Proceedings of the Institution of Civil Engineers
Water Management 159
June 2006 Issue WM2
Pages 95–101

Paper 14080
Received 05/01/2005
Accepted 25/10/2005

Keywords:
drainage & irrigation/mathematical modelling/water supply

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Improving allocation of irrigation water in southwest India

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Irrigation schemes in southwest India are heterogeneous in crops, area of irrigation units, soils and climate. The areas planned for irrigation each year under different crops and the scheduled duration of irrigation to each farmer are estimated, however, based on assumed uniform characteristics (planned schedule). In practice the schedules are not followed and users mostly over-irrigate their fields (the actual schedule). In this paper a simulation–optimisation model is used to develop two alternative (proposed) schedules based on full irrigation and on optimised deficit irrigation within the framework of area-proportionate water distribution, taking heterogeneity into account. As a case study, the allocation and water delivery plans were obtained for one irrigation scheme for the actual, planned and proposed schedules and compared using the simulation–optimisation technique. This showed that the proposed schedule for deficit irrigation had the maximum monetary productivity (total net benefits) and area productivity (irrigated area) and that the equity of both proposed schedules was much higher than those for either the planned or actual schedules. The proposed schedules can be adopted within the framework of the existing system of water distribution, which shows that there is considerable scope for improvement in the performance of existing irrigation schemes without major capital investment.

1. IRRIGATION SCENARIO IN INDIA

The cultivation of crops is possible in India throughout the year, in three seasons. The Kharif season starts in July and lasts until mid-October, and most of the annual precipitation falls during this period as monsoon rains. The crops grown during this season thus do not need regular irrigation, but supplemental irrigation can be beneficial to avoid damage to the crop due to excessive stress during a long dry period. The crops grown during the Rabi season (mid-October to February) and summer season (March to June) do not receive much moisture from precipitation and are dependent on irrigation for their survival. During the summer season, crop water requirements are also high. Thus, in India, the periods of highest rainfall do not coincide with the periods of maximum water demand. The pattern of rainfall and cropping seasons described above has therefore led to the use of reservoirs with a branched irrigation network of main, secondary, tertiary and quaternary canals. River discharge is diverted during the rainy season and stored in reservoirs to be used for protecting the crops grown in the Kharif season during periods of water shortage and for growing irrigated crops in the Rabi and summer seasons.

Irrigation schemes in India are generally designed for an irrigation intensity of 30 to 40%.[1] Therefore even in wet years 100% of the command area cannot be irrigated, indicating the need for increasing the area under irrigation within the scheme by improved water management. The most viable option to increase the irrigated area and crop production with the currently available irrigation water is to improve the performance of existing irrigation schemes by adopting efficient irrigation practices so that the productivity (output) of the available irrigation water in the reservoir of each irrigation scheme can be increased.

The present study considers how to allocate land and water resources optimally in irrigation schemes within the framework of the existing water distribution system in order to use the water available in the irrigation scheme efficiently. Optimum allocation of irrigation water on a scientific basis will also help in reducing the gap between the potential created and the potential actually utilised by surface water irrigation schemes, estimated as 7·5 M ha in India.[2]

2. WATER DISTRIBUTION SYSTEMS IN INDIA

Over time the following practices for distributing water below the outlets of surface irrigation schemes have developed in India on the basis of requirements and experience[3,4]

(*a*) the Warabandi system
(*b*) the Shejpali systems
(*c*) localised systems
(*d*) field to field systems.

This paper focuses on the Shejpali systems, practised in the states of Maharashtra, Gujarat and parts of Karnataka. The main feature of these systems is that the government enters into some sort of agreement with the farmers for supplying water to them. Farmers submit applications for supply of water indicating the crops they wish to grow and the areas under them. The water available and demands are estimated by government irrigation authorities. Water is then apportioned on the basis of crops and overall demand. Irrigation authorities make proportionate reductions in the demand or irrigated area proposed by the farmers if the total demand is higher than the water available for irrigation, which is usually the case. The government issues permits or orders for the supply of water and the two together constitute the agreement.

