Reservoir Operation & Planning Using MIKE BASIN MODEL in Drought Affected Bundelkhand Region of M.P. (India)

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Abstract: *The system analysis for management of water resources can be performed either by optimization or simulation. Optimization is carried out to get the best possible solution under different constraints of water availability, area affinity and social commitment, while, simulation is carried out by studying the behavior of the system for multiple scenarios. In the present study, demand/supply analysis has been carried out by simulating different scenarios of climatic variability, cropping pattern and system efficiencies for Benisagar project situated in Rajnagar block of Chhatarpur district in Bundelkhand part of M.P. (India) using MIKE BASIN model. The Benisagar project is a medium project designed to supply water for irrigation, domestic need and historical Khajuraho temple complex. The probability analysis of rainfall has been carried out to identify average/wet and dry rainfall years. Detailed soil analysis in the command has been carried out to determine soil properties. The simulation results indicated that the irrigation demand and demand deficit in average/wet rainfall year for design cropping pattern is about 18.44 Mm^3 and 6.88 Mm^3 respectively with conveyance efficiency of 60% and application efficiency of 70% (Scenario: DCP-I). The demand deficit of the Benisagar command can be reduced to 2.77mm^3 by improving conveyance efficiency. The reduced demand can be supplemented by conjunctive use of surface and groundwater in average/wet years (Scenario: DCP-II). The simulation results indicated that the present capacity of the Benisagar dam may not be able to fulfill complete irrigation and domestic demands during dry/drought years. Suitable mitigation methods such as timely warning, alternative cropping pattern, reduction of losses and systematic releases can improve the situation in the region during drought/dry years.*

Keywords: *Simulation, reservoir operation, evapotranspiration, cropping pattern, irrigation demand, demand deficit*

1. Introduction

Reservoir operation involves consideration of a number of decision variables, multiple objectives as well as risk and uncertainty (Oliveira and Loucks, 1997) [1]. In addition, the conflicting objectives lead to significant challenges for operators when making operational decisions. Traditionally, fixed reservoir rule curves have been used for guiding and managing the reservoir operation. These curves specify reservoir releases according to different controls such as current reservoir levels, hydrological conditions, water demands and time of the year. Established rule curves, however, are often not very efficient for balancing the demands from the different users (Chang et al 2005 [2], Ngo et al, 2006 [3] Pederson et al, 2007 [4]). Therefore, it is necessary to develop efficient models for each scheme to allocate water for different conflicting demands with priority and minimum deficit. These models should be able to develop the water resource system spatially or in terms of network model, where different aspects of water supply, sharing, demands, priority, reservoir characteristics, crops, soil, climatic factors etc. can be assigned to determine system demand, supply and deficit in different time periods with the help of optimization or simulation. Optimization is a powerful technique that helps analyze most complex water resource system in detail for performance evaluation. In many situations, however, decision makers would be interested in examining a number of scenarios rather than just looking at one single solution that is optimal (Jaiswal et al, 2013)[5].

Jha and Gupta (2003) [6] described the application of MIKE BASIN simulation model to the Mun river basin located in northeastern Thailand. DHI (2003) [7]developed a surface budget model for the Lemhi river basin using MIKE BASIN resulted a surface water budget model and simulate several irrigation alternatives. DHI (2008) [8] developed MIKE BASIN model for river Mckenzie and its tributaries (MRMBM) that included a series of rainfall-runoff models constructed using DHI’s NAM model in order to provide catchment inflows to the model. Hassaballah et al (2012)[9] developed a methodology by coupling simulation-optimization approach for determining filling rules of proposed Mandaya Reservoir in Ethiopia with minimum impact on hydropower generation downstream at Roseires Reservoir in Sudan.

