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Performance assessment of irrigation system using MIKE 11

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ABSTRACT : Command under RBC is 212.56 km^2 with elevation difference of 56.70m., hydraulic model MIKE 11 was used for the performance assessment of RBC system of Pench Irrigation Project. The model setup was calibrated for 20 days in 2004 and validated for 20 days during in 2007. The calibration parameters, global resistance number and gate contraction coefficient for the calibration was found as 40 and 0.63, respectively whereas local resistance number ranges from 30 to 60. The values of PBAIS were estimated to be within 5%, and it increased from the head reach to tail reach. The values of NSE were observed to be decreased from head reach to tail reach. The values of performance criteria, *viz.,* PBAIS and NSE, selected for deciding the model efficiency was within the desired range during calibration as well as validation. A sharp decline in the performance ratio along the length of the main canal was observed for all the four years. This shows that the distributaries located in the head and middle reaches draw more than their share. This was verified with simulated flow data from MIKE 11 in the absence of the observed data.

KEY WORDS : MIKE 11, Hydrodynamic modelling, Performance of irrigation system, PBAIS, NSE

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Water is probably the only natural resource to touch all aspects of human civilization from agricultural and industrial development to cultural and religious values embedded in society. The ultimate irrigation potential of the India is estimated at 139.9 M ha of which irrigation potential from major and medium irrigation projects is assessed as 58.47 M ha. Irrigation potential created in the country from major and medium irrigation projects, which stood at 9.7 M ha in 1951, has risen to 36.98 M ha at the end of 2002 and 41.64 M ha, till the end of 2007 "as stated by Central Water Commission, (2012)". Improvement of canal irrigation performance can be obtained by shifting the focus of the policy makers and researchers to management of main canal system instead of trying to improve the distribution of water among the users below the outlet level. The success of irrigation operation and planning depend on quantification of supply and demand and equitable supply to meet the demand if possible or to minimize the gap between the supply and demand as mentioned by Chambers (1988).

Development of fully dynamic, unsteady models have provided with highly accurate hydraulic modelling methods. MIKE 11, is a software package for simulating flows, water quality and sediment transport in estuaries, rivers, irrigation channels and other water bodies as given by DHI (2007). MIKE 11 hydrodynamic model uses 1D implicit, dynamic wave routing based on Saint Venant equations for unsteady flow as mentioned by Kamel (2008). Use of hydraulic simulation models appears to be one of the appropriate tools for understanding the hydraulic behaviour of the system as a whole. MIKE 11 and MIKE SHE used for hydraulic and hydrological simulations, respectively to develop the irrigation optimization system (IOS) a decision support tool as given by Singh (1996). The MIKE 11 HD model applied to the Morava River Basin, Czech Republic and presented the application of MIKE 11 HD along with water quality model. The main objective of this study was to transfer the modelling technology in the field of water resources. They calibrated this model and presented some scenarios observed during the study Biza *et al*. (1997). Hydraulic model MIKE 11 used to simulate the distributary-wise canal releases. MIKE 11 was calibrated and validated during *Kharif* 1999 and 2000, respectively and reported to be perform well with relatively high validity for most of the locations in the canal system (Gupta *et al*., 2004). Considering the availability of modelling system and need to assess the performance of the irrigation system to augment the efficiency, hydrodynamic modelling has been carried to assess the performance of the Pench irrigation system.

METHODOLOGY

Pench Irrigation project is situated in Nagpur district, of Maharashtra State in India and the reservoir constructed on Pench river at village Navegaon Khairy. The Command area of the project is lies between $21^0$00' to $21^0$45'N latitude and $79^0$00' to $79^0$45'E longitudes and located in 11^{th} Agro-Ecological Region (K6C3) with an average annual rainfall of 1107mm over 1044.76km^2 of command. The project is serving domestic, industrial and irrigation demand through right and left bank canals of the project. The study was limited to Right Bank Canal Command which consists of Right Bank Main Canal, Tail Brach Canal (TBC), L4 Branch Canal (L4BC) and Khaperkheda Branch Canal (KBC). The total length of RBMC to Mathni is about 98 km. An intermittent delivery scheduling (variable discharge, variable duration and variable frequency) is being practiced with eight irrigations through canal supply over 7-19 days and equal or longer duration of canal closure. Major crops were cotton and paddy in *Kharif* and wheat in *Rabi* season.

