33

Research Report

Modernization Using the Structured System Design of the Bhadra Reservoir Project, India: An Intervention Analysis

R. Sakthivadivel
S. Thiruvengadachari, and
Upali A. Amarasinghe

International Water Management Institute

Research Reports

IWMI's mission is to contribute to food security and poverty eradication by fostering sustainable increases in the productivity of water through better management of irrigation and other water uses in river basins. In serving this mission, IWMI concentrates on the *integration* of policies, technologies and management systems to achieve workable solutions to real problems—practical, relevant results in the field of irrigation and water resources.

The publications in this series cover a wide range of subjects—from computer modeling to experience with water users associations—and vary in content from directly applicable research to more basic studies, on which applied work ultimately depends. Some research reports are narrowly focused, analytical, and detailed empirical studies; others are wide-ranging and synthetic overviews of generic problems.

Although most of the reports are published by IWMI staff and their collaborators, we welcome contributions from others. Each report is reviewed internally by IWMI's own staff and Fellows, and by external reviewers. The reports are published and distributed both in hard copy and electronically (http://www.cgiar.org/iwmi) and where possible all data and analyses will be available as separate downloadable files. Reports may be copied freely and cited with due acknowledgment.

Research Report 33

Modernization Using the Structured System Design of the Bhadra Reservoir Project, India: An Intervention Analysis

R. Sakthivadivel
S. Thiruvengadachari, and
Upali A. Amarasinghe

International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

The authors: R. Sakthivadivel and Upali Amarasinghe are senior irrigation specialist and research associate, respectively, at the International Water Management Institute (IWMI). S. Thiruvengadachari was formerly group director, water resources, National Remote Sensing Agency, Hyderabad, India, and is now a private consultant.

The cooperation extended by the Bhadra project authorities in providing data and towards field visits is acknowledged. The analysis of satellite data was conducted by the National Remote Sensing Agency in Hyderabad, India.

This work was undertaken with funds specifically allocated to IWMI's Performance and Impact Assessment Program by the European Union and Japan, and from allocations from the unrestricted support provided by the Governments of Australia, Canada, China, Denmark, France, Germany, Netherlands, and the United States of America; the Ford Foundation; and the World Bank.

Sakthivadivel, R., S. Thiruvengadachari, and U. A. Amarasinghe. 1999**.** *Modernization using the structured system design of the Bhadra Reservoir Project, India: An intervention analysis.* Research Report 33. Colombo, Sri Lanka: International Water Management Institute.

/ performance evaluation / irrigation programs / modernization / participatory management / farmer participation / farmer-agency interactions / farmer attitudes / remote sensing / rice / irrigated farming / water distribution / water supply / productivity / India / Bhadra Project /

ISBN 92-9090-385-6
ISSN 1026-0862

The International Irrigation Management Institute, one of sixteen centers supported by the Consultative Group on International Agricultural Research (CGIAR) was incorporated by an Act of Parliament in Sri Lanka. The Act is currently under amendment to read as International Water Management Institute (IWMI).

Contents

Acronyms

ABC	Anvery Branch Canal
BRP	Bhadra Reservoir Project
CADA	Command Area Development Authority
CCE	Crop Cutting Experiment
DBC	Davangere Branch Canal
FAO	Food and Agriculture Organization
ICC	Irrigation Consultation Committee
IWMI	International Water Management Institute
IRS IC	Indian Remote Sensing Satellite number IC
LBC	Left Bank Canal
LISS	Linear Imaging Self Scanning
M&E	Monitoring and Evaluation
MBC	Malebennur Branch Canal
MCOU	Main Canal Operating Unit
NDVI	Normalized Difference Vegetation Index
NRSA	National Remote Sensing Agency
NWMP	National Water Management Project
O&M	Operation and Maintenance
RBC	Right Bank Canal
SAR	Staff Appraisal Report
SRS	Satellite Remote Sensing
WiFS	Wide Field Sensor
WRCP	Water Resources Consolidation Project
WUA	Water User Association

Summary

Irrigation system modernization with the structured system design is increasingly adopted in irrigation improvement programs in the Indian subcontinent and elsewhere in view of less management efforts needed to operate such a modernized system. This report evaluates the performance of the Bhadra Reservoir Project in India—before, during, and after the introduction of modernization with the structured system design. The performance analysis, supported by data generated by remote sensing techniques, office records, field visits, and farmer surveys focused on water management, agricultural productivity, and farmer participation and perception. The analysis of the Indian Remote Sensing Satellite (IRS IC) Wide Field Sensor (WiFS) data on 20 overpass dates during the rice growth cycle particularly proved valuable to evaluate the water distribution between the distributary commands during the most recent *rabi* (January to May) season.

The structured system design and an equitable supply-based technology, central to the National Water Management Project (NWMP) intervention in the Bhadra project, did not succeed for various reasons analyzed in this report. The analysis indicates, among other things, that water utilization after the NWMP intervention has increased as a result of the cropping pattern being dominated by water-intensive crops such as rice during the rabi season. Preferential allocation to the head end of the command persisted even after intervention, with inequity setting in within the distributary command. The tail-end water supply deprivation was partially offset by farmers practicing deficit irrigation. The advancement of the *kharif* (July to November) and rabi seasons and the consequent, envisaged water saving have not taken place. The participation of farmers in decision making at the scheme level, and sharing of water at the distributary level and below were very poor. However, the gains in agricultural productivity achieved during the intervention period have not registered any significant decline.

The absence of a continuing support mechanism by way of institutional arrangements and the lack of effective farmer participation and involvement in implementing the operational plan have been the major causes for decline of the Bhadra project with water management sliding back to a quasi-demand-based supply. The productivity per unit of water was also on the decline. Strong farmer involvement thus holds the key for sustainable performance.

Modernization Using the Structured System Design of the Bhadra Reservoir Project, India: An Intervention Analysis

R. Sakthivadivel, S. Thiruvengadachari, and Upali A. Amarasinghe

Introduction

The structured system design enables control of water flow in irrigation projects through the use of proportional devices such as the Adjustable Proportional Module (APM) without human intervention, by adopting an intermittent, designed water supply in the distributary canals and operating with a systematic operational plan. This structured system concept, advocated by the World Bank (Shanan 1992), is being increasingly adopted in the Indian subcontinent and elsewhere in the rehabilitation and modernization of irrigation projects. Some of these modernized projects were under operation for more than 5 years after the withdrawal of World Bank assistance. A holistic performance evaluation of such systems, especially how well they have been sustained after the closure of loan facilities, is of great significance not only to the Indian subcontinent but also to other developing countries that try to adopt this concept with limited financial allocation for irrigation operation, maintenance, and management, and face increasing competition for water and interference by vested interests.

The structured system design is central to the World Bank-funded National Water Management Project (NWMP) that covered about 80 schemes in 11 States in India during 1988–95. Subsequent to the NWMP, this design was extended to the ongoing Water Resources Consolidation Project (WRCP) in the States of Tamil Nadu and Orissa. In view of its widespread adoption, there is a need to evaluate the structured system design in improving the irrigated agricultural performance. This report attempts to evaluate the Bhadra Reservoir Project (BRP) in the Karnataka State, which was one of the earliest projects to adopt the structured system design under the NWMP. The main objective of this report is to carry out a comparative analysis of the BRP before, during, and after the NWMP intervention. While the main focus is on water distribution and agricultural productivity, the analysis also briefly covers other relevant issues such as farmer participation, monitoring and evaluation, and training. The lessons learnt could be of use for future implementation of such projects.

The report builds upon the previous evaluation by the International Water Management Institute (IIMI 1995), which focused on water distribution, agricultural productivity, and training and farmer participation up to the 1993–94 rabi season. In the earlier study, it was found that farmer participation has shown no significant progress and planned farmer organizations have not been created; water distribution along the distributaries has improved; and significant improvements in agricultural output have occurred after the introduction of the NWMP program. The International Water Management Institute (IWMI) revisited the project to evaluate the sustenance of the NWMP impact 2 years after cessation of funding in 1995. The analysis addresses the following:

- In recent years, has there been a decline in irrigated area, and changes in cropping pattern and land and water productivity of rice, particularly in the tail-end areas after cessation of funding?

- Has water management deteriorated in terms of i) more than allocated water being used, ii) head-to-tail preferential allotment/use, iii) changes in irrigation seasons and crop calendar, and iv) changes in canal operation schedule?

- Current status of water user associations (WUAs).

A noteworthy feature of the comparative analysis is the application of satellite remote sensing (SRS) techniques to generate objective and disaggregated information on agricultural productivity during the rabi seasons, particularly on rice productivity per unit of land. Multidate data from the recently launched IRS IC satellite during the 1997 rabi season also provided indications of equity and reliability of water distribution between the distributary commands. Ground data were obtained from office records, field visits, and farmer surveys.

The comparative study argues that the successful operation of a structured system, particularly in a water-rich environment, is complex and requires realistic planning, rigorous implementation (involving wholehearted farmer participation), and a mechanism for sustaining the benefits of intervention after cessation of funding. A critical analysis of the proposed NWMP interventions for improved water management and an analysis of the actual water distribution and agricultural productivity across the command area during the implementation of the NWMP program and after cessation of funding support this argument.

