Hydraulic impact of Wan River project with MIKE 11

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Abstract: Hydraulic assessment of Wan River Project was carried out using MIKE 11 model from the Danish Hydraulic Institute (DHI). The approach for this model leads to unsteady flow simulations along stream channel reach. The study aimed the development of MIKE 11 model based on stream cross-section (L sections) and water release data. The global value of the model parameters i.e. manning's roughness coefficient (n) and ground water leakage coefficient was found as 0.028 and 7.11e-005, respectively. The hydraulic performance of wan river project was judged in terms of water delivery performance ratio and system performance ratio. The average water delivery performance ratio WDPR ratio for canal network of the project declines from 1.05 to 0.68, 0.68 to 0.39 and 0.39 to 0.28 for head, middle and tail reach, respectively. The system performance ratio revealed that the Main canal, Telhara and Warud distributory are drawing excess water, whereas Bathkhed distributory, Branch and Belkhed Branch canal are getting less water. The study concluded that there was uneven distribution of water among the distributories and hence there is need to reschedule the irrigation.

Keywords: hydraulic assessment, unsteady flow simulation, river modeling, MIKE 11 HD, Wan River project

Citation: Kale, M.U., M. B. Nagdeve, S. B. Wadatkar, M. M. Deshmukh, and A. N. Mankar. 2014. Hydraulic impact of Wan River project with MIKE 11. Agric Eng Int: CIGR Journal, 16(1): 21−31.

1 Introduction

In the present era, the objective of irrigation is not only to provide supplementary water for crop production but also to increase crop per unit drop of water. Thus, the basis for the development of irrigation facilities, tools and practices should be to make agriculture economically, socially and environmentally viable, where the returns are maximized and resources minimized. In India, 40% of the net irrigated area is under canal irrigation system. But, the performance of many irrigation projects has not been satisfactory (Swaminathan, 2006). The success of irrigation system operation and planning depends on the quantification of supply and demand and equitable distribution of supply to meet the demand if possible, or, to minimize the gap between the supply and demand.

Researchers developed numbers of models to improve the performance of irrigation projects. The mathematical models of canal operation and automation (Clemmens and Replogle, 1989; Loof et al., 1991; Malaterre, 1995, U.S. Army Corps of Engineers, 2002; Islam, 2005) developed over the years exclusively concentrate on hydraulic aspects of canal system. On other hand, a few attempts have been made to develop irrigation system management or decision support systems to assist water managers in taking appropriate decisions, e.g. CADSM (Prajamwong, 1994; Walker et al., 1995), INCA (Makin, 1995), IOS (Singh, 1999) etc. These models mainly focus on the demand and distribution aspects only.

The Danish Hydraulic Institute (DHI) developed the software tool MIKE 11 for simulation of flow, sediment transport and water quality in estuaries, river, irrigation system and similar water bodies. MIKE 11 is developed for simulating basic or complex hydrodynamic conditions found in rivers, lakes and reservoirs, irrigation canals and

Received date: 2013-09-14 **Accepted date:** 2014-01-18
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other inland water systems. The hydrodynamic module (HD) represents the heart of MIKE 11 and contains all core functionality for simulating hydrodynamic processes in the canals (DHI, 2007).

Wan River Project is the major multipurpose project in Akola district of Maharashtra State that fills to its full capacity almost every year. But it irrigates only 40 km^2 against designed irrigation potential of 151 km^2. Hydraulic assessment of irrigation system is pre-requisite to undertake measures to improve it's performance. Therefore a study was undertaken to assess the performance of canal network of Wan River Project using MIKE 11.

2 Methodology

The Wan River forms the part of northwest boundary of Akola district of Maharashtra State of India, after entering from the Amravati district. Wan River Project or Hanuman Sagar Reservoir is multipurpose major project constructed on river Wan, a tributary of Purna river, near village Wari Bhairavgarh in Telhara block of Akola district. The size of reservoir's catchment and command area is 278.94 km^2 and 276.83 km^2, respectively. The average annual rainfall of the catchment and command is 1,013 and 890 mm, respectively.

2.1 Governing equations

MIKE 11 HD solves the Saint-Venant equations using finite difference scheme to obtain the hydrodynamic state of the canal system. The Saint-Venant equations for conservation of mass and momentum are as follows (Equation (1) and Equation (2)):

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial(\propto \frac{Q^2}{A})}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0 \qquad (2)$$

where, Q = discharge, m^3/s; A = flow area, m^2; q = lateral inflow, m^2/s; h = stage above datum, m; C = Chezy's resistance coefficient, $m^{1/2}/s$; R = hydraulic or resistance radius, m; α = momentum distribution coefficient; g = ratio of weight to mass, 9.81 m/s; x = longitudinal distance in the direction of flow, m; and t = elapsed time, s.

2.2 MIKE 11model setup

The model was setup using four editors i.e., network, cross section, hydrodynamic parameter and boundary, provided in the HD module of MIKE 11 model.

2.2.1 Canal network definition

The river network editor was used to digitize the canal network layout, structures and to view graphical overview of the model. On the basis of available water release data required during the simulation, five first order canal branches were selected for study, along with main canal, of which details are given in Table 1.

Though there is a gradual decrease in the elevation along the canals, 101 falls are still presented in the selected canal network with magnitudes ranging from 0.5 m to 3.3 m.

