THE OPERATING SYSTEM OF THE MAHI RIGHT BANK CANAL (MRBC): AN ANALYTICAL STUDY

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Paper Presented at the

Workshop on
IIMI-India Collaborative Research
in Irrigation Management

13-14 February 1992
New Delhi, India

INSTITUTE OF RURAL MANAGEMENT (IRMA)
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Abstract

In this paper, an attempt is made to understand the operating mechanism of the Mahi Right Bank Canal, identify strengths and pitfalls in the system and the current operating procedure. We have also analyzed the interaction of farmers with the system. Based on these analyses, we recommend that privatization of the canal at the secondary level would lead to: (i) more efficient and equitable distribution of water between the head and tail of the canal and reduce salinity on the head reach of the canal system; (ii)) rationalize canal water pricing; (iii) enhance revenue realization by the government; and (iv) provide effective management with fewer/reduced points of administrative control.

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INTRODUCTION

In recent times, serious questions have been raised about the efficiency of investment in irrigation, particularly investment in large, surface irrigation systems. The Sixth Five-Year Plan emphasizes that returns from this investment, both in yield terms and in financial terms, have been disappointing. On the average, States have been losing more than Rs 4.3 billion per year on their irrigation investments (Planning Commission 1980). Average productivity with canal irrigated lands is reported to be in the neighborhood of 1.1 tonne per hectare (ha), not significantly higher than the rain-fed yield rate in a normal year (Venkateswarlu 1985).

The main concerns about large, canal irrigation systems are as follows: (1) average yields of crops on irrigated lands are still three to four times lower than what could be achieved; (2) those farmers who are located favorably at the head of the canal system receive an adequate (sometimes, more than adequate) amount of water at the expense of those located further down (the tail-enders); (3) the reliability of water delivery, in both quantity and timing, is deteriorating; and (4) long-term productivity is threatened by increased salinity, alkalinity, silting, waterlogging and flooding.

One of the reasons for the poor performance of many canal systems in India and elsewhere is the neglect of main system management (Chambers 1988). There are historical reasons for this neglect. The early, large canals of northwest India were designed for ease of management. Being run-of-the river diversions, questions of storage and reservoir management did not arise. Rotations were utilized, monitoring simplified, and canals and outlets designed to provide constant discharge (Malhotra 1982). The management of these canals was and is largely a question of maintaining physical works, avoiding silation and other damages, and following established routines for rotations according to well-understood rules (Chambers 1988). However, such ease in management in reservoir-based canal systems is not possible unless one wants to mismanage it. The performance of the system is related to the software and hardware of the system. In this paper, an attempt is made to understand the operating mechanisms of Mahi Right Bank Canal (RMBC) in Gujarat and to identify the areas that need to be improved for better performance of the system.

In this study, main system management has been defined as the management of software aspects including the capture, allocation, scheduling, and delivery of water in main systems down to, and including, outlets, and the disposal of water in drains below. It includes planning, decision-making, the operation of controls, and communications both upwards to managers and downwards to groups of farmers (Chambers 1988).

THE PHYSICAL SYSTEM

The Mahi-Kadana Irrigation Project has been developed in two stages. The first stage comprised the construction of a diversion weir across the River Mahi at Wanakbori village in Balasinor Taluka or Kaira District in Gujarat. The weir, completed in 1958, facilitated the diversion of the river flow to the canal system with negligible storage upstream of the weir. The second stage of irrigation development comprised the construction of a major reservoir in Santrampur Taluka of the Panchamahals District. It is located 70 km upstream of the Wanakbori weir. The Kadana Reservoir, known as Mahi Stage II, was constructed in 1978 with the primary objective of augmenting the supply of water to the MRBC command area. While the Wanakbori weir system was built primarily to provide supplemental irrigation for the monsoon crop, the Kadana Reservoir system was designed to store and supply irrigation water for winter and summer crops. An assured water supply has been made available in the canal command area and an irrigation potential of 263,000 ha (CCA - 2.12 lakh ha) has been created. Water from the Kadana Reservoir is released into the Mahi River and is carried downstream to Wanakbori. The natural flow of the river itself is used for the conveyance of the releases. Table 1 provides the details of the physical system of MRBC.

Table 1. Details of branch canals in the Mahi Bank Canal System.

Name of branch canal	Take-off point	Length of branch canal (km)	Design discharge at head (m^3/sec)	Type of lining	Name of branch taking off	Cultivable command area (ha)
Nadiad branch	40.65 km from Wanakbori weir	37.6	106.12	Sandwich type on sides and polythelene embedded in brick on the bed.	Matar and Cambay	23,565
Matar branch	35.85 km from Nadiad branch	19.2	18.40	"		13,266
Cambay branch	- do -	48.3	83.2	"	Limbasi	53,290
Limbasi branch	10.98 km from Cambay branch	35.4	27.45	"		31,060
Petlad branch	55.5 km from Wanakbori weir	58.56	56.2	"		41,666
Borsad branch	69.5 km from Wanakbori weir	23.7	38.1	"		37,140

Source: Department of Irrigation, MRMC, CADA, Nadiad.

ASSESSMENT OF WATER AVAILABILITY IN KADANA RESERVOIR

The Kadana Reservoir was designed for a gross storage capacity of 1,542.4 MCM and a live storage capacity of about 1,200 MCM. According to its design, the reservoir was expected to be filled at least three times every four years. The estimated seasonal flows of the Mahi River at the Kadana Dam site for the years 1891-1974 were estimated based on a regression equation relating the rainfall in the catchment area with the observed flows at the Kadana Reservoir site during the period 1958-1974. The estimated seasonal flow at 75 percent reliability, calculated using the method of plotting positions, is 3,724 MCM (WTC 1983). The corresponding value estimated by assuming the seasonal flows to be normally distributed is about 4,200 MCM. It is well-established that annual flows in rivers are approximately normally distributed. In view of the fact that about 96 percent of the annual flow occurs during the period June to October, the assumption of normal distribution of the seasonal flows is considered reasonable. Thus, the volume of seasonal flow, with 75 percent reliability, is of the order of 4,000 MCM. On the other hand, the gross storage capacity of the reservoir is only 1,540 MCM and the total seasonal irrigation requirement during the months of June to October is about 1,100 MCM for the proposed cropping pattern. The anticipated evaporation losses from the reservoir during the above season are of the order of 100 MCM. Thus, after meeting the total water requirement of about 1,200 to 1,800 MCM, the seasonal flows of the Mahi River are adequate to leave the reservoir full at the end of the monsoon season. Accordingly, based on the analysis of the hydrology of the Mahi River at the Kadana Dam site, the WTC (1983) study concluded that the reservoir gets filled every year by the end of the monsoon season with a profitability exceeding 75 percent. This conclusion is amply supported by a close look at the hydrograph of the Mahi River at the Kadana Dam site for the period June to September, 1979. Further, the data on maximum water levels in the Kadana Reservoir also show that the reservoir was full on 17th September, 1981 and again on 12th October, 192. There is, therefore, a good chance of having a full reservoir at the end of the kharif season, even after meeting the kharif irrigation requirements.

