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Performance Assessment of Modified Irrigation Scheduling for Pench Irrigation Project

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Abstract: *Alternative irrigation scheduling is essential to improve the present low overall efficiency of irrigation projects in India. Existing irrigation scheduling in Right Bank Canal of Pench Irrigation Project located in Nagpur district of Maharashtra was compared with nine developed modified schedules of varied rate rotation (variable discharge, constant duration and constant frequency). Water demand for the Right Bank Canal Command was estimated using CROPWAT. Percent deviation of demand from Existing scheduling was observed to be 2.71, 3.22, 0.93, 4.87, and 0.29 in 5, 5b, 7, 7b and 9 delivery schedules, respectively. Average supply and demand ratio for a period 7 year was estimated to be 0.82, 0.86, 0.90, and 0.84 for existing, 7, 7b, and 9 schedules, respectively. Weighted average (2004-07) of adequacy was obtained as 0.66 for existing schedule which is improved to 0.69, 0.72, and 0.68 for the 7, 7b and 9 schedules, respectively. Weighted average (2004-07) of dependability was obtained as 0.56 for the existing which was reduced to 0.51, 0.48 and 0.52 for the 7, 7b and 9 schedules, respectively. Average of (2004-07) equity value is obtained as 0.33 for the existing and which was reduced to 0.28, 0.24 and 0.29 for the 7, 7b and 9 schedules, respectively. By and large, considering all criteria an alternative delivery schedule '7b' with varied rate rotation having 7 irrigations annually of 12 days canal operation followed by 12 days of canal closure with the starting date September, 25th was found to be the best and can save 6.69 M m^3 of water as compared to Existing schedule and maintaining favourable water regime for the crop growth. This irrigation scheduling reduces the gap between supply and demand and results in 4.87 per cent of water saving as compared to existing irrigation scheduling.*

Keywords*: Irrigation Scheduling, CROPWAT, Adequacy, Dependability and Equity*

I. Introduction

Water is the limiting factor in most of the world. Increasing yield with sustainable food production depends mainly on irrigation. Increasing food production with the limited water resources is the main challenges for irrigated agriculture sector in 21st century. Hence monitoring the performance of irrigation system is meaningful. Most of the irrigation projects in India and South Asia perform at the low overall efficiency of 30-35% as in [1]. Moreover, lack of financial resources and infrastructure are the major obstacle to improve the efficiency of the system through structural alteration. Efficient operation and management is the only feasible alternative. This realization has shifted the focus of policy makers and researchers to improve the performance of canal irrigation through management suggested in ([2]-[4]).

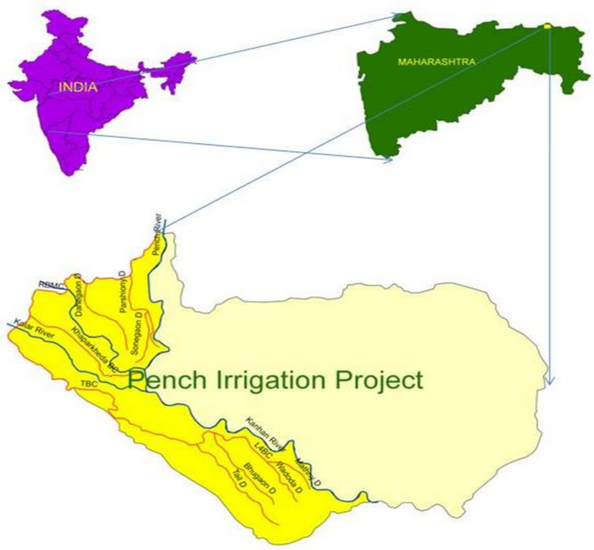
An improved approach to develop irrigation scheduling programme using the water balance method was suggested by [5]. An analysis of water delivery schedule based on a water balance simulation approach using a crop growth simulation model was made. Best modified rotation schedule resulted in 94% increase in yield of crops under the command as compared to on demand module as in [6]. The features of historical delivery schedules in the Right Bank Main Canal system of Kangsabati Irrigation Project was used to prepared nine modified schedules of varied rate rotation. An alternate schedule with three irrigations of 20 to 21 days duration, followed by 20 days of canal closure after the irrigation, was found to be well performed given in [7]. An irrigation water delivery scheduling model was developed to increase irrigation efficiency for a large scale rice irrigation project in Malaysia. Rainfall and evapotranspiration values were used to estimate weekly irrigation water deliveries through the water balance equation given in [8].