Bhadra Reservoir Project

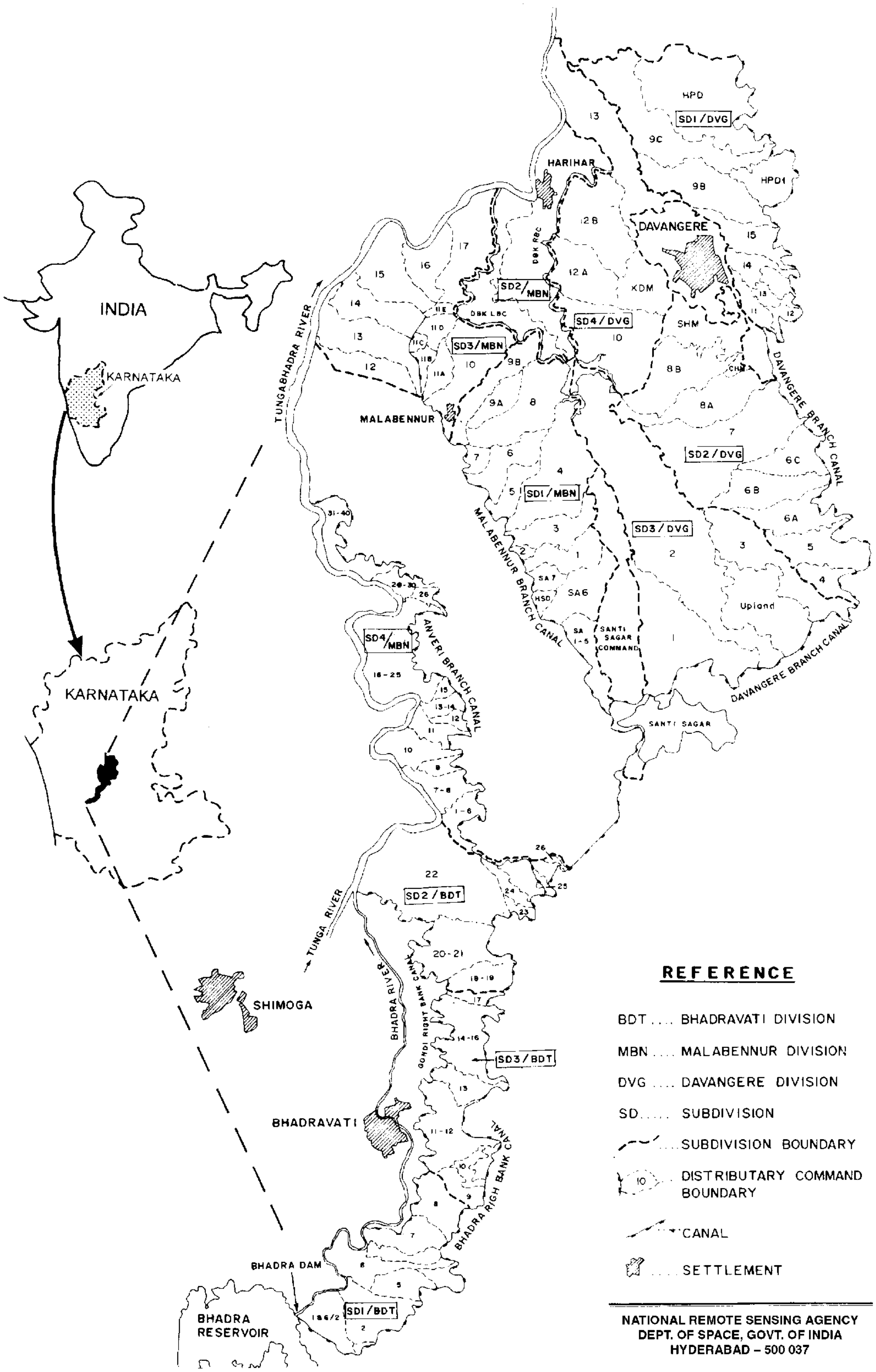
The BRP (figure 1) constructed between 1946 and 1966 has a gross storage capacity of 2,025 Mm^3, a live storage of 1,608 Mm^3, and a waterspread area of 11,200 hectares. The Krishna River Tribunal awards an annual withdrawal of 1,747 Mm^3 (61.7 thousand million cubic feet), including reservoir evaporation losses, to the BRP, with 1,400 Mm^3 specific to the Right Bank Canal (RBC) whose command is covered under the NWMP program.

The RBC, with a full supply discharge of 75 m^3, commands an area of 92,360 hectares with 29 distributaries taking off directly to irrigate 17,050 hectares. The Anvery Branch Canal (ABC) commanding 6,320 hectares branches off at 76.4 km down the RBC. The RBC bifurcates at 103 km into the Malebennur Branch Canal (MBC) benefiting 23,710 hectares, and the Davangere Branch Canal (DBC) benefiting 45,280 hectares. Administratively, the whole RBC command area is divided into three divisions: Bhadravathi canal division with three subdivisions, Malebennur canal division with four subdivisions, and Davangere canal division with four subdivisions.

The annual rainfall in the command area is about 800 mm, which decreases towards the tail end. The command area receives most of the rainfall during the southwest monsoon period of June–September. The mean monthly evapotranspiration is equal to or below rainfall during July–October, but is substantially above rainfall during the remainder of the year. Even during the southwest monsoon period, breaks in the monsoon are frequent, necessitating supplemental irrigation. The command area is gently rolling with moderate slopes. The red soil covers 60 percent of the command area. The majority of the holdings has less than 1 hectare each and is generally split into 2–3 parcels.

[1]A body appointed by the Government of India to apportion the Krishna River water among the riparian states.

FIGURE 1.
Location of the Bhadra project command area.



NWMP Program of Bhadra Reservoir Project

The NWMP program was implemented in the BRP during 1987–89 and most of the physical rehabilitation work was completed by that time. The estimated cost of the project was Indian Rs 5,500/ha (US$160/ha) at 1994 prices. However, the external funding for operation, maintenance, and management was continued up to 1995. Three periods—pre-intervention up to 1988, intervention from 1989 to 95, and post-intervention after 1995 are considered for analysis of performance.

The main objective of the NWMP program was to increase productivity and farm income in the existing irrigation scheme through a more reliable, predictable, and equitable irrigation service. This was to be achieved by developing the institutional capacity to plan, implement, and monitor improved O&M practices and providing low-cost infrastructure improvements to support the proposed operational plan. The improved water management was to come from a more systematic canal operation, reduction of irrigation wastage, optimization of cropping season, particularly during the rabi season, and reduction of crops with high irrigation demands by manipulating frequencies of irrigation and by making the best use of rainfall.

Before the introduction of the NWMP program, rice was grown wherever possible. Water availability was good in the distributaries that directly take off from the RBC and in the head reaches of the branch canals. Irrigation supply was very unreliable in the tail-reach areas, which led to the cultivation of mainly semidry crops (millet, sorghum, etc.). The cropping seasons were kharif, from July to November and rabi, from January to May. The NWMP program aimed at improving the use of water resources by providing irrigation supply starting from May, which would enable better use of rainfall by the kharif crops and lower the irrigation requirement for the rabi crop that would be sown in November. This plan required a carryover storage of 250 Mm^3 in the reservoir for irrigation supply in May and part of June. The seasonal calendar proposed under the NWMP program was kharif extending from May 15 to October 15 (153 days) and rabi from November 15 to April 15 (121 days).

The assumed cropping plan of the RBC command envisaged 100 percent cropping intensity in the kharif season. In the rabi season, rice was to be excluded by releasing water to the RBC intermittently during the first 2 months of the season. But even with 90 percent of the area under semidry crops, peak irrigation requirements in the dry season were so high that within the capacity limitations of the RBC, only 75 percent intensity could be supported. The distribution policy as incorporated in the Staff Appraisal Report (SAR) (World Bank 1986) envisaged that the command would be divided into four zones and every year, one zone, selected in rotation, would be left out of rabi irrigation.

Under the NWMP program, the available water resources are allocated proportionally within the command area. In principle, all farmers receive their shares based on the acreage they own and/or rent, irrespective of the crops grown and location of the farm. The following were the suggested modifications under the NWMP plan of activities.

- Sizing of distributaries and lower-level channels with proportional outlets to prevent the upper parts of the commands from monopolizing water withdrawals to the disadvantage of the lower commands.

- Establishment of a structured distribution system below the turnout from the RBC/branch canal in a distributary/minor and installation of a network of flow measuring structures at strategic locations.

- Development of systematic linkages between the O&M agency, other government agencies and farmers, and strengthening of the O&M

activities by setting up a Main Canal Operating Unit (MCOU).

- Making scheme-level monitoring and evaluation (M&E) the basis for monitoring operations.

- Submission of reports to the project committee on seasonal/annual operations (water delivery, irrigation efficiency, cropped area, farmer satisfaction, etc.) and modification of subsequent operational plans using this feedback.

- Training at various levels—orientation training for senior officers, training in planning for staff of O&M units, training in design to engineers, and implementation and operation training to scheme-level officers and field workers.

- Achieving effective farmer participation through holding meetings with farmers to discuss the NWMP plans.

- Organizing farmer committees at each outlet and higher-level committees for each minor and distributary.

Basic Data

The historical data on reservoir release and distribution in branch and distributary canals were collected from the BRP offices. Agricultural productivity data in terms of total irrigated area, area under rice and other crops, and rice productivity per unit of land were obtained through a digital analysis of the satellite data of the 1986–87 and subsequent rabi seasons. Satellite inventories for the 1994–95 and 1996–97 rabi seasons, which were not available at the time of the previous evaluation by the International Water Management Institute (IIMI 1995), have been subsequently conducted and used in the study. These data available at the pixel level (30 m x 30 m) can be aggregated for any desired aerial unit such as a distributary command or a branch-canal level. Since crop cutting experiment (CCE) data for the 1996–97 rabi season for sample rice plots were not available during the study, a satellite-based rice yield model was developed by normalizing the rice yield model of the 1992–93 rabi season to the current[2] season (see annex). An additional feature of the satellite inventory of the 1996–97 season is the analysis of 20 IRS IC satellite Wide Field Sensor (WiFS) data sets (having a repeatability of 5 days compared to 22 days for IRS-2A and IB) obtained during February–June 1997. The average WiFS-based Normalized Difference Vegetation Index (NDVI) for each distributary command plotted against time represents the rice growth profile during the rabi season and enables a comparative analysis of the rice condition through the season and between the distributary commands.

A farmer survey covering 105 farmers in 7 distributaries (one each in the head and tail ends of the RBC direct command, one each in the head and tail ends of the Malebennur branch canal, and one each in the head, middle, and tail ends of the Davangere branch canal) was conducted in April 1997 (figure 1). Typically, in each distributary, three villages were selected, one each in the head, middle, and tail reaches. Five farmers were selected from each village; the selection was based on village records and divided among farmers on the basis of landholding. A structured questionnaire was administered to the farmer respondents, and a database was organized for further analysis. Interaction with the water user associations (WUAs) enabled the evaluation of their current status and effectiveness.

[2]The term *current* in this report corresponds to 1997.

NWMP Operational Aspects: A Critical Analysis

The project report (Government of Karnataka 1986) contemplated that optimum water use would be achieved through more systematic canal operation by making the best use of available rainfall, reducing irrigation wastage, optimizing the cropping season, particularly during rabi, and reducing the cropped area demanding high irrigation by manipulating the irrigation frequency. This has not been completely or adequately addressed under the NWMP proposals for intervention in the Bhadra project. Significant deficiencies including unrealistic assumptions and incomplete attention to details have vitiated the planning process and led to unsatisfactory impacts during and after implementation.

While the structured system design ensures water equity by supplying water proportional to the area irrespective of the crop grown, the assumed cropping pattern under the NWMP program helped determine expected water requirements and the sizing of canal capacities. However, the assumed cropping pattern was unrealistic and farmer preference for water-intensive crops had hampered the smooth implementation of the NWMP program.