1.1. MIKE BASIN Model

MIKE BASIN is a multi-purpose, GIS based river basin simulation package, designed for analyzing water sharing problems and environmental issues at international, national and project scale. MIKE BASIN is powerful, yet simple to use, with lots of analysis capabilities for water resources engineering. It can be used for hydropower operation, hydrological modeling, irrigation demand and yield assessment, time series data management and water quality issues. MIKE BASIN can accommodate multiple multi-purpose reservoir system and individual reservoir can simulate the performance of specified operating policies using associated operating rule curves. For setting up irrigation model in MIKE BASIN software, various sub-models including climate, reference ET, soil water, runoff (optional), irrigation method, crop, yield (optional) and crop sequence are needed to be developed to define the heterogeneity of soil, climate, crop sequence and irrigation methods in the commands. The climate sub-model accepts a number of commonly available climatic variables and converts them to the input required by reference ET sub-model.

The reference ET sub-model provides reference evapotranspiration to crop sub-model at each time step of simulation. The model uses the standardized Penman-Monteith equation for calculation of reference evapotranspiration. The main task of the soil water model is to keep track of the amount of soil water available for soil evaporation and crop evapotranspiration at any time during the simulation. The task of the runoff model is to calculate the fraction of the precipitation that will leave the field as surface runoff and hence never enter the root zone. The irrigation sub-model is used to specify how and when a given field is irrigated. The crop sub-model is used in MIKE BASIN to compute crop evapotranspiration and soil evaporation for crops using soil moisture content and reference evapotranspiration. A crop sequence consists of a sequence of crop and characterized by a sowing date and optionally a reference ET and irrigation sub-model that will be used to irrigate the crop.

In MIKE BASIN, three types of storages reservoirs including rule curve reservoir, allocation pool reservoir and lake can be modeled and the input requirements depend on the type of reservoir selected. The channels are the segments that connect water users and hydropower nodes to a river or a reservoir in the model can be used to define application and conveyance losses in the system. After setting up all sub models, reservoirs and channel details and priority setting, the model can be run for simulation. The output files contain evapotranspiration, total irrigation demand, net flow, demand deficit, stored volume and water levels in reservoirs, channel flows etc at given time span assigned during simulation. In the present study, MIKE BASIN model for Benisagar multipurpose project situated in Rajnagar block of Chhatarpur district of Bundelkhand part of M.P. (India) has been developed for planning and management of reservoirs release with multiple demands and constraints.

2. Study Area

The Benisagar project is a medium multipurpose project situated in Rajnagar Tehsil of Chhatarpur district of Madhya Pradesh. The project consists of a Benisagar dam on river Khurar near Khajuraho and Benisagar feeder scheme on river Banne near village Satna in Rajnagar Tehsil (Figure 1). The catchment area of Benisagar dam is 76.85 km^2 and length of river Khurar up to dam site is 15 km. The gross and dead storage capacity of the Benisagar reservoir are 27.59 Mm^3 and 1.37 Mm^3 respectively. The gross command area of the project is 6802.46 ha while the cultivated area is 6267 ha. A Beniganj weir was constructed near Village Satna to partially divert water from river Banne to Benisagar reservoir.

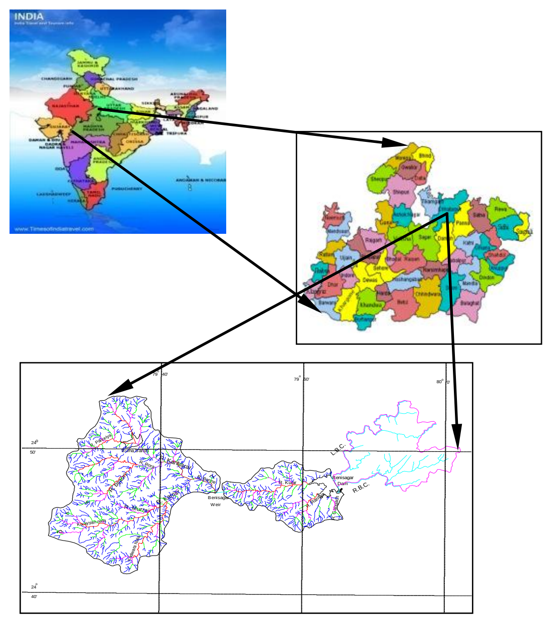

Figure 1: Base map of the study area

3. Methodology

For development of irrigation management and reservoir operation model for Benisagar project in MIKE BASIN, drainage and catchment boundary maps have been used as inputs and pseudo DEM, flow direction and accumulation maps have been generated for delineation of river reaches and catchment in the software. Two commands namely left and right command and a user node for water supply to tanks/domestic use have been digitized and joined through canals from the reservoir. The MIKE BASIN model for Benisagar reservoir, user nodes for supply of water to tanks/domestic supply and to both the commands have been depicted in Figure 2.