Table 1 Detail of canals

S. N.	Name of canal	Offtake point on the main/m	Length of canal /m	Designed discharge at canal head/$m^3\ s^{-1}$	Irrigation command area /km^2	Irrigation potential created/km^2
1	Main	Dam	14130	12.29	7.92	10.05
2	Bathkhed Distributory	2010	2247	0.75	5.00	6.36
3	Branch Canal	7810	12050	4.53	54.46	69.14
4	Telhara Distributory	9120	11280	4.53	28.42	36.09
5	Belkhed Branch Canal	11460	10770	4.81	24.38	30.21
6	Warud Distributory	14130	9550	2.70	30.82	39.14
		Total			151.00	190.99

2.2.2 Integration of inflow to reservoir in MIKE 11 model

There is no specific arrangement for inclusion of reservoir in the MIKE 11 model. Therefore a dummy canal having capacity matching to the reservoir was included at the head of network. The main canal originates as a branch, from this dummy canal. Using regulating structure, inflow and stage of reservoir was specified. The inflow to the reservoir predicted using Artificial Neural Network (ANN) technique (Kale et al.,

2012) was used.

2.2.3 Cross-section data

As the cross-section data is available at discrete points in the canal system, a space interval (dx-max) of 500 m was selected in this study and a large number of canal cross-sections were specified, with individual cross-section identified by canal name, topographical identification and the chainage. Locations where the distributaries are off taking and irrigation structures exist in the canal, the cross-sections were specified at both upstream and downstream of these features.

2.2.4 Boundary conditions

Boundary conditions are required to close the system of equations to be solved by the Double Sweep method. Boundary conditions were specified with daily discharge data at system source and water level at tail end points.

2.2.5 Hydrodynamic parameters

Parameters like initial conditions, type of wave, bed resistance, ground water leakage coefficient etc. were defined in the hydrodynamic parameter editor file that was used by the model during simulation.

2.2.6 Simulation control parameters

The simulation control parameters such as simulation time, simulation time step, data storage time and data to be stored were specified using simulation editor. The simulation period was specified by start and end dates. The time step should be fine enough to provide an accurate representation of wave propagations. The time step was finalized as one minute by trial and error method.

2.2.7 Calibration and validation of the model

The model was calibrated and validated using AUTOCAL, a generic tool under MIKE ZERO tool box, with resistance number and ground water leakage coefficient as model calibration parameters. Manning's roughness coefficient was used as resistance number. Based on availability of observed flow data, locations at 390, 70, 100, 100, 100 and 70 m along Main, Bathkhed, Branch canal, Telhara, Belkhed Branch and Warud distributory, respectively, were selected for calibration.

The model was calibrated for the period from 1st December 2009 to 31st March 2010 (having six irrigations – 70 days irrigation period). Calibrated model was validated for the period from 1st December 2010 to 31st March 2011 (having seven irrigations – 103 days irrigation period).

2.2.8 Model Performance

The performance of model was judged using two goodness-of-fit criteria recommended by the ASCE Task Committee (ASCE, 1993a), i.e. percent deviation of discharge (Q_{PD}) and Nash-Sutcliffe coefficient (R^2_{NS} along with root mean square error (*RMSE*) and coefficient of determination (r^2).

2.2.8.1 Percent deviation of discharge (Q_{PD})

The percent deviation of the simulated discharge from designed discharge data for each location was calculated using the following Equation (3):

$$Q_{PD} = \left(\frac{Q_o - Q_{sim}}{Q_o}\right) \times 100 \tag{3}$$

The value of Q_{PD} should be zero for a perfect model.

2.2.8.2 Nash-Sutcliffe coefficient of efficiency (Nash and Sutcliffe, 1970)

Nash-Sutcliffe coefficient of efficiency (R^2_{NS}) is used to assess the predictive power of models. R^2_{NS} is described by the following Equation (4)

$$R^2_{NS} = 1 - \frac{\sum (Q_o - Q_{sim})^2}{\sum (Q_o - Q_{av})^2} \tag{4}$$

R^2_{NS} value of 1 therefore indicates perfect fit.

2.2.8.3 Root mean square error

The root mean square deviation (*RMSD*) or root mean square error (*RMSE*) is a measure of the differences between values predicted by a model or estimated. *RMSE* was calculated by using following Equation (5):

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=0}^{N}(Q_{sim} - Q_o)^2} \tag{5}$$

2.2.8.4 Coefficient of determination

Coefficient of determination (r^2) is a statistical measure of how well the regression line approximates the real data points. It was determined by using following Equation (6)

$$r^2 = \frac{[\sum_{i=1}^{N}(Q_{sim} - Q_{sav})(Q_o - Q_{av})]^2}{\sum_{i=1}^{N}(Q_{sim} - Q_{sav})^2 \sum_{i=1}^{N}(Q_o - Q_{av})^2} \tag{6}$$

An r^2 of 1.0 indicates that the regression line perfectly fit the data.

where, Q_o = observed discharge, m^3 s^{-1}; Q_{av} = mean of the observed discharge, m^3 s^{-1}; Q_{sim} = simulated discharge,

$m^3 s^{-1}$; Q_{sav} = mean of the simulated discharge, $m^3 s^{-1}$, and N = number of observations.

2.2.9 System performance measures

The simplest, and yet probably the most important, operational performance indicator, i.e., delivery performance ratio (DPR) or Water delivery performance ratio (WDPR) (Clemmens and Dedrick, 1984; Clemmens and Bos, 1990; Molden and Gates, 1990; Gupta, 2008) was used to assess the performance of the system. The DPR indicates the degree of uniformity and equity of water delivery over the space in the canal system.

WDPR evaluates whether the flow at any location in the system is more or less than the intended (Bos, 1997), and is expressed as Equation (7):

$$WDPR = \frac{Q_{sim}}{Q_{s1}} \tag{7}$$

where, Q_{sim} = simulated discharge at particular location and Q_{sl} = scheduled discharge at particular location, which is the ideal flow rate that would occur if the shortage from the design discharge are proportionally distributed over the space. Q_{s1} at different locations is calculated as Equation (8):

$$Q_{s1} = (1 - \frac{Q_{ds} - Q_o}{Q_{ds}})Q_{ds1} \tag{8}$$

If the delivery performance ratio is close to unity, then management inputs are effective.