The setup preparation for the hydraulic model involves specifications of canal cross-sections, layout of canal network, head and cross regulators, upstream and downstream initial and boundary conditions and seepage losses. The map of the RBC system showing network of canals, data and design of hydraulic structures (Inline and off-taking structures) and historical daily discharges at the system source of Right Bank Canal system for 5 years (2004-08) were collected from office of the Executive Engineer, Irrigation Department, Nagpur. Flow rates at 7 different locations in the RBC system were collected from the respective section offices.

Description of MIKE 11 :

In MIKE 11 HD module, the cross section database can be regarded as a library storing data for a large number of cross section organized in such a way that every cross section is identified by canal name, topographical identification and chainage. The cross section data are defined as discrete points along the canal system. In this study, a maximum space interval of 1 km was selected (dx-max=1 km). At some places, where the structures exist in the canal, cross sections were specified both upstream and downstream of these features.

Information on the name and chainage of the canal, topographical identification, upstream and downstream connections, and maximum selected distance between two neighbouring points (dx-max) required for canal network definition. The topographical map of the study area was extracted from the index map of the command area. There was an elevation difference of 56.70 m between the head and tail ends of the system.

The RMBC system consists of two inline control structure in RBMC and one in TBC along with the head and tail regulator at the start and end of the canal. The inline control structures are operated with respect to the discharge in the canal at a particular location. The specifications of these control structures such as structure identification, location, type of gate, number and width of gate, sill level and control point definition are specified in the menu.

The initial conditions are needed to avoid the dry bed situation. The initial conditions can be specified as global values of water levels and discharges for the entire canal network or as local values at different distances of a particular canal. The boundary conditions may be internal or external. The internal boundary condition includes the specifications at nodal points and structures, whereas the external boundary condition includes the specification of constant values for H_1 or Q or time varying values for Q or H_1 at the starting point and endpoint. Before running the model simulation, control parameters such as simulation period, simulation time step, data to be stored and storage time have to be specified. The simulation period was specified by a start and end dates defined by year, month, day, hour and minute. MIKE 11 checks the actual time and reads all the data given as time series during the simulation.

Calibration and validation :

Calibration of a model is the process of adjusting model parameters to obtain a close agreement between the observed and simulated outputs. Validation of the calibrated model is essential to verify the calibration precision. In calibrating of MIKE 11 model setup, the resistance number, gate contraction coefficient and control parameters of the regulating structures were considered as model calibration parameters. The resistance number used in this model was defined as the reciprocal of the Manning's roughness coefficient which is otherwise known as Strickler's coefficient. Here the discharge value at a structure taken as the control parameter for the operation of gate in the structure. After setting up the model, an initial run was made with the default global values of resistance number and gate contraction coefficient was 30 and 0.61, respectively.

The simulation period of 20 days (January 12-31, 2004) with a simulation time step of 1 minute were selected for calibration. This time step selected for calibration because measured data are available throughout the canal length. After simulation, comparison was made between observed and simulated discharges at seven inline structure points. Based on the comparison, the model parameters were adjusted. This process was continued until the observed and simulated discharges were in close agreement. To assess the model performance PBAIS Moriasi *et al*. (2007) and NSE ASCE task committee (1993) were used. Calibrated model was then validated for the period of February 7-26, 2007.

Performance assessment :

Performance of irrigation system can be described as the ratio of an actual situation to the target situation and is characterised by indicators. These are represented by various combinations of performance parameters such as flow rate, volume and frequency equity, edequacy, dependability and efficiency are some of the performance indicators used for the evaluation of the irrigation water delivery system as mentioned by Molden and Gates (1990).

Considering the daily actual flow rate at the system source as a base, the flow rate which would ideally occur at various measuring points (scheduled discharge) was calculated using Eq. (1)

$$\mathbf{Q_{sl}} = \left(\mathbf{1} - \frac{\mathbf{Q_d - Q_o}}{\mathbf{Q_d}}\right)\mathbf{Q_{dl}} \qquad (1)$$

where,

Q_{sl} = Daily scheduled discharge at a particular location $m^3\ s^{-1}$

Q_d = Design discharge at the system source, $m^3\ s^{-1}$

Q_o = Daily observed discharge at system source, $m^3\ s^{-1}$

Q_{dl} = Design discharge at specific location, $m^3\ s^{-1}$.

