Proceedings of International Conference on Hydraulics, Water Resources and Coastal Engineering (Hydro2016), CWPRS Pune, India
8th – 10th December 2016

IRRIGATION PLANNING AND MANAGEMENT UNDER VARIABLE CLIMATIC, EFFICIENCY AND CONJUNCTIVE USE CONDITIONS

R.K. Jaiswal[1], R. V. Galkate[1], T. R. Nayak[1], T. Thomas[1], J. K. Jain[2], B. Baghel[2]
[1]*Scientist, National Institute of Hydrology, CIHRC, WALMI Campus, Bhopal 462026, India*
[2]*Water Resources Department, Govt. of M.P., Bhopal, India*
Email:rkjaiswal_sagar@yahoo.co.in

ABSTRACT

Despite high priority, massive investment and phenomenal growth in the irrigation sector since independence, the performance of irrigation systems, both in economic terms of crop yields, farm incomes and cost recovery as well as in water distribution terms of adequacy, equity, timeliness of water supplies has not been found encouraging. The scenarios based assessment of irrigation releases under variable climate, supplies, cropping pattern, efficiencies conditions and conjunctive use criterions has been carried out by developing MIKE BASIN model for Harsi command in Gwalior district of Madhya Pradesh (India). The temporal variations of supplies from different sources for Harsi command were determined for dry, wet and average rainfall years and spatial variation of soils, crops, conveyance & application efficiency and conjunctive use of surface and groundwater were used as inputs to develop sixteen different scenarios for design cropping pattern. Different simulation runs were made to assess irrigation demand, supply to command, demand deficit, reservoir level and capacity at different period of year. The simulation results confirmed that the demand of design cropping pattern may vary from 313.6 Mm^3 (MB-DCP-1 & 2) in wet rainfall years to 372.4 Mm^3 (MB-DCP-9 & 10) in dry or drought years. The demand deficit of 41.2 Mm^3 under existing 77% conveyance and 71% application efficiencies without using groundwater in wet years can be reduced to 2 Mm^3 by improving conditions of canals (81% conveyance and 76% application efficiencies), conjunctive use (10% demand from groundwater) and operation of reservoir as suggested by model. The sedimentation study of Harsi reservoir showed the loss of nearly 25% gross storage and the analysis of reduced capacity of reservoir confirmed adverse impact for design cropping pattern in dry or drought years mainly. The developed irrigation model can be used for operation of reservoir and irrigation management in the command using real time data.
Keywords: *Optimization, reservoir operation, irrigation releases, cropping pattern*

1. INTRODUCTION

Irrigation has been identified as one of the most critical input for agriculture development in India due to monsoon climate which limits rainfall to three or four months in a year and lot of spatial variability. To increase the crop production, the surface irrigation schemes are to be considered as the most feasible way in which the extra water is accumulated by constructing dam across the rivers and transfer this water to the field by a network of canal and distributaries during lean periods. Supplying optimal and timely water to crops is of utmost importance for increasing yield and number of models have been developed based on stochastic dynamic programming (SDP) for a single crop situation by Dudley et al., 1971; Dudley & Burt, 1973; Bras & Cordova, 1981etc. and for a multi crop situation by Rao et al., 1990; Vedula & Mujumdar, 1992; Vedula & Nagesh Kumar, 1996 etc. Raut et al (2010) used FAO model CROPWAT with the help of agro-meteorological and remote sensing data (1986–1998 and 2008) to calculate irrigation water requirements of wheat and mustard crops grown in western Yamuna canal command. These water requirements, when analyzed with canal and tube well water supplies for crops, show large scale deficiencies in the irrigation command area.

Reservoir operation involves many decision variables, multiple objectives as well as risk and uncertainty. The established rule curves which are most commonly used in reservoir operation are often not very efficient for balancing the demands of different users (Oliveira & Loucks 1997; Chang et al. 2005; Paderson et al. 2007). Bhadra et al. (2009) developed an integrated reservoir-based canal irrigation model (IRCIM) and successfully simulated the operation of the test reservoir after calibration and determined better delivery schedules than that actually practiced.