The performance of the system was also judged by using following Equation (9)

$$System\ performance\ ratio = \frac{Q_o}{Q_{intended}} \tag{9}$$

where, Q_{ds} = designed discharge at the system source; Q_o = observed discharge at the system source; Q_{dsl} = designed discharge of a specific location and $Q_{intended}$ = discharge expected at a specific location.

4 Results and discussion

4.1 Calibration of MIKE 11 model

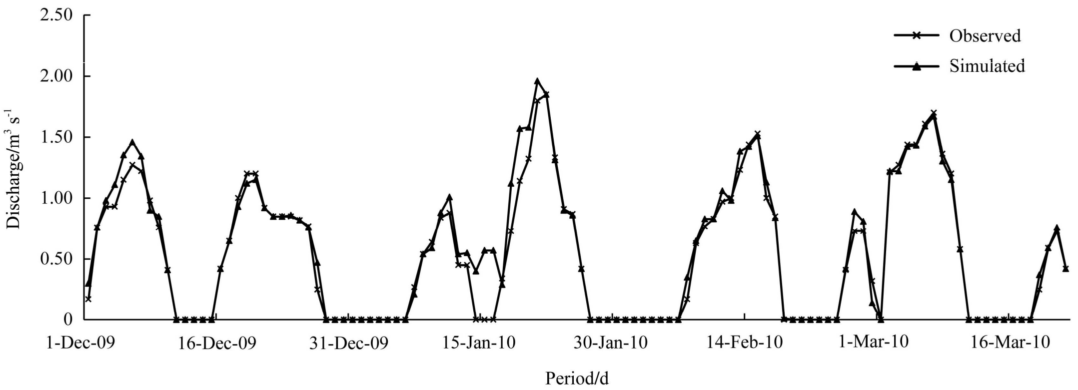
MIKE 11 model was calibrated for December 2009 to March 2010 using AUTOCAL function of MIKE ZERO toolbox. Calibrated global resistance numbers, i.e., Manning's roughness coefficient 'n' and global ground water leakage coefficient, were observed as 0.028 and 7.11e-005, respectively, for the canal network of the Wan River Project. The local resistance numbers and global leakage coefficient (seepage loss) were calibrated manually and were found to be ranged between 0.02 to 0.037, and 2e-006 to 0.001, respectively (Table 2). Such a variation in local resistance number and global leakage coefficient could be due to unlined sections of the canal, growth of water hyacinths and other weeds, and various soil types encountered over the canal length.

Table 2 MIKE 11 model calibrated and validated parameters

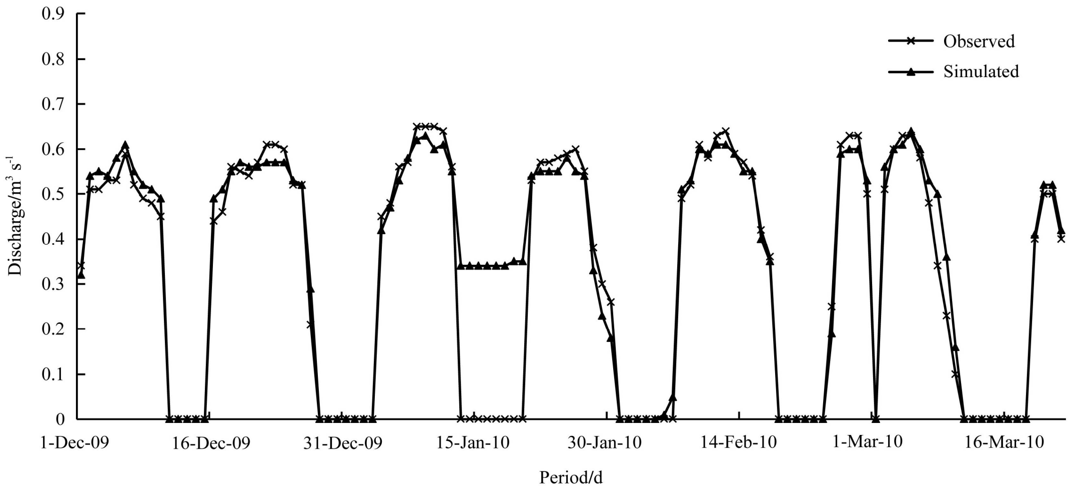
S. N.	Parameter	Distance from head of canal i.e. chainage/m	Value	
			Calibration	Validation
A	Bed Resistance i.e. Manning's n			
1	Global		0.028	0.028
2	Bathkhed distributory	0	0.02	0.020
3	Bathkhed distributory	50	0.02	0.020
4	Branch Canal	0	0.029	0.029
5	Branch Canal	90	0.031	0.031
6	Telhara distributory	0	0.03	0.030
7	Telhara distributory	90	0.03	0.030
8	Warud distributory	0	0.032	0.030
9	Belkhed Branch Canal	0	0.036	0.036
10	Belkhed Branch Canal	90	0.036	0.036
B	Ground Water Leakage Coefficient			
1	Global		7.11e-005	7.11e-005
2	Main	300	0.0001	0.0001
3	Main	990	0.0023	0.0023
4	Main	1020	0.001	0.001
5	Main	1600	0.0003	0.0003
6	Main	1635	0.00037	0.00037
7	Bathkhed distributory	0	2.00 e-05	2.00e-05
8	Bathkhed distributory	50	2.00e-05	2.00e-05
9	Bathkhed distributory	69	1.00e-06	1.00e-06
10	Branch Canal	0	0.0037	0.00775
11	Branch Canal	90	0.00038	3.72e-07
12	Branch Canal	7494	0.00037	0.00037
13	Branch Canal	7930	0.00037	0.00037
14	Branch Canal	7943	0.00037	0.00037
15	Branch Canal	8310	0.00037	0.0004
16	Branch Canal	11227	3.70e-04	0.00037
17	Telhara distributory	0	5.50e-05	5.50e-05
18	Telhara distributory	90	3.70e-05	3.70e-05
19	Belkhed Branch Canal	0	8.56e-05	8.56e-05
20	Belkhed Branch Canal	50	1.33e-05	0
21	Warud distributory	0	0	0
22	Warud distributory	4753	0.00037	0.00037

