Irrig Sci (2000) 19: 191–197

ORIGINAL PAPER

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A model for equitable distribution of canal water

Received: 21 December 1999

Abstract The equitable distribution of canal water is imperative to ensure social justice as well as crop productivity. In north-west India and Pakistan, water from the tertiary canal (watercourse) is distributed to the farmers through a rotational system of irrigation. In this system the duration of supply to each farmer is in proportion to his holding in the outlet (watercourse) command, without considering the seepage loss. The rate of seepage loss increases with increase in length of watercourse from head to tail. Thus, the farmers in the lower reaches get much less water per unit area than the farmers in the upper reaches. The farmers must be compensated for the seepage loss. Therefore, a model was developed to ensure equitable distribution of water to the farmers located on a watercourse in proportion to their land holdings giving due compensation for the seepage loss. The model is based on the assumption that soil throughout the length of flow is homogeneous and loss through evaporation is negligible. The model developed ensures an equitable distribution of water to the farmers according to their land holdings. A comparison of existing and revised time allocation reveals that the farmers located in the upper reaches were getting more time (up to 12.2 min per unit area), while the farmers located in the lower reaches have been getting less time (up to 28.1 min per unit area). The existing allocation of time of 0.75 h per unit area to all the farmers according to the old rules was revised to 0.546–1.219 h per unit area from head to tail. The conclusions drawn suggest that the strategy developed here should be adopted elsewhere in the existing system of irrigation for equitable distribution of canal water.

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Introduction

Equitable distribution of canal water to the farmers has been a major concern of managers, planners and researchers involved in irrigation (Abernethy 1986; Suryavanshi and Reddy 1986; Makin 1987; Steiner and Walter 1992). An age-old practice to ensure the equitable distribution of water from tertiary canal (watercourse) to the farmers successfully tried in north-west India and Pakistan is the rotational system of irrigation (known locally as *Warabandi*). This is a system of equitable distribution of the water available in the project by taking turns according to predetermined schedules specifying the day, time and duration of supply to each farmer in proportion to his holding in the outlet (watercourse inlet) command (Singh 1981; Malhotra 1982).

The distribution of water in the *Warabandi* system is shown in Fig. 1. The main canal feeds two or more branch canals, which operate in rotation and may or may not be able to run a full supply. Branch canals supply water to a large number of distributories, which must run a full supply in rotation. Distributories supply water to the watercourse through ungated fixed discharge outlets. Watercourse run a full supply when the distributory is running and the water is allocated between farmers on a watercourse according to a roster, on a 7-day rotation (Malhotra 1982). The cycle of turns on a watercourse or its branch starts from the head, proceeds downwards and ends at the tail. The supply is cut off from the head, when the turn of the last farmer is over. A farmer is given credit for the time lost in filling the empty watercourse between the place where the water enters the watercourse and the beginning of his holding, while the total filling time is debited to the common pool time of 168 h. The length of the upper portion of the watercourse, which has been filled during common time is discharged in the field of last farmer. Since this supply is not that efficient, rather than recovering the entire filling time from him, he is given some discount. The discounted value of the filling time is