To estimate the annual water demand of different crops, the CROPWAT, a decission support system developed by FAO were used in varous irrigation projects and deveoped alternative delivery scedules suggested by ([9]-[13]). Reference [14] shows the development of various indicators to assess the performance of irrigation delivery system in terms of structural and management. This paper describes the performance assessment of modified irrigation scheduling for Right Bank Canal Command of Pench Irrigation Project.

II. Methodology

Command area under Pench Irrigation Project is located between 21º00′ to 21º45′ N latitude and 79º00′ to 79º45′ E longitudes and situated in 11th Agro-Ecological Region of India, K6C3 (Fig. 1). The average annual rainfall of the canal command is 1107 mm with an area of 1044.76km^2. The project is serving domestic, industrial and irrigation demand through right and left bank canals. The investigation was limited to right bank canal command area which consist of Right Bank Main Canal (RBMC), Tail Brach Canal (TBC), L4 Branch Canal (L4BC), and Khaperkheda Branch Canal (KBC). The total length of RBMC to Mathni is about 98 km.

Fig. 1. Location map of Pench Irrigation Project



Estimation of irrigation demand

CROPWAT is used to estimate the irrigation water demand of cotton and wheat crops in the command area. Climatic data viz. rainfall, temeratures, relative humidity wind speed and sunsine hours; crop parameters viz. minimum and maximum root-zone depth, crop growth period, crop coefficients at different stages of crop growth and soil parameters viz. field capacity and wilting point; and irrigation supply dates in scheduling model were given as inputs to the model. Simulations were run for each crop over 10 years (2000-09).

For paddy, on irrigation supply day, if water depth of paddy field W_i falls below the minimum water depth (W_{min}), then irrigation IR is applied ($IR_i = W_{opt} - W_{min}$). W_{opt} Optimum water depth in the paddy field, W_{min} and W_{opt} has considered as 3 and 12 cm, respectively suggested by [15] and [16]. A uniform water depth has been considered in the entire field covered under a specific crop.

Considering existing and modified delivery schedules to compute daily irrigation water demand for RBC system. The total irrigation water was applied during the canal operation period and then summed up to obtained the total irrigation demand. The average irrigation demand in volumetric terms was then obtained by multiplying the average irrigation demand with ICA of the whole command. A conveyance efficiency of 40% is considered to calculate the irrigation demand at the system source for further comparison with supply.

Modified delivery schedule

The existing delivery schedule in RBC system is 'intermittent' (variable discharge, variable duration and variable frequency). Analysis of ten years (2000-09) canal release data of the RBC canal reveals that on an average canal runs for 84 days. It provides average five to nine irrigations of varying duration, frequency and discharge during *kharif* and *rabi* season. Development of alternative irrigation scheduling would ensure reliable supply, varied rate rotation scheduling approach (variable discharge, constant duration and constant frequency) was chosen. The numbers of irrigations was varied from five to nine irrigations with fixed duration of supply in each irrigation, followed by equal duration of canal closure. On the basis of moisture depletion study and considering the length of canal operation days, protective irrigation was needed in second fortnight of September. So, to account for the variation, starting dates are shifted by 5 days on either side of September, 20th . *i.e*. September 15th and September, 25th. The modified schedules were identified with a numerical character to represent the number of irrigations during a year in the schedule *i.e*. 5, 7 and 9. Further suffix 'a' and 'b' are used with the numeric character to represent the shifting from staring date of September, 20th *e.g*. suffix 'a' represents the starting of September, 20th whereas 'b' represents the starting date of September, 25th. The details of these developed schedules are presented in Table 1.