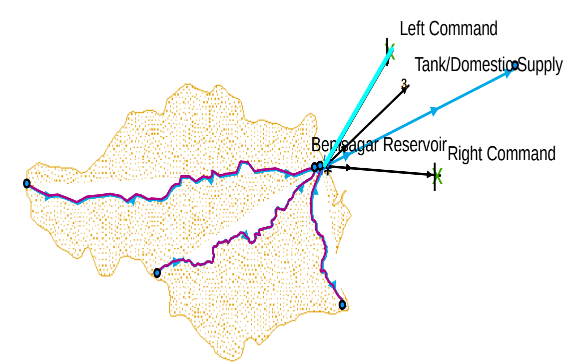

Figure 2: Conceptualized representation of Benisagar reservoir and its commands in MIKE BASIN

The climatological data of Khajuraho has been used in climate sub-model for computation of reference crop evapotranspiration. The areas of different crops under two soil groups have been determined using land use and soil maps of Benisagar command. The crop coefficients for different crops have been included in crop sub-model and their areas have been assigned in crop sequence. The reservoir details including elevation-area-capacity table, FRL, DSL, water supply priorities and reduction in supply have been defined in Reservoir properties tab. The detail soil analysis have been carried out that showed , the soils in the commands can be divided in two main groups with distinct field capacity, wilting point, porosity and other soil properties (Table 1). Reservoir levels, inflows, storages, annual rainfall from 1993 to 2008 have been used to develop different scenarios of design cropping pattern in MIKE BASIN model. The reservoir operating rule proposed in model consisted of any flow above FRL (310.89 m) has been allowed to go to the river from spillway. The maximum water level of 310.89 m is maintained during September. The zone from 310.89 m to 307.00 m is normal operation zone and water can be released as per requirement of domestic supply and crop requirement. The zone from 307.00 m to 304.72 m is considered as reduction zone and curtailed supply with reduction factor of 0.6 for irrigation and full supply to domestic supply on priority. No water from reservoir is considered to be supplied below 304.72 m. The model has been simulated for water year with reservoir at below dead storage level at the start of June 01.

4. Results & Analysis

The drought analysis of Rajnagar confirmed that the commands of Benisagar project fall under drought prone area and an efficient water resources management is required to cope up with the recurrent drought situation. For conducting irrigation management and reservoir operation studies, a MIKE BASIN model for designed cropping pattern has been developed. The crop coefficients and other factors for different crops have been assigned in crop sub-model. The area of crops under different soil groups, their date of sowing have been given in crop sequence sub-model. The crop sequence has been developed for designed cropping pattern of 3000 ha Maxican wheat, 300 ha ordinary wheat and 870 ha soybean. As the cultivation does not start simultaneously in whole command areas, wheat has been divided in three parts and soybean in two parts on the basis of sowing dates. The crop calendar for design pattern in Benisagar command has been given in Figure 3. The irrigation sub-model has been generated for defining irrigation method and trigger option. For simulation of reservoir release from Benisagar command, the following scenarios for changing rainfall, reservoir inflows and efficiencies conditions are employed.

