Basin Management. From Concepts to Best Practices. World Bank, Washington, DC.

Basin sustainability performance indicators and an agreed approach to monitor and report on how the basin is being managed and the resources consumed and protected, and

An ongoing capacity development process to implement 1 to 5 within each State.

These attributes are used to guide implementation of Decision Support System for Integrated Water Resources Development and Management. The second attribute is the most critical one for effective DSS (P) implementation in this project. How should these data, information systems and models be best used?

- **Learning by doing – adaptive management**

The key is to appreciate and use the decision sequences in water resources management and planning. This is sometimes called an adaptive management sequence, or a 'learning by doing' pathway (Figure 2). This cycle is one in which national and state governments plan water resources management and development with input from a broad range of other stakeholders. The cycle shown in the diagram is a 'learning-by-doing management cycle'. It helps managers incorporate what is learnt in the process of planning and managing water resources as it takes into account new information as it comes to hand. This allows water managers to adapt how they manage water to changing circumstances, for example, political changes, natural catastrophes, changes demands and from different sectors.

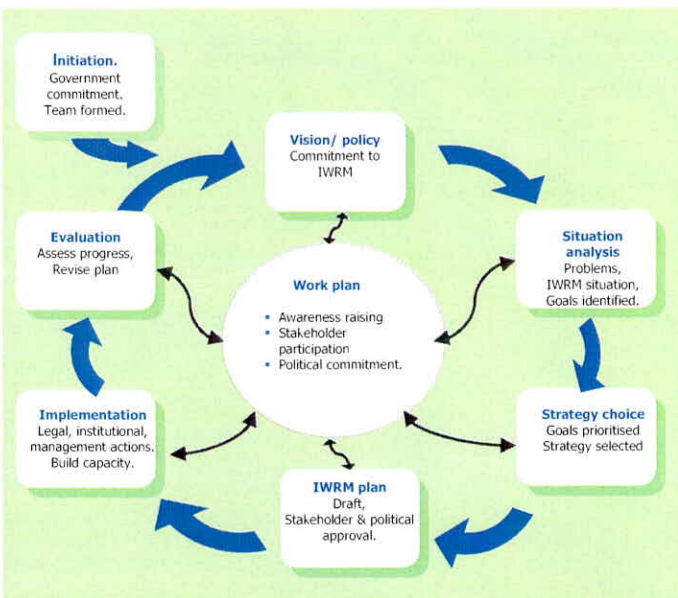

Figure 6-2. The adaptive process of IWRM

Decision-making in water resources management is a complex process but generally follows the circular route in Figure 2. Typical activities and questions asked include:

- Establish a work plan to address the specific water issue; before anything else, establish political commitment, an awareness raising programme and stakeholder participation
- Situation analysis:
  - Assess the current situation: what is happening to water resources (quantity and quality characteristics in the water cycle)? What are the forces that cause things to happen in and to water resource systems by water resource use practices? What are the interactive effects of these forces?
  - Establish a monitoring system so we can later see what difference this DSS (P) has made
- Strategy choice:

  - Can we model this water resource system behaviour? Do we have enough confidence in our models to know that if specific variables are changed, these are the outcomes?
  - Have we as water mangers involved relevant stakeholders in the decision process? Who are our stakeholders? Are they 'at the same table' with us? Do they understand this process of decision-making? Do we (as decision-makers in government) understand their desired outcomes and needs for water use?
  - What are agreed priorities and desired outcomes? Are they part of the social decision system of the river basin, the groundwater province or the State's water resources planning system? Once we have run the models and chosen a preferred scenario, what management actions are necessary implement the preferred scenario?
- IWRM plan:
  - Incorporate the preferred scenarios into an water management (IWRM) plan with ongoing stakeholder interaction to discuss the desirability of the scenarios;
  - Achieve stakeholder and political approval of the plan;
  - Implement the desired scenario within the existing legal and institutional framework;
  - At the same time, build capacity for implementation
- Monitoring and evaluation:
  - Monitor and evaluate the outcomes and report back to both the basin organisation and state water agencies;
  - Review the outcomes – this may mean the need to review the vision (desired goals) of the water planning and management process;
  - Run the models again to generate alternative scenarios if needed and revise the IWRM plan.

In progressing this sequence of activities, it is important to remember that decision-support tools are useful in predicting the outcomes of alternative plans and programmes. Optimisation and simulation models are other ways of examining certain problems. Optimisation simplifies problems, for example, by aggregating spatial descriptions of a particular problem. Simulation models can then be used to generate, for example, dynamic scenarios.