The high rainfall in the upper command (normal annual rainfall of 950 mm in Bhadravathi compared to 650 mm in the tail end of Davangere) that makes rice the preferred crop leads to spatial variability in the cropping pattern in the rabi season. In this traditional rice-growing area, the assumption to exclude rice in rabi by adhering to the operational schedule was bound to fail. Thus a more realistic assumption of a spatially varying cropping pattern and an alternative definition of equity by giving priority for assured water supply in the two seasons would have had better implementability. A careful analysis of the previous cropping response to irrigation supplies and the rainfall pattern, and consultation with farmer groups would have resulted in a more realistic cropping pattern. The steps and strategies required to achieve farmer consensus and participation for effective supply management and rotational water supply have not been sufficiently detailed and no specific funds have been earmarked for this activity.

To use rainfall effectively, the canal supply needs to be variable and capable of adjustment. However, the NWMP program proposed that the branch canals be designed with a capacity equal to the sum of capacities of the offtaking distributaries (with allowance for losses), and be operated at the maximum flow constantly. This would mean that if a distributary under a branch canal is closed due to less demand, the excess flow would just get redistributed among other distributaries or flow downstream. In either case, no saving would result.

When the main canal is operated at varying flow rates, closing a distributary can result in savings only if there is a corresponding change in the release at the RBC head regulator or when a closed distributary of similar capacity is opened. This requires a tightly operated system with excellent communication facilities and an effective decision-making system. The NWMP program did not propose to develop such supporting mechanisms. Thus the assumption of water saving through the effective use of rainfall under the NWMP program is invalidated at the planning stage itself.

The effective use of rainfall and the consequent reduced reservoir withdrawals were to be achieved by advancing the kharif sowing to mid-May by providing irrigation water from the storage carried over from the previous water year. This was corroborated by a simulation study showing that the carryover storage of 250 Mm^3 including the storage required to meet all the evaporation losses from the reservoir was available every year during 1974–84. The rabi sowing was to be correspondingly advanced to November, reducing the crop water requirements in this season.

The operational plan proposed running the Right Bank Canal (RBC) continuously during the advanced kharif season, resulting in a withdrawal of 985 Mm^3 from the reservoir. The withdrawal in the rabi season with three initial cycles of on-off operations is computed to be 674 Mm^3. Thus the annual withdrawal is 1,659 Mm^3, and with 175 Mm^3 allocated to the Left Bank Canal (LBC) and a reservoir evaporation of 172 Mm^3, the total withdrawal works out to 2,006 Mm^3 against an allocation of 1,747 Mm^3 by the Krishna River Tribunal Award. Any saving could only be achieved by operating the main canal with varying flow, and as mentioned earlier, this was not an effective proposition.

Comparative Analysis of Performance: Before, during, and after Intervention

This section compares the performance before, during, and after implementation of the NWMP program. The main focus will be on water management, agricultural productivity, and farmer perceptions, with less attention to other NWMP elements. The collapse of the guide wall at the entrance to the RBC in September 1991 marked a change from the then-prevailing 75 percent zoning to irrigate the whole area in the rabi season. Therefore, the performance during the period 1992–95 is taken to represent the impact during implementation unless otherwise specified. The post-implementation period is considered to be after 1995.

Water Management

The start of canal operation was delayed in three out of the six seasons during the pre-intervention period. It was on time, as planned, during the intervention period up to 1995 rabi. Canal operation occurred earlier than the planned date after the 1995 kharif season (table 1). The number of days the canal was operated also varied in all the seasons and the gap between the planned number of days and the actual number of days of operation was very wide, especially during the post-intervention period. Substantial deviations from the planned water distribution schedules under the NWMP program are seen (table 1) for all the three periods (pre-intervention, intervention, and post-intervention) investigated. The advancement of the kharif season to 15 May and, consequently, the rabi season to 15 November as contemplated in the original proposal has not been achieved and the seasonal calendar has varied widely from year to year, more so in the kharif season. The start of the kharif season was delayed particularly after 1994–95 because of the vagaries of the monsoon season. The gap between the planned and actual withdrawals from the reservoir is shown in figure 2. Water utilization during the rabi season became more critical when the 25 percent zoning policy under the NWMP program was abandoned during 1992–93, and the whole RBC command was provided with irrigation supplies. Excess water utilization in the rabi season thus has been increasing, against the computed rabi allocation of 674 Mm^3, from 19 percent during 1992–93 to more than 30 percent after 1994–95, when compared to 35 percent in the pre-NWMP year (table 2). Although withdrawals during kharif were less than those stipulated in the NWMP proposals, the annual withdrawals had been steadily increasing from 1992–93 to 1996–97 (0–5 percent). The marginal decrease in excess withdrawals in 1996–97 was due to poor rainfall in the BRP catchment (Bhadra catchment area received 1,245 mm in 1996 compared to the 1,569 mm normal rainfall)

TABLE 1.
Irrigation schedule: Planned and actual.

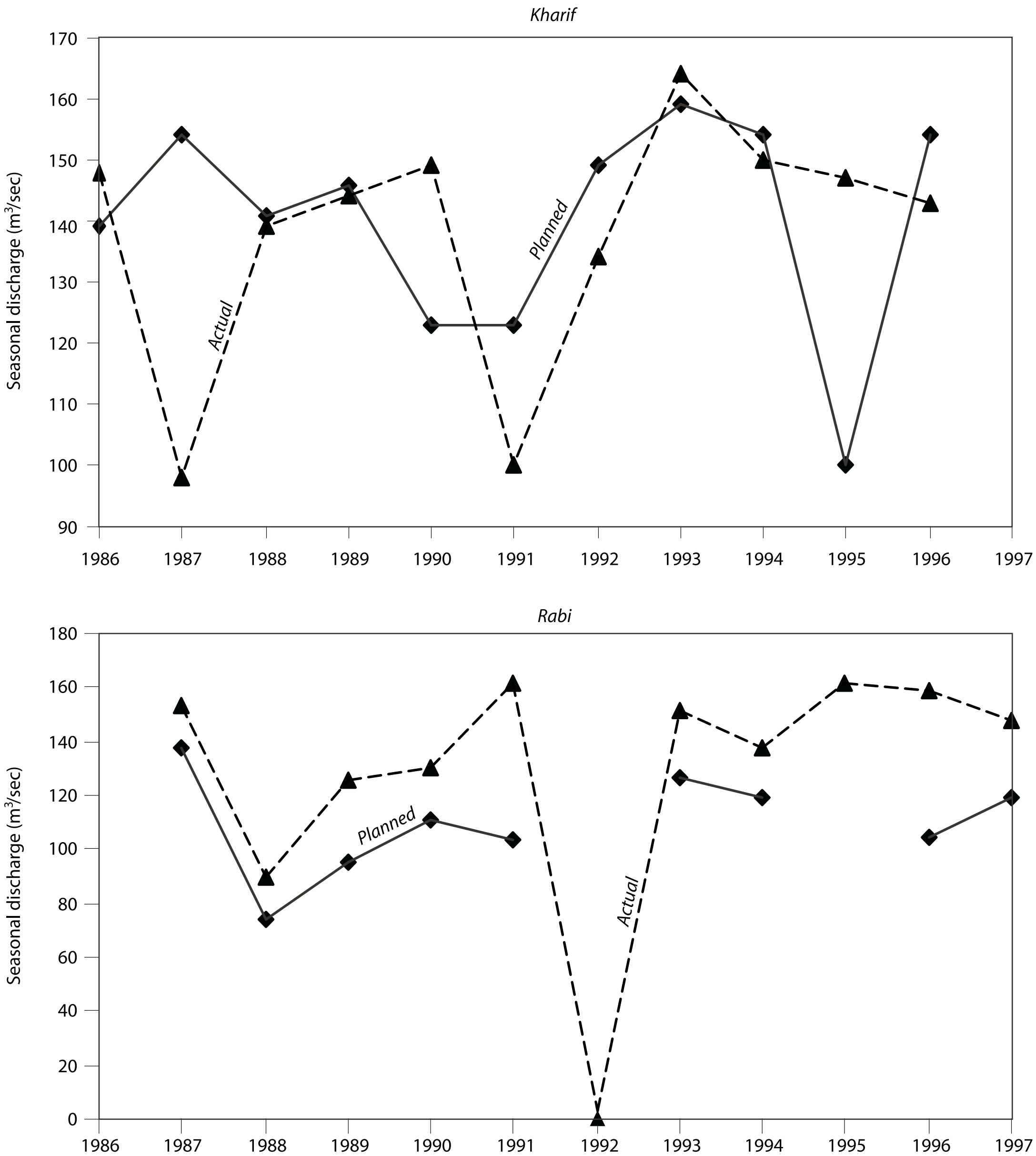
Type of intervention	Year and season	Planned schedule		Actual schedule	
		Start date	No. of days of canal operation	Start date	No. of days of canal operation
Pre-intervention	1986 rabi	1 Jan	64	1 Jan	91
	1986 kharif	5 July	139	7 July	148
	1987 rabi	15 Dec	138	22 Dec	153
	1987 kharif	15 June	80	29 June	98
	1988 rabi	28 Nov	72	11 Jan	88
	1988 kharif	5 July	126	7 July	139
Average	Rabi		91		111
	Kharif		115		128
Intervention with zoning	1989 rabi	6 Jan	94	8 Jan	125
	1989 kharif	8 July	146	9 July	144
	1990 rabi	1 Jan	110	2 Jan	129
	1990 kharif	15 June	123	16 June	149
	1991 rabi	1 Dec	102	4 Dec	161
	1991 kharif	5 June	123	12 June	100
Average	Rabi		102		138
	Kharif		131		131
Intervention without zoning	1992 kharif	5 July	149	6 July	134
	1993 rabi	1 Dec	126	1 Dec	151
	1993 kharif	25 June	160	27 June	164
	1994 rabi	27 Dec	142	28 Dec	137
	1994 kharif	26 June	153	26 June	150
	1995 rabi	-	-	18 Dec	161
	1995 kharif	21 Aug	92	13 July	147
Average	Rabi		134	Rabi	150
	Kharif		139	Kharif	149
Post-intervention without zoning	1996 rabi	22 Jan	103	27 Dec	158
	1996 kharif	30 July	124	11 July	143
	1997 rabi	18 Jan	118	1 Jan	147
Average	Rabi		111		153
	Kharif		124		143

Note: In the original proposal of the NWMP program, the kharif season was planned for 153 days and rabi for 121 days.

resulting in lower reservoir storage levels in this year. Thus the NWMP program objective of restricting water use within the Tribunal (law court) allocation has not been achieved, and water utilization, in contrast, has been increasing since 1992–93. The rather significant increase in water utilization since 1994–95 is perhaps due to the physical deterioration of the system caused by the lack of maintenance.