The hydrographs of the Mahi River at the Kadana Reservoir site during the years 1958-79 indicate that the inflows into the reservoir in October are also fairly significant. These inflows, together with the storage at Wanakbori are adequate to meet the demands of irrigation water in the command area for the month of October. Thus, the reservoir is likely to be full at the end of October as well (MTC) 1983). Therefore, water availability is not and should not be a limiting factor for the improved performance of the system. This is unlike many other systems in India where total availability of water was overestimated at the time of designing the project and later this itself became a limiting factor for the management of the system (Mitra 1986).

WATER CONTROL CAPACITY

In the following section, we describe the components of the system which allow water control.

1. As mentioned earlier, the main canal takes off from the right of the pick-up weir at Wanabokri. The Kadana Reservoir from which water is released into the Mahi River, has a live storage capacity of around 1,200 MCM. It is estimated that the lag between release of water at the head regulator and at the tail of the distribution system is 18 hours.

2. A total of 56 cross-regulator were provided along the main and branch canals, distributaries and minor offtakes to maintain a full supply level at the points, without having to wait for the water to flow down from above. A number of escapes at branch level are available to let out excess water and prevent overtopping.

3. The conveyance structures are lined with concrete at the main canal and branch levels; at the distributary level, it is for the most part unlined, except at certain minor and outlet offtakes. However, with (April-May, 1991) desiltation of canals, the earthen structures are in fairly good condition.

4. All the outlets down to the lower half of distributaries are gated in concrete, and can be raised or lowered manually. Although the gates are screw-bolted, it is not at all difficult for farmers to open or close the gates.

5. An outlet has an design capacity of 1 cusec with an average command size of 30 ha, but variations of these tertiary blocks range from 7 ha to 35 ha.

6. Field channels, except at the salinity-prone Cambay region, cover most of the Culturable Command Area (CCA) and are extensive.

7. Canal telephones connected to divisional and subdivisional offices are provided at important control stations of the main and branch canals.

8. At the subdivisional and even sectional levels, there are housing colonies in the same complex as the office premises and therefore 24-hour communication between supervisory and field staff is possible.

Following Wade's (1990) discussion on the issue of technical and organizational design, the Mahi-Kadana physical system can be described as "articulated" since the lowest-level outlet serving less than 30 ha has an adjustable gate. This system of water control facilitates adjustments in the outlet gate to permit variations in the distributary water level and in crop-water needs, thereby saving water. It is thus reasonable to describe the capacity for water control in this system as fairly good, as it was designed for water deliveries much closer to crop-water requirements, than the "Warabandi" kind of system.

MANAGEMENT STRUCTURE OF IRRIGATION BUREAUCRACY

The whole Mahi Canal CCA of 212,000 (2.12 lakh) ha comes under the management of the Mahi Irrigation Circle (MIC), headed by the Superintending Engineer. There are four divisions, including a drainage division each headed by a Executive Engineer (EE). Every division has 4 to 5 subdivisions, each headed by a Deputy Executive Engineer (Dy. EE). Normally a Dy. EE is in charge of four secondary canals and relevant sections of the main/branch canal. The next official in the hierarchy is the Section Officer, who may have a diploma in Civil Engineering and who is usually responsible for a single distributary or two/three minors. Responsibility for the allocation of area to be irrigated and any kind of accountability for achievement stop at this level. Below the Section Officer are the field staff consisting of *Karkoons* or Work Assistants and the *Chowkidars*. A Work Assistant is in charge of minor operations and the area of his jurisdiction varies from 400 ha to 800 ha while that of a Chowkidar varies from 75 to 350 ha. These Work Assistants are usually literate, but not as a rule, and the Chowkidars are rarely literate. Promotion prospects for them are absent.

PLANNING AND OPERATIONAL SCHEDULE

In the MRBC, an elaborate system of planning exits. First, at the system level, the area that would be irrigated under each crop is estimated on the basis of data of the past three years. Then the actual quantity of water allocated to each crop is determined using a factor called "hectare watering," which varies from crop to crop and with rotation. The system, therefore, seem to have in-built flexibility to accommodate changes in cropping pattern. However, an examination of the last 10-year data shows that the targets were never fixed as described above. Table 2 provides three-year moving averages of actual areas irrigated and targets fixed by MIC and the Government of Gujarat for the MRBC, for the corresponding years. It can be seen from the table that targets fixed by MIC and the Government closely follow each other. But three-year moving averages of past achievements (areas irrigated) depart significantly from targets fixed by both MIC and the Government of Gujarat; the deviation is over 40 percent in some years. Although it is difficult to understand why there are two separate targets for the MRBC and what their purposes are, *a priori*, it appears that these targets are not used in operation and management of the canal system.

At the second level of allocating water to the various divisions and subdivisions, the concept of demand seems to be ignored and water is allocated in proportion to the CCA of each irrigation division. There are two faults in this approach: (i) the inconsistency arising out of the use of different bases at different levels; and (ii) the method which ignores demand aspects may not lead to efficient allocation of the resources. Further, as we explore later, water allocation in scheduled preparation and in actual operation are based on two different parameters. Hence, no comparison of target and achievement will be meaningful.

Table 2. Target areas and three-year moving averages of performance in the MRBC.

Year	MIC Target ('000 ha)	Govternment Target ('000 ha)	Three -year moving average achievements ('000 ha)	Actual achievement	% variation over MIC target
	1	2	3	4	5
1981 - 82	190	190	-	118	
1982 - 83	190	190	-	135	
1983 - 84	165	160	-	121	
1984 - 85	175	175	125	132	+ 40
1985 - 86	137	137	129	109	+ 06
1986 - 87	175	168	121	167	+ 44
1987 - 88	182	187	136	188	+ 33
1988 - 89	180	200	155	150	+ 16
1989 - 90	175	175	169	151	+ 03.5

Once these allocation are made, a fortnightly schedule is prepared for each segment of the system. For kharif, there is only one rotation and a continuous supply of water is provided throughout the season and the actual amount of water flow is determined by the rainfall, crop water requirement, etc. During the rabi season, however, the whole system is divided in two parts based on geographical considerations. Each part of the system is provided irrigation in rotation, on the basis of 10 days on and 20 days off. These demands are conveyed everyday over the phone to the Nadiad Division which looks after the headworks. It is expected that every day, at 22 hours, the required quantity of water will be released so as to make water available the next morning for irrigation. There is no official record of such day-to-day changes in the demand. Absence of data makes it difficult to assess the sensitivity of the system in relation to changing water demand conditions. In addition, the fortnightly water allocation targets are fixed for each segment in proportion to the CCA and, therefore, does noty reflect actual demand conditions. It is, therefore, not possible to determine the Delivery Performance Ratio (DPR) that compares actual discharge to targeted or demand discharge. It is also not possible to determine how the fortnightly targets are broken into an operating procedure of 10 rotations.