Subsequently, the per cent deviation of the observed data from the designed discharge data for each location is given by, Eq. (2)

$$\mathbf{Q_{DL}} = \frac{\mathbf{(Q_{dl} - Q_{ol})}}{\mathbf{Q_{dl}}}\ \mathbf{x\ 100} \qquad (2)$$

where,

Q_{DL} = Daily per cent deviation of discharge at a location

Q_{ol} = Daily observed discharge at specific location, $m^3\ s^{-1}$.

RESULTS AND DISCUSSION

The results of the present study as well as relevant discussions have been presented under following sub heads:

Calibration of MIKE 11 :

Temporal variation of observed and simulated discharge at RBMC 23km, RBMC 45km, Parshioni, Dahegaon, Tail D and L4BC are depicted in Fig. 1. These figures show the simulated discharges were in close agreement with observed discharges in head reach, whereas, decreased in middle reach and increased tail reach. This might be due to deterioration of the canal network over a long time, which cannot be considered in the model setup and possible time required for the stabilization of flow in the channel.

To further evaluate the model performance, goodness of fit criteria *viz.*, PBAIS and NSE were used. Table 1 presents the results of above mentioned statistical tests between observed and simulated flow rates along the canal system. The values of PBAIS were estimated to be within 5%, and it increased from the head reach to tail reach. The values of NSE were observed to be decreased from head reach to tail reach because of the large fluctuations in daily observed discharges with respect to the mean observed discharge.

Table 1 : Statistical parameter at various locations for calibration period

Name of canal	Distance from system source, km	Statistical parameter	
		PBAIS, %	NSE
RBMC	23.00	0.497	0.744
RBMC	45.00	0.892	0.646
Parshioni	08.81	0.584	0.542
Dahegaon	15.90	0.945	0.499
Tail_D	71.94	2.567	0.353
L4BC	75.00	3.541	0.187

The calibrated model parameters are presented in Table 2. The calibrated parameters global resistance number and gate contraction coefficient was found to be 40 and 0.63, respectively whereas, local resistance numbers ranged from 30 to 60. Variation in local resistance number could be due to lined and unlined canal, soil types, hyacinths and other weeds encountered along the canal.

Table 2 : Calibrated model parameter

Parameter	Relative distance from the beginning of respective canals, km	Value
Global resistance number	-	40
Gate contraction coefficient	-	0.63
Local resistance number		
RBMC	23.0	60
RBMC	45.0	55
Parshioni	0	30
Dahegaon	0	30
Tail D	0	40
L4BC	0	30

Validation of MIKE 11 :

To verify the acceptability of MIKE 11 results, calibrated model was validated for the period of February 7-26, 2007. Fig. 2 shows the temporal variation of discharge at RBMC 23km, RBMC 45km, Parshioni, Dahegaon, Tail_D and L4BC. Similar to calibration case, simulated discharges was in close agreement with the observed values for the head and middle reaches.

The results of statistical tests for the validation period in 2007 presented in Table 3 revealed that the values of PBAIS were increasing from head reach to tail reach and the value of NSE was decreasing from head to tail reach. By and