- **Choose the right scale**

Specifying actions at the right scale is critical (Figure 3).

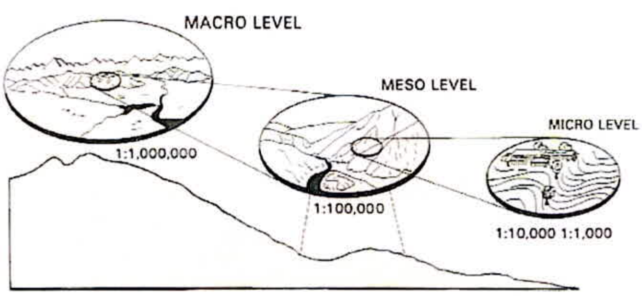

Figure 6-3. Basin management framework, plans and DSS (P) applications

	Policy/National	Implementation	Operational
Type of basin organisation	Transboundary (e.g.) commission	National, inter-state basin (e.g. commission, authority, association)	Local (e.g. land and water management group)
Basin management strategies and plans	Transboundary basin management agreement or plan; transboundary compact; national basin management plan	Sub-basin management plan or strategy, large sub-watershed or sub-aquifer or lake management plan	Local land and water management plan, storm water management plan, local planning scheme (administered by local government)

	Policy/National	Implementation	Operational
Level of decision-making	Highest political decision-making level, transboundary agreements	Province, state, district, territory (or national in small states)	Village co-operative, farm, factory, forest, local government, water use district
Natural resource system (as per figure above)	Part of a geographical zone, such as a river, lake or aquifer basin	Regional or local ecological system of a lake, river valley within a basin, or sub-aquifer within a aquifer province	Areas with relatively uniform ecological and hydrological conditions
Suggested Information and DSS (P) requirements	Interpreted information not raw data which describe current situation and scenarios	Specific outcomes in easily understood data sets for each scenario generated in DSS	Data, benchmarks and scenarios for both existing conditions and outcomes for each scenario in non-technical languages which is easy to understand

Identifying and targeting action needs to take place at several levels:

- At the *local* level, for specific farms, properties or neighbourhoods, municipalities and industries, such as site management plans
- At the *sub-basin* level, where there are cross-cutting issues which require a broader scale of management, such as storm water management plans, pollution control.
- At the *whole basin* level, where government and other institutions need to take action, on for example cost-sharing, tax incentives, laws to abate pollution, poverty reduction, building the capacity of water user groups.

At the local level, the best management practices can be targeted by and with farmers, producer organisations, local government planners, provincial government resource managers, extractive industries and manufacturing industries, nature conservation managers and recreation managers. The practices need to complement sub-basin management plans and the overall basin management plan. Some kind of co-ordination mechanism, such as national planning legislation, is needed to link bottom-up and top-down action as well as a reporting system between agencies and water user associations would help.

An IWRM Plan should show how basin action plans will be financed. Weighing up costs and benefits is a critical part of developing the basin strategy and deciding on the best options. This means identifying who will benefit and who will be disadvantaged.

Once water management options have been identified, the next steps are:

- To select the most cost-efficient set of options regarding selected priorities (i.e. the set of actions that will address the priorities (objectives) at the lowest cost;
- To assess the costs and benefits of the selected set of options (and how these costs will be divided between different sectors).

To do this economic analysis tools, such as cost-effectiveness analysis and cost-benefit analysis, can be used.

To achieve the objectives set as priorities there may be several alternatives (options). Cost-effectiveness analysis examines the costs (i.e. investment, operating costs) and benefits of each alternative. This gives basin managers a ranking of the alternative options according to the ratio of cost-effectiveness. Benefit sharing focuses attention on the value derived from water use and ecosystems, and takes into account water quality and risks, rather than focusing on the more contentious and less useful process of trying to allocate specific amounts of water to different parties.

- **Organisational strengthening to support decision-making**

Figure 4 shows recommended organisational changes to strengthen the implementation of DSS (P) in each Indian State where the applications have been or will be applied. Two organisations can be established: a DSS (P) User Group and a Water Planning Task Force in each State.