The observed and simulated discharges for the calibration period at five locations, i.e., at 390, 70, 100, 100, 100 and 70 m along Main, Bathkhed, Branch canal, Telhara, Belkhed Branch and Warud distributory, respectively, are presented in Figure 1. The simulated discharge values are in close agreement with the observed discharge values at most of the times. However, some mismatch is observed at the calibrating points during the third irrigation event in the Bathkhed distributory, the Belkhed branch canal and the Warud distributory, whereas during second, fourth and fifth irrigation events in the Branch, Telhara and Belkhed branch canals.

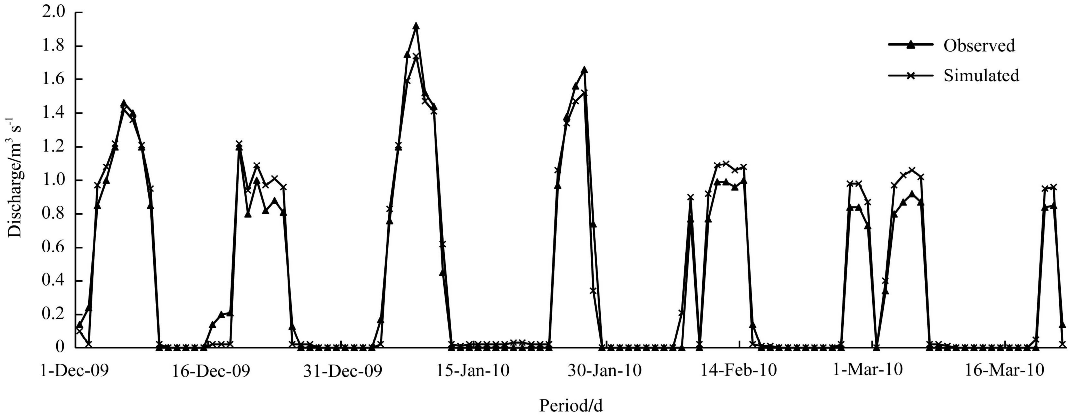
The results of the statistical tests between the observed and simulated flow rates for the calibration period are presented in Table 3. Root mean square error values were found to range between 0.09 and 0.25 m^3/sec. The coefficient of determination (r^2) between observed and simulated discharges ranged between 0.87 and 0.99, indicating the good correlation. Nash-Sutcliffe coefficient (R^2_{NS}) values ranged from 0.86 to 0.99, while the average R^2_{NS} value was found as 0.93. Percentage deviation of the discharge (Q_{PD}) values for various canals in the system varied between 4.97% and 10.99%, while average variation was 8.08%.