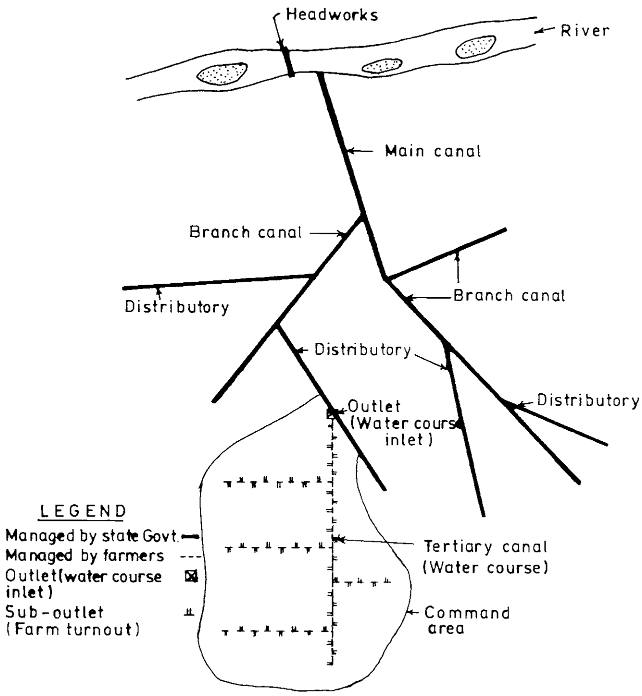

Fig. 1 Typical distribution system

known as depletion time and is credited to the common pool-time and debited from the account of the individual farmer. Usually, under normal soil conditions, the filling and depletion times are assumed to be 5 and 3 min per 67 m length of the watercourse, respectively. The flow time allotted per unit area is equal to (168 – total filling time + total deletion time)/total area, while the time allotted to each farmer is equal to (flow time of unit area × his area) + (his filling time − his depletion time). The depletion time is zero for all farmers except the last farmer.

Statement of the problem

In the design of the rotational system of irrigation as described above, the conveyance loss has not been considered. The rate of seepage loss increases with the increase in length of the watercourse from head to tail. Thus the farmers in the tail reaches get much less water per unit area than the farmers in the upper reaches, resulting in an inequitable distribution of water. Inequity has a direct influence upon productivity, but, whereas the parts of system that receive less than their agronomic requirements of water will produce less than their potential, the areas which receive more water than they need do not show improved yield, so that the excess water is not serving a productive purpose (Abernethy 1986). This means that regardless of its social undesirability, the inequality is also undesirable because of its poor utilization of some of the water which thus reduces the productivity of the available water. The farmers must be compensated for the seepage loss. Malhotra (1982) suggested that the watercourse should be divided into three or four segments. The farmer may be allotted time on the basis of actual flow in each segment. However the length of the watercourse is such that there is a significant difference in the flow even within the same segment. The farmer needs to be allotted time according to the actual discharge received by him. Therefore, in this paper a model has been developed incorporating the seepage loss along the length of the watercourse/or its branch, which ensures the equitable distribution of water according to the land holding of a farmer irrespective of his location on the watercourse. The model has been applied to a watercourse of the Kotkapura distributary in Punjab, India to demonstrate its usefulness.

Model formulation

The discharge along the watercourse decreases at an increasing rate due to seepage. Based on field observations, a best-fit equation was obtained using computer to predict discharge (Q_L) at any specific point at a distance (L) from the outlet head along the length of run of watercourse. The form of equation thus fitted was:

$$Q_L = \frac{aQ_0}{1 + \exp(bL - c)} \quad (1)$$

where

Q_L = discharge at any distance L from the outlet (watercourse inlet) head (cumecs); Q_0 = discharge at the outlet head of watercourse (cumecs); L = length of run (m) and a, b and c = constants determined with the help of computer.

Each farmer should be compensated for the reduced discharge. The discharge being provided to each farmer can be computed using Eq. 1 for a given distance between the watercourse inlet and farm turnout provided on the watercourse for diverting water from the watercourse to his fields. A seepage factor defined as the ratio of discharge released at the watercourse inlet to the actual discharge being received by the farmer may be determined for each individual farmer. Its value will always be greater than one. If A_1, A_2 ... A_n are the land holdings of farmers from head to tail and S_1, S_2 ... S_n are the seepage factors, then the time allotted per unit area ensuring equitable distribution of water can be computed as:

$$T_a = \frac{168 - \mathrm{TF} + \mathrm{TD}}{\sum_{i=1}^{n} A_i S_i} \quad (2)$$

where

T_a = time allotted per unit area
TF = total filling time
TD = total depletion time

A_i = area of ith farmer and
S_i = seepage factor of ith farmer.

