DECISION SUPPORT SYSTEM (DSS) FOR INTEGRATED WATER RESOURCES MANAGEMENT IN MADHYA PRADESH

Sanjiv Das[1*], R. V. Galkate[2], Sanjay Gupta[3] and H. L. Tiwari[4]

1. *Executive Engineer, State Water Data Centre, WRD, Govt. of MP, Bhopal, 462003, India. Email: sanjiv.das.bpl@gmail.com*
2. *Scientist D, National Institute of Hydrology, Regional Centre, Bhopal, 462016, India.*
3. *Senior Geophysicist, O/o Chief Engineer, BODHI, WRD, Govt. of MP, Bhopal, 462003, India.*
4. *Assistant Professor, Department of Civil Engineering, MANIT, Bhopal, 462003, India.*

(Corresponding author)*

ABSTRACT

Making decisions on water resources management and planning is a complex task due involvement of multiple social, economical and environmental issues. An appropriate Decision Support System (DSS) tool capable of handling huge temporal and spatial data, equipped with reliable hydrological and statistical models, analyze multi-criteria optimal scenarios and have user friendly interfaces could be the facilitating tool for decision makers to address water resources related issues, solve problem and make appropriate decision. The present paper describes the development of DSS in Madhya Pradesh (MP) for the upper Wainganga river basin to support decisions to address range of water resources problems in the basin. The DSS project was implemented in MP under the Hydrology Project Phase-II (HP-II) program of Ministry of Water Resources, Government of India funded by World Bank. Under the DSS project, the DSS (Planning) generic software was developed which was then customized using historical hydro-meteorological, groundwater levels, demographic, agricultural, reservoir, water bodies, structures and other information and data of Wainganga basin. Various scenarios addressing critical hydrological issues such as sub-basin wise water availability assessment, impact assessment of the canal infrastructure rehabilitation, efficient reservoir operations, seasonal groundwater planning were developed considering the Wainganga river basin as a management unit. The Mike Basin and DSS software were found to be a powerful tool to generate number of possible hydrological scenarios with alternate solutions which may enables the decision makers to analyze and chose the best one to execute. The DSS was tested to analyze the long term data and proved to be the best tool for addressing complex issues and making quick decision. However, efforts need to be focused on improving the effectiveness of DSS, its applicability, sustainability and utility in other basins of the state for development, optimization, planning and management of water resources.

Keywords: *Decision Support System, DSS (P), water availability, infrastructure rehabilitation, reservoir operations, groundwater planning*

1. INTRODUCTION

The challenges for water resources management and planning due to increasing, conflictive water demands call for appropriate concepts of management and development of a Decision Support System (DSS) for integrated water resources management (Kepeng and Juncang, 2013). A DSS is defined as an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems (Watkins 1995). In the 1960s researchers began systematically studying the use of computerized quantitative models to assist in decision making and planning (Raymond, 1966; Turban, 1967; Urban, 1967; Holt and Huber, 1969). In the 1980s many activities associated with building and studying DSS occurred in universities and organizations that resulted in expanding the scope of DSS applications (Power, D. J. 2007). Numbers of countries have developed customized DSS for water resources management like Egypt, United Kingdom, East Africa (Nile River Basin), West Africa (Volta River Basin), Germany, France, etc. Sieker et al. (2006) worked on the development of a methodology to guide and support an improved water resources management on the level of small watersheds (up to 300 km²) within the framework of a generic Decision Support System (DSS) in Germany. However sustainability of DSS is the major challenge for its successful extended implementation. Giupponi and Sgobbi (2013) conducted a survey and analysis of DSS implementation in developing countries with specific reference on Africa.

In India, the Ministry of Water Resources, Government of India has implemented DSS project under the Hydrology Project Phase-II (HP-II) funded by World Bank and Madhya Pradesh (MP) state was one of the participating state in the project. In MP; the DSS(P) software was developed under DSS project for the upper Wainganga River Basin to support decisions for water resources development and management and share data and information within the user organization considering the data availability and the range of water resources problems in the basin.

