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Optimum lining of distribution network for effective reduction in ground water withdrawal in a distributary canal command

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Abstract
Water is the crucial input for crop production. Canal irrigation is always preferred by the farmers over the other conventional methods due to lower cost of irrigation and ease in its application. But because of limited water availability at the reservoir, the canal water alone may not be sufficient to irrigate the whole command area. On the other hand the lower conveyance efficiency of the distribution system results in further reduction in the actual availability of water at farmers' field. Under such conditions the conjunctive use of canal water and water from other sources like ponds or tubewells, has been practiced in all most all the canal irrigated commands. Now due to the alarming decline of water table in many commands the emphasis is given to reduce the ground water withdrawal and to enhance the conveyance efficiency of the canal distribution systems. The water losses in the form of seepage through bed and banks of irrigation canal network is the prime cause of poor distribution efficiency in a canal command. This not only affects the system performance but also had created waterlogging problem in many canal commands. Therefore, this substantial loss of water through canal seepage clearly indicates that the lining of canal system, to enhance the efficiency and to conserve the land and irrigation water, is badly needed. Keeping it in view the present study was taken up to evaluate twenty four lining alternatives, involving partial or full lining of the distributary, minors and watercourses, in terms of benefit - cost ratio, increase in canal water availability at field level and reduction in ground water withdrawal in Bulandshahr distributary command of Upper Ganga canal system. The benefits for an alternative are obtained by using linear programming model. The study reveals that the optimum lining of distribution network will result in more than 50 percent increase in canal water availability at field level. This increased canal water availability intern would result in seven to eight percent reduction in ground water withdrawal in the command. On the basis of different constraints different alternatives of lining have been suggested.

INTRODUCTION

The importance of irrigation in increasing the level of food, feed, fodder and fibers production was realised long back of country's independence and great strides have been made in expending irrigation. The further expansion of irrigation may only be possible by utilizing the existing water resources with utmost efficiency by avoiding wastage during conveyance and application. In an irrigation system in operation numerous losses such as seepage losses, breaches of embankments (accidental or deliberate), evaporation losses from the exposed surface area and from weeds and plants in the channel bed, sides and embankments and operation losses, takes place. Of the above, seepage forms a significant component of the total losses. The losses of water through seepage, in Northern India, are of the order of 17 to 45 percent through main canal and branches, 8 percent through distributary and minors and 20 percent through watercourses (Ummat and Prem,1981). Garg *et al.*(1985) reported that the seepage losses from the Upper Ganga canal varies from 1 to 3 cumec per million sqm of wetted area.

This excessive seepage from the Upper Ganga canal system calls for lining of distribution network to enhance the conveyance efficiency for additional water availability at farmers' field; to prevent waterlogging in some areas parallel to main canal and to check the depletion of water table in the areas where the ground water is being withdrawaled to supplement the canal water. The question then arises as to what extent the system should be lined ? Several studies have been conducted so far to know the extent of lining in the commands of several canals (Pathak *et al.*, 1971; Sogani, 1979; Khepar and Chaturvedi, 1981; Gupta, 1982; Ahluwalia, 1983; Sakthivadiaval and Shanmagham, 1984; Pandya and Sharma,1985; Singh *et al.*, 1987) considering one or two canal conveyance components. In this study three major components viz. distributary, minor and watercourses are taken simultaneously and a rapid approach for benefit evaluation, using linear programming technique, has been used.

MATERIALS AND METHODS

The present study was conducted for the Upper Ganga canal command, to evaluate different combinations of partial or full lining of distributary, minors and watercourses. The Bulandshahr distributary, one of the major distributaries of the Upper Ganga canal, was selected for present study. The distributary takes off at Sanota in Bulandshahr district and runs almost parallel to the main canal feeding to eight minors namely, the Ladlabas, Pitobas, Kazimpur, Garden gul, Machkauli, Chiti, Kiryaoli and Deorala minor, along with 177 direct outlets operating on it. The CCA of the distributary is 12704 ha.