Correspondingly the time allotted to each farmer is given by:

$$T_i = T_a \times A_i \times S_i + F_i - D_i \quad (3)$$

where

T_i = time allotted to each farmer
F_i = filling time of ith farmer
D_i = depletion time of ith farmer.

The input data required for the model includes distance of farm turnout from the watercourse inlet, discharge available at watercourse inlet, allotted filling and depletion times per m length of run. The model was coded in Fortran 77. The model deals with two situations i.e. the computation of time already being allotted to the farmers according to existing practice and the allocation of revised times.

Model application

To demonstrate the usefulness of the model, it was applied to watercourse number 34790R of the Kotkapura distributory of the Sirhind canal system in Punjab, India (Fig. 2). The watercourse comprises four branches: ABD, BC, AEF and EG. The length of each branch and its associated command area are illustrated in Fig. 2.

The layout plan showing the positions of farm turnouts on different branches of the watercourse selected is shown in Fig. 2. The information on the existing rotational system of irrigation (*Warabandi*) was collected from the revenue section of the irrigation department. From the *Warabandi* layout plan, ownership map etc, specific information was developed on distance from watercourse inlet to farm turnouts, filling time, depletion time and time of operation in each reach during a week. The watercourse remains in operation, on average, for 279 days in a year. The full supply discharge of watercourse is 52 l/s. The command area is 215.3 ha. The actual discharges at different locations along the watercourse were measured by Parshal flume. The Parshal flume was fixed in such a way that no water could escape from sides or through the bottom, both on the upstream and downstream sides. The lowest level of the Parshal flume was kept level with the watercourse bed. The actual discharge available at the different locations measured with Parshal flumes is given in Table 1 (Khepar 1980).

The output of the model includes seepage factor (S_i), filling and depletion times (F_i and D_i), existing time, revised time (T_i) and time currently allotted to each farmer. The impact of improved strategy on time allotted per unit area was also investigated.

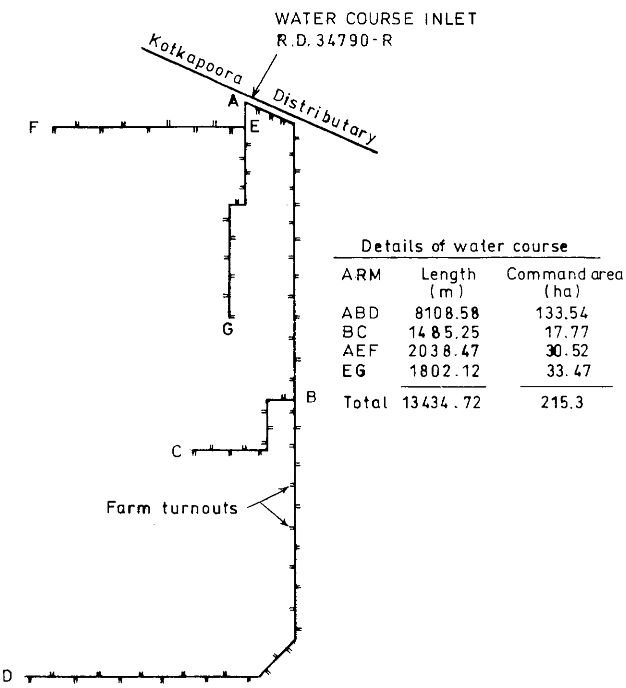

Fig. 2 Layout of water course (RD 34790) showing position of farm turnouts

Results and discussions

As already discussed, the best-fit equation was obtained using data reported in Table 1 to predict discharge at any distance from the head end of the watercourse. The equation thus obtained is:

$$Q_L = \frac{1.2272 Q_0}{1 + \exp 2.38 \times 10^{-4}(L - 7582.719)} \quad (4)$$