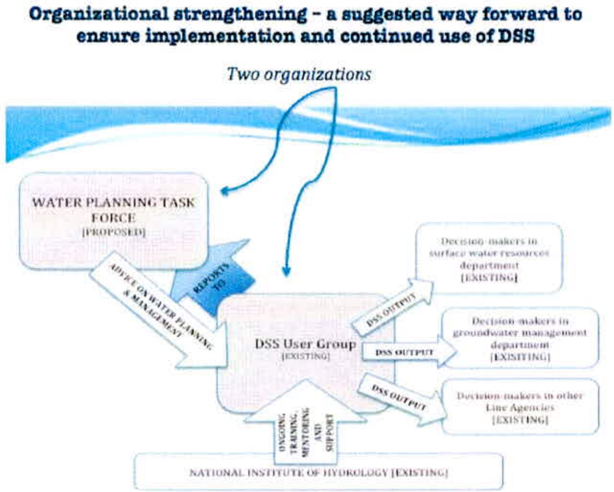

Figure 6-4. Organizational changes to facilitate DSS (P) use

- ***A DSS (P) User Group***

The first step is to ensure that the key decision-makers in the case studies, e.g. operational staff in seasonal water allocation, State agency and basin organisation water planners , are involved in the project through a functioning entity which is endorsed by the Secretary of the leading water agency in each State.

The DSS (P) applications in each State were developed to address specific water resources development, management and planning needs for those States. The way to link these DSS (P) applications and their outputs more closely to decision-making in each water agency is to ensure the heads of key Line Agencies convene (or reconvene) a DSS (P) User Group from water Line Agencies in their State and which includes the existing DSS (P) users from the project.

The DSS (P) User Group can comprise:

- State water agency staff
- Water user associations
- National Institute of Hydrology adviser

The role of the DSS (P) User Group can be to:

- Run the models in the DSS, review scenarios and select the preferred scenario
- Establish and run a monitoring process on the implementation of the preferred outcome from the DSS (P) application
- Report learnings gained from implementation of preferred scenario and use of DSS (P) to State Water Planning Task Force
- Improve/refine application of the DSS (P) in the light of learnings
- Distribute lessons learned from to Line Agencies associated with DSS (P) project in each State at a national DSS (P) workshop

- ***State-level Water Planning Task Force***

There is also a need for an organisation to coordinate action between the DSS (P) team and line agencies in each State in the long-term, once the project is finished. If this is not done, the valuable gains made in the short-term will be lost, and yet another externally-funded and driven project's applications will be forgotten. All too often this happens in India, as evidenced by recent World Bank and ADB-funded projects in Orissa.

The DSS (P) can meet the challenges of State water planning. This activity is best done if it is placed closely to the high-level decision-makers. Consequently, a coordinating organisation, a Water Planning Task Force (WPTF) is proposed. It will serve as the core decision support for State level water allocation and management decisions. It is also a good way of making the relevant people in each state aware of the DSS (P) and its possibilities.

The WPTF can comprise:

- Cabinet level water, agriculture, industry and other relevant ministers
- Senior advisers from relevant agencies
- Executive member of National Institute of Hydrology

The WPTF will – hopefully – appreciate the DSS (P) and help creating interest and regular application by relevant users, also outside the groups project staff are in contact with now. It is possible that the existing decision processes in each State are not clearly defined nor have been mapped. It will be necessary to do this as a matter of priority so that the roles and responsibilities of the Water Planning Task Force can be expediently defined and supported politically by each State Government.

Table 3 lists features of the WPTF, following a request for more information by Line Agency staff; more than what was provided in the 2011 Maharashtra DSS (P) users' survey for comment.

Table 3. Features of a proposed State Water Planning Task Force

Question	Consultant's response
What is the institutional set up of the WPTF	It can be based at Executive level in government, acting as a high level organisation coordinating the functions of water development, water allocations, water quality management ands State water planning.
What is the membership, roles and responsibilities of the WPTF	Membership – Minsters and Secretaries of relevant departments; chairpersons of river basin organisations Roles and responsibilities - a State-level coordinating organisation, which will use basin-level assessments and modelling runs of the DSS (P) to address existing water planning and management decisions.
Can this coordinating organisation be a river basin organisation and, if so what are its roles and responsibilities	Not really, as it focuses on State and basin level water allocations, but it can function more effectively if the Chairpersons of river basin organisations are members; River basin allocations and management decisions can be adopted by proposed (or existing) river basin organisations
What will be the role of the existing Technical Advisory Group	This can continue and be part of the proposed DSS (P) User Group
What is required to make the organisational reforms work?	The proposed organisational reforms will require: • Ministerial support to succeed • Ongoing commitment of Member Secretaries and basin organisation Chairs • A small but able Secretariat, familiar with the use of DSS (P) in water planning

The establishment of a WPTF will not be straightforward. This can be achieved using a stepped path:

- Establish and maintain political support that overcomes defence of existing institutional power systems and bureaucratic inertia. Use a strategy:
    - Direct representation to the line department/water ministry Secretary
    - Agreement by the Secretary to initiate discussion with Ministers to establish WPTF
- Hold a national workshop for State water agencies on lessons learned from at least the Maharashtra, Gujarat and Chhattisgarh DSS (P) applications, and to identify adoption pathways of the DSS (P) applications in other States.