The study area has an average annual rainfall of 76.54 cm. Besides rainfall, the water supply from the Upper Ganga canal system and ground water through shallow tube-wells are two important sources of irrigation in the command. The canal water supply being limited, the irrigation department supplies water to irrigate only a part of its CCA, with water allowance of about 28 l/s per 648 ha of CCA, at the minor head. Shallow tube-wells of 10-20 l/s discharge capacity operate in the command to supplement the canal water. Wheat during *rabi* and maize during *kharif*, occupying 54 and 43.25 percent area, respectively, are two major crops of the command. Sugarcane, mustard, barley and fodder are other crops which occupy 15.19, 12.40, 7.31 and 5.0 percent area, respectively, during *rabi* season. The fodder crops occupy 5.0 percent area during *kharif* season. The cropping intensity in the command is 182.34 percent.

Lining Alternatives

Under financial constraints it may not be feasible to line the whole canal network because the total lining of a canal system can add from 10% to 35% of the cost of the irrigation projects. For such a situation partial lining of major components of the distribution system appears to be the feasible alternative to check the conveyance losses. Keeping this in view, twenty four combinations of partial or full lining of distributary, minors and watercourses (Table 1) have been considered for evaluation in terms of increase in conveyance efficiency, reduction in ground water withdrawal and benefit-cost (B-C) ratio.

Table 1. Lining alternatives for distributary canal network.

Alternative	Combina-tion	Alterna-tive	Combination	Alternative	Combina-tion
Control	$a_0+b_0+c_0$ *	T_9	$a_5+b_1+c_0$	T_{18}	$a_{20}+b_0+c_1$
T_1	$a_0+b_0+c_0$ #	T_{10}	$a_{10}+b_1+c_0$	T_{19}	$a_0+b_1+c_1$
T_2	$a_1+b_0+c_0$	T_{11}	$a_{15}+b_1+c_0$	T_{20}	$a_1+b_1+c_1$
T_3	$a_5+b_0+c_0$	T_{12}	$a_{20}+b_1+c_0$	T_{21}	$a_5+b_1+c_1$
T_4	$a_{10}+b_0+c_0$	T_{13}	$a_0+b_0+c_1$	T_{22}	$a_{10}+b_1+c_1$
T_5	$a_{15}+b_0+c_0$	T_{14}	$a_1+b_0+c_1$	T_{23}	$a_{15}+b_1+c_1$
T_6	$a_{20}+b_0+c_0$	T_{15}	$a_5+b_0+c_1$	T_{24}	$a_{20}+b_1+c_1$
T_7	$a_0+b_1+c_0$	T_{16}	$a_{10}+b_0+c_1$		
T_8	$a_1+b_1+c_0$	T_{17}	$a_{15}+b_0+c_1$		

- Optimal cropping pattern
* - Existing cropping pattern
a_0 - Unlined watercourses
a_1 - Watercourses lined down to 5 ha
a_5 - Watercourses lined down to 10 ha
a_{15} - Watercourses lined down to 15 ha
a_{20} - Watercourses lined down to 20 ha
b_0 - Unlined minor, b_1 - Lined minor
c_0 - Unlined distributary
c_1 - Lined distributary

Conveyance Loss

The conveyance losses in the minors and watercourses, worked out by using in-flow-outflow method, were found to be 2.36x10^{-6}, 3.67x10^{-6} $m^3/s/m^2$ and 0.36x10^{-6}, 0.89x10^{-6} $m^3/s/m^2$ respectively for unlined and lined conditions. The conveyance losses in the distributary, as per data available from the office of the Bulandshahr division of Upper Ganga canal are taken to be 0.028 and 0.014 cumec per km respectively for unlined and lined conditions.

Benefit-Cost Ratio

The benefit - cost ratio for different lining alternatives are estimated using annual cost method. The benefits from the command for different alternatives are obtained by using the linear programming model.

The linear Programming Model

The model is formulated for the Bulandshshr distributary command having a rotational water supply to obtain return from command under various lining alternatives.