The value of R^2 for this is 0.9957. While developing this equation it was assumed that the soil is homogeneous throughout the length of flow and loss through evaporation is negligible. The actual discharge available to each farmer located on different branches of the watercourse using Eq. 4 and the corresponding seepage factor were determined. The filling time and depletion time pertaining to each farmer were also determined. The total filling time is 16.52 h while the depletion time

Table 1 Measured flow rate at different locations on the watercourse from head to tail and computed percentage seepage loss per 100 m length

Distance from outlet head (m)	Discharge (cumec)	Seepage loss per 100 m length (%)
5	0.050	0.204
985	0.049	0.270
1740	0.048	0.684
2653	0.045	0.767
3522	0.042	0.788
4730	0.038	1.230
5800	0.033	1.322
6946	0.028	2.052
7990	0.022	–

is 10 h. The command area is 215.3 ha. Thus the existing flow time per unit area is (168 – 16.52 + 10.0)/215.3 = 0.75 h.

Revised allocation of time

The seepage factor, existing and revised allocations of time to head, middle and tail end farmers located on different branches of the watercourse are given in Table 2. The details pertaining to each farmer, though computed, are not reported in this table due to limitation of space. However, the existing and revised times allocated to each farmer on all the branches of the watercourse including ABD, AEF, EG and BC are indicated in Figures 3, 4, 5 and 6, respectively.

A perusal of Table 2 reveals that the farmers located in the head reach of branch ABD (the longest branch) and on branches located on BC have also been getting slightly more time as these are located a little on the upper side of the middle reach. However the farmers located on the lower reach of branch ABD have been getting less time than acceptable to them.

A comparison of existing and revised times allocated to the farmers located on branch ABD of the watercourse is given in Fig. 3. This figure clearly shows that the farmers located in the upper half have been getting more water than those in the lower half, and that the farmers located in the tail end have suffered most. Figure 4 reveals that though the revised times for all the farmers located on branch AEF are less than the currently allocated times, the farmers in the upper reaches had the major advantage of inequitable distribution of water. A perusal of Fig. 5 also reveals that the revised time allotted to farmers located on branch EG is less than the existing time, these all being located on the head reach except in few cases where the filling time was insignificant. Fig. 6 gives the comparison of existing and revised times allotted to the farmers located on branch BC. The revised time is slightly longer than the existing time. The farmers on the lower reach benefit most from the revision. The total time (i.e. 168 h) remains the same in the existing and revised schedule of allocating the water.

Time allocated per unit of area irrigated

The existing time allocated per unit irrigated area is 0.75 h. The revised time allotted per unit area varies from head to tail (from 0.546 h to 1.219 h). A comparison of existing and revised time allotted per unit area is plotted in Fig. 7, which reveals that the farmers located