A schedule, known as 'Shejpali', fixing the order or sequence of turns to different farmers for the sanctioned crop area is prepared for each irrigation rotation by following a tail-to-head irrigation approach, that is farmers at the tail-end of the canal are served first and those at the head of the canal are served last. The irrigation interval depends on the rate of water consumption by the crops, that is high water consuming crops may be supplied with water in each rotation, whereas the less water demanding crops on the same outlet may get irrigation on alternate rotations.

In this system the demands are estimated by assuming uniform characteristics of the command and the farmers themselves decide when the irrigation is adequate for the crop being irrigated. Once a farmer's crop area has been irrigated during the rotation, the farmer passes on the supply of water to the next farmer. With the limited water supply in the scheme and the history of unreliable water delivery (mostly due to underestimation of demands or overestimation of supply), farmers are not sure about when the next irrigation will be, so they tend to over-irrigate. This leads to a breakdown in the system so that farmers at the head take water first in order to satisfy their requirements.

The rigid Shejpali system was introduced to overcome this drawback of Shejpali in many irrigation schemes. In rigid Shejpali, the sequence of irrigation for each farmer is fixed, along with the date, time and duration of irrigation, again using a tail-to-head system. This prohibits them from overdrawing water. However, in practice rigid Shejpali also breaks down and farmers at the head take water first, leading to a head-to-tail system and over-irrigation of their fields. One reason for this is the unrealistic schedule of water distribution. The schedules are determined without taking into consideration soil type, appropriate losses in conveyance, distribution and application processes, the capacity of the water distribution system, etc. This results in inappropriate water allocation and farmers are left with the feeling that they are not getting their due share of water. This tends to cause them to apply as much water as possible as and when they get the supply. The water distribution actually practised is thus to over-irrigate starting from head to tail.

The Shejpali system was designed at a time when irrigation water was plentiful relative to demand. Now, due to water scarcity and increasing demand for irrigation together with weak irrigation management, Shejpali systems are not being properly followed in most irrigation schemes.

3. EVALUATION OF SHEJPALI SYSTEM

3.1. Schedules

The existing schedules considered in this paper are the planned schedule of rigid Shejpali and the actual schedule of deliveries. These schedules are evaluated and compared with two alternative schedules proposed in this paper.

3.1.1. Planned schedule (Pln). The planned schedule (rigid Shejpali) in the irrigation scheme consists of applying a fixed depth of water at predetermined intervals to all the crops grown on different soils in the allocation units, thus ignoring heterogeneity within the irrigation scheme. Furthermore, this allocation scheme does not consider variations in distribution and conveyance efficiencies between allocation units.
The allocation of water to different units is proportional to the demands of water in terms of area to be irrigated from different units. In practice, demands for water are generally received from all the farmers for their total croplands in the allocation unit due to the benefits of irrigated agriculture over rain-fed agriculture. Hence the allocation of water to different allocation units in the planned schedule is proportional to the culturable (cultivable) command area (CCA) of these allocation units.

3.1.2. Actual schedule (Act). As in normal practice the actual schedule consists of following irrigation turns from head-to-tail rather than according to 'fixed turn' and farmers irrigating crops according to their concept of adequate irrigation (mostly over-irrigation) instead of 'fixed duration'. In this process not all the farmers get water.

3.1.3. Proposed schedules. Two alternative schedules are proposed in this study. These are based on full irrigation (Pr-F) and deficit irrigation (Pr-D) within the framework of area-proportionate water distribution followed in Shejpali.

(*a*) *Full irrigation (Pr-F).* In Shejpali, the crops and the area under these crops are presumed to be given adequate irrigation but this is an oversimplification as the planned deliveries are based on a fixed depth at a fixed interval to different crops grown in different units. This fails to take into account firstly that the full irrigation depth to fill the root zone to field capacity differs from crop to crop and soil to soil and, secondly, that the conveyance efficiencies of the canal network, the distribution efficiency of different allocation units and the application efficiency within the farm influence the water required to be delivered from the headwork so that the full irrigation depth can be applied at the farm. This paper takes these factors into account to prepare an allocation schedule for adequate irrigation within the framework of rigid Shejpali, considering the details of the irrigation scheme. This is referred to as 'proposed schedule–full irrigation' (Pr-F).