The NWMP program postulated equity on the basis of water delivered proportional to the area irrigated, irrespective of the cropping pattern. Deviations from equity are seen, when the head reaches receive preferential deliveries at the expense of the tail-end portion (table 3). The direct commands under the RBC and the ABC draw more than their share, with a marked decrease in water receipts in the MBC and the DBC. The tail end of the DBC seems to be the main sufferer, with only 41.9 percent allocation against 46.5 percent postulated under the NWMP program and even lesser than in the pre-NWMP 1986–87 rabi season. The inequity evident even during the kharif season indicates that the higher amount of rainfall in the head reach had not been appropriately utilized. The inequity between the head and tail reaches has also been increasing in recent years. The similarity in inequity in the kharif and rabi seasons seems to be the result of the similarity in the extent of rice cultivation in both seasons.

FIGURE 2.
Comparison of actual and planned seasonal delivery through the years.



In addition to the preferential allocation to the head-end branch canals, inequity also exists between the distributaries under each branch canal, though in a different manner. The Normalized Difference Vegetation Index (NDVI) profiles, derived from IRS IC satellite wide field sensor (WiFS) data of 20 overpass dates through the 1997 rabi season, enabled the analysis of spatial and temporal homogeneity with regard to equity, adequacy, and timeliness of water distribution (figure 3). The NDVI profiles of the RBC suggest a different cropping pattern from other branch canals as NDVI started with a high variability (20–100) whereas other branch canals were within a limited range (20-40). The dispersion of the profiles within each branch canal and the highest NDVI value reached are also different. The tight bunching and similar magnitude and shape of profiles in the DBC and MBC commands indicate better equity, and similar adequacy and timeliness, contrary to the ABC and RBC commands. These indicate, as corroborated by the high yield in table 4, better management in the middle and water-short tail end of the command compared to the upper part with excess water withdrawal. The gaps in the data of the NDVI profiles are due to cloud cover in the WiFS data coverage on these overpass dates.

It has not been possible to operate all the distributaries simultaneously at specified discharges in the kharif season because the distributaries in the upper reaches drew higher than the specified discharges and the RBC capacity was inadequate. The rabi operational plan calls for a strict calendar for an on-off operation of all the distributaries simultaneously with the RBC also following the calendar. Rabi zoning has been abandoned since the 1992–93 rabi season. The RBC has been operated continuously since 1994

TABLE 2.
Excess withdrawals from the reservoir.

Year	Excess withdrawal (% of planned withdrawal under NWMP program)*	
	Annual	Rabi season
1986–87	1.1	35.1
1992–93	–	19.2
1993–94	4.2	21.1
1994–95	4.7	30.0
1995–96	5.2	32.0
1996–97	4.8	26.7

*With reference to 1,959 Mm^3 planned under the NWMP program for annual withdrawal, and to 674 Mm^3 for rabi withdrawal.

TABLE 3.
Water shares among the branch canals and the ratio of actual to nominal share.

Season	Total	RBC		ABC		MBC		DBC	
	discharge MCM	Actual share %	Actual/ nominal %	Actual share %	Actual/ nominal %	Actual share %	Actual/ nominal %	Actual share %	Actual/ nominal %
Kharif									
1986	767.4	19.1	85	9.6	148	25.3	104	46.0	99
1992	822.7	22.1	98	9.4	145	23.5	96	45.0	97
1993	914.6	24.4	108	9.3	143	22.5	92	43.8	94
1994	861.5	20.1	89	9.6	148	24.1	99	46.2	99
1995	856.5	26.1	115	8.2	126	23.5	96	42.2	91
1996	884.0	28.7	127	8.2	126	21.5	88	41.6	89
Rabi									
1987	911.5	25.2	112	8.4	129	23.3	95	43.1	93
1993	804.4	25.1	111	8.4	129	23.6	97	42.9	92
1994	816.0	24.7	109	8.6	132	23.4	96	43.3	93
1995	876.7	20.2	89	8.9	137	21.5	88	40.4	87
1996	890.4	23.6	104	8.9	137	23.5	96	44.0	95
1997	849.2	27.2	120	8.1	125	22.4	92	41.9	90
	Nominal share (designed as per the NWMP program)	22.6		6.5		24.4		46.5	

Notes: RBC= Right Bank Canal; ABC= Anvery Branch Canal; MBC= Malebennur Branch Canal; DBC= Davangere Branch Canal.

FIGURE 3.
Distributary-wise seasonal vegetation index profiles under different branch canals (1997 rabi season).

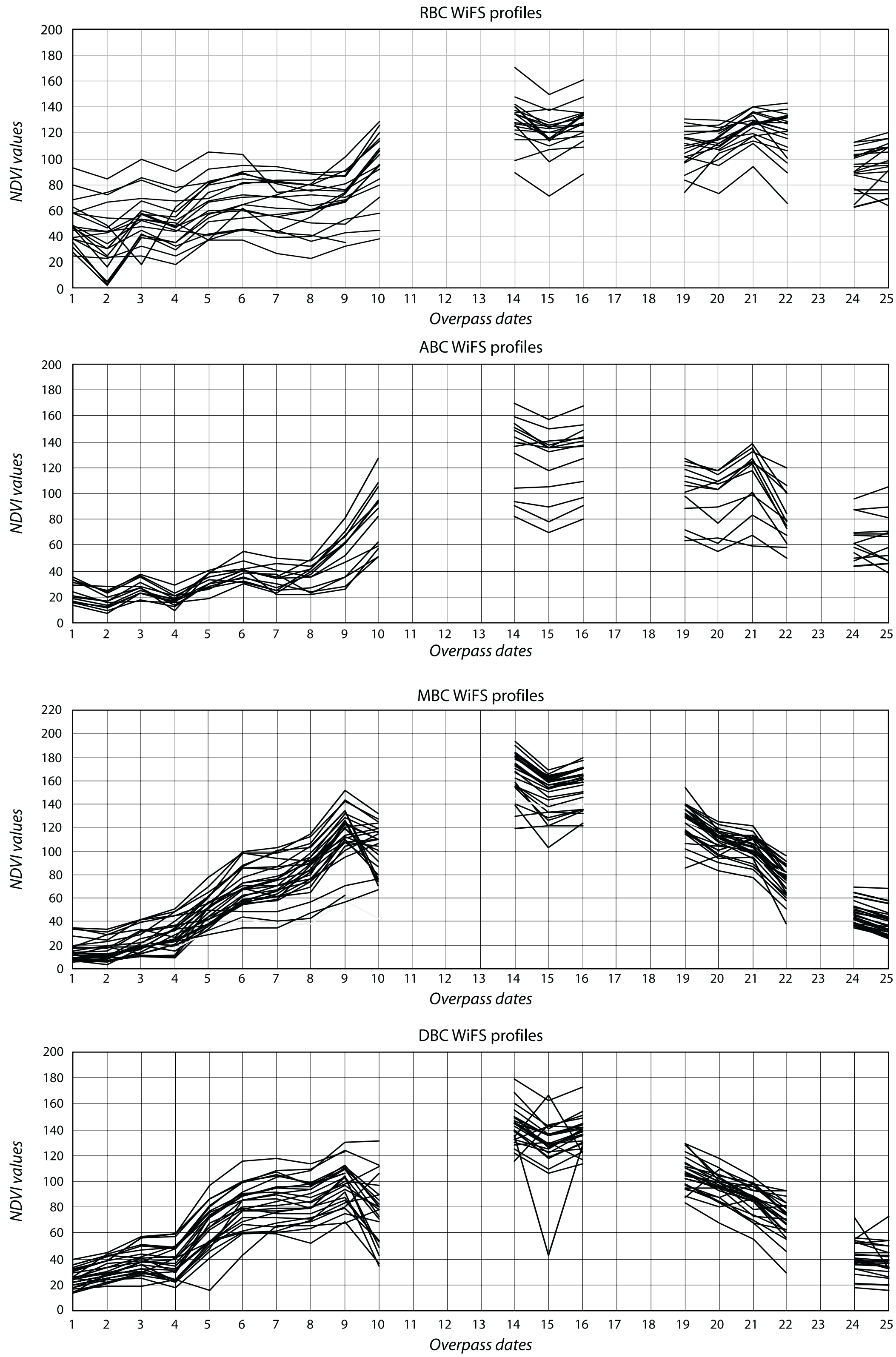


TABLE 4.
Satellite-derived cropping pattern in the Bhadra command area: Irrigation intensity, percentage of rice area, and rice yield during the rabi season.

Division	Sub-division	1986–87			1989–90			1992–93			1993–94			1994–95			1996–97		
		Irr. int. %	Rice area intensity %	Rice yield (t/ha)	Irr. int. %	Rice area intensity %	Rice yield (t/ha)	Irr. int. %	Rice area intensity %	Rice yield (t/ha)	Irr. int. %	Rice area intensity %	Rice yield (t/ha)	Irr. int. %	Rice area intensity %	Rice yield (t/ha)	Irr. int. %	Rice area intensity %	Rice yield (t/ha)
Bhadravathi																			
(RBC)	No.1	95.0	60.0	2.4	53.0	21.0	4.5	88.0	61.0	3.8	95.0	64.0	4.2	83.0	52.0	4.5	73.0	57.0	4.4
	No.2	46.0	40.0	3.7	84.0	68.0	4.7	91.0	61.0	4.2	75.0	53.0	4.2	81.0	59.0	4.2	80.0	53.0	3.3
	No.3	71.0	37.0	3.4	102.0	27.0	4.2	140.0	49.0	3.8	124.0	30.0	4.6	115.0	48.0	4.7	112.0	36.0	3.2
	Total	67.0	48.0	3.2	78.0	46.0	4.6	101.0	58.0	4.0	92.0	49.0	4.3	90.0	54.0	4.4	85.0	49.0	3.6
Malabennur	No.1	99.0	72.0	4.3	79.0	90.0	6.1	116.0	89.0	5.8	113.0	83.0	5.6	109.0	88.0	5.8	110.0	86.0	4.5
	No.2	48.0	56.0	3.3	40.0	46.0	5.0	42.0	66.0	4.0	61.0	54.0	4.5	62.0	67.0	4.0	58.0	62.0	4.2
	No.3	74.0	59.0	4.1	55.0	60.0	6.0	80.0	73.0	4.9	77.0	75.0	5.2	71.0	84.0	5.4	78.0	79.0	4.4
	No.4	79.0	61.0	3.7	79.0	79.0	5.7	98.0	77.0	4.9	76.0	72.0	5.2	85.0	81.0	5.4	83.0	72.0	3.8
	Total	80.0	65.0	4.1	66.0	76.0	5.9	91.0	81.0	5.3	87.0	76.0	5.3	86.0	84.0	5.5	88.0	80.0	4.3
Davanagere	No.1	61.0	45.0	3.8	74.0	23.0	4.9	81.0	52.0	4.0	73.0	60.0	4.8	67.0	59.0	4.6	71.0	56.0	3.7
	No.2	92.0	54.0	4.0	98.0	40.0	5.2	108.0	67.0	4.5	102.0	69.0	4.6	99.0	67.0	4.6	104.0	71.0	4.6
	No.3	79.0	59.0	3.7	35.0	44.0	4.5	86.0	78.0	4.4	92.0	78.0	4.4	91.0	75.0	4.4	90.0	73.0	4.8
	No.4	65.0	42.0	3.4	68.0	35.0	5.2	72.0	63.0	4.5	69.0	74.0	4.9	73.0	71.0	4.8	69.0	73.0	3.8
	Total	75.0	51.0	3.8	69.0	35.0	5.1	87.0	66.0	4.4	84.0	71.0	4.6	83.0	68.0	4.6	84.0	69.0	4.3
Command area total		75.0	56.0	3.8	69.0	51.0	5.4	91.0	69.0	4.7	87.0	69.0	4.9	85.0	71.0	5.0	85.0	69.0	4.2

Note: Irr. int. = Irrigation intensity.

yet a set calendar has not been followed in the on-off operations of distributaries, implying the tacit acceptance of field realities.