IRRIGATION DEMAND: PROCEDURE FOR INDENTING

From the viewpoint of the Irrigation Department, and for ensuring maximum flexibility of water supply, many improvements and facilities have been provided. The *Shejpali* method is followed in water distribution in the Mahi-Kadana system. This method requires that farmers submit their applications for water requirements by crop, a few weeks in advance of the cropping season. A fairly comprehensive system is prescribed for obtaining "demand applications" from the farmers. The date for receiving applications is notified in local newspapers; the Section Officer, *Karkoons* and *Chowkidars* notify the date to village panchayats and farmers personally. The application forms are checked for right of ownership, crops to be grown, and the no-dues certificate obtained from the irrigation *Talati*. After these verifications, a pass is issued to the concerned farmer certifying that he/she is entitled to take water for irrigation.

For those farmers who have taken water without prior approval, the *Karkoon* notes the date of taking water and the area and type of crop irrigated. A "confession" called *Ekrarnama* is taken to this effect from the concerned farmer; if he/she refuses to do so, the Karkoon has to obtain signatures of at least two witnesses and the department charges one-and-a-half times the ordinary rate. Farmers who cannot obtain a no-dues certificate from the talati are usually not permitted to take water. Those farmers who apply later than prescribed date are also charged one-and-a-half times the ordinary rate. The system also prescribes norms for surprise checking of authorized and unauthorized irrigations: at a rate of 100 percent of the irrigators by Karkoon, 20 percent by Sectional Officer, 5-10 percent by Dy. EE and 2 percent by Executive Engineers in each season.

From the above discussion, one may think that the system should operate smoothly. However, the *de facto* operating procedure is quite different. First of all, the date for receipt of applications is extended invariably every year (Table 3), often, due to poor demand. It appears to us that the system supplies water irrespective of demand placed by the farmers. Therefore, farmers are not serious about the submission of applications. There are other consequences; sometimes, in the interim period, unauthorized users would fill up the Ekrarnama form and pay one-and-a-half times the ordinary charge. Others who do not, and wait for extension of date are charged only the ordinary cess.

Second, those farmers who have not paid their irrigation dues are not given irrigation passes. But there is no mechanisms to prevent them from using canal water and, therefore, the only recourse for them is the Ekrarnama. This is a vicious circle; low demand leads to extension of the date, which in turn affects farmers' attitudes; and they do not apply on time, hence, less demand.

In essence, the system is heavily dependent upon the lower level functionaries for obtaining demand applications. Our resident investigators in three distributary areas report that the stipulated procedure is not followed. Often, the Chowkidars and Karkoons distort the procedure and earn illegal rent. We

Table 3. Details of extension of Application Period for Mahi Project.

Sr No.	Year	Season	Normal last date for applications	Extension in Application Period	Reasons for extension of Application Period
1	2	3	4	5	6
1.	1985-86	Kharif	31-07-85	31-08-85	Due to prevalent rainfall situation.
				30-09-85	Due to less rainfall.
				30-10-85	Canals were operated in September.
2.	1985-86	Rabi	31-12-85	15-01-86	The application forms for volumetric levy were not available in time.
				20-01-86	Due to prevalent situation.
3.	1985-86	Hot Weather	31-03-86	21-04-86	Water was given only for fodder crops due to scarcity.
4.	1986-87	Kharif	10-06-86	31-07-86	Negligible application received in time.
				15-01-86	-
				21-08-86	-
				01-10-86	-
5.	1986-87	Rabi	30-11-86	31-12-86	-
6.	1986-87	Hot Weather	31-03-87	-	-
7.	1987-88	Kharif	31-07-87	25-09-87	Due to improved water availability from Kadana.
				08-10-87	Too few applications received.
				31-12-87	Due to prevalent scarcity situation.
8.	1987-88	Rabi	NA	NA	-
9.	1987-88	Hot Weather	29-02-88	30-08-88	Due to improved water availability from Kadana.
				15-09-88	Too few applications received.
10.	1988-89	Kharif	31-07-88	31-08-88	Due to improved water availability at Kadana.
				15-09-88	Too few applications received.
11.	1988-89	Rabi	31-11-88	-	-
12.	1988-89	Hot Weather	31-03-89	-	-
13.	1989-90	Kharif	31-07-89	31-08-89	Due to prevalent situation.
				18-09-89	Due to prevalent situation.
				30-09-89	Due to prevalent situation.
14.	1989-90	Rabi	30-11-89	18-12-89	-
				15-01-90	-
15.	1989-90	Hot Weather	31-03-90	10-04-90	As a special consideration.
16.	1990-91	Kharif	31-07-90	31-08-90	Due to prevalent situation.
				01-10-90	Due to prevalent consideration.
17.	1990-91	Rabi	30-11-90	15-01-91	As a special consideration.
18.	1990-91	Hot Weather	-	-	Canal closed for maintenance.
19.	1991-92	Kharif	31-07-91	31-08-91	-
				17-09-91	-
20.	1991-92	Rabi	30-11-91	30-12-91	As a special consideration.
				20-01-92	Due to representation of farmers.

noticed several cases of Ekrarnama, where the farmers were not aware of the actual situation. There are other indications which suggest that the lower level functionaries work under pressure. When the Irrigation Department receives too few applications, it extends the date, pressurizes Chowkidars and Karkoons to increase the number of demand applications, who, in turn, pressurize farmers and use other means to increase the number of demand applications. As seen from Table 4, less than 50 percent of the demand applications were received within the prescribed period; sometimes the number of applications is as low as 1 percent or 7 percent. There are several reasons for this and we will return to these issues when we discuss farmers' interaction with the irrigation system.

Table 4. Details of irrigation application for Anand Division of Mahi Project.