Various operating models and decision support system (DSS) have been developed and applied by researchers to address the issues of water supply from reservoirs for irrigation planning, flood management, power generation, multi objectives operation, enhancement of efficiencies (Martin et al. 1984; Koch and Allen 1986; Arumugam et al. 1997; Majumdar and Ramesh 1997; Prajamwong et al. 1997; Panigrahi and Mujumdar 2000; Manoli et al. 2001; Cancelliere et al. 2002; Reddy and Nagesh 2006; Reddy and Nagesh 2007; El-Mesiry et al. 2007; Kim et al. 2008; Canon et al. 2009; Li et al. 2012; Nikoo et al. 2013; Wang and Liu 2013; Ahmadi et al. 2014 etc.). The optimization is a powerful technique that helps analyze complex water resource system for obtaining the most economical/viable solution. In many situations, 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). Thus, there is a potential for improvement of reservoir operating policy with the help of optimization or development and examination of scenarios.

1.1 MIKE BASIN model

The MIKE BASIN model developed by Danish Hydrological Institute (DHI), Denmark to address complex issues water sharing, water allocation, reservoir operation, water quality and conjunctive use of surface and groundwater on basin scale in simple and intuitive yet in-depth insight for water resources planning and management (DHI, 2006). Typical areas of the MIKE Basin applications are water availability analysis, optimization, irrigation planning, analysis of multi-sector demands, ecosystem studies, infra structure planning etc (Srinivas, 2007). Lerson et al. (2006) presented a study proposes the coupling of a strategic scale water resources management simulation model (MIKE-BASIN) and a finite difference groundwater model (ASM), as a tool to support decision making in data scarce environments. Jaiswal et al 2013 & Jaiswal et al 2014 applied MIKE BASIN model for irrigation management and reservoir operation for reservoir having sharing agreement among different stake holders. The MIKE BASIN is a versatile, GIS based decision support tool for integrated water resources management and planning. The MIKE BASIN philosophy is to keep modeling simple and intuitive, yet provide in-depth insight for planning and management. For hydrological simulations, MIKE BASIN builds a network model in which branches represent individual stream and nodes represent confluences, diversions, reservoirs, or water users.

1.2 Study area & data used

The study area for the present study is Harsi reservoir and its command situated on river Parvati at 25°45' N latitude and 77°58' E longitude on river Harsi at about 100 km from the Gwalior and 55 km from Dabra town of Madhya Pradesh (India). The location map of Harsi irrigation project in Madhya Pradesh has been given in Fig. 1. The Harsi project is an irrigation project designed to irrigate 62675 ha culturable command area (CCA) with 91057 ha gross command area (GCA) in the command. Due to increasing demand of irrigation water in the command area and shortage of water in Harsi reservoir, water from Kaketo dam, Mohini pick up weir and Madikheda dam is transferred to this reservoir. The design cropping pattern in Harsi command consists of 21662 ha high yielding variety wheat, 15128 ha dwarf wheat, 2161 ha gram and 2161 ha mustard in rabi while 1081 ha soybean, 15560 ha paddy and 648 ha urad in kharif season. For the study, rainfall data of Dabra for identification of dry, average and wet rainfall year, climatic data of Datia, soil and crop data of Harsi command, elevation-area-capacity curve and other details of Harsi reservoir and supplies details from Kharkhara reservoir, Madikheda dam and Mohini picup weir were used.