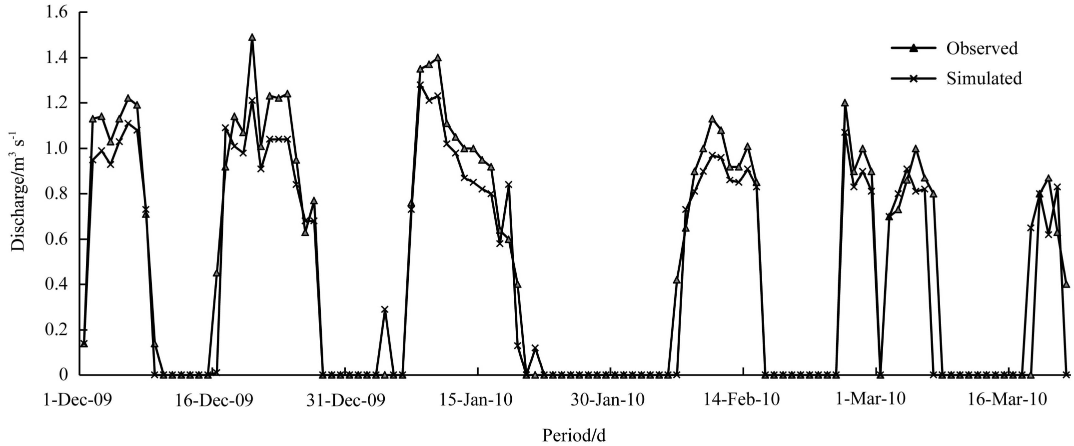
a. Main canal



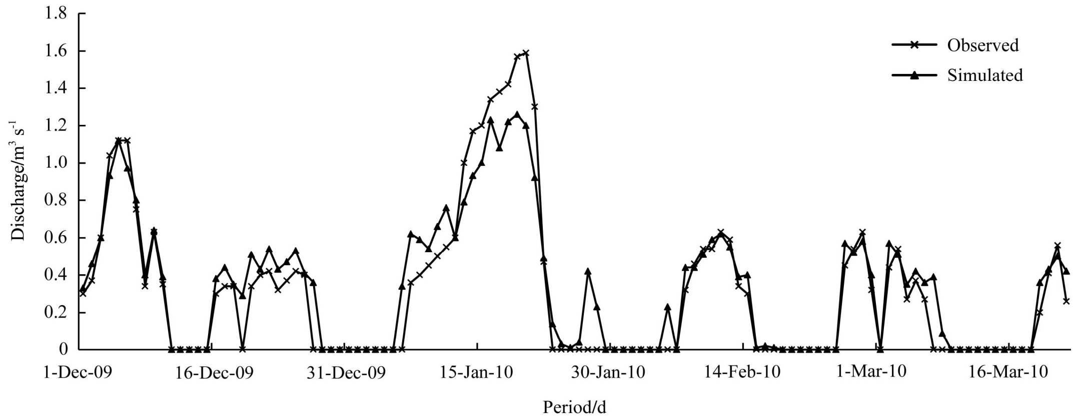
b. Bathkhed distributory



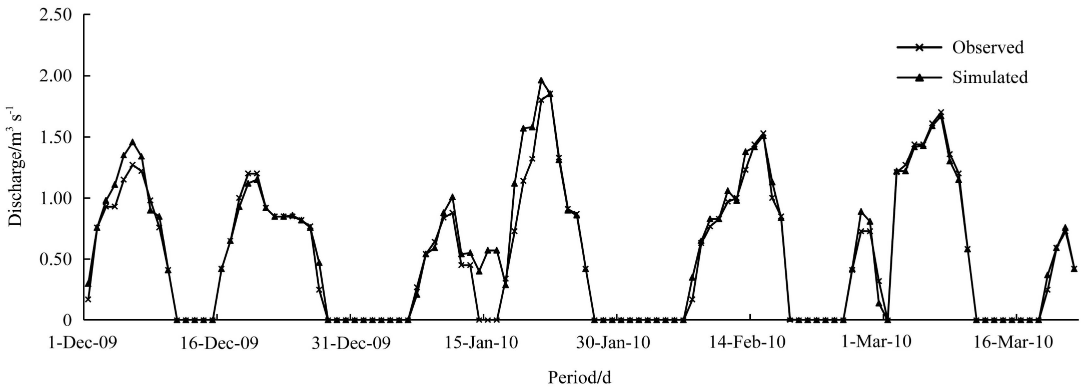
c. Branch canal



d. Telhara distributory



e. Belkhed branch canal



f. Warud distributory

Figure 1 Observed and simulated discharges for calibration period

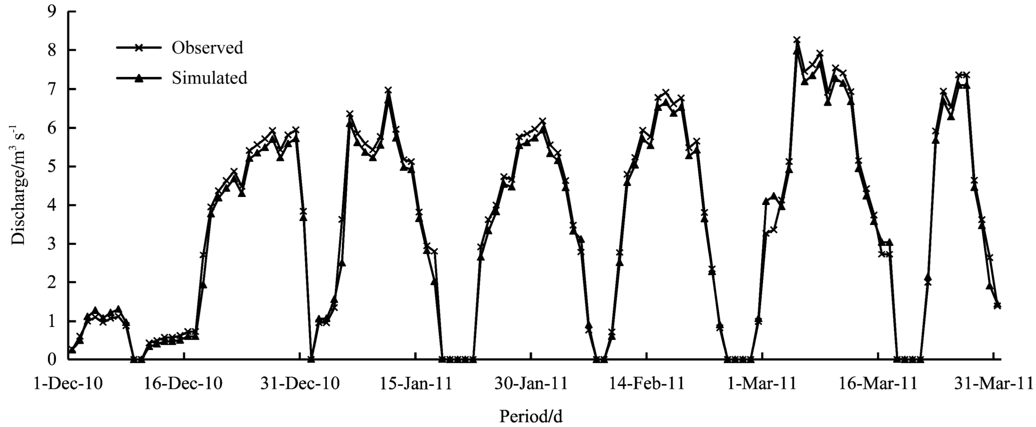
Table 3 Statistical analysis of calibrated results

Name of Branch	*RMSE*	r^2	R^2_{NS}	Q_{pd}
Main	0.25	0.99	0.99	4.97
Bathkhed Distributory	0.10	0.87	0.86	5.03
Branch Canal	0.09	0.97	0.97	10.99
Telhara Distributory	0.15	0.92	0.91	10.39
Belkhed Branch Canal	0.13	0.91	0.89	10.41
Warud Distributory	0.12	0.96	0.95	6.71
Average	0.14	0.94	0.93	8.08

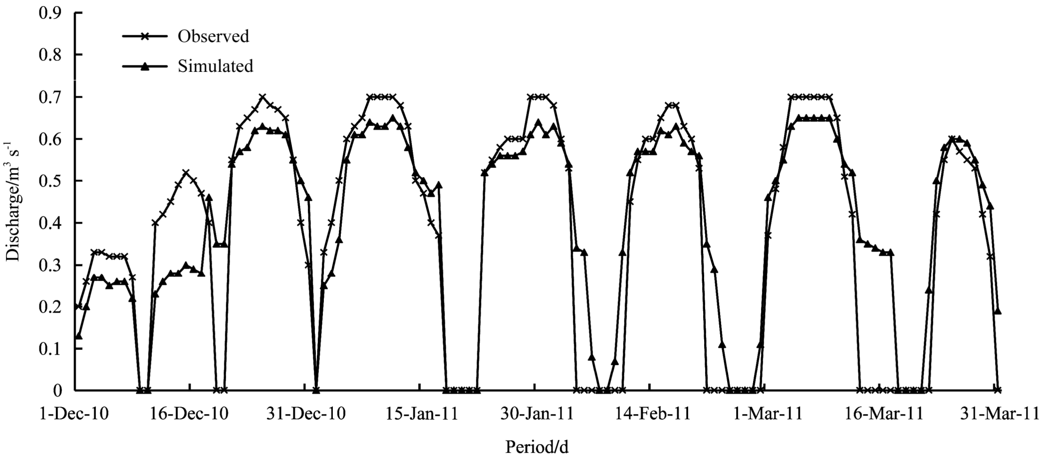
4.2 Validation of MIKE 11 model

Calibrated MIKE 11 model was validated manually for the period from December 2010 to March 2011. Table 2 presents the model parameters for validation period. The observed and simulated discharges for the validation period at 390, 70, 100, 100, 100 and 70 m along Main, Bathkhed, Branch canals, Telhara, Belkhed Branch and Warud distributory, respectively, are presented in Figure 2. The simulated discharges were in close agreement with the observed values for the most part of the system as evident in the Figure. But mismatch between observed and simulated discharges are seen in all canals except Main and Warud distributory during all irrigations. It is cleared from the figure that more mismatches between the observed and simulated discharges were observed in the canals which are laterally offtaking from the Main canal.