Year	Season	Duration	Total applications received in the duration	Cumulative applications received	Last date of application	% applications received within first prescribed period
1989-90	Kharif	16-07-89 to 31-03-87	1438	1438	31-07-89	07
		01-08-89 to 31-08-89	7366	8804	31-08-89	
		01-09-89 to 30-09-89	7670	16474	30-09-89	
		01-10-89 to 15-11-89	3247	19721	-	
1989-91	Rabi	Upto 30-11-89	9224	9224	30-11-89	41
		01-12-89 to 18-12-89	4134	13358	18-12-89	
		19-12-89 to 15-01-90	4948	18306	15-01-90	
		After 15-01-90	3923	22220	-	
1989-91	Hot Weather	Upto 31-03-90	5196	5196	31-03-90	38
		01-01-90 to 10-04-90	2828	8024	10-04-90	
		After 10-04-90	5570	13594	-	
1990-91	Kharif	Upto 31-07-90	5056	5056	31-07-90	26
		01-08-90 to 31-08-90	4506	9562	31-08-90	
		01-09-90 to 30-09-90	2300	11862	01-10-90	
		After 01-10-90	6899	18761	-	
1990-91	Rabi	Upto 30-11-90	6489	6389	30-11-90	52
		01-12-90 to 15-01-91	5432	11921	15-01-91	
		After 15-01-91	1537	13458	-	
1991-92	Kharif	Upto 31-07-91	208	208	31-07-91	01
		01-08-91 to 31-08-91	6333	6541	31-08-91	
		01-09-91 to 17-09-91	3371	9912	17-09-91	
		After 17-09-91	6281	16193	-	

CONDITION UNDER EXISTING DESIGN AND MANAGEMENT REGIME

As seen in Table 5, planned irrigation differs from actual irrigation. This might be due to three reasons: First, the cropping pattern that has actually developed is markedly different from the one proposed in that the areas under "heavy water using crops" are considerably higher than expected. Consequently, less area than planned for could be irrigated with the same amount of water. Second, there may be unauthorized irrigation which is not reported in the area irrigated. Third, in estimating areas to be irrigated, irrigation duties assumed are much larger than the actual while transmission and distribution losses assumed are smaller than the actual, resulting in less area than that planned for being actually irrigated. The actual cropping pattern, in fact, has changed in favor of water-intensive crops, particularly, rice, whose area is twice of what was anticipated in the project document. However, as we noted in earlier sections, even after meeting all the requirements of kharif crops, the Kadana dam would usually be full of water and, therefore, this cannot be a plausible reason for the decreased performance. The transmission loss in MRBC is assumed to be about 50 percent (1/2% seepage losses in main and branch canals, 70% of carrying efficiency of the distributaries and minors and 70% water application efficiency). One of the studies, however, estimated transmission losses to be 50 percent to 60 percent, or more (WMS P, 1983).

ANALYSIS OF WATER TABLE MOVEMENTS: TALUKA-WISE TIME SERIES DATA

There exists a good groundwater market in the MRBC command area. On an average, 175,000 (1.75 lakh) ha are irrigated annually by groundwater resources in the Mahi command. *A priori*, therefore, there appears to be a good conjunctive water use in the MRBC command area. However, a closer examination of data reveals that the water table is rising alarmingly in the head reach of the canal system.

An excellent system of monitoring the variations in the subsoil water table, evolved and implemented by the Gujarat Irrigation Department since 1957, highlights the direct and substantial impact of canal irrigation on groundwater conditions. Each year, two recordings are taken of the depth of the water table from the ground surface -- one before the onset of the monsoon and one after the monsoon -- on a sample of 1,450 wells in the MRBC command area.

A random sample of 155 wells spread over an equal number of villages was chosen out of a total of 1,450 observation wells representing the entire MRBC command area. For each taluka, simple averages were computed of the monsoon and the inter-monsoonal changes in water table during each year of the period studied. The levels of the water table at different locations would be affected by topographical features, but temporal changes in water levels would remain the same. Hence, the simple averages plotted are a good indicator of the water table fluctuations in the entire taluka. Figure 1 presents the movements in the water table in each of the seven MRBC talukas over the 1967-84 period.

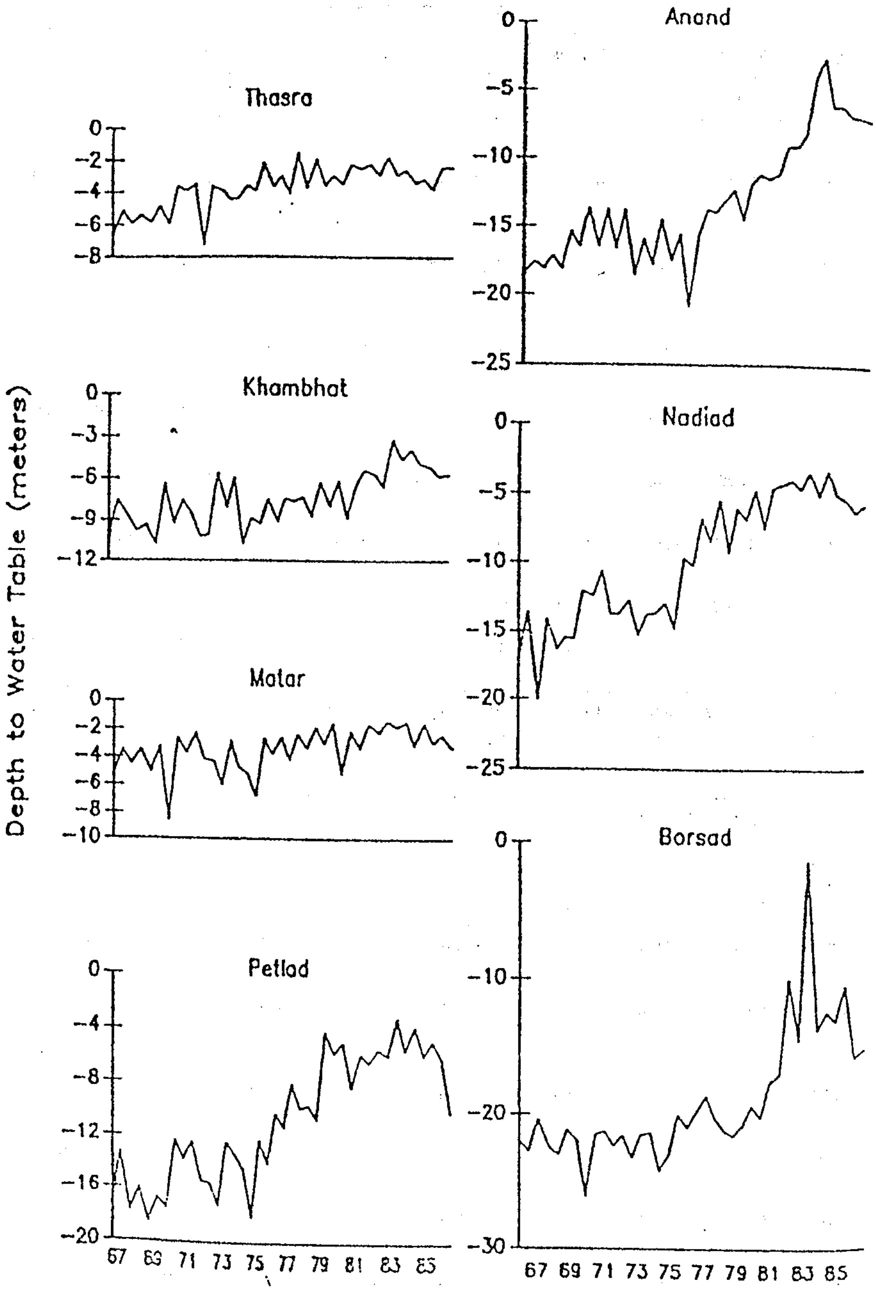
Table 5. Details of cropping pattern of Mahi Right Bank Canal Project.