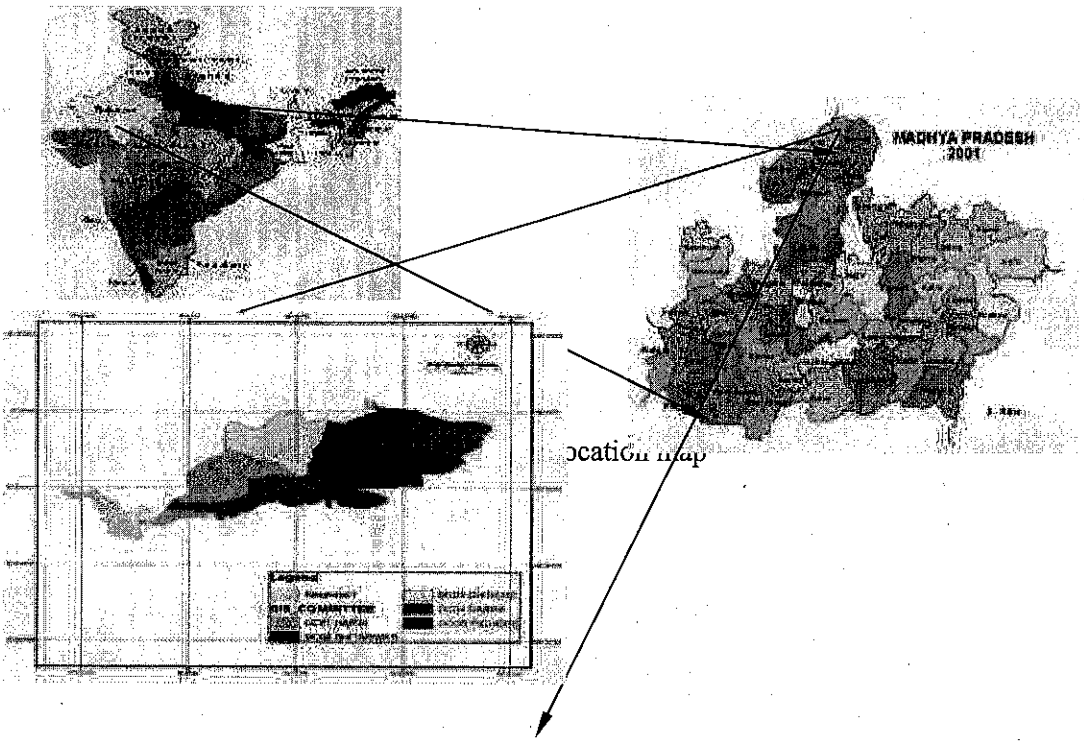

Table 5.3(a). Designed cropping patterns and crop duration in Harsi command of Harsi dam in Gwalior district (M.P.)

S.N.	Name of Crop	Crop duration	Area sown (ha)
1.	KHARIF		
	Paddy 1	10 July-Oct- 4month	7780
	Paddy 2	20 July-Nov- 4month	7780
	Urad	15-June- 4 month	648
	Soybean	15 July-Oct 4- month	1081
	TOTAL		17290
2.	RABI		
	Wheat dwarf 1	10 Nov-March-5month	7564
	Wheat dwarf 2	20 Nov-Apr-5month	7564
	Gram	10 Oct-Feb-5month	2161
	Mustard	15 Oct-Feb-5 month	2161
	Wheat HYV 1	10 Nov-March-5month	10806
	Wheat HYV 2	20 Nov-Apr-5month	10806
	TOTAL		41063
3.	Sugarcane	01 Feb-Jan	4322
	G. TOTAL		62675

2. METHODOLOGY

The methodology for irrigation management under changing scenarios includes building model in MIKE BASIN, defining reservoir and irrigation nodes and their characteristics and run simulation for determination of demands, supplies to the node, demand deficit and reservoir storages and different periods of time. All information regarding the configuration of the river branch network, location of water users, channels for intakes and outlets to and from water users, reservoirs need to be defined by on-screen editing or using DEM. A schematic representation of water management through MIKE BASIN is presented in Fig. 2.

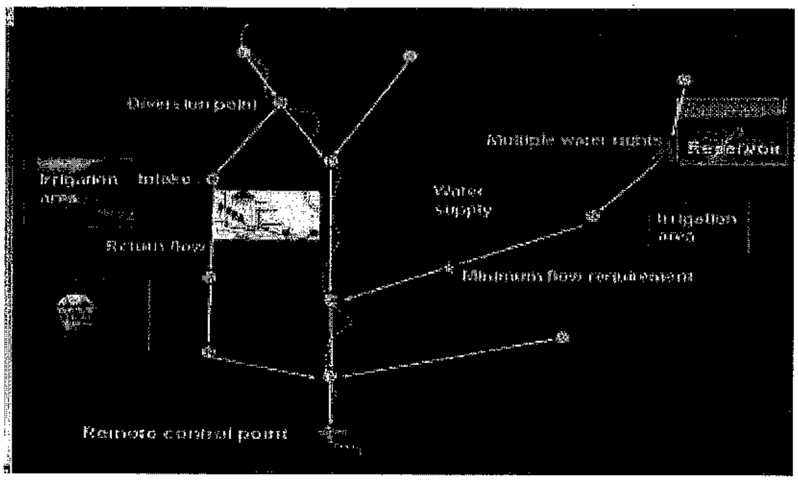

Figure 2. A representative MIKE BASIN model (Reproduce from MIKE BASIN Manual)