2. DSS IN INDIA

The DSS project was implemented in India under the HP-II program with the help of consultant Danish Hydraulic Institute (DHI), Denmark. The National Institute of Hydrology, Roorkee, was the nodal agency for the coordination, development and implementation of DSS in India. The list of nine participating states and six Central agencies in DSS are given in Table 1. The nine DSS participating states in India are shown in Figure 1.

Table 1: States and Central Agencies Participating in DSS-WRPM Project

Participating States	**Participating Central Agencies**
Andhra Pradesh	National Institute of Hydrology (NIH)
Chhattisgarh	Central Water Commission (CWC)
Gujarat	Central Ground Water Board CGWB)
Karnataka	Central Water and Power Research Station (CWPRS)
Kerala	India Meteorological Department (IMD)
Madhya Pradesh	Central Pollution Control Board (CPCB)
Maharashtra	
Orissa	
Tamil Nadu	

Figure 1: DSS participating states in India

2.1 DSS Framework

The DSS framework includes generation of data base using data collected from field and historical data, preparation of temporal and spatial data base, generation of GIS layers, application of appropriate hydrological model, optimization, model simulation, alternate decisions and web publication. The generated information on analysis of alternate decisions was used to make final decisions as shown in Figure 2.

2.2 DSS Components

A DSS, also called DSS(P) software was developed for integrated water resources development and management of water resource systems to address the following five components.

1. Surface water planning
2. Integrated operation of reservoirs
3. Conjunctive surface water and ground water planning
4. Drought monitoring, assessment and management
5. Management of both surface and ground water quality

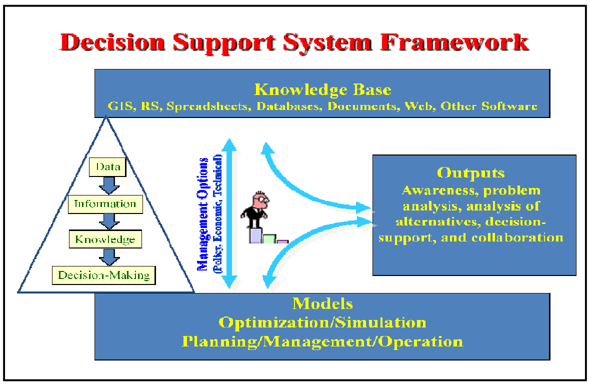

Figure 2: DSS framework in India

2.3 Stages for development of DSS

The development of DSS was planned through following six stages.

1. Need Assessment
2. DSS Model Conceptualization
3. Data Base Generation
4. Development of generic DSS package
5. DSS Customization
6. Web publication through Dashboard

The purpose of the first stage, Needs Assessment exercise was to assess the nature of water resource issues in the case study of respective state to make a preliminary assessment of the nature of the required DSS, software, hardware needs, capacity building and training needs of the state departments (DHI, 2009). The second stage, DSS Model Conceptualization included planning of Decision Support System in terms of its overall structure, the modelling software to be associated with the DSS and selected methodologies for each component (DHI, 2010). During the third stage, Data Base Generation, the DSS team worked towards identifying, collecting, formatting, and importing data for the DSS Planning

Project. The purpose of this exercise was to outline the structure and framework of the database development as well as the collection, for-matting, and population of data into the database (DHI, 2010). The fourth stage, Development of generic DSS package, covered the development of the Generic DSS software and its applications to the pilot model area, i.e. the Upper Bhima catchment in Maharashtra. The software was mainly described from the user's point of view, including software architecture followed by a description of selected DSS applications to the pilot model area (DHI, 2011). The fifth stage, DSS Customization included the customization of the DSS (Planning) software to meet the requirements of respective state. The customization task was completed with the considerable effort of data processing and analysis as well as development and application of respective river basin models, carried out by state implementing agencies under guidance from the DHI Consultant and National Institute of Hydrology (DHI, 2011). The sixth and final stage was the Web publication through Dashboard. The purpose of this exercise was to produce definition of web pages of DSS information.