A major departure from O&M regulations is that the pressure exerted by farmers for water could not be withstood and, consequently, there was a changeover from supply- to demand- management. Gates were reintroduced at the heads of some minors in some tail-end distributaries of the DBC, which marked a departure from the structured system design of the NWMP program, indicating a tendency to correct for deviation in water distribution in the upper command by an ad hoc solution at the tail end.

In spite of the well-constructed measuring structures at the distributary offtakes and along the RBC, the monitoring of system operations has remained weak. Only three distributaries, the same every year, were covered under intensive monitoring. The monitoring report does not highlight the difference between targeted and actual deliveries, the relative performance along the sample distributaries, and the implications of the existing cropping pattern on the operational plan. The scheme-level report is also inadequate without an emphasis on the pattern of deliveries within the system and the extent of equity. The M&E exercise does not cover groundwater status. An indication of the deteriorating M&E efficiency was the greatest difficulty faced by the authors in obtaining canal discharge data from the divisional offices. While, during the early years of the NWMP intervention, the data were compiled and documented at the division and circle offices, the data of 1996–97 had not been compiled at these offices even after the end of the rabi season.

Agricultural Productivity through the Years

The spatial variability in irrigation intensity, percentage of rice area, and rice yield across the canal divisions in the rabi season are shown in table 4.

The overall irrigation intensity has increased (statistically significant at 5% level) from 75 percent during 1986–87 to 91 percent during 1992–93. The irrigation intensity in the subsequent rabi seasons has declined from that of 1992–93, and is not significantly different from the level before the implementation of the NWMP program. The area under rice has increased (significant at 5% level) from 56 percent during 1986–87 to 69 percent during 1992–93. The rice area in the subsequent rabi seasons is similar to that of 1992–93, but is significantly different (at 5% level) from the rice area in the 1986–87 rabi season. The average rice productivity per unit of land, both during and after the intervention years is significantly different from that of the 1986–87 rabi season. However, the average rice yield during 1996–97, i.e., the first rabi season in the post-intervention period, is significantly lower (at 5% level) than that recorded during the intervention period. The agricultural performances in all three divisions, i.e., Bhadravathi in the head end, Malebennur division in the middle, and Davanagere in the tail end have more or less the same trend as that shown for the total command area (table 4). For example, in the Davangere canal division, the irrigation intensity rose from 75 percent during 1986–87 to 87 percent during 1992–93 (significant only at 10% level). The irrigation intensity in the subsequent time periods, for example, 84 percent during 1996–97, is not significantly different (at 5% level) from the irrigation intensity during the 1986–87 rabi season. The rice intensity in the tail-end section has increased from 51 percent during 1986–87 to 66 percent during 1992–93 (significant at 5% level) and has stabilized since then. The rice yield has significantly increased (at 5 percent level) from 3.8 tons/ha during 1986–87 to 4.4 tons/ha during 1992–93. The yields during the other time periods during and after intervention are also significantly higher than those in the 1986-87 rabi season.

The irrigation deliveries are available only at the divisional level. The rice productivity per unit of water diverted at the reservoir has been steadily declining through the years from 0.45 kg/m^3 during the 1992–93 rabi season, to 0.36 kg/m^3 during the 1996–97 rabi season, against 0.25 kg/m^3 during the 1986–87 rabi season (table 5).

The decrease in irrigated area, rice intensity, and yield during the 1996–97 rabi season is attributable partly to poor reservoir inflows and partly to greater conveyance losses due to poor maintenance of, as well as damage to, irrigation structures. Field visits and observations made by the authors during farmer surveys indicate broken irrigation structures in many places in the tail end. However, the decline in rice productivity per unit of land from previous years is more as the farmers irrigate the near-normal areas with less depth of water due to conveyance losses and less reservoir withdrawal. These findings are well reflected by the WiFS NDVI profiles of different branch canals (figure 3).

Farmer participation

Farmer participation in the NWMP program is extremely weak. Of the five activities proposed under the NWMP program for farmer participation—meeting with farmers, creating a farmer organization below each outlet, organizing a water utilization committee for each minor or distributary, farmer training, and creation of a scheme-level committee—none materialized. However, the Bhadra Command Area Development Authority created nine village-based farmer cooperatives between 1992 and 1994. Among these, the tail-area farmer cooperatives were relatively stronger than the head-end cooperatives in solving their water problems during the implementation of the NWMP program. One such farmer cooperative, started in 1992 at Tiruchughatta at the tail end of the 8th distributary in the DBC, was doing well during the implementation of the NWMP program. When the authors visited it in 1997, it had become defunct, although the name of the organization remained. The situation was the same with two other organizations that the authors visited in 1997. The functions of the scheme-level committee suggested under the NWMP program are carried out by the traditional district-level Irrigation Consultation Committee (ICC), which is less effective. Out of the 39 members on the committee, only 4 are farmers; they too are nominated as political representatives and are not elected directly by the farmers of the BRP. Most importantly, the ICC neither evaluates the system performance nor oversees the NWMP program activities.

TABLE 5.
Rice productivity through the rabi seasons.

Year	Water supplied (Mm^3)	Equivalent rice area[a] (ha)	Rice productivity per unit land (t/ha)	Equivalent rice production[b] (t)	Rice productivity per unit water[c] (kg/m^3)
1987	911.5	60,394	3.8	229,497	0.25
1993	804.4	77,612	4.7	364,776	0.45
1994	816	73,877	4.9	361,997	0.44
1995	876.7	73,364	5	366,820	0.42
1997	849.2	72,836	4.2	305,911	0.36

[a]Computed as rice area + 0.6 x non-rice area (non-rice area water consumption is approximately 0.6 times the consumed water per unit rice area).

[b]Computed as equivalent rice area x rice productivity per unit of land.

[c]Computed as equivalent rice production divided by water volume diverted at the reservoir during the rabi season.

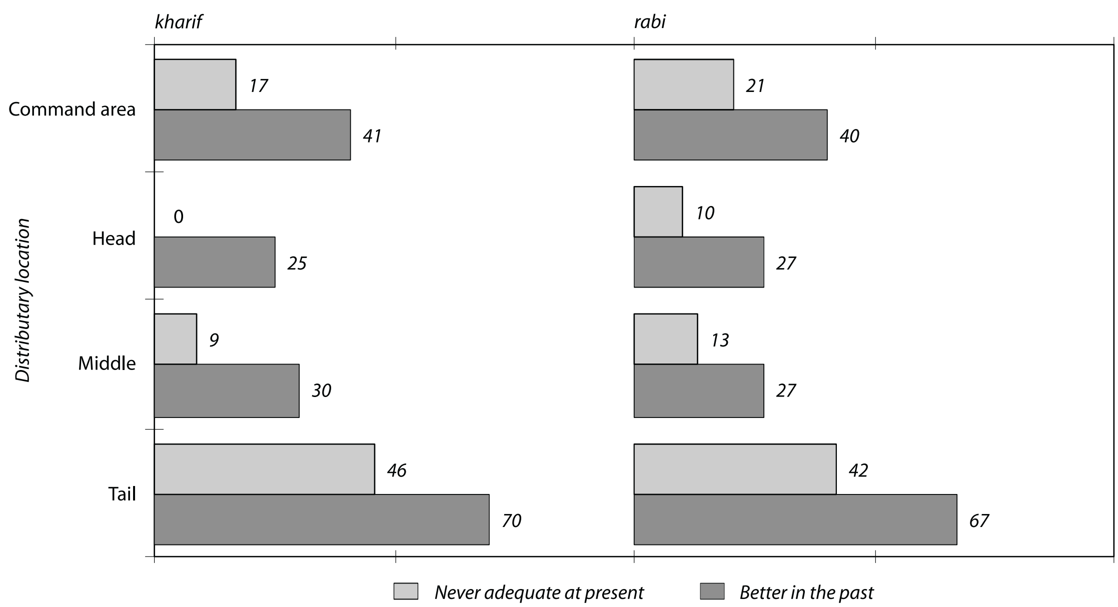
Farmer perceptions

The analysis is based on the data generated using a farmer-survey questionnaire. Three levels of aggregation are considered for the analysis. The first level considers the total command area as a unit. The second level considers the grouping of distributaries as the head, middle, and tail end. The third level clubs the parcels at the head, middle, and tail reaches along distributaries as separate units. The results of the analysis for the first two levels are presented in figures 4–7 while the analysis of the third level is presented in figures 8–11. The results presented in these figures depict the present condition (as of 1997) of water distribution as well as the change of performance and the condition of the system before and after rehabilitation.

Figure 4 presents the irrigation adequacy of the current supply and change since the rehabilitation of the kharif and rabi seasons. The horizontal bars show the percentage of the sampled farmers who reported "never adequate at present"[3] and "better in the past," i.e., before rehabilitation. For the command as a whole, only 20 percent of the farmers reported that they never received adequate water in either irrigation season. However, there is head-tail disparity of current water adequacy along the main canal.

For kharif, almost 45 percent of the farmers in the tail end have reported that water was never adequate compared to 9 percent in the middle end and nearly zero percent in the head-end distributaries. The farmer perception of current adequacy is significantly dependent on the location of the distributaries (Pearsons chi-square=35.6 for kharif and 21.7 for rabi, df=4). In the command area, 40 percent of the farmers reported that adequacy was better before rehabilitation than after rehabilitation. The percentage of farmers with such opinion varied from the head end (25%) to the tail end (70%).