2.1 Reservoir node

The MIKE BASIN can accommodate multiple multi-purpose reservoir system and individual reservoir based on specified operating policies and operating rule curves. Reservoirs can be inserted anywhere on the river branches except on river bifurcation nodes or the most upstream nodes. In MIKE BASIN, three types of storages reservoirs can be modeled as rule curve reservoir, allocation pool reservoir or lake. The rule curve reservoir has a single physical storage and all users can draw water from the same storage, while individual user has certain storage right within a zone in allocation pool reservoir and lakes have no operation rules. The outflow from a lake can be restricted by a spillway relationship. For reservoir operation in MIKE BASIN, its general, operation, spillway and water quality (optional) properties need to be specified.

2.2 Irrigation node

An irrigation node represents an irrigation area comprising one or more irrigation field, which are drawing water from same source(s). In order to define heterogeneity of soils, crops, irrigation and climate, various sub-models including Climate, Reference ET, Soil water, Runoff, Irrigation method, Crop, Yield and Crop sequence are needed for irrigation planning. The climate sub-model accepts a number of commonly available climate inputs and converts them to the input required for Reference ET sub-model. The evapotranspiration rate may either be computed based on climate sub-model or provided directly as time series. 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. Presently, the FAO56 soil water model which is a simple water balance model that keeps track of the soil moisture content in a surface storage from where soil evaporation can take place and a root zone storage that provides water for transpiration is available. The depth of the surface storage is specified as the depth of evaporable layer and depth of the root zone equals the root depth at any time during the simulation.
The crop sub-model is used in MIKE BASIN to compute crop evapotranspiration where dual crop coefficient model are used to calculate transpiration and soil evaporation separately and thus allows a more accurate quantification of the consequences of using different irrigation technologies and stages. The crop stages divided into an initial, development, middle and late crop stage for which the length of stage and Basal crop coefficient (K_{cb}) are assigned. The K_{cb} is considered as constant in the initial and middle stages and follow a linear variation between the stages. The root depth determines the maximum depth from which the crop can extract water and the minimum and maximum depth has to be specified. It is assumed that the maximum depth is obtained at the beginning of the middle stage and the variation between the initial depth and the maximum depth is determined by the following relationship.

$$R = \frac{(K_{c} - K_{c,ini})}{(K_{c,mid} - K_{c,ini})}(R_{max} - R_{min}) + R_{min} \quad (1)$$

Where, $K_{cb,ini}$ is the initial crop Basal coefficient, $K_{cb,mid}$ is the Basal coefficient in middle stage, R_{max} is the maximum root depth and Rmin is the minimum root depth. The influence of the surface roughness on the evapotranspiration is taken into account through a climatic factor applied to the Basal crop coefficient. The vegetation height (*H*) is assumed to scale with the Basal crop coefficients and is calculated as:

$$H = \frac{(K_{c} - K_{c,ini})}{(K_{c,mid} - K_{c,ini})}H_{max} \quad (2)$$

The irrigation sub-model is used to specify how and when a given field is irrigated and presently, FAO 56 irrigation model is available in the model. The wetting fraction is also an important factor to determine how much irrigation is required before the surface soil storage is filled. The spray loss is the fraction of the irrigation water that is evaporated before the water reaches the soil surface. In the MIKE BASIN following three trigger options are available to determine when to start irrigation in the field.

- Fraction of Total Available Water (TAW): Irrigation starts when the soil moisture content reaches the specified fraction of TAW. The TAW is defined as the volume of water contained in the root zone at field capacity.
- Fraction of Readily Available Water (RAW): Irrigation starts when the soil moisture content reaches the specified fraction of RAW. RAW is defined as the volume of water that can be transpired by the crop without exposing the crop to soil water stress and can be calculate using the following equation:
  $$RAW = (1 - p) * TAW \quad (3)$$
  where, p is a factor based on sensitivity of crop with soil moisture stress, or more specifically the fraction of the totally available water (TAW) at which soil moisture stress will start to reduce crop transpiration.
- Specified depletion depth: Irrigation will start when the soil moisture content reaches the specified depletion. When the irrigation has started as per the trigger option, the application depth is calculated according to available following three application option:

The channels are the segments that connect water users and hydropower nodes to a river or a reservoir. The flow losses and flow capacity times series are the optional time series required to define lose or gain of water due to seepage and lose of water due to evaporation. The flow capacity time series of river/channel is used to determine the maximum capacity that never be exceeded at any case. After setting up all sub models, reservoirs, channel details and priority setting, the model can be run for simulation. The most general output items at the irrigation node is written to the MIKE BASIN output files and imported into Arc GIS contain evapotranspiration, total irrigation demand, net flow, demand deficit, stored volume and water levels in reservoirs, channel flows etc at given time span.