3. DSS IN MADHYA PRADESH

In Madhya Pradesh state DSS was developed for the upper Wainganga River Basin. The area covered under Wainganga Basin in Madhya Pradesh is about 25480 km^2 as shown in Figure 3. This area come under humid region with mean annual rainfall varying between 1000 to 1600 mm. Wainganga flows 580 km south to join the Wardha River, a headwater of the Godavari. The Madhya Pradesh part of Wainganga covers Betul, Chhindwara, Seoni, Balaghat and Mandla districts. Major tributaries of the Wainganga river within the State of MP are Pench, Kanhan, Bagh, Bijna, Thanwar, Bawanthadi and Uskal (Nahara). Two major dams are located in the Wainganga catchment, i.e. Sanjay Sarowar and Thanwar, at the upstream of Dhuty weir. The main crops grown in the basin are paddy, jowar, maize, wheat, pulses and oil seeds. The broad soil groups are shallow black soils with red soil and deep black soil in the eastern parts of the region. Arable land of the basin is 25 %, forest covers an area of 3.45 million ha in the basin and 2.55 million ha is a reserved forest.

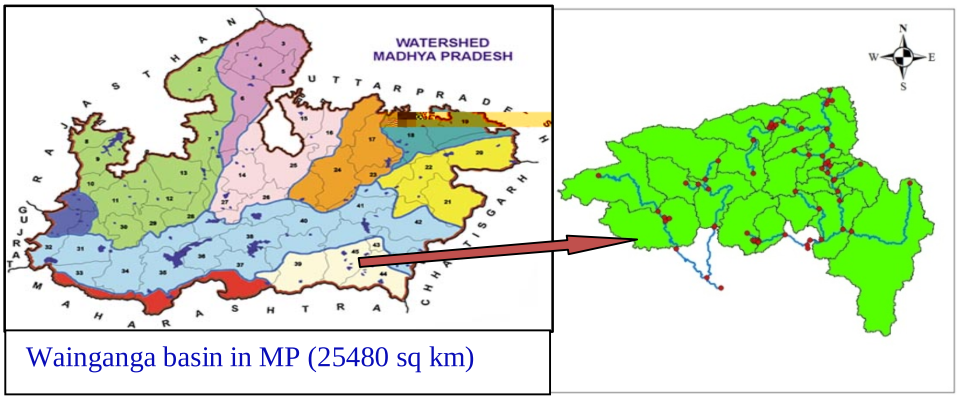

Figure 3: Watershed Map of MP showing location of Wainganga Basin

4. METHODOLOGY

Department of Water Resources, Govt. of Madhya Pradesh State worked on DSS for optimum allocation of water for present and future water use. The DSS therefore included assessments of the surface and groundwater availability and the various water demands. It also enabled analysis of multi-reservoir operation, seasonal surface and groundwater planning, conjunctive use, irrigation scheduling, cropping patterns, etc. The extensive data collection was carried out by the state WRD for hydro-meteorological data, gauge and discharge data, groundwater data, GIS data base, water use like irrigation, domestic, industrial, agricultural and demographic information. The DSS was developed to work on the interfaces of Arc GIS, Mike Basin, Mike Zero, Mike11, Mike Hydro softwares. Under the DSS the first task was to develop Wainganga basin model in Mike Basin software as shown in Figure 4. Mike Basin is professional engineering software developed by Danish Hydraulic Institute (DHI), Denmark. The river system is represented in Mike Basin (MB) model by digitized river network which can be generated directly in Arc Map 9.1 (DHI. 2003). It has multi-purpose GIS-based river basin simulation package designed for analyzing water sharing problems, environmental issues and water allocation representing the hydrology of the basin in space and time.