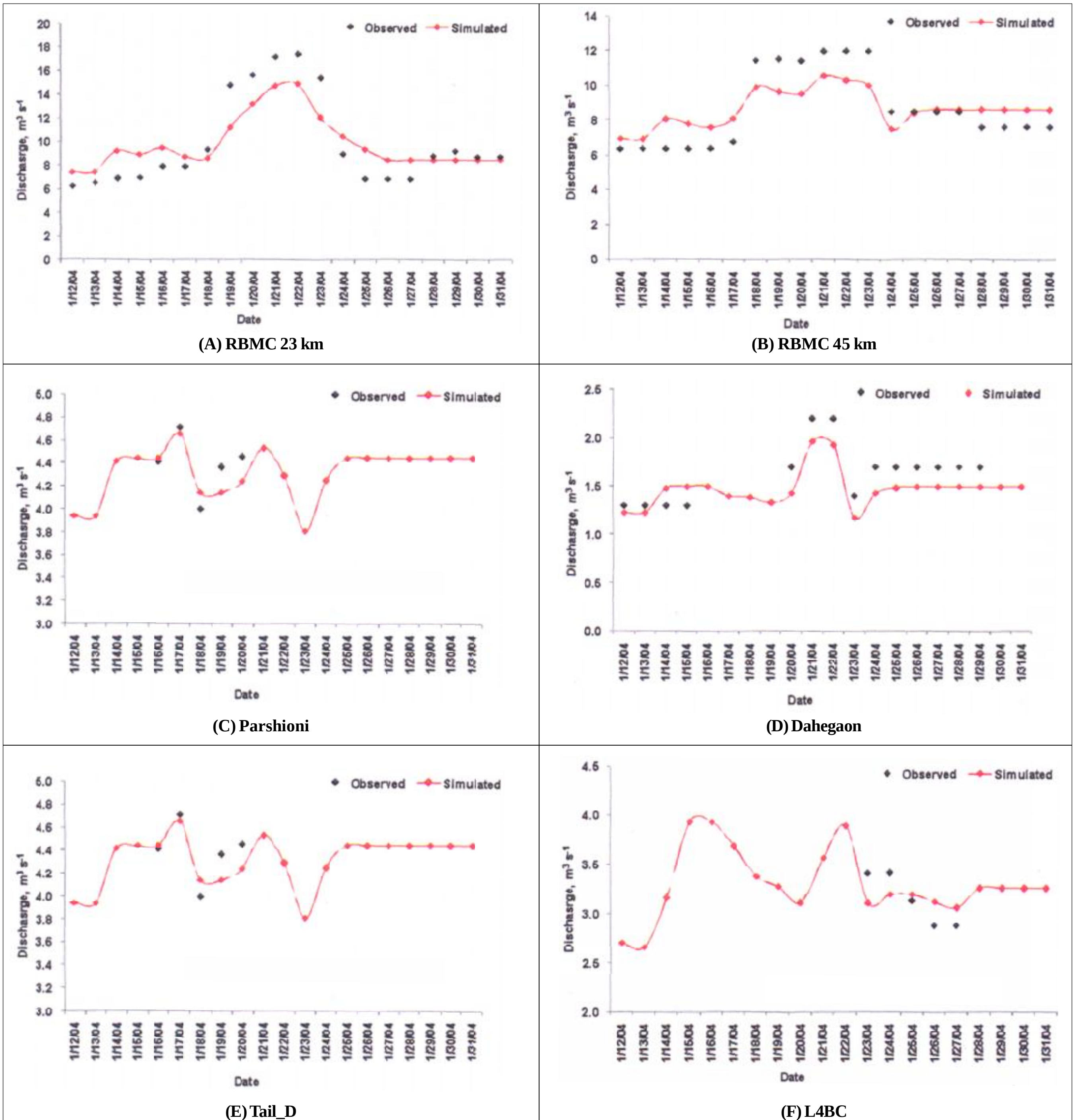

Fig. 1 : Comparison of observed and simulated discharges for calibration period

large the values of performance criteria, *viz.*, PBAIS and NSE, selected for deciding the model efficiency were within the desired range during calibration as well as validation. Considering the overall acceptability of the model performance, the model setup was taken as calibrated.

Performance assessment :

For ideal system performance ratio of the observed discharge at a specific location Q_{ol} to the scheduled discharge at that location Q_{sl} (Q_{ol}/Q_{sl}) should be unity for all the locations. Table 4 presents the average ratio Q_{ol}/Q_{sl} of