Table 1. Details of alternative delivery scheduling

Schedule notation	No. of irrigation/y	Starting date,	Rotation lengh, days	Operative rotioan Period
Existing	Intermitent	Varying	Varying	Varying
5	Five	Sept., 15	17	15 Sept. to 2 Oct.; 19 Oct. to 5 Nov.; 22 Nov. to 9 Dec.; 26 Dec. to 12 Jan.
			16	29 Jan. to 14 Feb.
5a	Five	Sept., 20	17	20 Sept. to 7 Oct.; 24 Oct. to 10 Nov.; 27 Nov. to 14 Dec.; 31 Dec. to 17 Jan.
			16	3 Feb. to 19 Feb.
5b	Five	Sept., 25	17	25 Sept. to 12 Oct.; 29 Oct. to 15 Nov.; 12 Dec. to 19 Dec.; 5 Jan. to 22 Jan.
			16	8 Feb. to 24 Feb
7	Seven	Sept., 15	12	15 Sep. to 27 Sep.; 9 Oct. to 21 Oct.; 2 Nov. to 14 Nov.; 26 Nov. to 8 Dec.; 20 Dec. to 01 Jan.; 13 Jan. to 15 Jan.; 06 Feb. to 18 Feb.
7a	Seven	Sept., 20	12	20 Sep. to 02 Oct.;14 Oct. to 26 Oct.; 07 Nov. to 19 Nov.; 01 Dec. to 13 Dec.; 25 Dec. to 06 Jan.; 18 Feb. to 2 Mar.; 11 Mar. to 23 Mar.
7b	Seven	Sept., 25	12	25 Sep. to 07 Oct.;19 Oct. to 31 Oct.; 12 Nov. to 24 Nov.; 06 Dec. to 18 Dec. 30 Dec to 11 Jan.;23 Jan. to 04 Feb.;16 Feb. to 28 Feb.
9	Nine	Sept., 15	10	15 Sep. to 25 Sep.; 05 Oct. to 15 Oct.; 25 Oct. to 04 Nov.; 14 Nov. to 24 Nov.; 04 Dec. to 14 Dec.;24 Dec. to 03 Jan.; 13 Jan. to 23 Jan.; 02 Feb. to 12 Feb.
			4	22 Feb. to 26 Feb
9a	Nine	Sept., 20	10	20 Sep. to 30 sep.; 10 Oct. to 20 Oct.; 30 Oct. to 09 Nov.; 19 Nov. to 29 Nov.; 09 Dec. to 19 Dec.; 29 Dec. to 08 Jan.; 18 Jan. to 28 Jan.; 07 Feb. to 17 Feb.;
			4	27 Feb. to 03
9b	Nine	Sept., 25	10	25 Sep. to 05 Oct.; 15 Oct. to 25 Oct.; 04 Nov. to 14 Nov.; 24 Nov. to 04 Dec.; 14 Dec. to 24 Dec.; 03 Jan. to 13 Jan.; 23 Jan. to 02 Feb.; 12 Feb. to 22 Feb.;
			4	04 Mar. to 08 Mar

Performance assessment

Three performance indicators as in [14] were used and presented below

Adequacy

A measure of performance relative to adequacy for a region or sub-region R served by the system over a period T is given as

$$P_A = \frac{1}{T}\sum_T \quad \frac{1}{R}\sum_R p_A \tag{2}$$

where,

$p_A = Q_D/Q_R$ if $Q_D \le Q_R$

$p_A = 1$ otherwise

The function P_A impose an upper bound on point evaluations of adequacy, that is when Q_D exceeds Q_R the delivery was considered as adequate, regardless of the magnitude of excess. Here Q_D denotes the actual amount of water delivered by the system and Q_R denotes the amount of water required for consumptive use, leaching, land preparation and farm application and conveyance losses downstream of the delivery point.

Dependability

It is defined as the temporal uniformity of the ratio of the delivered amount of water to the required or scheduled amount. An indicator of the degree of dependability of water delivery is the degree of temporal variability in the ratio of amount delivered to the amount required over a region. This variability may be measured by

$$P_D = \frac{1}{R}\sum_R CV_T\ \frac{Q_D}{Q_R} \tag{3}$$

Where, $CV_T(Q_D/Q_R)$ = temporal coefficient of variation (ratio of standard deviation to mean) of the ratio Q_D/Q_R over the time period T.

Equity

An appropriate measure of the performance relative to equity would be the average relative spacial variability of the ratio of the amount delivered to the amount required over the time period of interest. The measure is given by

$$P_E = \frac{1}{T}\sum_T CV_R \frac{Q_D}{Q_R} \quad (4)$$

Where CV_R (Q_D/Q_R) = special coefficient of variation of the ratio Q_D/Q_R over the region R. This measure describes the degree of variability in relative water delivery from point to point over the region. The closure is the value of P_E to zero, the greater the degree of equity (special uniformity) of water delivery.

III. Results and Discussion

Irrigation water demand

Irrigation water requirement for the major crops in RBC system was estimated using CROPWAT (Table 2). Minimum water requirement for the RBC system was 129.39 M m^3 in schedule 7b and maximum water requirement was observed to be 146.21 M m^3 in schedule 9b. Average irrigation water demand (7 years) 2002-08 at the system source for different delivery schedules were estimated using CROPWAT and presented in Table 2. As evident, five alternative delivery schedules *i.e.* 5, 5b, 7, 7b and 9 performs better than existing and other developed alternative delivery schedules resulted in lesser demand. Percent deviation of demand from Existing scheduling was observed to be 2.71, 3.22, 0.93, 4.87, and 0.29 in 5, 5b, 7, 7b and 9 delivery schedules, respectively. This shows that only these schedules are capable of judiciously utilizing the canal water in conjunction with the rainfall. Therefore in subsequent analysis only these schedules were considered for further analysis for evaluating the performance.