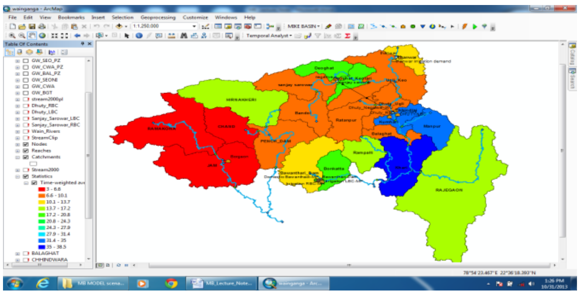

Figure 4: Wainganga basin model in Mike Basin software

4.1 Hardware-Software Availability at State Data Centre, Bhopal

The work carried out to make requisites hardware and software available at centre as below.

- Server installed in State Data Centre Bhopal, LAN and Broad Band connections are available.
- Servers can be accessed through LAN in state data centre Bhopal.
- High speed workstation computers were installed in Data Centre for level 2 users.
- Servers were configured for internet access from remote computers.
- Arc GIS, Mike Basin, Mike Zero, Mike11, Mike Hydro, DSS (P) were installed on computers and server.

4.2 Installation of DSS(P) Software in State Data Centre, Bhopal, MP

- DSS hardware: Database server and Web server and workstation computers were installed in the State Data Centre, Bhopal
- DSS (P) software was loaded in server and local personal computers in State Data Centre, Bhopal.
- The data base of Wainganga basin was uploaded in the local host PC (Figure 5)
- Different Scenarios were generated for Waingangā basin using DSS (P).

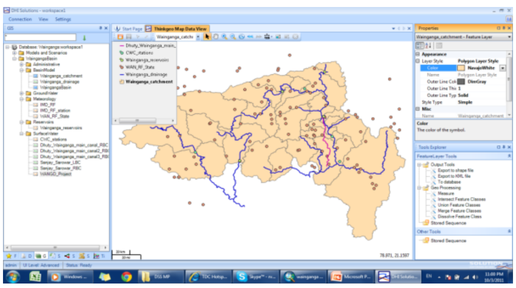

Figure 5: Wainganga Time series – GIS layers associations in DSS(P) interface

5. RESULTS AND DISCUSSION

5.1 Data Availability

5.1.1. Meteorological Data

There are a total of 35 non-recording rain gauge stations in the Wainganga Basin which have been established under Hydrology Project Phase - I. In addition, there are many rain gauges maintained by revenue Department at each Block or Taluk level. There are few 'Full Climatic Stations' (FCS) of IMD and CWC. Data have been computerized in SWDES software, meant for data validation, at the State Water Data Centre at Bhopal.

5.1.2. Hydrological Data

Data of 14 G.D stations of state are available. The data of State and CWC GD sites have been computerized using SWDES. The ground water data of 77 observation wells and 24 piezometers of Central Ground Water Board, 230 observation wells and 28 piezometers of state Ground Water Survey have been entered through GWDES.

5.1.3. GIS Data

The state has prepared GIS data base with the help Madhya Pradesh Council of Science and Technology (MP-COST), Bhopal. The GIS data base include thematic layers on Catchment boundary, drainage network, roads network and villages, water bodies, Land use and land cover map, soil map etc.

5.1.4. Water Use Data

The abstraction of water for irrigation, domestic, industrial and other uses is a key data requirement for water resources planning. This information was collected by the state from various divisions in Wainganga basin. Irrigation demands were estimated with the available tools.

5.2 Needs Assessment Activity

The Needs Assessment activity for M.P. was carried out in May, 2009. The Issues identified under Needs Assessment Activity are explained below.

i. Assessment of water resources availability to obtain a better basis for the water management and planning.
ii. The water infrastructure has not been adequately maintained and considerable losses of water are seen. It would be useful to assess the impact of rehabilitating the infra-structure.
iii. Identification of efficient use of water by the projects, which are existing and under construction.
iv. Crop selection and the corresponding water requirements, particularly in dry years.