3. RESULTS AND ANALYSIS

For scenarios based irrigation planning, data related to supplies from other sources, reservoir data, soils, crops etc were determined. The storage capacity of Harsi reservoir was not found sufficient to fulfill all irrigation demand of the command; therefore this reservoir received water from Kaketo reservoir situated up-stream of Harsi reservoir on river Parvati. The water from Madikheda dam on river Sindh is released to Mohini Pick weir from where it diverted to a tributary of Parvati which ultimately reached to Harsi reservoir. The data related to supplies of water were analyzed to determine firm supplies of water from different sources to the system and presented in Table 2.

Table 2. Annual replenishment of water in Harsi reservoir

S.N.	Source of water to the system	Quantity (Mm^3)
1.	75% Dependable yield of Harsi Reservoir (Live storage)	192.66
2.	Deduction for seepage and evaporation (15% approx)	28.66
3.	Remaining usable water	164.00
4.	From Kaketo feeder reservoir during summer	36.79
5.	From Mohini pick-up weir through feeder channel during Monsoon (average diversion)	107.07
6.	From Madikheda dam	199.33
7.	Replenished water (Approximately 75% of sum of 4, 5 and 6)	263.19
8.	Total water available for irrigation (8=3+7)	427.19

The MIKE BASIN based irrigation model consisting of all reservoirs and command have been developed for Harsi reservoir project. For development of irrigation management and reservoir operation model for Harsi reservoir and its command, the DEM of study area has been as input and automatic delineation of sub-watersheds have been performed using facility available in the software. A reservoir node was digitized at the outlet of basin connected with canal to a command node. The water transfer nodes were also digitized to transfer water from Madikheda dam and Mohini pick up weir. The representation of MIKE basin model for Harsi reservoir, water transfer from Kaketo reservoir, Madikheda dam and Mohini Pickup Weir and supply of water to its command has been depicted in Fig. 3.

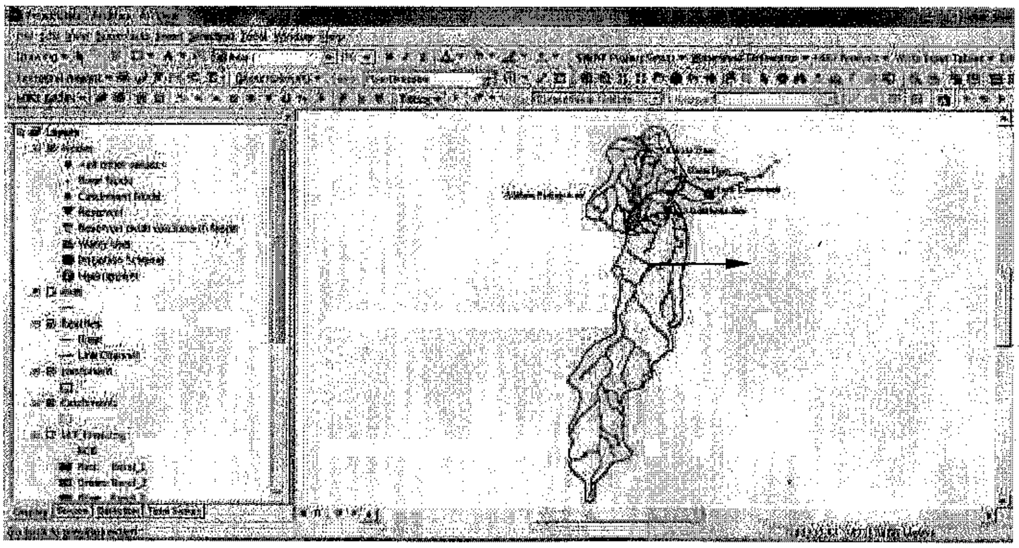

Figure 3. Representation of MIKE BASIN model for Harsi reservoir and its command

The reservoir details including elevation-area-capacity table, F.R.L., D.S.L., water supply priorities and reduction in supply have been defined in Reservoir properties tab (Table 3). The climatological data of Datia was used in climate sub-model for computation of reference evapotranspiration. Various sub models including climate, reference ET, soil, crop, irrigation were developed considering variability of climate, soils, crops, irrigation methods etc. All these sub-models were used to define cropping pattern under variable climatic condition in the command which ultimately connected with reservoir through connecting channel which incorporated application and conveyance losses.