FIGURE 4.
Irrigation adequacy in the command area—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %).



[3]The term *at present* also corresponds to 1997 as the term *current*.

As in the case of current adequacy, the farmer perception of change in adequacy since rehabilitation is also significantly dependent on the location of the distributary (chi-square=18.2 for kharif and 11.8 for rabi, df=4). A possible reason for this type of response in the context of water diversion into the canal being stepped up may be due to the increased irrigated area after rehabilitation with high percentage of rice cultivation requiring more water.

Figure 5 presents irrigation equity and change in equity before and after rehabilitation for both the kharif and rabi seasons. The horizontal bars represent percentage of farmers who reported “rarely fair at present” and “better in the past.” The figure indicates that equity is not a major problem in the head and middle reaches while it is a problem in the tail-end distributaries, where 24 percent of the farmers during kharif and 61 percent of the farmers during rabi reported “rarely fair at present.” Farmer perception of current equity is significantly dependent on the distributary location (chi-square =19.2 for kharif and 23.8 for rabi, df=4) as the majority of the farmers in the head end reported either “mostly” or “sometimes fair” and the majority of the farmers in the tail end reported either “sometimes” or “rarely fair.” A quarter of the farmers in the command area perceived that equity was better before rehabilitation. However, this percentage was very high (57% for kharif and 73% for rabi) for the tail-end farmers who perceived both adequacy and equity as problems mainly because of the shift to irrigate larger areas with rice and the constraints in pushing sufficient water to the tail-end distributaries.

Figure 6 presents farmer perception of the functional condition (current and also the change since rehabilitation) of the canals within the unit, and also at the main system level. Uniformly from the head end to the tail end, about 60 percent of the farmers reported that the condition of canals is poor within the unit at present. About 40 percent of the farmers in each reach reported that the functionality of the main system is poor at present. However, with regard to the change in

FIGURE 5.
Irrigation equity in the command area—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %).

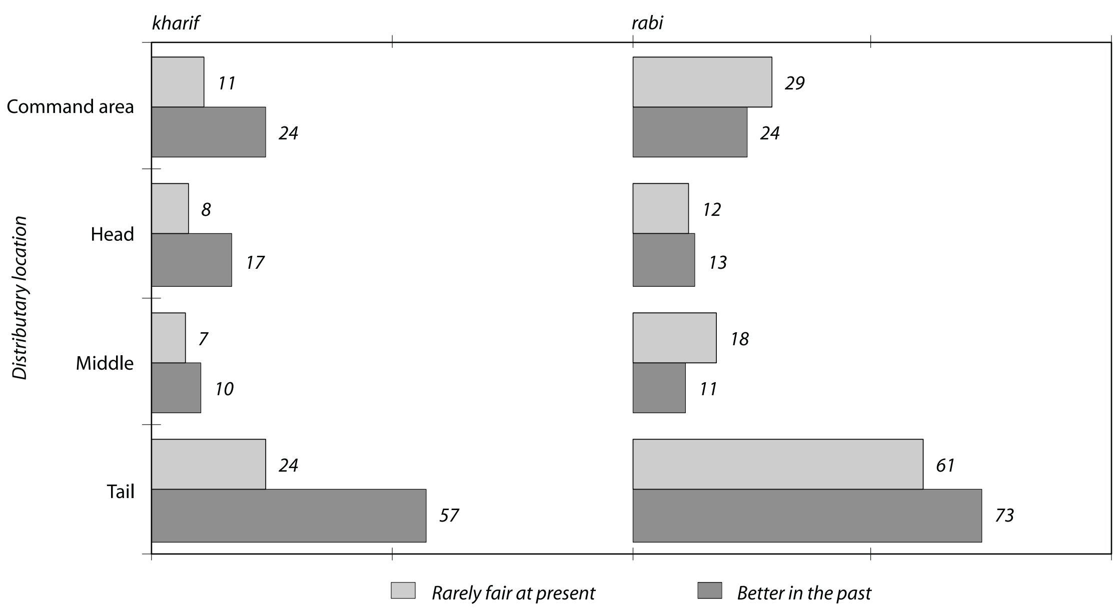
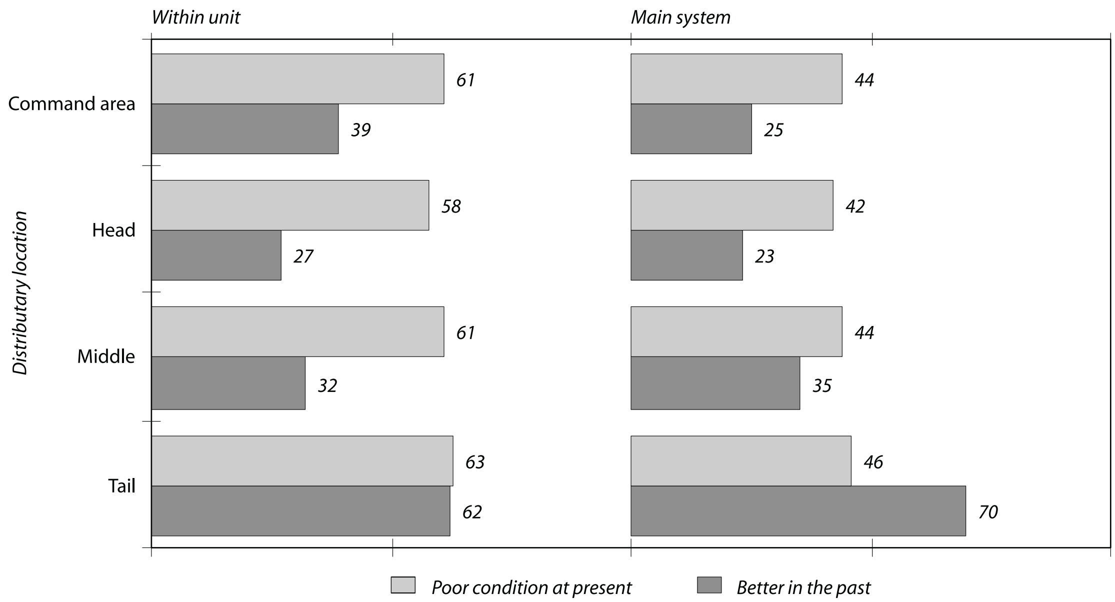


FIGURE 6.
Functional condition of irrigation canals in the command area—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %).



functionality of the system, both within the unit and in the main system, about 30 percent of the farmers in the head and middle ends and about 70 percent of farmers in the tail end reported that functionality was better for the whole system before rehabilitation. As mentioned above, the farmer perception of change since rehabilitation is significantly dependent on the location of their distributaries (chi-square=10.1 for within unit and 19.15 for main system, df=4). Major reasons for this kind of perception appears to be the mismatch between the water requirement of the irrigated area with high intensity water-loving crops and the main system constraint coupled with operational policy adopted by the irrigation agency.

Figure 7 is a representation of the frequency of conflicts at present as well as the change in the frequency of conflicts after rehabilitation. When water becomes inequitable and inadequate, especially in the tail end, conflicts increase. About 33 percent of the farmers in the whole command have reported frequent conflicts at present. However, this number in the tail-reach distributaries is 48 percent. Also, 36 percent of the farmers in the command area and 57 percent at the tail end reported that conflicts became more frequent since rehabilitation. The farmer perception of conflicts at present and also since rehabilitation is significantly dependent on the location of the distributaries (chi-square=20.7 for present and 12.4 for change since rehabilitation, df =4).

From figures 8 and 9, it can be seen that while the responses of farmers with regard to adequacy and equity in kharif are different along the head, middle, and tail reaches of the tail-end distributaries, the responses during rabi are distinctly different. Farmers in the middle and tail reaches reported more about inadequacy and inequity than those in the head reach. The inadequate and inequitable distribution of water has also given rise to conflicts among farmers (figure 11), especially within the head and tail reaches. Figure 10 presents the farmer responses, “poor condition now” and “better in the past,” to the functional condition of the tail distributaries within the unit and the main system supplying

FIGURE 7.
Frequency of conflicts in the command area—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %).

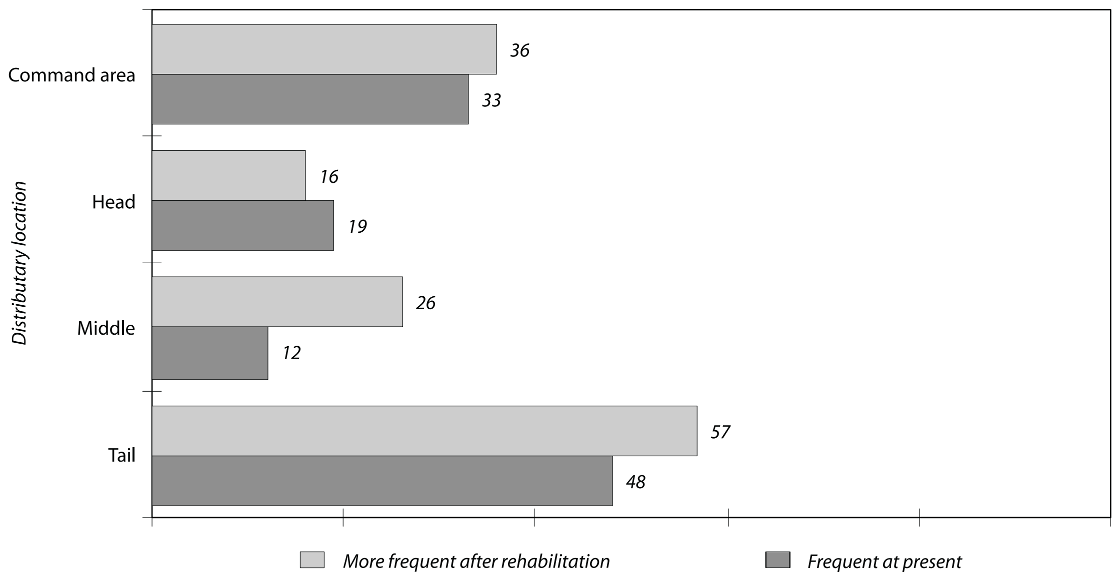


FIGURE 8.
Irrigation adequacy in tail-end distributaries—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %).