- Call for running or reruns of different scenarios and identify preferred management options in a pilot application as a matter of priority
- Run scenarios in the context of existing surface and groundwater regulations
- Provide directives to Minsters, WPTF and State water agency staff to:
    - Discuss how they will use outcomes and report back to WPTF
    - Select a preferred outcome and justify its selection in a short internal technical note and a widely publicised press release and report back to WPTF
    - Prepare work tasks to implement the preferred outcome and report to state agencies.

This pathway can be established immediately in each State by the Line Agencies working with NIH, relevant Secretaries and Minsters, and the DHI project staff. As a national player in the water sector, NIH is ideally placed to lead this process at the conclusion of the project. It is critical that NIH discuss their role further with the DSS (P) project team about how this leadership role will take place, their roles and responsibilities and the financial sustainability of the implementation pathways in this report.

The following table is a summary of the implementation pathway trajectories based on Interim Report Volume II which described the DSS (P) Customization for the first three states.

Table 4. Schematic of features of DSS (P) project and proposed implementation pathways

Feature/State	Maharashtra	Chhattisgarh	Gujarat
Core State Water Issues	Multiple issue management: • Drought adaptation and groundwater overexploitation • Increasing inter-sectoral competition in water use • Integrated reservoir operations to minimize drought and flooding impacts • Conjunctive use • Water pollution assessment on Ujjani Dam	Water use efficiency: • Conjunctive use of surface and groundwater in command areas • Drought management	Optimum allocation of water: • Analysis of multi-reservoir operation • Analysis of irrigation scheduling • Analysis of cropping patterns • Analysis of conjunctive use.
Lead water agency (ies)	Groundwater Surveys Development Agency Water Resources Department	Water Resources Department	Narmada and Water Resources Department (Central Designs Organization) and Ground Water Resources Development Corporation Ltd
Project Case study /scale /model /applications	Upper Bhīma Basin Size: 14,712 km^2, main stem river length: 275 kms Model - MIKE BASIN Purpose: seasonal planning for groundwater; seasonal planning for surface water; long-term planning – multiple use; scenario analysis	Seonath river basin Size: 30,860 km^2, main stem river length: 380 kms Model: MIKE BASIN Purpose: Making water available for irrigation and domestic water supply during the summer season; estimation of inflows into the reservoirs; improving groundwater availability in the semi critical blocks; drought management in years below normal monsoon rainfall.	Mahi River Study Area Size: 34,842 km^2, main stem river length: 583 kms) Model: MIKE BASIN Purpose: model scenarios in changes in water demands, infrastructure, management etc.
Project achievements			
Common	• Development of DSS (P) and real applications in each state, with Upper Bhima serving as model • Some agency interest established in DSS (P) in each of three states • Ability to create scenarios with currently available data sets • Ability to connect with existing water reform processes and mandates to see opportunities to link to water		