Objective function

$$Maximize \quad Z = \sum_{j=1}^{M} \sum_{k=1}^{R} P_j A_{jk} \tag{1}$$

Constraints

Land avainability constraints:

$$\sum_{k=1}^{R} \sum_{j=1}^{M} A_{jk} \leq AL_k \tag{2}$$

Water availability constraints:

$$\sum_{j=1}^{M} \frac{IR_{ijk}\ A_{jk}}{AE_i} \geq CV_{ik} \qquad \forall\, k \tag{3}$$

Crop area constraints : The crop area constraints imposed, are based on the requirements of the food, feed and fodder requirements of the farmers and livestocks in the command.

Oil Seed (Mustard):

$$A_{jk} \langle A_{mk} \qquad \forall k \tag{4}$$

Cereals (Wheat and Maize):

$$\begin{aligned} &Wheat: A_{jk} \geq A_{wk} \quad \forall k \\ &Maize: A_{jk} \geq A_{bk} \quad \forall k \end{aligned} \tag{5}$$

Rabi fodder : The fodder crops in the command are grown to feed the livestock owned by the farmers, therefore, the area under these crops is kept at the existing level (A_{frk}).

$$A_{jk} = A_{frk} \qquad \forall k \tag{6}$$

Where A_{jk} = Area under j^{th} crop in k^{th} minor command (ha), P_j = Gross return from j^{th} crop (Rs./ha), A_{lk} = Total avaiable land for cropping (ha), CV_{ik} = Canal water avaiability in the command during i^{th} period, A_{bk}, A_{wk} = area(ha) under Maize and Wheat crops in k^{th} minor command, respectively, AE_i = Field application efficiency during i^{th} period, IR_{ij} = net irrigation requirement of j^{th} crop during i^{th} period (cm). The required ground water withdrawal, is estimated by substracting the available canal water from the total water consumption of the crops during i^{th} period.

Cost Estimation

The cost of a lining alternative includes the cost of lining (including maintenance and repair cost) and the cost of crop cultivation (including the cost of irrigation through canal and ground water). Bricks in mortar type lining is used for lining of the distributary and minors, whereas, the water courses are lined with pre-casted concrete lined sections of 1m length each. The cost of lining is estimated on the basis of standard norms and prevailing rates of materials. An economic life of 30 years and a discount rate of 18 per cent has been used to estimate the annual cost of lining. The actual expenditure on maintenence and repair of unlined distributary, minor and watercourses, available from the Bulandshahr Division Ganga Canal, are Rupees (in thousands) 25, 15 and 1.5 per km, respectively.

The annual cost of lining per ha, estimated for all the alternatives, are given in Table 2. The average cost of canal water as charged by the State Irrigation Department is Rs. 3.00 per ha-cm. The cost of tubewell water, on the basis of cost of construction, operation, repair and maintenence, is estimated to be Rs. 54.35 per ha-cm, for an average discharge of 40 m^3 per hour and operation time of 1600 hours. The cost of cultivation (ploughing, harrowing, seed and seeding, irrigation labour, fertilizer, inter-culture operations and harvesting) for different crops is estimated on the basis of prevailing rates of material and labour charges in the command.

Irrigation Water Requirement

The net irrigation requirement for different crops are estimated by using the Modified Penman Method. The field application efficiency based on the sampling data in the command is found to be 69 per cent.

Table 2. Economic analysis of different lining alternatives.