C.C.A. : 2.12 LAKH HECTARES

Sr No.	Name of crop	Planned crop pattern ha	%	Year 1980-81 ha	%	Year 1981-82 ha	%	Year 1982-83 ha	%	Year 1983-84 ha	%	Year 1984-85 ha	%	Year 1985-86 ha	%
				ACTUAL CROP PATTERN											
1.	Rice Coarse Fine	 40486 16194	 19.03 7.61	59864	28.14	62201	29.24	66956	31.48	62215	29.25	72207	33.95	57735	27.14
2.	Kharif & others	51498	24.21	1047	0.49	550	0.26	2823	1.33	603	0.28	866	0.41	74	0.006
3.	Wheat & other Rabi crops	68583	32.24	13305	6.25	16702	7.85	14202	6.68	9047	4.25	11605	5.45	10319	4.85
4.	Follow-on crops	34332	16.14	2269	1.06	2865	1.35	3163	1.49	2097	0.98	2040	0.96	5520	2.59
5.	Perennial crops	2834	1.33	895	0.42	1308	0.61	2019	0.95	926	0.43	760	0.36	635	0.30
6.	Tobacco & Cotton	34332	16.34	13135	6.17	7996	3.76	9061	4.26	7795	3.66	11087	5.21	9638	4.53
7.	Hybrid Bajri	12145	5.71	11015	5.18	12761	6.00	15708	7.38	13076	6.15	10054	4.73	12277	5.77
8.	Groundnut	-	-	637	0.30	3582	1.68	8760	4.12	15048	7.07	11638	5.47	2297	1.08
	Total:	260404	122.6	102167	48.01	107965	50.75	122692	57.69	110807	52.07	120257	56.54	98495	45.266

Sr No.	Name of crop	Year 1986-87 ha	%	Year 1987-88 ha	%	Year 1988-89 ha	%	Year 1989-90 ha	%	Year 1990-91 ha	%
		ACTUAL CROP PATTERN									
1.	Rice (coarse)	78054	36.70	24411	11.48	75449	35.47	75074	35.29	65760	30.91
2.	Kharif & others	9407	4.42	39962	18.78	1364	0.64	1776	0.83	3477	1.63
3.	Wheat & other Rabi crops	17856	8.31	34507	16.22	16429	7.72	16042	7.54	31157	14.65
4.	Follow-on crops	3276	1.54	4543	2.13	3654	1.72	2918	1.37	506	0.24
5.	Perennial crops	1363	0.64	2140	1.00	3047	1.43	4419	2.07	2972	1.40
6.	Tobacco & Cotton	12146	5.71	9315	4.38	12106	5.69	12337	5.80	885	4.18
7.	Hybrid Bajri	18627	8.76	52913	24.88	16257	7.64	14013	6.59	1275	0.60
8.	Groundnut	12337	5.80	7048	3.13	5432	2.55	3721	1.75	961	0.45
	Total:	153066	71.88	174839	82.00	133738	62.86	130300	61.24	106993	54.06

Figure 1. Behavior of the groundwater table in the seven Talukas in the Mahi Right Bank Canal Command, 1967-85.



Several emerging patterns are of interest. First, in talukas like Thasra, which are located at the head of the canal system and in parts of Matar, the bulk of which have poor internal drainage capacity, the water table was already quite high in 1970, when our analysis began. Second, the trend rate of rise in water table has been far slower in these talukas than in the Borsad, Anand and Nadiad talukas where the water table was lower to start with. The "carrying capacity" of the aquifer has been reached rapidly, as it were, and many parts of these talukas can now retain much smaller portions of seepage from rainfall and from canal flows than before (Burt 1964; Dasgupta 1986). In many low-lying areas of these talukas, such as the villages of Kalsar, Agarwa and others in Thasra, much of Khambhat and neighbouring villages from Matar and Petlad, the diseconomies of waterlogging have already reached serious proportions. In some Thasra villages, many fields have long been abandoned and are devoid of much vegetation even during summer. On the other hand, the areas which are far away from the head and which have well-drained soils, rapid rises in water tables had stimulated major investments in groundwater irrigation.

In a simple modeling exercise using the 1967-85 annual data and aimed at understanding the trends in water table movements, the pre-monsoon depth of the water table in a given year, Wt was seen as the sum of that in the previous year and the net change in storage consisting of two elements: D_{1t} representing the monsoon rise in the water table and D_{2t}, the inter-monsoon change (mostly fall) in it. That is:

$$W_t = W_{t-1} + D_{1t} + D_{2t} \quad \ldots\ldots\ldots\ldots (1)$$

A number of regressions suggested that (D) was strongly influenced by rainfall (R_t in meters), canal water release in the head reach during the kharif season (KR_t in million day-cusecs) and W_{t-1}. The best fit obtained was:

$$D_{1t} = -3.29 + 0.273\,R_t + 0.277\,KR_t + 0.23\,W_{t-1} \quad \ldots\ldots\ldots\ldots (2)$$
$$(-2.15)\ (4.71)\qquad (1.17)\qquad (3.22)$$

$$R^{-2} = 0.236$$

Figures in brackets below the coefficients represent t-ratios. The intercept dummies introduced for talukas were insignificant except for Borsad (6.33) and Matar (2.12). Likewise, D_{2t} was found to be influenced by the change in the density of groundwater based water lifting devices measured as the ratio of the number of electrically operated water lifting devices per 1,000 ha of cultivated area (L_t) and the canal water releases during the rabi and summer releases (RSR_T in million day-cusecs).

$$D_{2t} = -1.39 - 0.0446\ L_t + 0.133\ RSR_t \quad \ldots\ldots\ldots\ldots (3)$$
$$(-6.03)(\ 2.58)\quad (-2.48)$$

$$R_{-2} = 0.4196$$

Here too, the taluka-wise dummy variables for the intercept terms were significant for Nadiad (2.49), Petlad (2.79), Matar (2.85) and Khambhat (2.5) whereas 1.39 was the intercept for the Thasra, Anand and Borsad talukas.