Table 2 Existing and revised time allocated to the farmers

Farmer no.	Distance from outlet head (m)	Computed discharge (cumecs)	Seepage factor, S	Area, A (ha)	SA	Filling time (min)	Depletion time (min)	Existing time allotted (h)	Revised time allotted (h)	Revised time allotted per unit area (h/ha)
Arm ABD										
1	83.82	0.0509	1.02	1.68	1.71	6	0	1.36	1.09	0.587
2	326.86	0.0504	1.03	6.97	7.18	18	0	5.53	4.44	0.593
3	419.09	0.0502	1.04	0.98	1.01	7	0	0.85	0.70	0.595
27	3456.62	0.0414	1.26	8.41	10.56	15	0	6.56	6.33	0.723
28	3892.5	0.0398	1.30	1.01	1.32	33	0	1.31	1.31	0.751
29	4133.9	0.0389	1.33	3.15	4.20	18	0	2.66	2.72	0.768
54	7523.51	0.0247	2.10	1.27	2.67	5	0	1.04	1.62	1.209
55	7590.56	0.0244	2.13	1.69	3.59	5	0	1.35	2.15	1.224
56	7987.88	0.0226	2.29	1.01	2.31	30	0	1.26	1.83	1.319
57	8108.58	0.0221	2.34	10.0	23.46	9	363	1.61	7.60	1.350
Arm AEF										
1	241.4	0.0506	1.03	4.5	4.62	18	0	3.7	2.96	0.591
2	375.51	0.0503	1.03	4.08	4.21	10	0	3.23	2.59	0.594
5	1086.3	0.0486	1.07	4.55	4.87	24	0	3.81	3.20	0.615
10	1944.6	0.0462	1.12	0.6	0.67	14	0	0.68	0.62	0.647
11	2038.47	0.0459	1.13	3.83	4.33	7	91	1.48	1.09	0.651
Arm EG										
1	83.82	0.0509	1.02	1.07	1.09	6	0	0.9	0.73	0.587
2	573.74	0.0498	1.04	10.21	10.64	37	0	8.28	6.74	0.600
5	885.14	0.0491	1.06	1.97	2.27	4	0	1.55	1.27	0.609
9	1802.12	0.0466	1.11	7.36	8.20	25	81	4.59	3.79	0.641
Arm BC										
1	3540.7	0.0411	1.26	2.75	3.48	9	0	2.21	2.15	0.728
2	3735.16	0.0404	1.29	3.88	4.99	15	0	3.16	3.12	0.740
6	4261.53	0.0384	1.35	1.04	1.41	14	0	1.01	1.04	0.778
7	4321.88	0.0382	1.36	0.26	0.35	4	0	0.26	0.27	0.783
11	4717.5	0.0367	1.42	1.12	1.59	10	0	1.01	1.08	0.816
12	4905.25	0.0359	1.45	4.1	5.92	14	66	2.21	2.55	0.832
Total	–	–	–	215.3	280.48	991.09	601	168.00	168.00	–

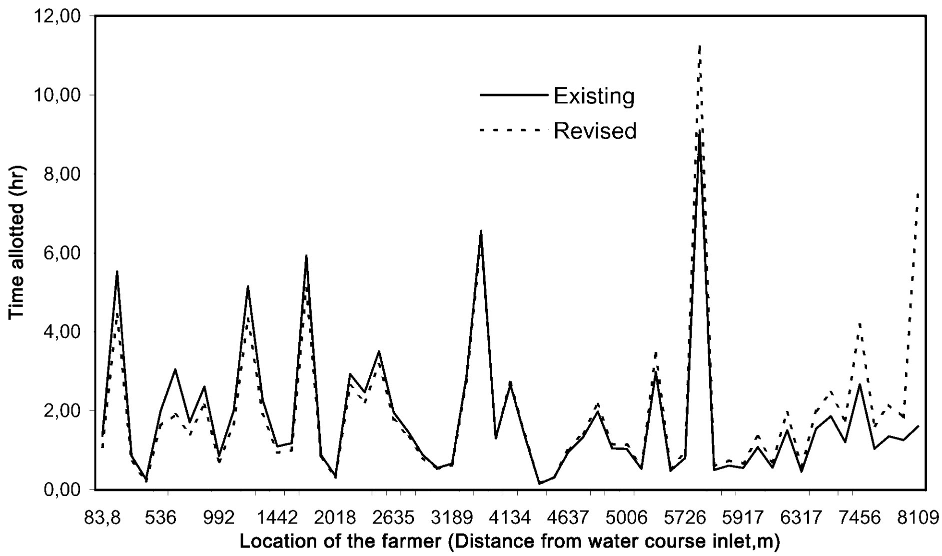

Fig. 3 Existing and revised times allotted to each farmer located on the watercourse branch ABD