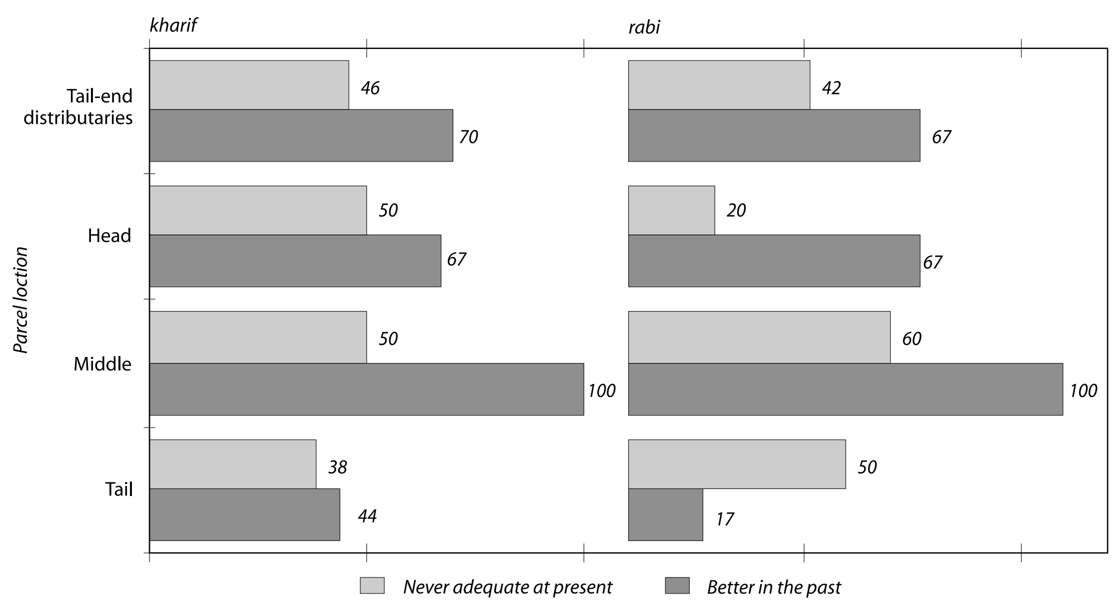


FIGURE 9.
Irrigation equity in tail-end distributaries—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %).

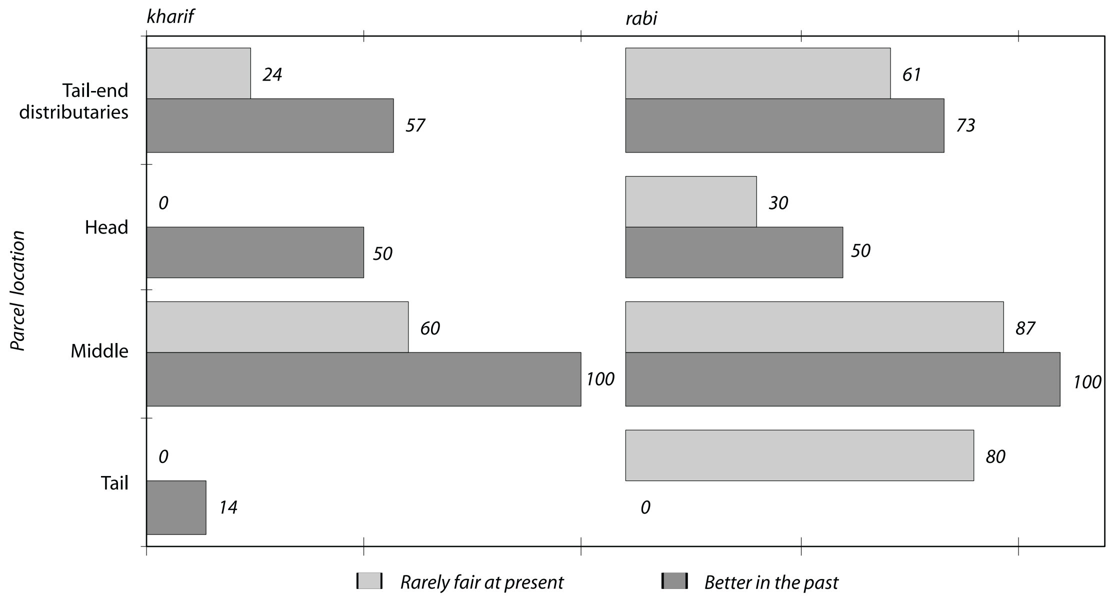


FIGURE 10.
Functional condition of irrigation canals in tail-end distributaries—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %).

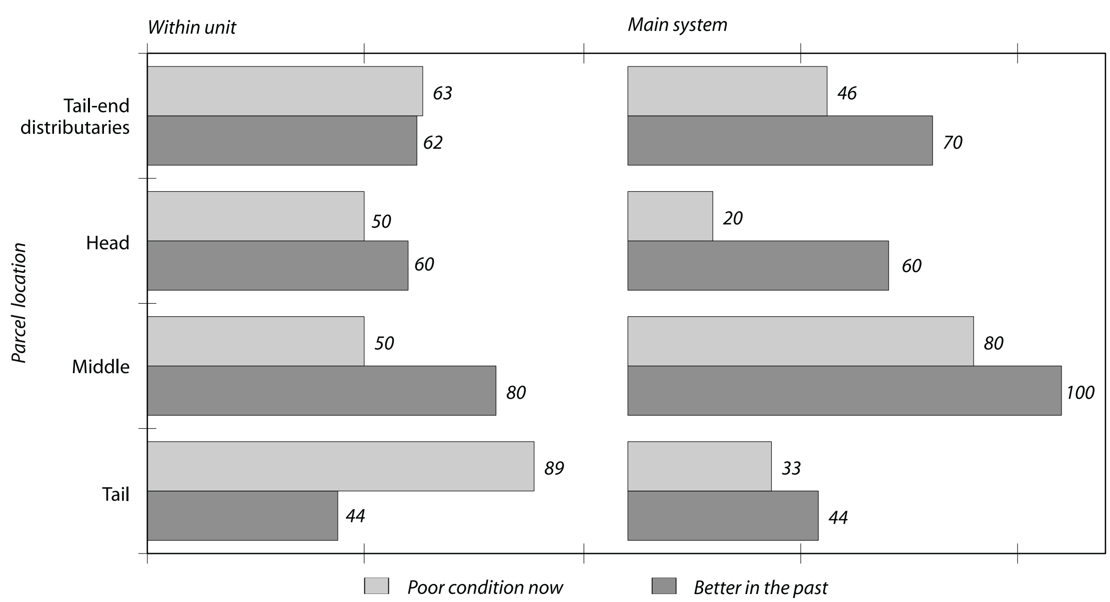
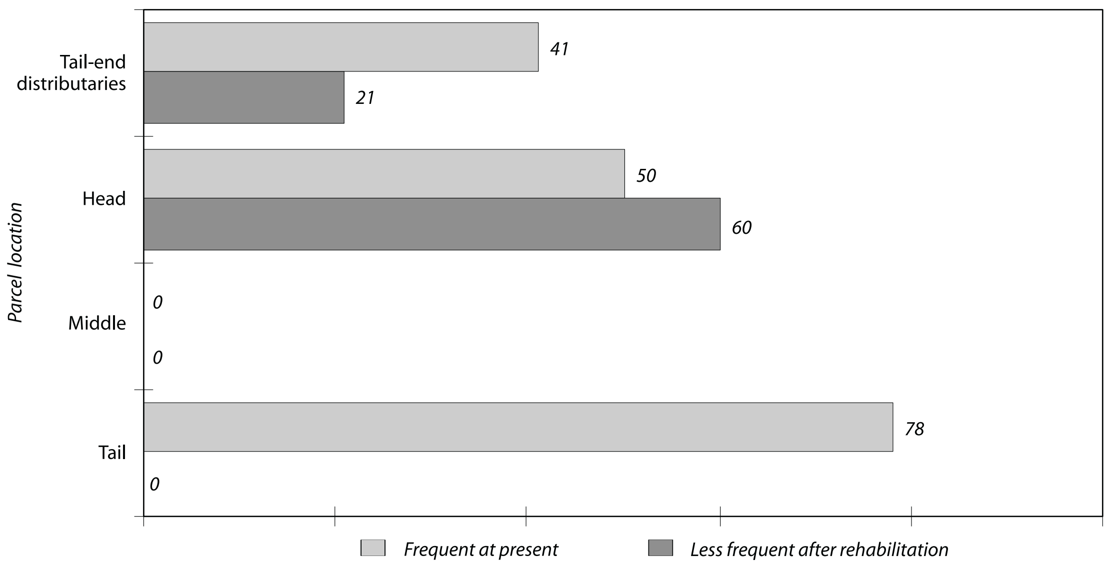


FIGURE 11.
Frequency of conflicts in tail-end distributaries—present condition and change since rehabilitation: Responses to farmer-survey questionnaire (in %)



water to these distributaries. The first observation is that the functionality within the units (distributaries) is poorer than at the main system and that the functionality of both the distributary and the main system was better before intervention than it is now. Again within the units, the tail-reach farmers (89%) feel that the present condition is poor compared to 52 percent of the farmers in the head reach. Though the number of farmers in each category is not adequate for a statistical analysis, a major conclusion that can be drawn from figures 8 to 11 is that there is inequity and inadequacy of water supply among field plots within the tail distributaries and that those plots within middle and tail reaches suffer more than the plots in the head reaches.

Impact of Closure of World Bank Credit

World Bank credit for the Bhadra Reservoir Project closed in March 1995, after incurring an expenditure of about US$11 million[4] against the estimated US$5.5 million. The balance work estimated to cost US$0.22 million has not yet been completed. The impacts of the credit closure in regard to both financial and supervisory inputs are reflected in the slackening of system performance. With the closing of the additional O&M funds coming from the external credit, maintenance has become poor and structures that are broken in many places have not been reconstructed. The actual performance in recent years has shown an increasing deviation from the NWMP program objective of more equitable, reliable, and predictable irrigation supplies, which could not be achieved even during the NWMP period. The agricultural calendars stipulated in the NWMP program proposal have not been followed; actual and planned operations were different, and the advancing of the kharif season could not be implemented due to farmer unwillingness. Water utilization, particularly in the rabi season, has been increasing and agricultural performance (total

[4]US$1.00 = Indian Rs 35.00

irrigated area, area under rice, and rice yield) has been on the decline. The tail-end deprivation, due to preferential water allocation to the head-reach areas, is stressing agricultural performance in this command, though, through deficit irrigation, farmers at the tail end have maintained irrigation and rice intensities. Farmer participation, and particularly the institution of water user association (WUA), has declined. No new WUA has been formed and the existing ones have become nonfunctional. The farm survey indicates that a large majority feels that system performance was better in the past than it is now.