(*b*) *Deficit irrigation (Pr-D).* Most irrigation schemes in the semi-arid tropics are characterised by limited water supply and heterogeneity in the soils, the crops to be irrigated and the weather. Therefore it is a complex task to allocate land and water resources to different crops and different units of the command area and to schedule the irrigation water deliveries according to the objectives of the irrigation scheme. With recent advances in irrigation modelling, it is possible to allocate water optimally to different crops considering the complex climate–crop–soil relationship, and also to schedule optimum irrigation water deliveries.[5] Where water is scarce compared to land area (as in the irrigation schemes in Maharashtra, India[1]), the deficit irrigation approach could be more beneficial than adequate irrigation to meet crop water requirements[6–9] by increasing the area irrigated and agricultural production. Deficit irrigation is defined as the practice of applying water in the amounts and at intervals such that the crop is subjected to stress during certain days in the crop's growth period, resulting in a reduction in water requirement and crop yields. This paper considers the use of deficit irrigation to prepare land and water allocations and schedules within the framework of rigid Shejpali, considering heterogeneities in the irrigation scheme. In this study, this is referred to as 'proposed schedule–deficit irrigation' (Pr-D). Deficit irrigation is based on the variable depth irrigation approach suggested by Gorantiwar and Smout.[10] This approach consists of applying irrigations with different degrees of deficit during each irrigation interval and selecting the optimum deficit.

4. EVALUATION METHODOLOGY

In order to evaluate the different schedules, it is necessary to: (i) simulate the performance of actual and planned schedules; (ii) prepare allocation plans and schedules for the proposed schedules of full and deficit irrigation, considering heterogeneities in the irrigation scheme; and (iii) simulate the performance of these schedules and compare them with actual and planned schedules. This evaluation requires information for each schedule on the allocation of land and water resources to different crops grown in different allocation units, and the crop production and total net benefits. This can be estimated from simulation modelling that describes the complex systems influencing water demand in the irrigation scheme.[11,12] In addition, for the proposed schedules, land and water resources can be allocated to different crops optimally within the water available for irrigation, with the help of optimisation modelling. This study used the Area and Water Allocation Model (AWAM)[13,14] based on a simulation–optimisation technique to generate the information necessary for comparing and evaluating different schedules.


Fig. 1. Main canal of Nazare Medium Irrigation Scheme

4.1. Case study

The Nazare Medium Irrigation Scheme in a semi-arid region of Maharashtra State in India was selected as a case study. Detailed information on this is presented by Gorantiwar.[13] For this study, the irrigation season was considered to spread over the Rabi and summer crop seasons.

The gross reservoir capacity and dead storage capacity of the reservoir are 22·313 and 5·684 Mm^3, respectively. One main canal (Figs 1 and 2) originates from the headworks with a full supply discharge of 1·528 m^3/s and length of 3·05 km. It supplies one distributory canal, which is 11·75 km long and has the same carrying capacity, 1·528 m^3/s. The CCA of the irrigation scheme is 3539 ha. There are 28 direct outlets (four on the main canal and 24 on the distributory canal) and four minors (all on the distributory canal). There are nine outlets on the minors, but details of these could not be obtained. Therefore, the CCAs of the 28 direct outlets and four minors were considered as allocation units (AUs), resulting in 32 AUs. The AU numbers 5, 9, 12, and 20 are related to minors and the others to direct outlets.

Based on previous investigations (see Gorantiwar[13]) the distribution efficiency of each AU related to an outlet was considered to be 86% and the distribution efficiency of each AU that comprised the CCA of a minor was considered to be 68·8%, for all the irrigations. A field application efficiency of 75% was assumed for all the crops on all soils and for all irrigations.