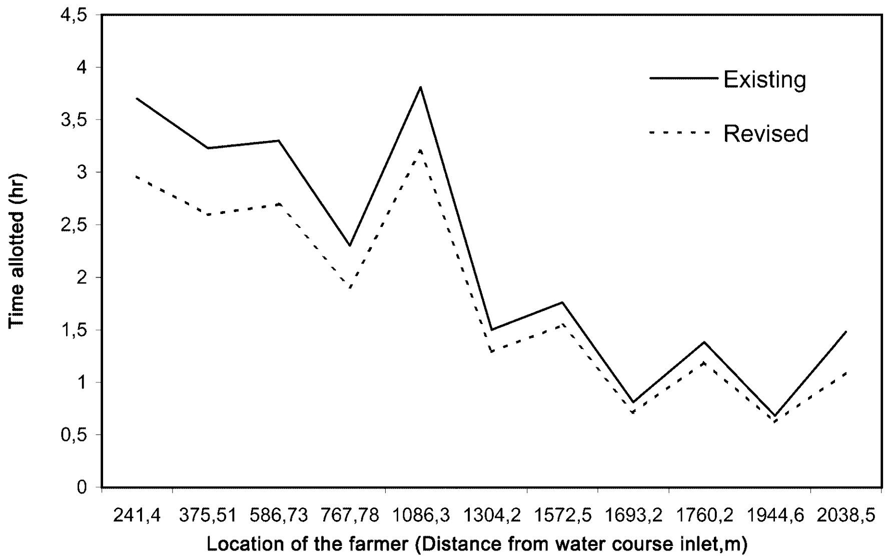

Fig. 4 Existing and revised times allotted to each farmer located on the watercourse branch AEF

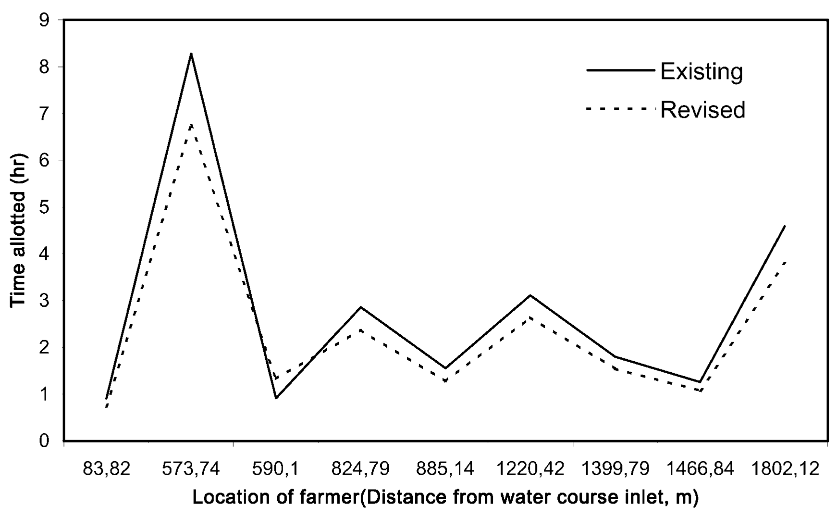

Fig. 5 Existing and revised times allotted to each farmer located on the watercourse branch EG

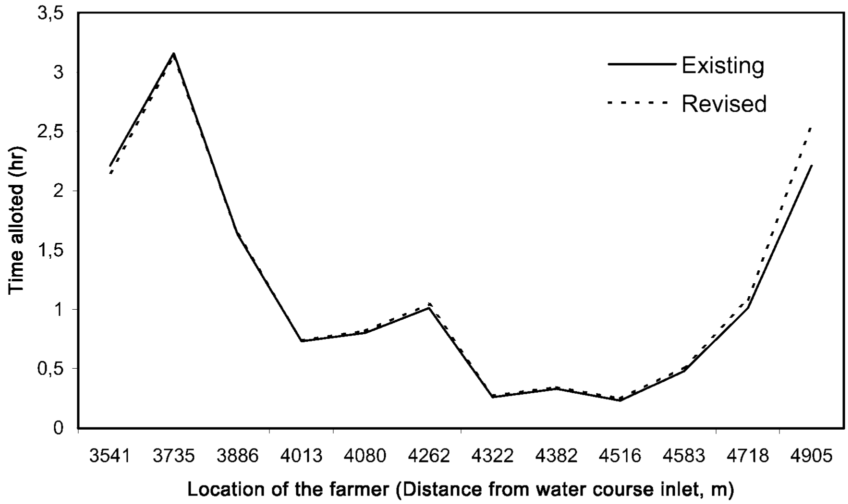

Fig. 6 Existing and revised times allotted to each farmer located on the watercourse branch BC