DCP-I: Average/wet year, conveyance efficiency 60% and application efficiency 70%

DCP-II: Average/wet year, conveyance efficiency 70% and application efficiency 80%

DCP-III: Dry rainfall year, conveyance efficiency 60% and application efficiency 70%

DCP-IV: Dry rainfall year, conveyance efficiency 70% and application efficiency 80%

Table 1: Reservoir, soil and irrigation details

Description	**Benisagar reservoir**	
Reservoir detail		
Crest level	314.33 m	
Flood Control Zone	310.89 m	
Normal operation zone	307.00 m	
Minimum operation level	304.72 m	
Reduction factor	0.60	
Soil details	**Soil 1**	**Soil 2**
Field capacity	11.55	20.29
Wilting point	3.82	7.49
Initial water content	11.55	20.29
Depth of evaporable layer	0.1 m	0.1 m
Porosity	0.35	0.45
Gross command area	**Soil 1**	**Soil 2**
Left command	126.09 ha	2739.05 ha
Right command	2109.19 ha	1299.67 ha
Irrigation details		
Irrigation method	Flooding	
Wetting friction	0.70	
Spray loss	0.05	
Trigger option-	Friction of Readily available Water (RAW): 0.30	
Application option	Friction of Readily available Water (RAW): 0.80	

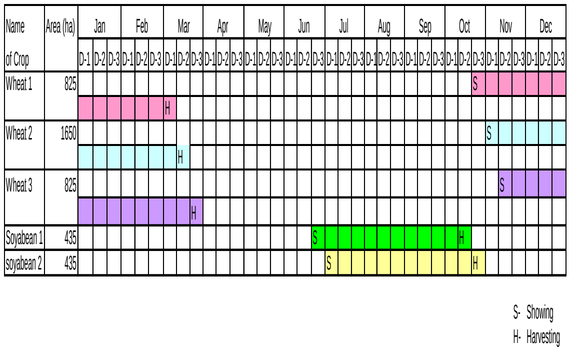

Figure 3: Design cropping pattern

For creating different scenarios, the changes have been made in incoming monthly water in the reservoir as per wet/average or dry year rains and losses through canals. After simulation run, the model provides water availability at different nodes, irrigation demand and demand deficit in commands, supply and deficit for user node, volume of water and reservoir levels in different periods. The graphical representation of irrigation demand (*ID*) and demand deficit (*DD*) of left and right command in Benisagar command for design cropping pattern (*DCP-I* to *DCP-IV*) has been presented in Figure 4. The total demand and demand deficit for both commands and tank node have been depicted in Table 3.

Table 3: Demand and deficit for users in Benisagar command (Mm^3)

Scenario	Left command		Right command		Tank supply	
	ID	*DD*	*ID*	*DD*	*D*	*DD*
DCP-I	7.34	2.34	10.29	3.88	0.81	0.64
DCP-II	6.55	1.00	8.73	1.50	0.81	0.27
DCP-III	13.01	10.67	19.20	15.79	0.81	0.81
DCP-IV	11.19	8.12	16.06	11.84	0.81	0.81

ID= Irrigation demand, *DD*= Demand deficit, *D*= Demand

From the analysis of simulation results for design cropping pattern in Benisagar command from MIKE BASIN, it has been observed that the irrigation demand and demand deficit in average/wet rainfall year may be estimated as 18.44 Mm^3 and 6.88 Mm^3 respectively at 60% conveyance efficiency and 70% application efficiency. If the conveyance efficiency and application efficiency increased to 70% and 80% respectively and reservoir operation may be conducted as suggested by the simulation results, the demand deficit can be reduced to 2.77 Mm^3 only that can be supplemented through groundwater. In case of dry rainfall years, when the rainfall is not sufficient to fill the reservoir completely, the demand deficit reaches to 27.27 Mm^3 considering conveyance efficiency as 60% and application efficiency as 70%. If conveyance efficiency increased to 70% and application efficiency to 80 %, the irrigation demand reduced to 20.77 Mm^3 with efficient water management, reduction of losses and proper releases especially in dry years.