Summary of Analysis

Many interventions as contemplated in the Staff Appraisal Report of the NWMP program could not be fully operationalized for various reasons analyzed in this report.

In spite of these deficiencies, the agricultural performance (irrigation efficiency, rice irrigation intensity, land and water productivity) of the project has significantly improved during the intervention and the post-intervention periods compared to the pre-intervention period. For example, in the tail end Davangere canal division, the irrigation intensity rose from 75 percent during 1986–87 to 87 percent during 1992–93 and slightly declined to 84 percent during 1996–97. The rice intensity in the tail end increased from 51 percent in 1986–87 to 66 percent during 1992–93 and has stabilized since then. The rice yield significantly increased from 3.8 tons/ha during 1986–87 to 4.4 tons/ha during 1992–93 and slightly declined to 4.3 tons/ha during 1996–97. The productivity per unit of water delivered at the reservoir increased from 0.25 kg/m^3 in 1986–87 to 0.45 kg/m^3 during 1992–93 and slightly declined to 0.36 kg/m^3 during 1996–97.

After the closure of World Bank credit in 1995, there has been a declining trend in all other agricultural performance indicators, except in rice irrigation intensity. Data are not sufficient to pinpoint whether this decline is due to the deteriorating condition of the physical management systems, or poor reservoir inflow in 1996–97, or both.

Three major factors appear to have constrained the potential performance of the system. They are:

- switching to a cropping pattern dominated by water-intensive crops such as rice during the rabi season,
- abandoning the zoning of area (as envisaged by the NWMP program) and irrigating the full extent of the command during the rabi season, and
- the lack of proper institutional mechanisms such as farmer organizations and their committed involvement in operation, maintenance, and management of the system.

Lessons Learnt

The management problems in a structured system are directly related to the level of structuring. Supply management, in the context of a heterogeneous cropping pattern of different irrigation requirements cannot succeed unless farmers organize to coordinate water distribution below the distributary, minor, or outlet. The structured system shifts the responsibility for operation and maintenance from the operating agency to the farmers. Thus in a traditional demand-based system such as the Bhadra Project, farmer organizations at the scheme level and at the appropriate subunit level are necessary prerequisites for the success of a structured system. This did not happen in the Bhadra Project where the emphasis continued to be on system rehabilitation rather than on farmer training and organization. Farmer participation both in decision making at the scheme level, and in O&M at the distributary level needs to be given primary importance, and detailed guidelines and mechanisms need to be put in place in the early stages of implementation itself.

The design of the structured system in the Bhadra Project was constrained by limited funds provided for institutional strengthening within the system and the need to work within the existing hydraulic system limitations. The operating procedures of the structured system did not explicitly take into account the heavy rainfall and its spatial variability across the command area. The proposed cropping pattern was unrealistic, particularly in the context of complete absence of farmer acceptance and adherence to rules of operation. Farmer involvement in planning, design, and implementation is crucial and it needs to be committed and motivated.

The successful operation of a structured system also requires a concomitant institutional change. In the Bhadra Project, for instance, the Karnataka Irrigation Act legalizing "localization" (traditional demand-based system) has created confusion between supply and demand management. This confusion continued and exerted pressure on the scheme-operating agency and its functions.

Farmer involvement and the acceptance of the operational plan are essential for a supply-based technology. In the absence of a scheme-level committee and functional farmer associations, the NWMP experiment in Bhadra was bound to fail. The conflicts among the farmers continued and resulted in undue pressures on the scheme operators who tinkered with the operation in an ad hoc fashion. The slide back into a quasi-demand-based supply and the ad hoc functioning prevented rigorous implementation of the operational plans resulting in less equity, reliability, and predictability.

The maintenance of the system failed in view of insufficient grants, more so since it had not been transferred to the WUAs. The farmers continued to feel that maintenance is the responsibility of the Irrigation Department, which did not have adequate funds anyway. Damages to structures by farmers continued with no repairs being undertaken. The formation of WUAs and transfer of O&M responsibilities of the structured system are essential for a successful O&M activity. A strong M&E program will support the reviewing and refining of operational plans.

In the absence of a continuing support mechanism by way of institutional arrangements and farmer participation, the Bhadra Project is showing signs of decline, with water management sliding back to a quasi-demand-based supply. Strong farmer involvement thus holds the key to sustainable performance.

Satellite-Based Rice Yield Estimation in the 1996–97 Rabi Season

Since crop cutting experiment data (in which rice yields are estimated on ground from statistically sampled plots) for 1996–97 were not available during the study period, the satellite-based rice estimation model developed for the 1992–93 rabi season was updated for the 1996–97 rabi season through satellite data normalization procedures.

The existing rice yield model, which is based on IRS satellite LISS-I sensor data of the 1992–93 rabi season, was normalized for LISS-I data of the 1996–97 rabi season by comparing the two sets of data for stationary targets whose reflectance remained unchanged. The difference in NDVI value was found to be only 3–4 digital counts, which is not significant, and hence the 1992–93 model can be used unchanged for LISS-I data of 1996–97. The LISS I based model was then normalized for LISS-III data of the same season by regressing NDVI of concurrent LISS I and LISS II data of 7 April and 10 April 1997. The rice yield model is now normalized for LISS III data of 7th April 1997. However, the model based on the single date (7 April 1997) needs to be updated for NDVI data of the milking stage of the rice crop, which would occur in different calendar periods across the command area due to staggered rice transplantation.

Time composite WiFS data were generated by picking the maximum Vegetation Index (VI) value (corresponding to milking stage of rice) from a set of coregistered 12 WIFS data sets from mid-March to May 1997. The ratio of WiFS-derived NDVI data of 10 April 1997 to time composite NDVI is computed and applied to LISS-III derived NDVI data, to compute the expected peak (time composite) LISS III NDVI value for use in the model.

The assumption that LISS III and WiFS are equally sensitive to vegetation response was tested. The ratios of LISS III NDVI data of 10 April and 4 May were computed, as also the ratios of WiFS data of the same dates and regressed with each other. The slope of regression line is 0.96, indicating equal sensitivity of LISS-III and WiFS to the vegetation response.

Since Crop Cutting Experiment (CCE) data for the 1996–97 rabi season were not available, the updated rice yield model was validated through farmer enquiries and enquiries with the Bhadra Command Area Development Authority and irrigation engineers. In an earlier study, a similar category of the rice yield model of the 1992–93 rabi season had however been validated against actual CCE data of the 1993–94 rabi season, with deviations from predicted to actual being less than 10 percent (Murthy et al. 1995).

Literature Cited

Government of Karnataka. 1986. *Project report (Bhadra Reservoir Project).* National Water Management Project. Karnataka: Government of Karnataka.

IIMI (International Irrigation Management Institute). 1995*. Evaluation of schemes under NWMP-II: Bhadra scheme in Karnataka State and Sathanur scheme in Tamil Nadu.* Colombo, Sri Lanka: International Irrigation Management Institute.

Murthy C. S.; S. Jonna; P. V. Raju; S. Thiruvengadachari; and K. A. Hakeem, 1995. Paddy yield prediction in Bhadra project command area using remote sensing data. *Asia-Pacific Remote Sensing Journal* 8(1): 79-84.

Shanan L. 1992. Planning and Management of Irrigation Systems in Developing Countries. *Agricultural Water Management* 23(1-2): 234.

Thiruvengadachari S.; and R. Sakthivadivel. 1997. *Satellite remote sensing for assessment of irrigation system performance: A case study in India.* Research Report 9. Sri Lanka: International Irrigation Management Institute.

WRDO (Water Resources Development Organization). 1986. *Project report of Bhadra Reservoir Project (BRP).* Bangalore: Government of Karnataka.

World Bank. 1986. *Staff appraisal report. National Water Management Project, Karnataka Bhadra Project.* Washington D.C.: The World Bank.

20. *Indicators for Comparing Performance of Irrigated Agricultural Systems.* David J. Molden, R. Sakthivadivel, Christopher J. Perry, Charlotte de Fraiture, and Wim H. Kloezen, 1998.

21. *Need for Institutional Impact Assessment in Planning Irrigation System Modernization.* D. J. Bandaragoda, 1998.

22. *Assessing Irrigation Performance with Comparative Indicators: The Case of the Alto Rio Lerma Irrigation District, Mexico.* Wim H. Kloezen and Carlos Garcés-Restrepo, 1998.

23. *Performance of Two Transferred Modules in the Lagunera Region: Water Relations.* G. Levine, A. Cruz, D. Garcia, C. Garcés-Restrepo, and S. Johnson III, 1998.

24. *Farmer Response to Rationed and Uncertain Irrigation Supplies.* C. J. Perry and S. G. Narayanamurthy, 1998.

25. *Impacts of Colombia's Current Irrigation Management Transfer Program.* Douglas L. Vermillion and Carlos Garcés-Restrepo, 1998.

26. *Use of Historical Data as a Decision Support Tool in Watershed Management: A Case Study of the Upper Nilwala Basin in Sri Lanka.* W. K. B. Elkaduwa and R. Sakthivadivel, 1998

27. *Performance Evaluation of the Bhakra Irrigation System, India, Using Advanced Information Technologies.* Wim Bastiaanssen and D. Molden, 1998.

28. *Performance Evaluation of the Bhakra Irrigation System, India, Using Remote Sensing and GIS Techniques.* R. Sakthivadivel, S. Thiruvengadachari, Upali Amerasinghe, W.G.M. Bastiaanssen, and David Molden, 1999.

29. *Generic Typology for Irrigation Systems Operation.* D. Renault, and G.G.A. Godaliyadda, 1999.

30. *Mechanically Reclaiming Abandoned Saline Soils: A Numerical Evaluation.* S. A. Prathapar and Asad S. Qureshi, 1999.

31. *Gender Issues and Women's Participation in Irrigated Agriculture: The Case of Two Private Irrigation Canals in Carchi, Ecuador.* Elena P. Bastidas, 1999.

32. *Water Scarcity Variations within a Country: A Case Study of Sri Lanka.* Upali A. Amarasinghe, Lal Mutuwatta, and R. Sakthivadivel, 1999.

33. *Modernization Using the Structured System Design of the Bhadra Reservoir Project, India: An Intervention Analysis.* R. Sakthivadivel S. Thiruvengadachari, and Upali A. Amarasinghe, 1999.

INTERNATIONAL WATER MANAGEMENT INSTITUTE
P O Box 2075, Colombo, Sri Lanka
Tel (94-1) 867404 • Fax (94-1) 866854 • E-mail iwmi@cgiar.org
Internet Home Page http://www.cgiar.org/iwmi

ISBN 92-9090-385-6

ISSN 1026-0862