5.3 Work Done Under DSS

Various activities carried out for Madhya Pradesh state under DSS (P) are described in brief as given below:

5.3.1 Development of Mike Basin Model of Wainganga

The Mike Basin Model was developed for Wainganga basin as shown in Figure 2 and the details are given below:

i. All the database of SWDES and GWDES for Wainganga basin was converted to *dfso* files and uploaded in MIKE BASIN model as shown in Figure 6.
ii. Created a Geo-database incorporating all the relevant available spatial and temporal information.
iii. With the help of DEM-90m of Wainganga basin, rivers were traced and catchments were delineated
iv. Time series data on rainfall, runoff, groundwater levels, reservoir details, water bodies, etc. were imported in MIKE BASIN and linked to GIS features.
v. MIKE 11 NAM model calibrated for selected sub catchments and runoff time series were generated for remaining catchments.
vi. The water demands at all user nodes were evaluated and data imported in MB model.
vii. Reservoir Simulation done for three reservoirs.
viii. Various scenarios are simulated in MB model.

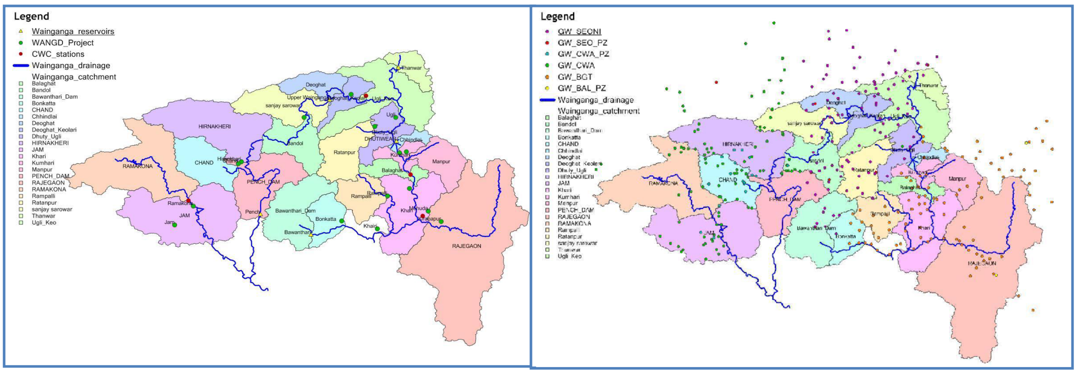

Figure 6: MIKE BASIN Model of Wainganga basin and locations of GW OB wells

5.3.2 DSS(P) Software

i. DSS hardware: Database Server and Web server and workstation computers were procured and installed in State Data Centre, Bhopal
ii. DSS(P) software was loaded in server and local personal computers in State Data Centre, Bhopal.
iii. The officers of WRD department were trained by DHI to explore and use the different options of DSS(P) software.
iv. The data base of Wainganga basin was uploaded in the local host PC.
v. Different Scenario generated for Waingangā basin using DSS(P).

5.3.3 DSS(P) Customization

i. All available GIS and time series data has been imported to the DSS database and a range of model applications performed (Figure 7).
ii. River basin modelling of reservoir and canal performance to assess the impact of canal maintenance.
iii. Rainfall-runoff modelling to assess catchment runoff and groundwater recharge in sub-basins.
iv. River basin model application to assess the performance of the Rajiv Sager project, currently under construction in the area.
v. Seasonal groundwater planning for Dhuty RBC command area.