Table 3. Details of Harsi Reservoir and its commands used in MIKE Basin model setup

S.N.	Description	Benisagar reservoir
1.	Reservoir detail	
	Crest level	268.90 m
	Flood Control Zone	264.93 m

	Normal operation zone	258.0 m	
	Minimum operation level	252.07 m	
	Bottom Level	251.00 m	
	Reduction factor	0.80	
2.	Soil details	Soil 1 (Loamy)	Soil 2 (Clay)
	Field capacity	0.41	0.28
	Wilting point	0.27	0.15
	Initial water content	0.2	0.14
	Depth of evaporable layer	0.01 m	0.15 m
	Porosity	0.55	0.40
	Gross command area	31651 ha	31024 ha
3.	Irrigation details		
	Irrigation method	Flooding	
	Wetting friction	0.95	
	Spray loss	0.05	
	Trigger option	Friction of Readily available Water (RAW): 0.20	
	Application option	Friction of Readily available Water (RAW): 0.80	

For development of different scenarios, suitable change have been made in time series to represent rainfalls, climatic parameters, reservoir inflows, inflows from other sources, groundwater uses, conveyance losses and application losses as per requirement of specific scenario. The results of probability analysis of rainfall were used and 2011, 1993, 1974 and 2002 were considered as representative wet, average, dry and 75% rainfall years. The variation of climate and rainfall, conveyance and application efficiencies (present and suggested) and conjunctive use of water have been introduced in inputs to develop 16 different scenarios from MB-DCP-1 to MB-DCP-16 as given in table 4.

Table 4. Scenarios for MIKE BASIN based irrigation management

S. N.	Cropping Pattern	Rain and climate	Conveyance efficiency		Application efficiency		Ground water contribution	Scenario
			Main & Dist. canal efficiency	Field channel efficiency	Field application efficiency	Operational efficiency		
1.	Design	Wet year	86%	90%	75%	95%	0 %	MB-DCP-1
2.	Design	Wet year	86%	90%	75%	95%	10 %	MB-DCP-2
3.	Design	Wet year	90%	95%	80%	95%	0 %	MB-DCP-3
4.	Design	Wet year	90%	95%	80%	95%	10 %	MB-DCP-4
5.	Design	Average year	86%	90%	75%	95%	0 %	MB-DCP-5
6.	Design	Average year	86%	90%	75%	95%	10 %	MB-DCP-6
7.	Design	Average year	90%	95%	80%	95%	0 %	MB-DCP-7
8.	Design	Average year	90%	95%	80%	95%	10 %	MB-DCP-8
9.	Design	Dry year	86%	90%	75%	95%	0 %	MB-DCP-9
10.	Design	Dry year	86%	90%	75%	95%	10 %	MB-DCP-10
11.	Design	Dry year	90%	95%	80%	95%	0 %	MB-DCP-11
12.	Design	Dry year	90%	95%	80%	95%	10 %	MB-DCP-12
13.	Design	75 % Rain	90%	95%	80%	95%	0 %	MB-DCP-13
14.	Design	75 % Rain	90%	95%	80%	95%	10 %	MB-DCP-14
15.	Design	75 % Rain	90%	95%	80%	95%	0 %	MB-DCP-15
16.	Design	75 % Rain	90%	95%	80%	95%	10 %	MB-DCP-16

From the analysis it has been observed that irrigation demands on Harsi reservoir may vary from 295.96 Mm^3 in wet years, 86% conveyance efficiency and 76% application efficiency (MB-DCP-3 & 4) to 372.37 Mm^3 in dry year, 77% conveyance efficiency and 71% application efficiency (MB-DCP-9 & 10). The irrigation demand, deficit, net flow and groundwater uses for different scenarios have been presented in Fig. 4. The demand deficit for design cropping pattern at 75% probable rainfall year may be 40.93 Mm^3 (MB-DCP-13) under present efficiency condition which can be reduced to 6.83 Mm^3 (MB-DCP-13) by improving efficiencies and further to 0.78 Mm^3, if conjunctive use of surface and groundwater is applied in the command. The demand deficit in dry rainfall years and present efficiencies conditions was computed through simulation in scenario MB-DCP-9 is about 86.11 Mm^3 can be reduced to 25.30 Mm^3 by better management, improving efficiencies and 10% use of groundwater through consumptive use.