Climatological data were collected from a local meteorological observatory and assumed to apply uniformly over the reservoir and entire command area. The command area has been classified with four different types of soils. The crops considered in the analysis were gram, sorghum, onion, wheat (Rabi crops), groundnut and sunflower (summer crops). The other data needed for the simulation model were either locally available or documented by FAO[15,16] and given by Gorantiwar.[13]

This paper focuses on evaluating and comparing the different schedules and demonstrating the effectiveness of the simulation–optimisation model to generate optimal allocation plans according to the proposed schedules. In order to capture the influence of the schedules separately, some parameters influencing the irrigation water deliveries were considered as uniform, though the AWAM was able to consider variations, for example the application efficiency, which is a function of soil, crop and deficit, was considered uniform for all these variables. Similarly, climatological data from only one year were used.

5. RESULTS

The land and water resources were allocated to different crops grown on different soils in different units, and the crop production and total net benefits were simulated with the help of the simulation–optimisation technique for the four different

Fig. 2. Outlet gate of main canal of Nazare Medium Irrigation Scheme

schedules: planned (Pln), actual (Act), proposed-full (Pr-F) and proposed-deficit (Pr-D) schedules. The study used the fixed cropping distribution followed in Nazare Irrigation Scheme, which consists of gram 36%, sorghum 29%, onion 14% and wheat 21% in Rabi and sunflower 33% and groundnut 66% in summer. It was assumed that 55% of water is utilised in Rabi and 45% water is utilised in summer season on the basis of past records and the general cropping pattern in the irrigation scheme.

5.1. Planned schedule (Pl)

As described earlier, the planned schedule (rigid Shejpali) in the irrigation scheme is based on assumed uniform characteristics of the command area. The irrigation depth of 70 mm per irrigation at an interval of 21 days during Rabi season was proposed in the planned schedule of the Nazare Irrigation Scheme.[13] During the summer season the same irrigation depth at a reduced interval of 14 days was considered. For some crops grown on some soils, this schedule may result in deficit irrigation, however, this may not be the *optimum* deficit irrigation.

5.2. Actual schedule

Farmers in this region flood their fields and allow water to spill over irrigation furrows.[17] This results in excessive application losses through deep percolation and runoff. According to local experience, this over-application may be up to 100% of the full irrigation depth, depending on the crop. For this study, however, an average 50% over-irrigation was considered in the analysis. The actual schedule was thus based on head-to-tail irrigation, with 50% over-irrigation at each irrigation, at an interval of 21 days during the Rabi season and 14 days during the summer season.

5.3. Proposed schedules

Plans were obtained for seven sets of irrigation interval. These were 14, 21, 28 and 35 days both in Rabi and summer season, 21 in Rabi with 14 in summer, 28 in Rabi with 21 in summer and 35 in Rabi with 21 in summer.

5.4. Comparison parameters

The allocation plans for different schedules obtained from the simulation–optimisation technique were compared in terms of monetary productivity (output), area productivity (irrigated area) and equity. Monetary productivity is the ratio of total net benefits of the schedule for which the monetary productivity is to be estimated to the total net benefits of the schedule (giving maximum total net benefits among all the schedules considered for comparison). The maximum net benefits were obtained for the proposed schedule of deficit irrigation for an irrigation interval of 14 days. Therefore the productivity was estimated with reference to this schedule.

The area productivity is the ratio of the area allocated for irrigation to the CCA of the irrigation scheme. Equity is considered as the area-proportionate distribution of water. Equity is computed by modifying the inter quartile ratio[18] as the ratio of the average allocation ratio for water allocated to all land in the quarter which receives least water to the average allocation ratio in the quarter which receives most water.[13] The allocation ratio for water allocated is the ratio of the proportion of water allocated to the AU to the proportion of CCA of the AU. A detailed discussion of these comparison parameters may be found in the literature.[19]

6. COMPARISON

6.1. Planned and actual schedules

The productivity and equity values for planned and actual schedules are presented in Fig. 3. This shows that both monetary and area productivities are about 25% higher for the planned schedule than the actual schedule when farmers over-irrigate by 50%. The reduction in area and benefits with the actual schedule is because of over-irrigation. The equity is zero for the actual schedule and 0·76 for the planned schedule. This is because farmers at the head of the distribution system take as much water as they want in the actual schedule, as they take water first. The tail-end farmers are left with no water. However, in the planned schedule, the allocation is area proportionate based on uniform characteristics of the irrigation scheme, which is more equitable. Thus the allocation by the actual schedule is less satisfactory than the planned schedule. The results indicate the need to enforce rigid Shejpali and discourage the farmers from disrupting the planned schedule—a major challenge for the irrigation authorities.