5. Conclusions

The Bundelkhand region in M.P. (India) experiences frequent drought and also lacks in efficient management practices of the existing water resources system. An efficient reservoir operation and planning are essential to cope up with the intricate situation. MIKE BABIN is a simple but efficient tool for water resources management on inter and intra basin level to deal with priority, reservoir regulation, rainfall-runoff modeling, hydropower and water quality issues. MIKE BASIN based simulation analysis has been carried out in the Benisagar command in Chhattarpur district of M.P. (India) for development of four different scenarios based on variable rainfall, reservoir inflows and communication efficiencies. Benisagar project is an important medium project in Bundelkhand region designed to irrigate commands and supply water to tanks/domestic supply in world heritage of Khajurah temple complex. The analysis of inflows in the reservoir and simulation results showed that reservoir with its complete filling during average/wet years is not able to meet total demand of 18.44 Mm^3 with 60% conveyance efficiency and 70% application efficiency (*DCP-I*). By improving conveyance and application efficiencies through reservoir releases, the demand deficit can be reduced to 2.77 Mm^3 (*DCP-II*).. During dry rainfall years, the reservoir may not be able to fulfill the total demand of 33.02 Mm^3 of the system because of less inflow that may result into demand deficit of 27.27 Mm^3. To overcome such situation, an early warning system and awareness among farmers for suitable change in cropping pattern under drought situation would be necessary.

6. References

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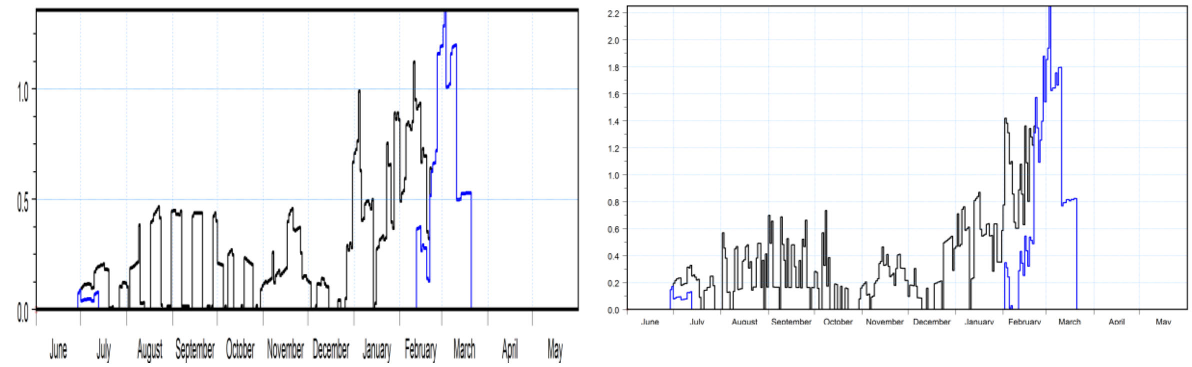
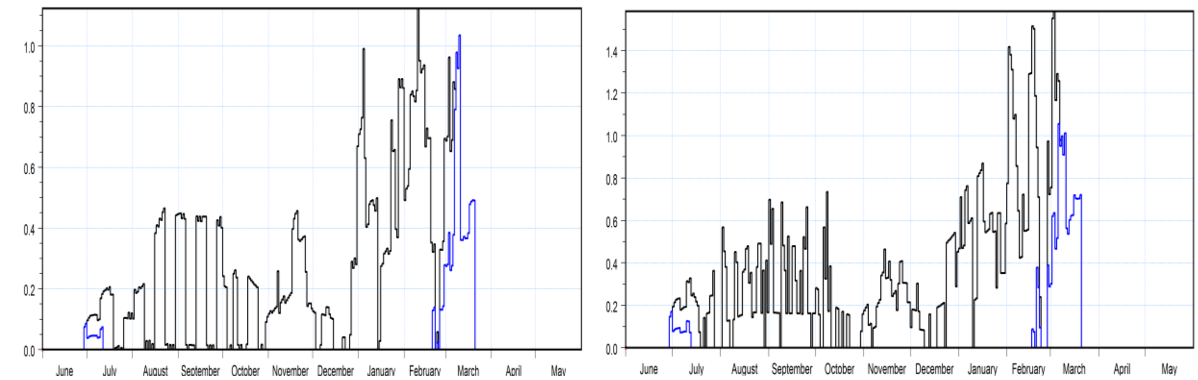
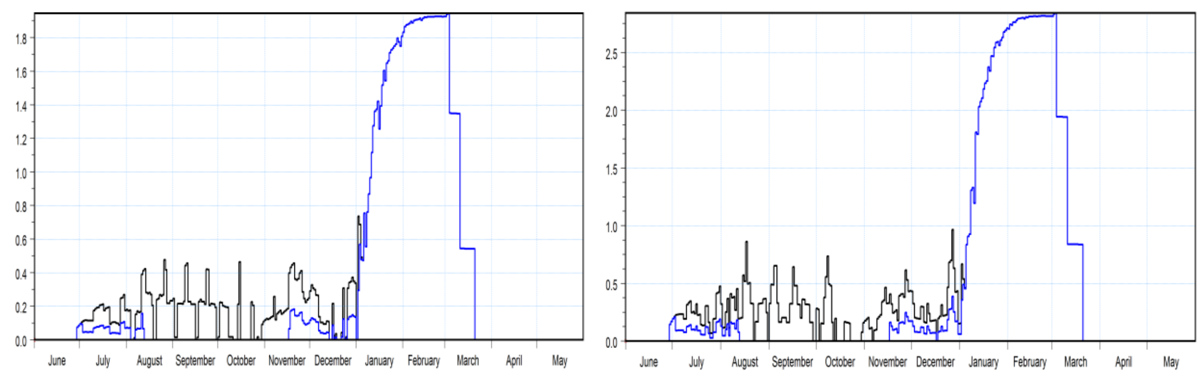
Left canal Right canal