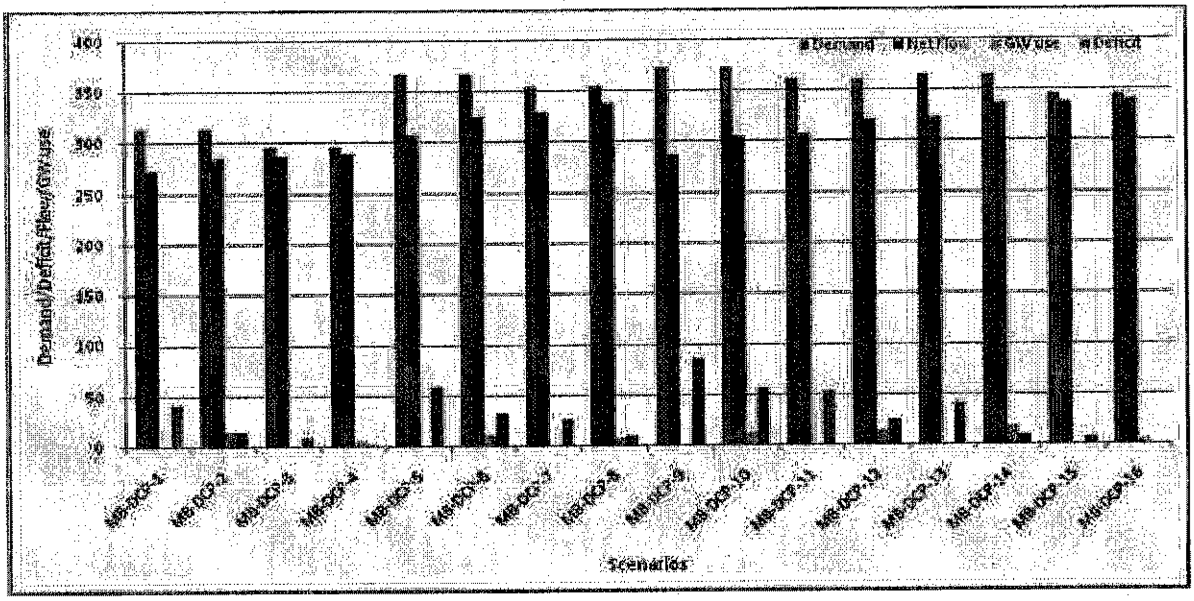

Figure 4. Demand, net flow to command, groundwater use and deficit under different scenarios (Mm^3)

4. CONCLUSIONS

The systematic and scientific approach of irrigation management may be helpful to reduce distribution losses, equitable distribution of water and increase in crop yields which lead to overall livelihood in the region. Total water available in Harsi command is about 427 Mm^3 but spatial distribution and present efficiencies make demand deficit under most of climatic conditions. The MIKE BASIN model developed for Harsi command take care of all climatic, soil, supplies, consumptive use and efficiencies conditions where irrigation planning can be made well in advance for maximization of crop yield. The simulation results confirmed the demand of design cropping pattern may vary from 295.96 Mm^3 (MB-DCP-1 & 2) in wet rainfall years to 372.4 Mm3 (MB-DCP-9 & 10) in dry or drought years. The demand deficit of 41.2 Mm^3 water under existing 77% conveyance and 71% application efficiencies without using groundwater in wet years can be reduced to 2 Mm^3 by improving conditions of canals (81% conveyance and 76% application efficiency), conjunctive use (10% demand from groundwater) and operation of reservoir as suggested by model. The demand deficit in dry years under present condition may be about 86.11 Mm^3 which cannot be easily met through other sources especially in dry years and improved efficiencies and consumptive use can bring this deficit to 25.59 Mm^3. The scenarios based assessment of demand/supply, reservoir condition and flows to command are helpful to water resource managers to plan releases from reservoir optimally.

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