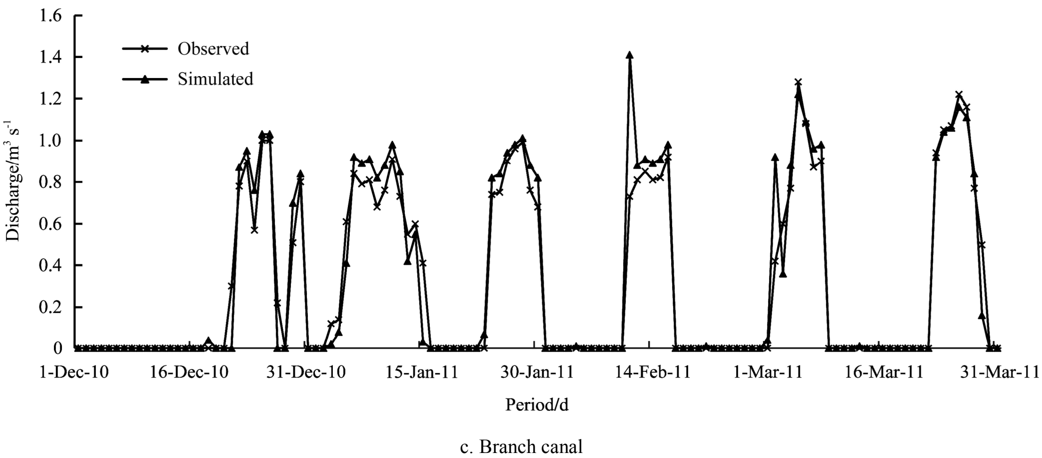
The results of statistical tests for the validation period are presented in Table 4. Root mean square error values were found to vary from 0.08 to 0.26 $m^3 s^{-1}$. Coefficient of determination ranged from 0.86 to 0.99, showing good correlation between observed and simulated discharges. Nash-Sutcliffe coefficient values were found to vary from 0.86 to 0.99, while average value was 0.94. Percentage deviation of discharge (Q_{PD}) values varied from 6.01% to 9.7%, while average value is 8.23%. Percentage deviation of discharge for all canals was within 10%. Considering the overall acceptability of the validation results, it is concluded that the model performs well with relatively high validity for most of the locations in the canal system.