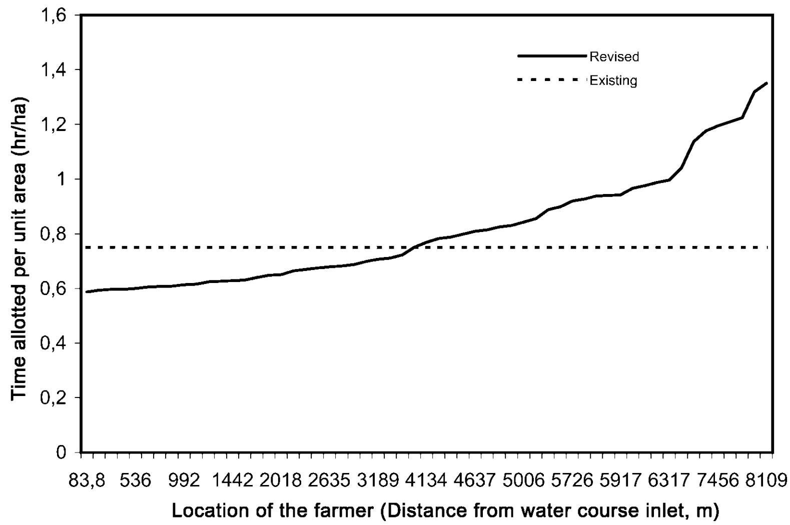

Fig. 7 Existing and revised times allotted per unit area

in the upper reaches were getting up to 12.2 min per unit area more time, while the farmers located in the lower reach have been getting up to 28.1 min/unit area less time. Under the new system, of the 89 farmers located on the watercourse, 49 would get slightly less time while 36 would get more than they did under the old rules. There would be no change for the remaining four farmers.

Limitations of the study

The present study has the following limitations

1. The farmers who will be allocated less time as per the proposed system of distribution may resist the change.
2. The accumulated seepage from the watercourse will increase.

It is expected that the State Government will be in a position to introduce the proposed system of water distribution to provide social justice to the farmers under rule 92 of section 55 of the Canal Act, which ensures the equitable distribution of water (Malhotra 1982). The Government has succeeded in the past in introducing such reforms (e.g. consolidation of land holdings, Tenancy and Land Ceiling Act) through motivation and legal action. The increased seepage due to the introduction of the proposed reforms will be re-used through pumping by tube-wells. In the canal command area, not only in the Indian Punjab but in the entire Indo-Gangetic plains, more than 50% of the area under irrigation is irrigated by wells. No doubt the re-use of seepage losses increases the pumping cost but this may be compensated with the additional availability of ground water which can be used by the farmer as and when required, which will narrow the gap between demand and supply of canal water.

Conclusions

The studies have revealed that the existing rotational system of irrigation results in inequitable distribution of canal water, resulting in social injustice. The farmers located in the upper half of the watercourse have been getting more water than those in the lower half, though the farmers located in the tail end are the greatest sufferers. The strategy developed ensures an equal distribution of water per unit area to all the farmers being provided irrigation from a common watercourse irrespective of the location of their land holdings from the watercourse inlet. The limitation of the study, that the farmers who got more time according to the old rules may resist the change, can be taken care of by the State Government under the Canal Act, which provides for equitable distribution of canal water.

The application of the model to one of the watercourse in Punjab, India, demonstrates its suitability for wide-scale adoption.

Acknowledgement The authors are grateful to the Indian Council of Agricultural Research for providing financial support to carry out the present study under the National Professorship project.

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