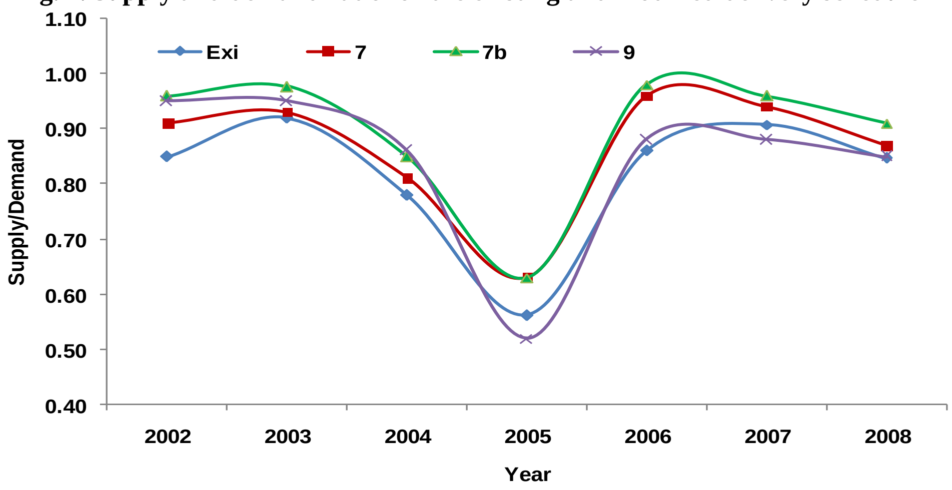
Table 2. Schedule wise Irrigation water requirement for the major crops in RBC system

Schedule	Irrigation Requirement, M m^3				% deviation of demand from Exi. schedule
	Cotton	Paddy	Wheat	Total	
Exi	47.63	43.27	45.11	136.01	0.00
5	34.71	50.00	47.62	132.33	2.71
5a	36.79	53.71	47.70	138.20	-1.61
5b	43.40	37.77	50.46	131.63	3.22
7	51.07	36.40	47.28	134.75	0.93
7a	49.66	40.63	51.48	141.77	-4.23
7b	38.91	43.92	46.55	129.39	4.87
9	47.15	44.58	43.89	135.62	0.29
9a	44.55	47.13	47.32	139.01	-2.20
9b	45.82	50.03	50.36	146.21	-7.49

Irrigation water supply and demand ratio

Irrigation water supply and demand ratio for the altermative irrigation schedule were calculated to select the best the modified irrigation schedule over existing irrigation schedule. The variation of supply and demand ratio for the existing and modified delivery schedules over 7 years period is presented in Fig 2. In an ideal case this ratio should be one the schedule in which this ratio is on or near to one was selected as the best irrigation schedule. Average supply and demand ratio for a period 7 year were estimated to be 0.82, 0.86, 0.90, and 0.84 for existing, 7, 7b, and 9, schedule, respectively. This clearly shows, superiority of the schedule 7b (Irrigation start date the September, 25^{th} *i.e.* seven irrigations with 12 days canal operation and 12 days canal closure) followed by 7 (Irrigation start date the September15^{th}, i.e. seven irrigations and with 12 days canal in operation and 12 days canal closure and 9 (Irrigation start date the September 15^{th}, *i.e.* 9 irrigations with 10 days canal operation and 10 days canal closure over existing schedule.

Fig. 2. Supply and demand ratio for the existing and modified delivery schedule



Performance indicators:

Three performance indicators *viz.* adequacy, dependability and equity were selected to assess the performance of the delivery system in different reaches during 2004, 2005, 2006 and 2007. Table 3 shows weighted average values of adequacy for Existing, 7, 7b and 9 schedules are 0.66, 0.69, 0.72 and 0.68, respectively. This is to have an overall idea of adequacy over the entire command of the delivery system. The increase in adequacy values substantiates the narrowing the gap between supply and demand of the system.

The dependability values, a measure of temporal distribution of the ratio of supply to demand for the different reaches during 2004, 2005, 2006 and 2007 were estimated and depicted in Table 3. A marked improvement was also seen for schedule 7b over 7, 9 and existing. The four years average weighted dependability was obtained as 0.48, 0.51, 0.52 and 0.56 for 7b, 7, 9 and Existing schedules. The results substantiates that schedule 7b, is better than the 7, 9 and existing.