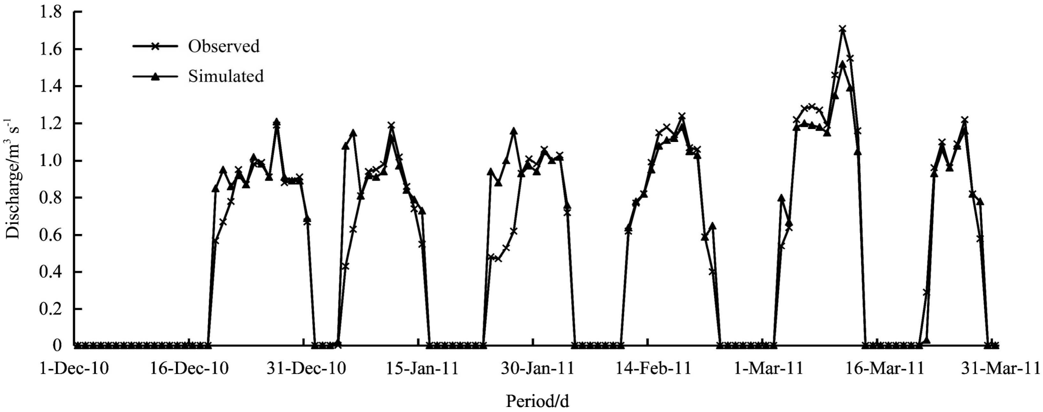
a. Main canal



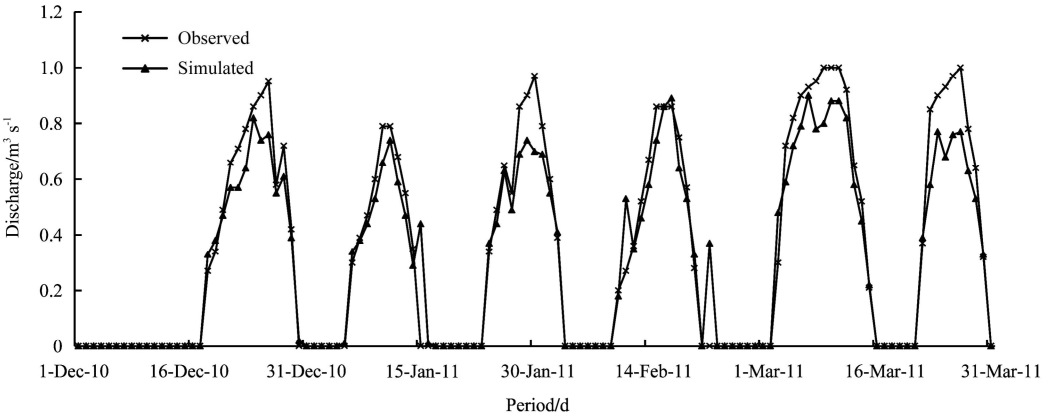
b. Bathkhed distributory



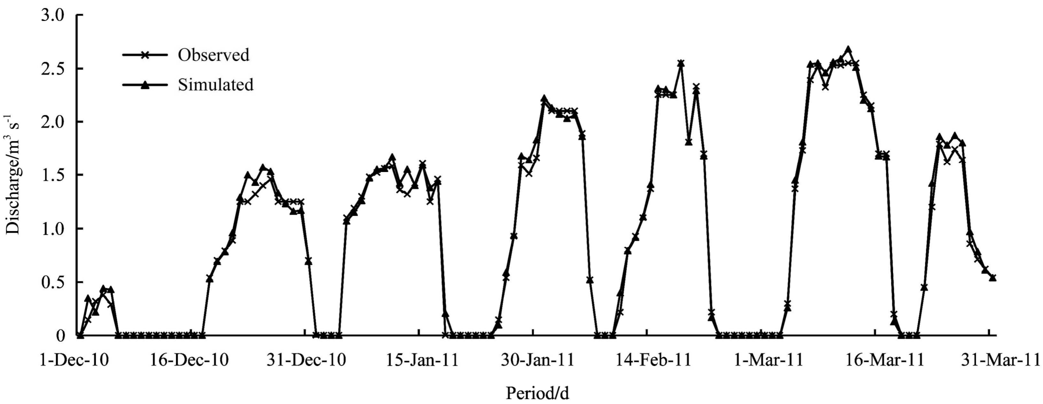
c. Branch canal



d. Telhara distributory



e. Belkhed branch canal



f. Warud distributory

Figure 2 Observed and simulated discharges for the validation period

Table 4 Statistical analysis of validated results

Name of Branch	*RMSE*	r^2	R^2_{NS}	Q_{pd}
Main	0.26	0.99	0.99	6.72
Bathkhed Distributory	0.13	0.86	0.86	9.70
Branch Canal	0.11	0.94	0.92	9.67
Telhara Distributory	0.13	0.92	0.96	9.43
Belkhed Branch Canal	0.10	0.96	0.94	7.82
Warud Distributory	0.08	0.99	0.99	6.01
Average	0.14	0.94	0.94	8.23

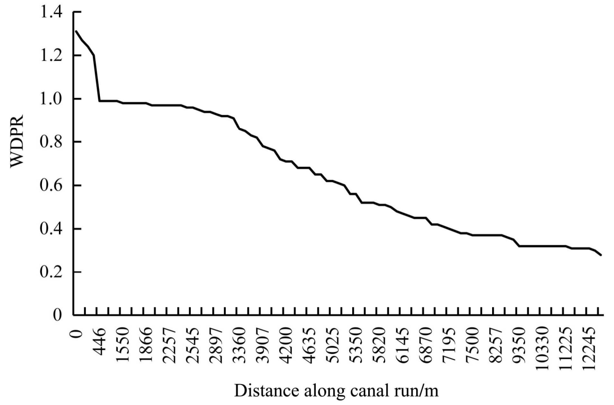
4.3 Performance analysis of System

Water delivery performance ratio, considered as a performance indicator, was calculated for several locations in the canal system for December 2010 to March 2011. The average ratio for each location was also calculated and plotted along the canal (Figure 3). For ideal system performance, this ratio should be 1.0 for all locations. The variation in the WDPR along head, middle and tail reach of each canal is presented in Table 6.

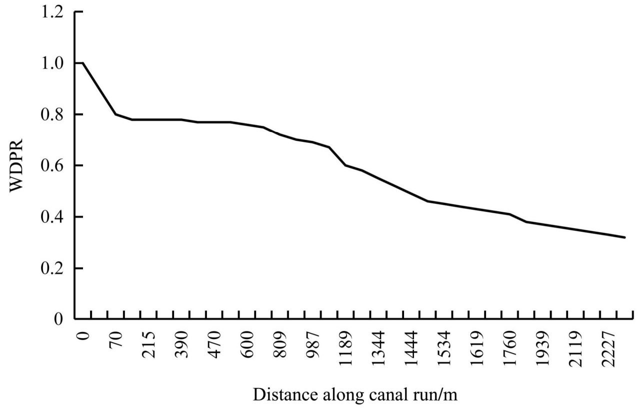
The average WDPR declined from 1.31 to 0.65, 0.65 to 0.32 and 0.32 to 0.30 for head (0 to 4.7 km), middle

(4.7 to 9.5 km) and tail reaches (9.5 to 14.13 km), respectively, along the main canal during December 2010 to March 2011. From igure 3 it is cleared that only 30% water (of intended) is available in tail reach of canal system, in existing irrigation schedule. Similar trend is observed in all canals.

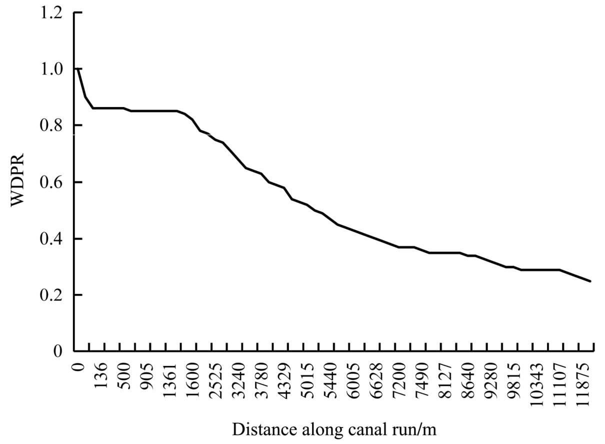
The average WPDR ratio for the Wan river project canal network declined from 1.05 to 0.68, 0.68 to 0.39 and 0.39 to 0.28 for head, middle and tail reach, respectively. It clearly indicates that less than 40% water than the indented was available at the end of middle reach, which declined approximately to 30% at the end of the tail reach. Variation in WDPR confirmed tail end deprivation in canal irrigation system of this project.