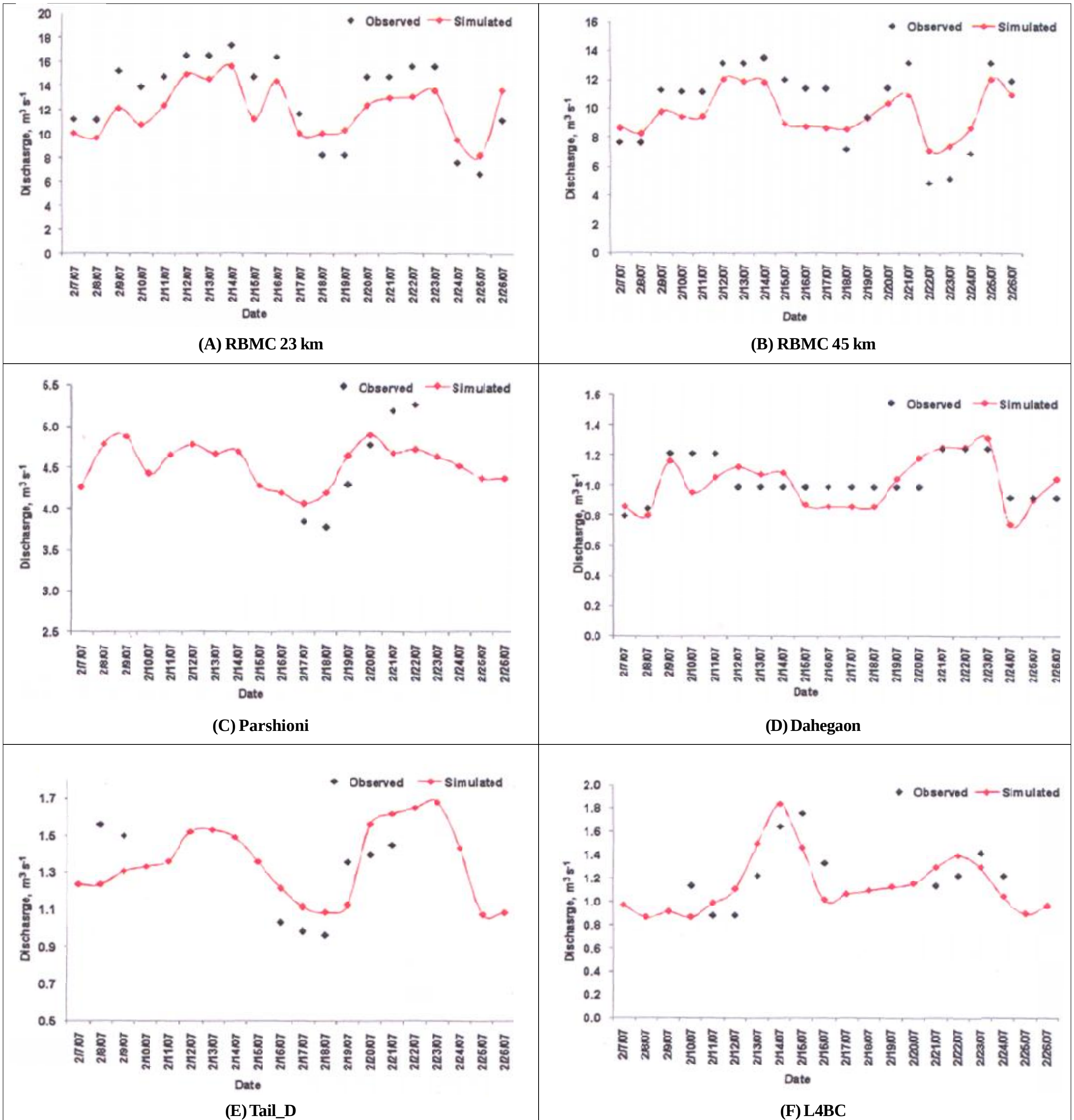

Fig. 2 : Comparison of observed and simulated discharges for validation period

each location during 2004-07, the ratio was decreasing from head to tail reach for all four years. Table showed that the distributaries located in the head and middle reaches drew more water than their share.