Table 3. Estimated average adequacy and dependability during 2004-2007

Schedule	Reach	Adequacy	Dependability
Exi	Head	0.79	0.31
	Middle	0.60	0.59
	Tail	0.51	0.90
	Average	**0.66**	**0.56**
7	Head	0.81	0.29
	Middle	0.66	0.57
	Tail	0.55	0.88
	Average	**0.69**	**0.51**
7b	Head	0.82	0.25
	Middle	0.68	0.54
	Tail	0.59	0.78
	Average	0.72	0.48
9	Head	0.80	0.28
	Middle	0.63	0.56
	Tail	0.56	0.84
	Average	**0.68**	**0.52**

The equity values, a measure of the spatial distribution of the ratio of supply to demand, during irrigation periods for the four schedules were computed and presented in Table 4. Similar to the adequacy a marked improvement in the equity value is seen for schedule 7b compared to other schedules in all four years. The four years average equity is estimated to be 0.33 for existing schedules which is reduced to 0.28, 0.24 and 0.29 for 7, 7b and 9 schedules respectively. The results substantiates that estimated equity value for 7b is better over other schedules.

IV. Conclusions

Deviation of water demand from Existing schedule was observed to be positive in 5, 5b, 7, 7b and 9 schedules, which shows the water saving of 2.71, 3.22, 0.93, 4.87 and 0.29 per cent, respectively. Average supply and demand ratio was estimated to be 0.82, 0.85, 0.90 and 0.87 for the Existing 7, 7b and 9 irrigation schedules, respectively. Weighted average (2004-07) of adequacy was obtained as 0.66 for existing schedule which is improved to 0.69, 0.72, and 0.68 for the 7, 7b and 9 schedules respectively. Weighted average (2004-07) of dependability was obtained as 0.56 for the existing which was reduced to 0.51, 0.48 and 0.52 for the 7, 7b and 9 schedules, respectively. Average equity value (2004-07) obtained as 0.33 for the existing and which was reduced to 0.28, 0.24 and 0.29 for the 7, 7b and 9 schedules, respectively. By and large, considering the performance criteria, an alternative delivery schedule '7b' with varied rate rotation having seven irrigations annually with 12 days canal operation followed by 12 days of canal closure with the starting date the September, 25^{th} was found to be the best which can save 6.69 M m^3 of water as compared to Existing schedule and maintaining favourable water regime for the crop growth. The irrigation periods also cover the expected dry spell in the region and critical growth stage of the rice crop.

Table 4. Estimated equity during 2004-07

Schedule	Irrigations	Years				Average
		2004	2005	2006	2007	
Exi	1	0.15	0.38	0.11	0.3	0.24
	2	0.2	0.29	0.38	0.47	0.34
	3	0.32	0.31	0.19	0.42	0.31
	4	0.4	0.53	0.24	0.21	0.35
	5	0.45	0.48	0.42	0.51	0.47
	6	0.36	0.36	0.32	0.38	0.36
	7	0.42	0.26	0.39	0.15	0.31
	8	0.29	0.22	0.45	0.27	0.31
	Average	**0.32**	**0.35**	**0.31**	**0.34**	0.33

7	1	0.13	0.36	0.09	0.28	0.22
	2	0.18	0.27	0.28	0.25	0.25
	3	0.3	0.29	0.37	0.34	0.33
	4	0.38	0.31	0.22	0.19	0.28
	5	0.33	0.36	0.34	0.29	0.33
	6	0.34	0.34	0.3	0.26	0.31
	7	0.4	0.24	0.27	0.13	0.26
	Average	**0.29**	**0.31**	**0.27**	**0.25**	0.28
7b	1	0.1	0.12	0.18	0.25	0.16
	2	0.15	0.24	0.13	0.24	0.19
	3	0.27	0.26	0.14	0.37	0.26
	4	0.26	0.22	0.19	0.16	0.21
	5	0.29	0.43	0.31	0.46	0.37
	6	0.31	0.31	0.27	0.13	0.26
	7	0.37	0.39	0.14	0.1	0.25
	Average	**0.25**	**0.28**	**0.19**	**0.24**	0.24
9	1	0.18	0.13	0.15	0.19	0.16
	2	0.25	0.37	0.24	0.24	0.28
	3	0.25	0.18	0.36	0.34	0.28
	4	0.24	0.34	0.34	0.26	0.30
	5	0.26	0.47	0.38	0.28	0.35
	6	0.35	0.34	0.32	0.34	0.34
	7	0.36	0.2	0.38	0.59	0.38
	8	0.3	0.36	0.24	0.16	0.27
	9	0.24	0.29	0.15	0.37	0.26
	Average	**0.27**	**0.3**	**0.28**	**0.31**	0.29

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