By substituting (2) and (3) into (1), we get a water balance equation that reflects one dimension of the optimization problem discussed earlier. Note that the intercept term will change across talukas

due to significant dummy variables in equations (2) and (3). The general equation that results is:

$$W_t = -4.68 + 0.273R_t + 0.277KR_t + 0.133RSR_t - 0.0446\,L_t$$

$$+ 1.23\,W_{t-i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

While our direct interest is in equations 2 and 3, equation 4 also offers useful insights. First, it shows that while all canal water releases raise the water table, kharif releases (KR_t) raise it over twice as much as do the rabi and summer releases (RSRt); as a result, where feasible, releasing more water in rabi and summer at the expense of kharif may help reduce waterlogging. Second, the large value of the coefficient and its statistical significance suggests that the higher the water table is in an area, the smaller the value of D_{1t} and the lower its capacity to absorb rainwater and canal water seepage. Alternatively, in a dynamic sense, the greater the groundwater pumping in an area, the larger the space available for absorbing more water and the greater the recharge to the aquifer.

Groundwater pumping, denoted by L_t, emerges as the only antidote to the rising water tables in our model, thereby proving the value of tubewells in providing vertical drainage in waterlogged areas. The extent to which groundwater is pumped varies across talukas. Regression analysis indicates a strong quadratic relationship between the build up of pumping capacity and the depth of the water table.

An equation with high t ratio but low explanatory power indicates the following:

$$L_t = 9.4 + 2.5\,W_t - 0.086\,W_t^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

(2.91)(3.37) (2.64)

$$R^{-2} = 0.126$$

In all the areas with high water tables, groundwater irrigation is either technically infeasible or economically unattractive. For instance, in Khambhat and parts of Matar, L_t is low because groundwater is saline and difficult to irrigate with. Other high water table areas such as Thasra in the head reach of the system are typically well served by canal water which is reliable, abundant and several times cheaper than groundwater. As a result, groundwater irrigation is on the decline in such areas. Private investment in wells tends to stagnate or even decline in precisely those areas where their vertical drainage is most needed; on the other hand, it picks up momentum in those areas which are poorly served by canals (and, therefore, poorly recharged) where it may potentially result in over-exploitation of the aquifer (Shah 1988).

SELECTED DISTRIBUTARIES

The selection of three distributaries to represent the whole Mahi-Madana system was an importance first step in conducting the research at the subsystem level. Umreth Distributary located advantageously in the top end of the system and taking off from the main canal has an impressive performance, its annual irrigation intensity exceeding 165 percent. In contrast, Borsad Distributary's performance (annual irrigation intensity of 40%) is low considering its middle level position in the system. This has been mainly attributed to topographical factors. However, apart from the original canal design, lack of adequate water control capacity and other factors are more responsible for this poor performance. We will investigate these issues in greater detail subsequently.

Sansad Distributary has typical characteristics of the secondary canals in the Cambay region with clayey soils, and with consequent monoculture of kharif rice. Since each of these distributaries have variegated soils, and physical and locational conditions, the study of each, individually and in contrast with each other, does provide a better understanding of the system performance.

Minors located in head, middle and tail ends of the canal were selected within the representative distributaries since there was a significant difference in irrigation intensity from head to tail in most distributaries.

Within the selected minors, the methodology was to select sample farm holdings operating within sample outlet commands, but located at different points along the water course. This was done using minor and outlet command maps and records available within the irrigation department and through observation of actual field conditions.

In addition to the characteristics described above, other features of our selected distributaries are:

1. Umreth, Borsad and Sansad distributaries serve command areas of 2,532 ha, 2,393 ha and 3,200 ha, with total canal lengths of 32.35 km, 24.48 km and 40.79 km and design capacities of 128 cusecs, 62 cusecs and 150 cusecs, respectively.

2. Umreth Distributary has 9 minors which command 80 percent of the area. In Sandad Distributary 87 percent of the area is commanded by minors, and the direct outlets are few in number.

3. In contrast, the number of direct outlets in Borsad Distributary are far too high and command nearly 60 percent of the total CCA. This considerably reduces water control capacity, as the release of small quantities of water becomes difficult to control. Besides, maintenance costs of direct outlets are also greater and with reduced water control, less water is available for downstream users.

4. There are only four minors in Borsad Distributary and therefore in our selection of sample minors, two direct outlets in the tail were also chosen in addition to two minors to represent the distributary hydraulic system.

METHODOLOGY FOR MEASUREMENT OF WATER DISTRIBUTION

Following the selection of three representative distributaries, an attempt was made to understand the delivery performance at the head of secondary canal reaches and at outlet/farm gate level. Discharge readings in the Mahi-Kadana system at zero of distributary were being taken every two hours by the Irrigation Department staff. The Water and Land Management Institute (WALMI) measurement team was engaged in spot checking to make sure this data is accurate or within permissible error. These measurements can be made into expressions of equity and reliability, by constructing ratio-measures. A few readings have been taken at the minor level every three days, the frequency could not be increased due to logistical and supervisory constraints. Minors were calibrated after using leveling instruments; this measure is only an approximate indicator of the actual discharge.

At the farm-gate level, both subjective and objective investigations of water availability are being carried out. Farmers are interviewed frequently to gather data on dates and duration of irrigation. However, there are two kinds of problems encountered in this effort. One is, since the main kharif crop is rice and it requires long hours of irrigation, interruptions and obstructions are not uncommon, especially during peak demand and the farmer himself may not be able to report the duration of each irrigation accurately. Second, farmers are often under the impression that their responses will influence water allocations and the possibility of strategic bias cannot be ruled out.

Discharge measurements were also made at field level every three days for each outlet. Given that it is almost impossible to know in advance which farmer will receive water at a specific time, one had to literally follow the course of water flow. Discharges very considerably within the same day and at different points. Due to supervisory constraints, measuring at each field level was ruled out. These measurements, therefore, can indicate the degree of conveyance loss at the water-course level and provide data on the duration and total volume delivered for a few field sites.