Feature/State	Maharashtra	Chhattisgarh	Gujarat
	planning		
Implementation challenges			
Common challenges	• Need for a lead organization to be identified to progress DSS (P) in each State and decision of lead agency to be supported by other agencies • Increased awareness of DSS (P) potential and current uses • Political support for rollout in three states • Ability to show value of DSS (P) applications throughout lead and other agencies • Mixed experiences in State water planning mitigates against an easy entry of DSS (P) to current water planning processes		
Implementation pathways			
Common actions	Lead agency: • Identify and appoint a DSS (P) champion at senior level in the lead State Agency to maintain energy in DSS (P) applications in each State – by Q3, 2011 DSS (P) User Group: • Establish and maintain a DSS (P) Users Group on each State, led by DSS (P) task champion – by Q4, 2011 • Lead taken by lead water agency in each State • Governance/reporting: answerable to the Chief Minister and Minister for Water Resources and including senior member of lead agencies and river basin organization chairs • Membership, constitute by end Q4, 2011 Water Planning Task Force: • Lead taken by: existing DSS (P) users • Governance/reporting to: report to WPTF on progress on immediate State application • Instituted by: end Q2, 2012 • DSS (P) Planning database should be the hub for GIS and time series data of State Agencies by end of Q4, 2011 • Construct secure VPN to link nodes and to facilitate access to, reading and ease of adding data within each State by end Q4, 2011 Awareness raising: • Establish public information portal and awareness raising campaign, lead by DSS (P) User Group • Focus: State water planning using DSS (P) • When: Q1-Q2, 2012		
State specific actions – Q3, 2012 to end Q4, 2014	Complete construction of and maintain DSS (P) planning database hub and links between Pune, Mumbai, Nasik offices and the DSS (P) server. Progress four applications: • Seasonal planning for groundwater – assess groundwater recessions • Seasonal planning for surface water – perform any time, not just at end of Monsoon • Long-term planning – multiple use/conflict demand assessments (agricultural vs urban vs industrial) • Scenario analysis - test potential of new reservoirs, artificial recharge, inter-basin transfer, conjunctive surface and	Complete construction of and maintain DSS (P) planning database hub and links between agency offices and the DSS (P) server. Be the central hub for GIS and time series data of GoC Surface Water Department, GoC Ground Water Department and other government organizations dealing with the surface or ground water of the state. Progress these applications: • Conjunctive use model of command areas and seasonal groundwater planning • Proposed Ravishankar Reservoir to Tandula Reservoir Transfer. Further analyses with refined input data to assess the obtainable benefits • Making water available for irrigation and domestic water supply during the summer season; • Internal training - state water	Complete construction of and maintain DSS (P) planning database hub and links between agency offices and the DSS (P) server. Progress these applications: • Model scenarios in changes in water demands, infrastructure, management etc. including multi-reservoir operation • Drought management analysis of the proposed Left Bank High Canal and other potential measures • Internal training - state water agencies to organises internal training in GIS and time series man-

Feature/State	Maharashtra	Chhattisgarh	Gujarat
	groundwater use. • Internal training - state water agencies to organises internal training in GIS and time series management (2012-2014)	agencies to organises internal training in GIS and time series management (2012-2014)	agement (2012-2014)

• Other issues

• Facing 'new' issues in the DSS

There is the need to address what happens when new issues to be addressed in DSS (P) are expected by executive level staff, who hear more about the project and propose their own agenda. Also, ownership of past issues seems piecemeal.

Project staff may wish to consider the following actions:

- DSS (P) User Group leader to contact relevant Secretaries and inform them of previous project activities which led to agreement on what issues the DSS (P) will address;
- Suggest new items for DSS (P) can be considered where and when support for project extension becomes available;
- Promote water balance modelling as primary tool to assist water allocation decisions in which security of water supplies (and quality) for drinking and sanitation is first priority; conjunctive use modelling must be part of this activity; undertake in context of existing surface and groundwater regulations.

If this does not happen, there is a possibility that Secretaries may distance themselves from the project.

• DSS (P) awareness raising

There is a need to strengthen processes for awareness raising, communication and facilitation of the use of DSS (P) software in Line Agencies. The following actions can be used.

For the DSS (P) User Group:

- Prepare and distribute a short newsletter by email, say three times a year; copy in Dashboard Manager
- Establish/continue to include all Line Agencies in regular project meetings
- Include demonstrations of Upper Bhima applications in Dashboard Manager (now done); replicate similar applications in other states
- Prepare a post-project programme for a Training and Outreach Plan – one day workshops for administrators, organised by NIH
- Circulate list of current and future applications in project newsletters.

For the proposed Water Planning Task Force:

The WPTF as a good way of making the relevant people in the state aware of the DSS (P) and its possibilities, particularly:

- Sharing data and information within the government organisations
- Sharing information with external stakeholders via the internet
- Applying the models to analyse management options etc.

• Monitoring performance

For each case study of DSS (P) use in the project, there is a need to monitor:

- Actual use of DSS

- Evidence of adoption
- Expected outcomes
- Evidence of actual outcomes

The information collected in this monitoring process can be used to:

- Report back to state water agencies, basin organisations (where they (will) exist) and lead water stakeholders in each case study;
- Review the outcomes of DSS (P) use – this may mean the need to review the objectives of the IWRM process in each case study area;
- Run the models again to generate alternative scenarios if needed and revise any IWRM plans that have been developed.

- **Conclusion**

The DSS (P) applications in the states demonstrate the power of the technology to support water resources development, planning and management. The key to successful use of DSS (P) by State Line Agencies is to establish organisational reforms as outlined in this Discussion Note. This will work provided there is ongoing ownership by Line Agencies, supported by NIH.

There is a need for a discussion on how the process moves forward after the project finishes.