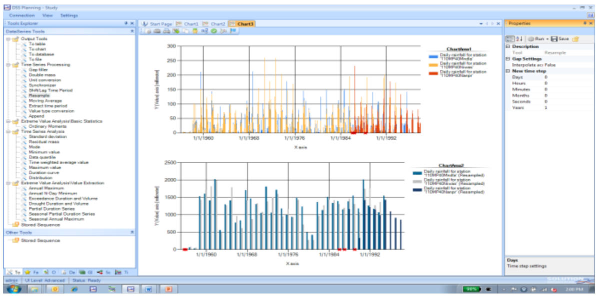

Figure 7: DSS(P) interface showing data processing

5.4 Development of Applications in DSS(P)

5.4.1 Water Availability Assessment in Wainganga Basin

Under this application, the Wainganga basin was sub divided into 22 sub-catchments the time series of surface runoff and ground water recharge were generated for different sub catchments for 40 year period using MIKE 11 NAM Model. The NAM rainfall runoff model was developed for the catchment having GD site and discharge information. Once that model calibrated and validated, it was used to simulate discharge in all sub-catchments. The results of NAM model calibration, showing comparison between observed and simulated discharge at Sanjay Sarovar site is shown in Figure 8. The NAM rainfall runoff model was found to be the best suitable model for Wainganga basin. The Wainganga basin observes 7215 MCM/year runoff at 75% dependability.

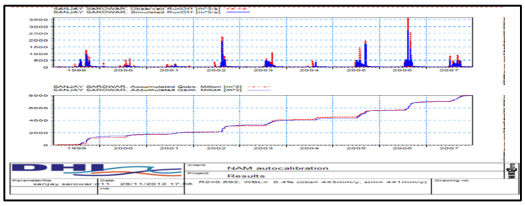

Figure 8: Comparison of observed and simulated runoff

5.4.2 Seasonal planning of Sanjay Sarowar project

Sanjay Sarowar project is one of the major irrigation projects of this basin on river Wainganga. The Dhuty wear at the downstream of Sanjay Sarovar supplies water for irrigation through its left and right bank canal system. The major water uses at Sanjay Sarowar are Sanjay Sarowar Irrigation User, Domestic Use of Seoni city and Dhuty releases 78 MCM/Year. The model application was developed for seasonal planning of Sanjay Sarower. Main inputs used in the model were crops grown and its area, water user demands, initial reservoir Level. The results were shown in terms of variation in reservoir water level and storage at various probabilities, planning for crop selection and optimal utilization of available water. The water level and stored volume in Sanjay Sarowar Reservoir at various dependable levels is shown on Figure 9.

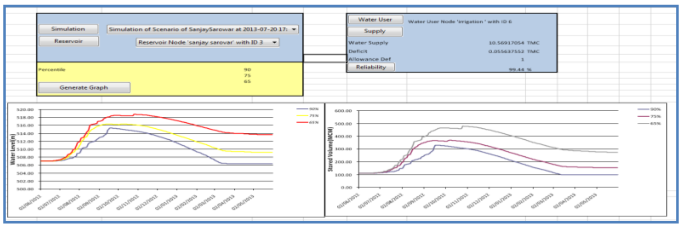

Figure 9: Water level and Stored volume in Sanjay Sarowar Reservoir

5.4.3 Impact assessment of infrastructure rehabilitation programme

The canal systems of Sanjay Sarowar scheme and Dhuty weir are in bad shape, their condition is deteriorated due to major cracks and damaged canal embankments and lining and it is assumed that major part of water supplied in command area is being lost through leakages and seepage. In such circumstances the major concern of the state WRD is to take up the rehabilitation programme to meet the challenge. This issue is being addressed through DSS(P) software. It is assumed that the present canal losses of the system are 30% and what will be the impact on additional water availability and additional crop yield if the canal water losses are reduced to 15% by appropriate rehabilitation measures. From the analysis it observed that around 65 MCM additional water is available if canal losses are reduced to 15% from 30%. The results are given in Figure 10.