Field conditions for the rice crop were monitored (using a method similar to the one developed by the International Rice Research Institute to get a better idea of water adequacy at field level and also account for the influence of topographical and soil variations on the moisture level. Every third day, water status of the selected plots was noted and ranked as follows:

1. Soil dry/water shortage.
2. Soil semi-wet/moderate or low shortage.
3. Soil wet/saturated condition.
4. Standing water, with height of water measured at different points and the mean value taken.

Based on these observations, a Water Adequacy Index (WAI) was computed for each plot using a weighing procedure. The period considered was from September 1st to October 20th, with minor variations according to location to account for different planting dates. The period covered the water sensitive critical phase of the rice plant. The weighing assigned was the number of days in the 1st category plus double the number of days in the 2nd group plus triple the number of days in the 3rd category and four times the number of days in the last category. A score of 4.1 was assigned to a field with 1 cm standing water, 4.2 for 2 cms and 4.3 for 3 cms and so on.

This methodology closely parallels the one used by Murray-Rust, et al. (1984), except for the addition of information on height of water level in the field. The minimum score, since it was calculated for 17 days, would be 17 and the maximum greater than 68, depending on the height of field water level.

After the WAI is calculated for each plot, it can be regressed against distance from the outlet/water source to examine whether there is any secular decline in the index with increase in distance from the water course. Further, the average WAI for head minor, versus tail minor can be calculated, as well as for a distributary for comparison.

Needless to say, the WAI as an observational measure is applicable only to the rice crop. Since rice is the dominant crop in these areas for kharif, it is not unreasonable to concentrate on study delivery performance for that crop.

Analysis is still being carried out for Sansad Distributary and results are not included in this report.

For the rabi season, the touch and feel method is being used for wheat and tobacco crops to record field conditions every day. While conjunctive and groundwater use is often commonplace in downstream reaches, the issue of efficiency and equity of canal water versus groundwater will be addressed through a survey-based farmers study at the Petland Distributary.

These statistics alone will not determine whether physical system limitations, operational problems or socio-political and management problems are the cause of good/bad performance. These can be identified through other components of the project study.

DELIVERY PERFORMANCE AT DISTRIBUTARY AND FARM LEVEL

For discharge readings at the distributary level, we had to rely on the Irrigation Department's data. The target discharges and area to be irrigated, as explained earlier, do not reflect anticipated demand and therefore the DPR ratio itself is not a very meaningful figure. And, for Umreth Distributary, no target figures were available. A third factor was that the WALMI team was able to carry out only a limited number of spot-checking measurements using more accurate measuring devices. Given these constraints, we attempt to draw a few inferences from Table 6 and Table 6a.

Table 6. Discharges at distributary head regulator, Borsad Distributary.

Rotation No.	Rotation Period Discharge cusecs	@ Avg. Daily Variation (DPR)	Coeff. of Target Ratio	@ Avg. Actual Variation	Coeff. of Target	AI/DC	Achievement
3)	16/08/91 to 31/08/91	44.878125	16.131	0.932532	16.126632	1.85	1.01
4)	01/09/91 to 15/09/91	23.345000	45.50	0.200010	59.828	1.79	1.53
5)	16/09/91 to 30/09/91	62.963333	9.43	1.051726	9.44114	1.74	1.58
6)	01/10/91 to 14/10/91	65.857142	13.90	1.030167	13.90318	1.65	1.47
7)	16/10/91 to	49.642857	31.10	1.263636	31.11006	1.85	2.04

Table 6a. Umreth Distributary.

Rotation No.	Rotation Period	@ Avg. Daily Discharge in cusecs	Coeff. of Variation %
3)	13/08/91 to 28/08/91	115.625	2.592
4)	06/09/91 to 21/09/91	115.625	8.63135
5)	27/09/91 to 07/10/91	93.636	13.86646
6)	16/10/91 to 24/10/91	113.333	8.31884

During the first two rotation periods, the canals were closed due to rains. Although rainfall in this period is a regular occurrence, it seems that rainfall (likely) is not taken into account. The coefficient of variation is fairly low for Umreth Distributary except in the third rotation, when it is higher and since data on the area irrigated by crop for the corresponding period is not available, it is difficult to give the possible reason.

In comparison, the coefficient of variation for the comparable time period for Borsad Distributary is much higher, as is to be expected from a distributary located further downstream. Using the target figure for this subsystem, the DPR ratio was calculated for each rotation period. Since the canal was closed for nearly a week in the third rotation due to breaches, the average daily discharge is low and the coefficient of variation high. During the peak demand period of 15th September to 15th October, the discharge was close to the design capacity of 62 cusecs, and the DPR ratio was close to one.

However, there is always a lag in water delivery in response to crop water demand in Borsad Distributary at the beginning of the critical phase of the rice crop, creating moisture stress and leading to excess demand even in the head reaches. The results are hoarding of water and overirrigation. The operation of minor gates do not follow any closely set pattern. The Section Officer's decision to close a particular minor and open another is not known more than a day or so in advance. This is the case even after the end of the monsoon, when there has been sufficient time to assess the area cropped under rice. Therefore, one cannot draw the conclusion from the DPR alone that the canal operations are functioning efficiently, even if we accept the discharge readings at face value.

We had regressed the WAI on distance from the outlet for all the plot observations in Umreth Distributary, using dummy variables for minors.

The results are as follows:

$$\text{WAI} = \underset{(6.72)}{57.70} - \underset{(-4.10)}{0.0062}\ \text{DISOUT} + \underset{(4.78)}{11.95}\ \text{MM}^{*} + \underset{(2.33)}{5.71}\ \text{TM}^{**}$$

$$R^2 = 0.39$$

** MM – Middle Minor ** TM = Tail Minor

These results indicate that if a plot were to be located just adjacent to the outlet of the head minor, the expected WAI would be 57.70, whereas for a plot similarly located in the middle minor, the expected WAI = 57.7 + 11.5 = 69.65, and the comparable one for the tail minor = 57.7 + 5.71 = 63.41. Inspite of being located at the head, the minor has a lower WAI, primarily due to its higher topography relative to the other minors, although it commands a smaller CCA. We do not believe that this can be generalized for all the distributaries as in MRBC.

All the coefficients are significant at 99 percent. The negative coefficient on DISOUT confirms our expectation that WAI is inversely related to the distance along the field channel and decreases by 6 units for a 1,000-ft increase in the length of field channel. Spatial inequity in terms of lesser water being available for tail-end farmers in the water course is therefore a clear-cut phenomenon of even the head distributary.