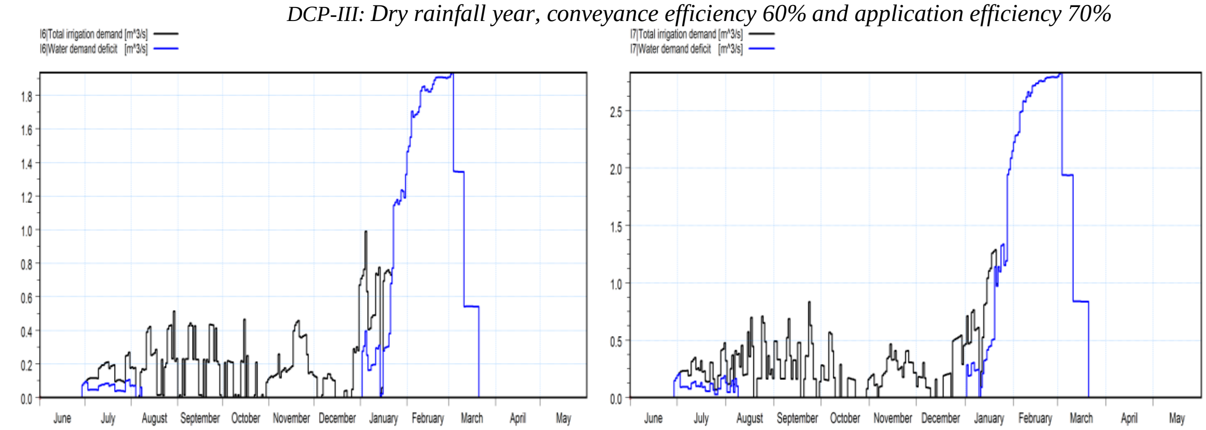
DCP-I: Average/wet year, conveyance efficiency 60% and application efficiency 70%



DCP-II: Average/wet year, conveyance efficiency 70% and application efficiency 80%



DCP-III: Dry rainfall year, conveyance efficiency 60% and application efficiency 70%



DCP-IV: Dry rainfall year, conveyance efficiency 70% and application efficiency 80%

Figure 4: Irrigation demand and demand deficit in commands of Benisagar dam (*DCP-I* to *DCP-IV*)

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