6.2. Proposed schedules

Productivity and equity values for the proposed schedules of full and deficit irrigation for different irrigation intervals were obtained. The maximum monetary productivity was obtained with the irrigation interval of 21 days in Rabi and 14 days in

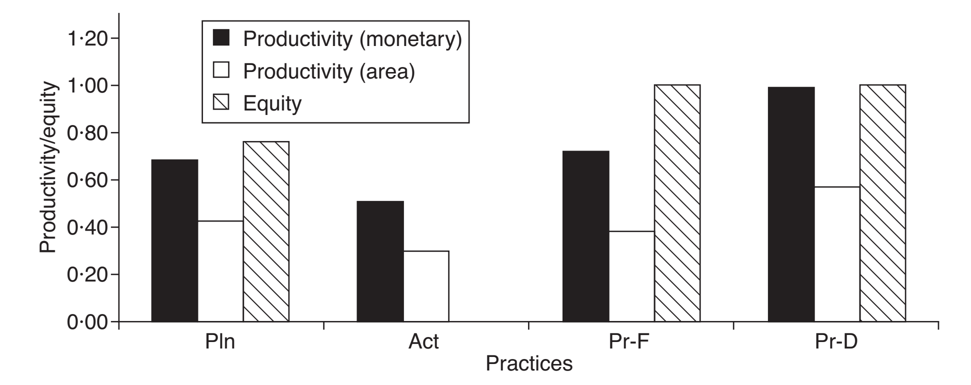

Fig. 3. Productivity and equity for different practices

summer for both schedules. The equity was 1·0 because these schedules use area–proportionate water allocation at the AU.

6.3. Actual, planned and proposed schedules

Table 1 shows the area and water allocation plans for the actual, planned and proposed full irrigation and deficit irrigation schedules for the irrigation interval of I-21-14 days. The water allocation values are at AU level, after taking into account estimated conveyance losses from the headworks to the AUs, resulting in different total volumes delivered at AU level from the four schedules. Table 1 shows that under the actual schedule, more than half the AUs get no water at all.

6.4. Results

The productivity and equity for actual, planned and proposed schedules are shown in Fig. 3 and indicate that productivity and equity are highest for the proposed schedule of deficit irrigation and lowest for the actual schedule. The monetary productivity of the proposed schedules of full irrigation and deficit irrigation are respectively 5% and 45% more than the planned schedule. The area productivity of the proposed schedule with full irrigation is lower than that of the planned schedule. This is because the fixed-depth application in the planned schedule is less than the full irrigation depth. This has inadvertently resulted in deficit irrigation in the planned