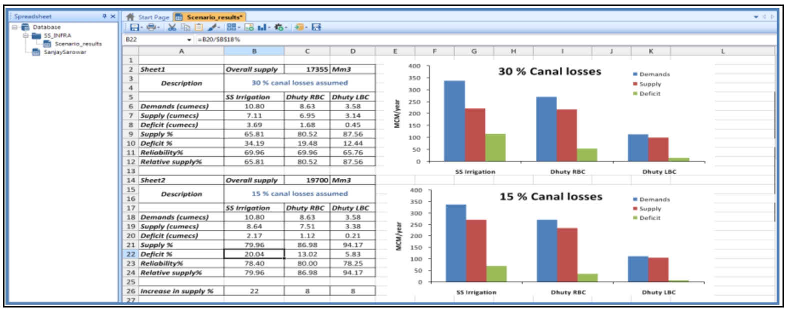

Figure 10: Bar graph showing decrease in water deficit if canal losses are reduced

5.4.4 Reservoir operation

An analysis has been carried out for the Sanjay Sarowar dam for improved flood control based on the forecast of the inflow to the reservoir. This would enable pre-release from the dam and thereby an increase in the available flood cushion before inflow starts increasing. This Analysis shows that the flood risk downstream of Sanjay sarowar may be significantly reduced if reliable inflow forecast are available. The simulated reservoir levels with and without inflow forecast for the two initial reservoir levels are shown in Figure 11.

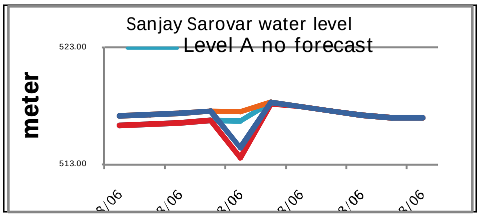

Figure 11: Simulated reservoir levels with and without inflow forecast for the two initial reservoir level

5.4.5 Performance evaluation of Rajiv Sagar Project (Bawanthadi)

The Rajiv Sagar (Bawanthadi) Project is a joint venture between the states of Madhya Pradesh and Maharashtra, constructed on the river Bawanthadi as shown in Figure 12 in MIKE BASIN Model. The Dam site is near village Kudwa in Katangi tehsil of Balaghat district in M.P. and village Sitekasa of Tumsar tehsil of Bhandara district in Maharashtra. The construction of the dam and the Left Bank Canal is being carried out by Madhya Pradesh while the Right Bank Canal is constructed by Maharashtra. The cost of the dam is to be shared equally by the two states. On completion, the project is proposed to irrigate 18,615 Ha. of land in Balaghat district in M.P. by Left Bank Canal and 17,537 ha. of land in Bhandara district in Maharashtra by Right Bank Canal. At 158% Crop Intensity 29,412 Ha. land of Balaghat District and 27,708 Ha. Land of Bhandara District will be irrigated. The performance of the Rajiv Sagar

Project has been tested in the river basin model using the available catchment runoff series from 1976 to 2006 onwards.

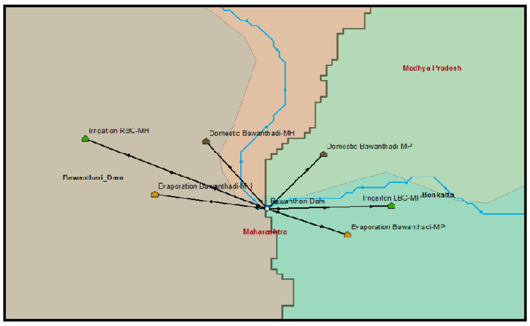

Figure 12: MIKE BASIN Model of Rajiv Sagar Project (Bawanthadi), Joint venture of GOI Madhya Pradesh and Maharashtra

From the analysis it can be inferred that out of 33 years selected for analysis, a significant deficits in Irrigation demands can be observed during three years only, i.e. 1987-1988, 1989-1990 and 2004-2005. Sufficient water will be available to meet the full water demands in approximately 90% of the years.

5.4.6 Seasonal groundwater planning for Dhuty RBC

The objective of this application to develop seasonal groundwater planning model in Dhuty RBC area to predict how much groundwater will be available at the end of May based on the groundwater level at the end of October. The MIKE BASIN Setup of GW seasonal planning is shown in Figure 14. Comparison between observed and simulated ground water depth is shown in Figure 14.