The plot between per cent deviation of discharges at system source and the per cent deviation of discharge at specific locations *viz*., head, middle and tail reach is presented in Fig. 3. For all three reaches, there was an increase in per cent deviation of discharge with an increase in per cent deviation in the head reach. However, the tail reach was found

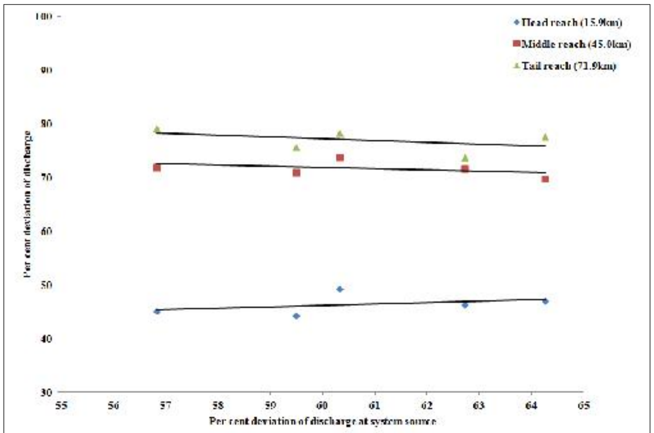

Fig. 3 : Spatial variation of the irrigation system

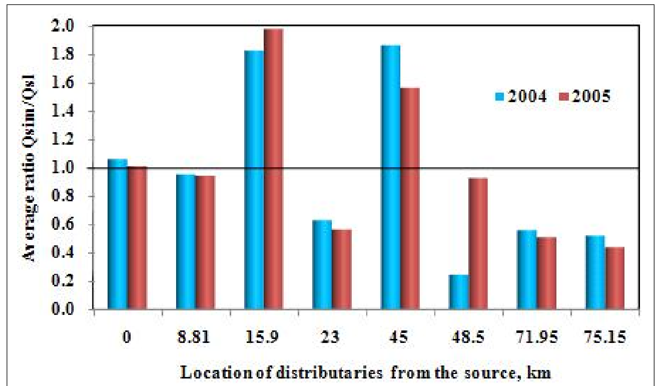

Fig. 4 : Performance level of distributaries during 2004 and 2005

to be more sensitive to a discharge deviation at the system source than the head and middle reaches.

To verify the excess withdrawal by some of the distributaries in the absence of observed flow rate, MIKE 11 simulated data were used. Temporal average of the ratio of the daily simulated data flow rate to the scheduled flow rate was calculated for the distributaries. Performance level of distributaries for the irrigation period 2004 and 2005 is depicted in Fig. 4. For most equitable distribution, the ratio should be 1. However, except for the some distributaries, most of the distributaries located at head and middle reaches drawn excessively higher than their share. This has resulted in scarcity of flow to many of the distributaries of the middle and tail reaches. To overcome this problem of inequity in flow delivery, there is need to intensify the monitoring of the flow rate at various control structures. The factors responsible for excess withdrawal, such as improper fixing of the sill level of the head regulators, larger gate opening, improper control of inline structure on the main canal and inadequate maintenance have to be examined to diagnose the exact reasons so as to overcome the mismanagement of the irrigation system.

Conclusion:

Calibration and validation results of MIKE 11 showed the model performed satisfactorily for most of the location in the canal system. The calibrated values of the global resistance number and gate contraction coefficient were found to be 40 and 0.63, respectively for the RBC system. The local resistance for various distributaries number however, ranged from 30 to 60. A sharp decline in the performance ratio along the length of the main canal was observed for all the four years. This showed that the distributaries located in the head and middle reaches drew more water than their share. This was verified with simulated flow data from MIKE 11 in the absence of observed data.

Table 3 : Statistical parameters at various locations for validation period 2007

Name of canal	Distance from source, km	Statistical parameters	
		PBAIS, %	NSE
RBMC	23.00	0.57	0.57
RBMC	45.00	0.77	0.34
Parshioni	08.81	0.54	0.43
Dahegaon	15.90	0.95	0.39
Tail_D	71.94	3.41	0.27
L4BC	75.00	3.89	0.23

Table 4 : Year wise daily average performance ratio of delivery system during 2004-07

Performance ratio	Distance from system Source, km				
(Qol/Qsl)	0.0	23.0	45.0	48.5	71.9
2004	1.00	0.84	0.76	0.62	0.62
2005	1.00	0.91	0.89	0.69	0.61
2006	1.00	0.87	0.90	-	-
2007	1.00	0.82	0.73	-	-

The flow fluctuation at the system source affect the tail reach beneficiaries than the head reach beneficiaries because for a given deviation at the system source, the deviation at the tail reach was greater than that of head reach. These results suggested that the MIKE 11 model can be used for managing the irrigation system more efficiently.

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