						Proposed schedule			
		Actual schedule		Planned schedule		Full irrigation		Deficit irrigation	
AU no.	CCA: ha	Area: ha	Water: ha m	Area: ha	Water: ha m	Area: ha	Water: ha m	Area: ha	Water: ha m
1	39	78	57·54	21·31	11·98	19·21	8·99	22·21	8·84
2	36	53·26	51·84	19·61	11·01	13·11	8·3	20·49	8·16
3	8	16	17·59	4·33	2·43	2·91	1·85	4·55	1·81
4	27	35·63	32·59	14·29	8·03	9·83	6·23	15·36	6·12
5	395	294·8	258·41	164·45	115·55	194·6	113·8	224·89	111·89
6	33	47·44	47·26	17·13	9·63	11·71	7·61	18·86	7·47
7	59	74·67	67·71	29·69	16·68	21·49	13·6	33·58	13·37
8	22	30·63	28·89	10·93	6·15	8·01	5·07	12·52	4·99
9	211	119·59	135·55	83·05	58·35	76·85	60·79	120·07	59·77
10	68	74·67	67·71	33·37	18·76	24·77	15·67	38·69	15·41
11	62	74·67	67·71	30·04	16·88	22·58	14·29	35·28	14·05
12	142	89·61	101·57	54·57	38·34	51·72	40·91	80·81	40·22
13	127	65·52	56·13	60·99	34·28	46·25	29·27	72·27	28·78
14	81	0	0	38·4	21·58	29·5	18·67	46·09	18·35
15	217	0	0	102·86	57·82	79·03	50·02	123·49	49·18
16	82	0	0	37·79	21·23	40·4	18·9	46·68	18·58
17	145	0	0	66·86	37·58	52·69	33·42	82·63	32·86
18	147	0	0	66·47	37·37	53·42	33·88	83·78	33·31
19	118	0	0	53·33	29·97	42·98	27·2	67·15	26·74
20	661	0	0	232·93	163·65	240·19	190·43	375·29	187·24
21	65	0	0	28·44	15·98	23·07	14·98	37·14	14·73
22	156	0	0	68·25	38·37	55·35	35·95	89·13	35·35
23	30	0	0	12·75	7·17	10·9	6·92	17·09	6·8
24	37	0	0	15·73	8·84	13·45	8·53	21·08	8·38
25	89	0	0	37·67	21·17	32·34	20·51	50·72	20·17
26	93	0	0	39·36	22·13	33·79	21·44	53	21·08
27	115	0	0	47·81	26·87	41·78	26·51	65·54	26·06
28	30	0	0	12·43	6·98	10·9	6·92	17·09	6·8
29	32	0	0	13·26	7·45	11·62	7·37	18·24	7·25
30	87	0	0	35·31	19·85	31·62	20·05	49·58	19·72
31	35	0	0	14·09	7·92	12·72	8·06	19·95	7·93
32	90	0	0	36·23	20·37	32·7	20·74	51·29	20·39
Total	3539	1054·5	990·5	1503·7	920·4	1351·5	896·9	2014·5	881·8

Table 1. Area and water allocation for actual, planned and proposed schedules (note: irrigation interval = 21 days (Rabi) and 14 days (summer))

schedule, spreading the available water over a comparatively larger area. However, the proposed schedule with deficit irrigation has greater area productivity than the planned schedule. This is because it is based on the optimal deficit. The application efficiency is considered to be same for both deficit and full irrigation schemes though it would tend to increase with the degree of deficit which would further enhance the benefits of deficit irrigation.

The equity of both the proposed schedules is 30% higher than the equity of the planned schedule. This is because the planned schedule assumed uniform characteristics of the command area, in particular the application, distribution and conveyance efficiencies, allocating less water to farmers towards the tail-end (Table 1).

The proposed schedule of optimal deficit irrigation thus has greater benefits than the proposed schedule of full irrigation or the planned schedule of fixed-depth irrigation. In actual practice of existing Shejpali, the farmers at the head tend to disrupt the schedule. This is mainly because they lack confidence that they will get an assured supply of water. The allocation and deliveries estimated by considering heterogeneity in the irrigation scheme could help boost farmers' confidence in planned deliveries of irrigation water. This, coupled with increases in monetary and area productivities due to adoption of optimal deficit irrigation, would spread the extent of irrigation over a larger area and to more farmers. This in turn would provide a more feasible schedule of rigid Shejpali. Thus the proposed schedule of optimal deficit irrigation (Pr-D) can be adopted beneficially within the framework of the existing system of water distribution. Section 7 provides some guidelines on implementation of the proposed schedules (detailed analysis of the implementation is beyond the scope of this paper).

7. IMPLEMENTATION OF THE PROPOSED SCHEDULES

Under the current rigid Shejpali system, farmers are not following the planned irrigation schedule laid down by the authorities, so it would be difficult to implement a change to an alternative schedule such as the schedules of full and deficit irrigation proposed in this paper. In order to encourage such changes, irrigation schedules should be based on actual field conditions. Schedules thus need to be developed for each crop cultivated on different soils in different units of the irrigation scheme and these schedules need to be implemented in practice.