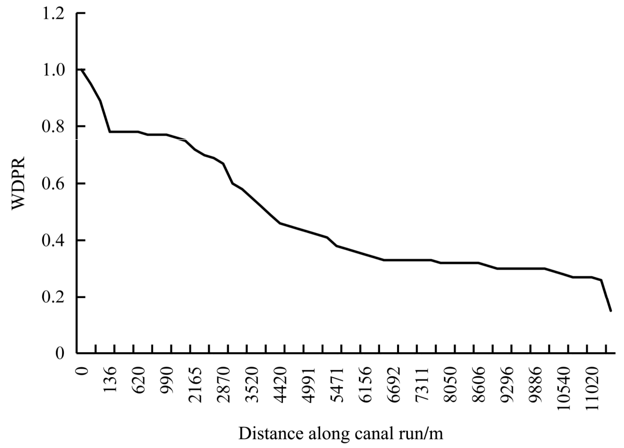
a. Main canal



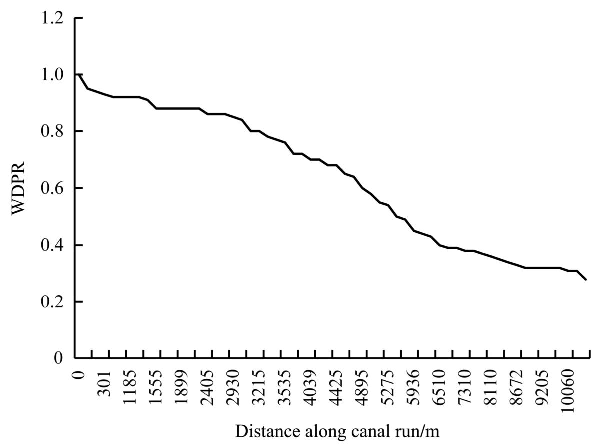
b. Batkhed distributory



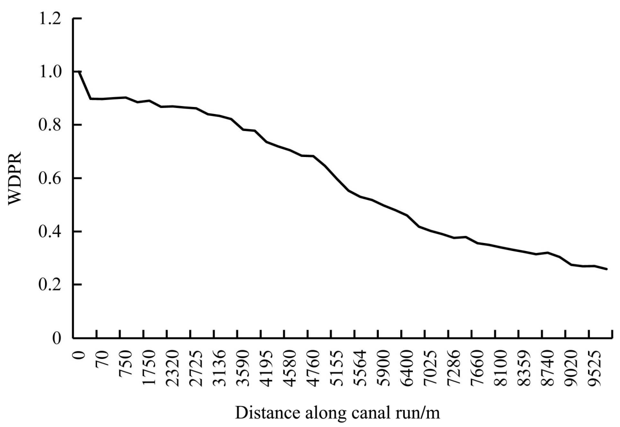
c. Branch canal



d. Telhara distributory



e. Belkhed branch canal



f. Warud distributory

Figure 3 Spatial distribution of water delivery performance ratio

Table 6 WDPR for head, middle and tail reach of the canals

Name of Branch	Head reach	Middle reach	Tail reach
Main	1.31 - 0.65	0.65 - 0.32	0.32 - 0.30
Bathkhed Distributory	1 - 0.75	0.75 - 0.46	0.46 - 0.33
Branch Canal	1 - 0.59	0.59 - 0.35	0.35 - 0.26
Telhara Distributory	1 - 0.49	0.49 - 0.33	0.33 - 0.26
Belkhed Branch Canal	1 - 0.76	0.76 - 0.39	0.39 - 0.28
Warud Distributory	1 - 0.82	0.82 - 0.46	0.46 - 0.26
Average	1.05 - 0.68	0.68 - 0.39	0.39 - 0.28

4.3.1 Spatial distribution of water to distributories along the main canal

The temporal average of the ratio of daily simulated to scheduled flow rate was calculated for all the distributories to verify the inequitable distribution of water withdrawal. For ideal or most equitable flow distribution, the ratio should be 1.0. Figure 4 presents the performance level of distributaries during the validation period, i.e., December 2010 to March 2011.

Figure 4 clears that the Main canal, Telhara and Warud distributory are drawing excess water, whereas Bathkhed distributory, Branch and Belkhed Branch canal are receiving less water. The system performance results thus, indicate that the irrigation distribution was considerably non-uniform to different distributaries. Therefore, there is a need to reschedule the canal releases to obtain equity in irrigation distribution.

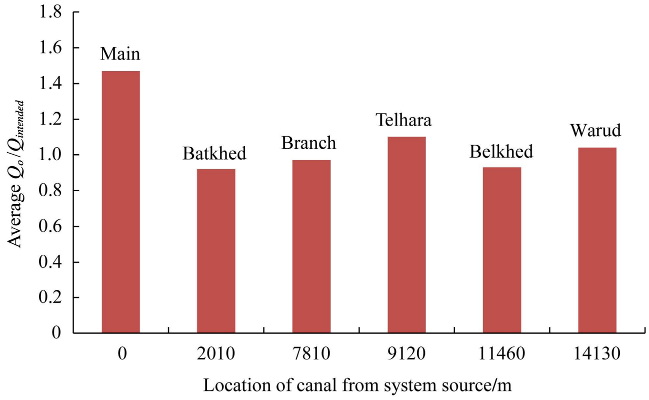


Figure 4 Temporal variation of discharges along the main canal

5 Conclusions

MIKE 11 simulated canal flows close to observed one with high accuracy in terms of root mean square error (0.14 $m^3 s^{-1}$), Nash Sutcliffe coefficient (0.94) and percent variation of discharge (8.23%). As within given irrigation schedule the performance of Wan River Project in terms of WDPR is poor, as well as the water distribution to different distributories is uneven, thus there is a need to reschedule the canal releases to obtain equity in irrigation distribution so as to improve the performance of the canal system.

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