LA	ICE	ICWA	RGWW	ACL	BCR
Control	00.00	00.00	00.00	298.80	1.32
T_1	00.00	00.00	00.00	298.80	1.69
T_2	24.91	68.85	10.41	2013.80	1.49
T_3	16.57	46.10	7.17	1496.50	1.54
T_4	9.64	26.78	4.05	991.95	1.60
T_5	4.89	13.15	2.20	649.40	1.65
T_6	1.77	4.44	0.81	423.45	1.68
T_7	5.57	15.69	2.31	1070.70	1.59
T_8	34.43	95.34	14.35	2785.70	1.41
T_9	24.71	69.07	10.30	2268.40	1.45
T_{10}	16.70	46.51	7.19	1763.85	1.51
T_{11}	11.21	36.39	4.97	1421.30	1.55
T_{12}	7.62	21.45	3.24	1195.35	1.57
T_{13}	7.66	21.51	3.24	1250.85	1.56
T_{14}	37.87	105.25	15.74	2965.85	1.36
T_{15}	27.76	77.44	11.57	2448.55	1.46
T_{16}	19.35	54.06	8.10	1944.00	1.50
T_{17}	13.59	37.96	5.67	1601.45	1.53
T_{18}	9.81	27.50	4.05	1375.50	1.55
T_{19}	14.42	40.29	6.01	2022.75	1.47
T_{20}	49.31	137.44	20.60	3737.85	1.30
T_{21}	37.63	104.94	15.62	3220.45	1.37
T_{22}	27.91	77.84	13.88	2715.90	1.42
T_{23}	21.26	59.36	8.91	2373.35	1.44
T_{24}	16.90	47.20	7.29	2147.40	1.46

LA - Lining alternative, BCR - Benefit - cost ratio ACL - Annual cost of lining (Rs./ha)
ICWA - Increase in canal water availability at field head (%), RGWW - Reduction in ground water withdrawal (%), ICE - increase in conveyance efficiency (%)

RESULTS AND DISCUSSION

The benefits for each alternative are derived from the output of the Linear Programming model. The cropping pattern for all the alternatives remains the same, only the cost varies due to variable quantity of tubewell water used as per the need. The benefit cost ratio (B-C ratio), reduction in ground water withdrawal, increase in the conveyance efficiency, incremental B - C ratio and cost of each alternative is summerized in Table 2.

The results in Table 2 indicate that only twelve alternatives out of the twenty four, have B - C ratio greater than 1.5 and qualify for being economically feasible as per the recommendations of Irrigation Commission, India (1972). The B - C ratio for these alternatives varies from 1.50 for T_{16} to 1.68 for T_6 and resulting increase in conveyance efficiency varies from 1.77 per cent for T_6 to 19.35 per cent for T_{16}. Amongst these twelve economically feasible alternatives only three (T_3, T_{10} and T_{16}) results in substantial increase in canal water availability at farmers' field i.e. by 46.10, 46.51 and 54.06 per cent, respectively, alongwith higher B - C ratio.

Under alternative T_3, 50 to 80 per cent length of all the watercourses have lining. This would result in an increase of 46.10 per cent in canal water availability at field head and

7.17 per cent reduction in ground water withdrawal. The lining of watercourses under T_3 thus, Would provide a better equity distribution among the farmers in the command.

Under alternative T_{16}, about 76 per cent number of watercourses have lining, alongwith the lining of distribuatry. This would result in 54.06 per cent increase in canal water availability at field head resulting in 8.10 per cent reduction in ground water withdrawal. Under this alternative lining of distributary would result in better equity distribution of water among the minors in the command.

The alternative T_{10}, ranks in between T_3 and T_{16} from the point of view of B - C ratio as well as reduction in conveyance losses and ground water withdrawal. Under this alternative, the number of lined watercourses in the command are equal to that under T_{16}. The linign proposed under T_{10} would result in 46.10 per cent increase in canal water availability at field head and 7.19 per cent reduction in ground water withdrawal. The lining of minors under this alternative would result in better equity distribution of water among the watercourses, which may enable the tail end farmers to get their due share of canal water.

CONCLUSIONS

Based on the study it may be concluded that alternative T_3, i.e. lining of watercourses down to 5 ha command, may be the best feasible alternative for lining under financial constraints as it has the lowest initial investment. The alternative T_{16}, i.e. lining of watercourses down to 10 ha command along with lined distributary, is more economical in the situations where the ground water withdrawal in prime concern. The alternative T_{10}, i.e. lining of watercourses down to 10 ha command aliong with lined minors, may be recommended in the situations, where both the initial investment and canal conveyance efficiency/losses are considered simultaneously along with supply of water to the tail end users.

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