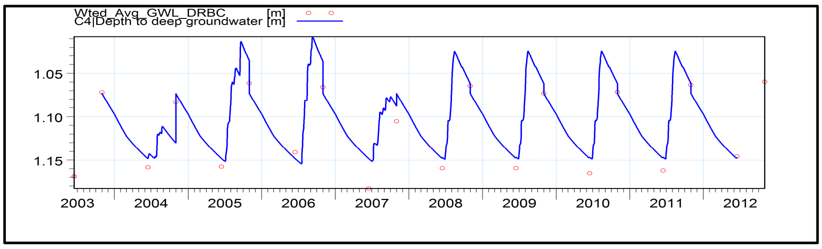

Figure 14: Comparison between observed and simulated ground water depth

The seasonal groundwater planning model tested for its accuracy in simulating GW levels for Dhuty RBC area and found efficient. The model can be used for predicting GW levels of May (pre-monsoon) using information on GW levels in October (post- monsoon) and it can be used to manage the GW demand in the study area

5.4.7 Dashboard manager

Dashboard Manager (DBM) is a module for creating web pages for water resources application. The Dashboard manger can be used as a web page to display the monitored data and the results of the DSS for the public information. The Dashboard interface of DSS in Wainganga basin is shown in Figure 15. The purpose of DBM is to produce definition of web pages. These definitions are 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 are generated and sent to the users. The DBM is a client server application. The Dash Board Manager (DBM) which is being developed for MP under DSS should include the following information for user's access. Meteorological data Ground Water Data and Information In the form of site Locations, time series Plots and tables in different time scale, Statistical information etc

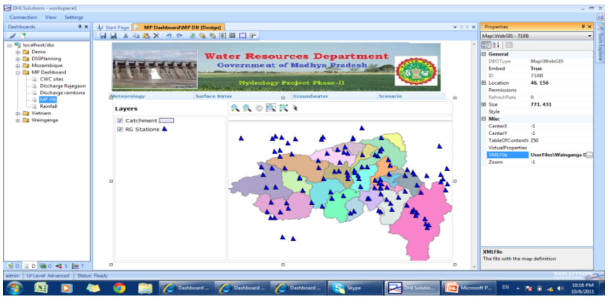

Figure 15: Dashboard interface of DSS in Wainganga basin

6. CONCLUSIONS

The Ministry of Water Resources, Government of India has implemented DSS project under the Hydrology Project Phase-II (HP-II) funded by World Bank for integrated water resources development and management in nine states. In Madhya Pradesh the DSS was developed for Wainganga Basin to support decisions in water resources development and management and share data and information within the user organization considering the data availability and the range of water resources problems in the basin. The approach of integrated river basin management (IRBM) was found very effective to address hydrological issues under DSS. The hydrological modelling tools used under DSS like MIKE 11, MIKE ZERO, MIKE BASIN, MIKE HYDRO, DSS(P) were found accurate, reliable and capable to manage the huge amount of data, perform analysis, simulation, multi-objective evaluation of results and providing the essential information required in decision making were used for DSS development.

The rainfall runoff model developed using NAM model were found performing well in the Wainganga basin and this models were successfully used for simulation of discharge time series in adjacent ungauged sub-basins of Wainganga basin. The runoff thus generated was used to assess water availability of sub basin with high degree of accuracy. The Mike Basin and DSS softwares were found to be a powerful tool to generate number of possible hydrological scenarios with alternate solutions which may enable the decision makers to analyze and chose the best one to execute. The DSS(P) customized for Wainganga basin may be used as pilot basin in MP to extend its work in other basins of MP to address issues of water resources management. The data base generation was the important task in DSS development; it was felt that good data base would results in generation of more realistic scenarios with high accuracy. DSS software thus developed under HP-II was found to be the very important and powerful tool in planning and management of water resources in Madhya Pradesh. However efforts also needs to be focused on improving the effectiveness and applicability of DSS, its sustainability in MP, training and capacity building, networking, data infrastructures and, very importantly, learning from past experiences and adopting enhanced protocols for DSS development.

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