This study is mainly related to the first requirement. The preceding sections of this paper show how the AWAM developed by the authors fulfils this requirement. They also show that there are substantial overall benefits of changing to one of the alternative schedules. Some suggestions for implementing these schedules in practice are discussed briefly below.

The proposed schedules of full and optimised deficit irrigation differ from traditional supply practices. As these schedules depend on the crop and soil type and climatic conditions, it is necessary to consider fields having the same crop and soil characteristics and then find optimised allocation plans and water delivery schedules. By following this approach the AWAM generates optimised irrigation programmes for different crop–soil units of different AUs of an irrigation scheme. These irrigation programmes provide information on areas to be cultivated for irrigation, water to be delivered and depth of water to be applied in the field for each crop–soil unit of each AU of the irrigation scheme.

Surface methods are used for delivering irrigations to crops in the irrigation schemes under study. For this purpose farmers normally use different irrigation methods according to the crop type. These are flooding, border, check basin and furrows. Traditionally in all these methods, water control is carried out manually. The farmers cut off the supply several minutes after the advance is completed in border and furrow methods or fill the fields/check basins several millimetres deeper than required. This practice causes over-irrigation and leads to the breakdown of the rigid Shejpali schedule.

Adoption of the proposed schedules, in particular the schedule based on deficit irrigation within the existing framework of rigid Shejpali, is a management-intensive process. How to do this is beyond the scope of this paper but the active participation of farmers, irrigation authorities, agricultural extension workers and scientists is needed to bring about modifications to the existing system.

(*a*) The traditional system of manual water control needs to be changed to some other form of managed control, for example siphons, gated pipes, tubes, etc.
(*b*) For efficient irrigation water management it is essential to follow the selected schedule, including the authorised depth of irrigation for the field. This can be done by controlling the time of irrigation at a controlled discharge. Some modifications to the field irrigation method may be needed, such as land levelling, modifying the length and width of borders or changing the inflow into each furrow to spread water over the field in the allowed time. Thus it is necessary to have information on the different characteristics of irrigation methods (field slope, stream size, stream duration, cut-off time, etc.) for each crop–soil unit in order to apply the desired irrigation depth in the root zone.
(*c*) The necessary information could be generated by agricultural universities in these regions and transferred to farmers through the Agricultural Extension Service of the Department of Agriculture; this would require strengthening of these institutions for research and capacity-building activities.
(*d*) The motivation of farmers to adopt these changes is important. They need to be convinced of the need to use water efficiently and the validity of the schedules for their conditions; training in the improved irrigation practices is also required. Research is needed on how best to do this and institutes for this purpose already exist (for example, agricultural universities, water and land management institutes); the Department of Irrigation would be well placed to mobilise and co-ordinate this work.

8. CONCLUSIONS

The case study on one irrigation scheme in Maharashtra, India with the help of the simulation–optimisation technique indicated that when the planned area–proportionate water allocation (rigid Shejpali) is replaced in practice by over-irrigation from head-to-tail, then the production, irrigated area and equity are considerably reduced. This shows the overall advantage of the existing planned schedule over actual practice (which benefits a few farmers at the expense of the majority), and the losses currently incurred by the inability of irrigation management to implement this planned schedule.

Furthermore, if the scheduling was based on a more scientific approach that takes account of variability (in soils, crops, irrigation efficiencies) in the command area, then the production, irrigated area and equity could be increased over the planned schedule. Such a schedule based more closely on actual conditions should be more acceptable to farmers. Additional gains in production and irrigated area could be made by adopting the optimal deficit irrigation approach, rather than full irrigation.

The proposed schedules could be adopted within the framework of the existing system of water distribution, which shows there is considerable scope for improvement in the performance of existing systems without major capital investment. Achieving these potential improvements, however, would require increased attention to strengthening irrigation management and motivating farmers to introduce an improved scheduling approach.

In general, where irrigation water is scarce compared to land area, it is advisable to schedule irrigation based on optimal deficit irrigation with area-proportionate water distribution to enhance both productivity and equity.

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