No trend in increase/decrease in number of irrigations per plot and duration of irrigation along various points in the water course was observed. The qualifications expressed in the earlier section about getting accurate information on these variables must however be kept in mind. Sample discharge measurements along the water course revealed the wide variations in flow at field level. Differences in flows from head field to tail field vary from one outlet command to another, depending on the topography, number of intermediary fields, and the bifurcations, lengths, and conditions of the field channels. Water management under these conditions also becomes a difficult task.

In our sample plots for Borsad Distributary, the number of canal irrigated rice plots was around thirteen. With a few observations, a regression could not be run as for the previous secondary canal. However, the average WAI is lower for Borsad Distributary than for Umreth Distributary.

ANALYSIS OF CROP DISTRIBUTION BY IRRIGATION SOURCE

Figures shown in Appendixes 1 and 2, pertaining to outlet command, are data gathered for the sample outlets in a survey by our resident field staff and are more reliable than the Irrigation Department data.

Data in Appendix 1 shows that the irrigation intensity (canal) decreases as we move towards the tail. It also appears that wherever canal water is available, rice is the preferred crop except in lands located at a higher level than the canal, where water has to be pumped using electric motors, and where the crop grown is tobacco. Besides, tobacco, unlike rice, requires regulated irrigation and cannot tolerate flooding; therefore better water control is required to irrigate this crop. The area under perennial crops and bajra is quite negligible.

In Borsad Distributary (Table 7) a large number of middle and tail outlets are non-functional while one tail minor, Chuva, is defunct. There are also a number of unauthorized or *Kutcha* outlets from which direct pipes are laid directly to field, and these exceed the number of authorized (*pucca*) in certain locations. These Kutcha outlets also have capacities greater than 1-cusec discharge, which is the design capacity of the pucca outlets. Consequently, water control by the irrigation staff is poor, and as discussed earlier, even in the peak season no systematic procedure is followed in rotating water flows within a distributary.

Table 7. Count of authorized/unauthorized outlets.

Distributary	Name of Minor	Design Discharge	Outlets Authorized/ Functional	Non-functional Outlets	Kutcha Outlets
Umreth	SM 2R (Head)	4.70	5	-	6
	SM 52 (Middle)	19.50	13	-	10
	SM 91 (Tail)	15.10	12	-	8
Borsad	SMGL (Head)	7.95	8	4	4
	Vehra Minor (Middle)	19.20	11	13	5
	Direct Outlets	62.00	54	13	16

The Borsad Distributary command also has certain interesting socio-political dynamics which influence water allocation. Most of the farmers in the head areas come from Borsad and belong to the Solanki community which, although a backward community, is dominant politically. They are also considered to be less cooperative and more quarrelsome among themselves compared to the Patels.

Whether the original canal design was itself influenced by the presence of this community is not known. The villages of Vehra and Dedhadra in the middle and the tail village of Debassi consist mostly of Patels, Parmars and others. At two outlet commands in the head minor, some influential farmers from the Solanki community with large land holdings have been able to prevent canal water from reaching the tail outlets, so that they would have more buyers for their tubewell water.

Appendixes 2A to 2H give the outlet-wise area irrigated by source and the crop distribution. The area irrigated by canal decreases progressively from the head minor towards the tail outlets and consequently, so does the area under the rice crop. In the tables, we see that in the tail outlet command, most of the area is rain-fed and bajra is grown. Six out of nine farmers growing bajra have nonagricultural off-farm activity as the primary occupation, and with the non-availability of canal water, the choice of bajra, which requires relatively less labor and other inputs, appears reasonable.

Rice is the main crop in Vehra minor command, whether irrigated by canal, or well water, or both. Farmers in the upper reaches of Vehra minor get water almost at will. Besides, the outlet gates are in a state of disrepair, with leakages from the minor. Consequently, there is, almost always, excess water, which is undrained. Severe waterlogging problems occur in and around the core outlet command area of the middle outlets, again, from minor leakages and stagnating rain water. With field channels below the farm level, and with channel configuration being very irregular with a number of bifurcations, the water flow from field channels is almost nil in the tail of the outlet command. In the tail outlet of Vehra minor, there is a tank which overflows during the monsoon giving a picture of lax and unregulated water distribution. Farmers' cultivation practices also reflect a fair degree of indifference during the kharif season.

Lift irrigation from the canal is practiced in the tail of direct outlet no.1, with canal water being delivered in to a defunct well and then pumped out and sold at the groundwater market rate of Rs 15 per hour. Tail direct outlet No. 2 has only tobacco grown in its command area and is irrigated entirely by well water. Canal water has not reached this outlet for the last several years.

FARMERS' RESPONSE TO WATER DISTRIBUTION

A number of farmers were interviewed in the representative distributaries of the Mahi-Kadana system to record their experiences in regard to operating procedure and water allocation and their assessment of performance. Irrespective of location, farmers were unanimous in declaring that the procedure for submission of forms for canal water is tedious. The forms require certification by the village *Talati* and he was often unavailable when needed. Senior Irrigation Officials, on the other hand, have complained that the date for submission of application gets extended to the middle of the season, causing problems in collecting dues. The head-distributary farmers favored continuous flows of water for any kind of rotation. Their complaints, by and large, centered around the poor condition of some of the physical structures and field channels and consequent leakages.

Growing dissatisfaction was expressed with regard to timeliness and adequacy of water flow as one moved further along the water course. When quizzed about the political pressure brought on by farmers on the Irrigation Department, they claim it is necessary for the active functioning of the canal in the peak demand period.

Upstream farmers of the middle distributary were also against any kind of rotation at minor level; rather they felt that the water flow was quiet erratic and there was not sufficient communication from the Irrigation Department with regard to the operational schedules of minors and owners. The middle farmers of this distributary face many problems in regard to the current operating procedures, or in reality, what they perceive as lack of any such procedures. They categorically stated that the main problem was caused by the inability of the Irrigation staff to maintain proper flows at the lower reaches. They were inclined towards fixed rotation in the minors, if it enabled them to receive water in the peak/critical period of kharif rice crop growth. They have suggested that following the Warabandi type of fixed delivery schedule is one way of bringing about equitable distribution of water in the command area. They view lower irrigation officials as being concerned with paper work and the higher ones as indifferent to their concerns. Wastage of water and hoarding due to uncertainty in flow upstream were given as reasons for the deprivation downstream. Usual complaints on the weed growth in the minors on field channels were almost universal.

A documentation of the main practices of farmers to gain water control in response to slack operating procedure and the inability of the field staff to enforce certain rules are given in Table 8. Given that it is the natural tendency of farmers to attempt to reduce the distance of water delivery to their fields, construction of kutcha outlets and pipelines are not surprising. Staggered or late planting is, to some extent, a cause for wastage of water. Also, in head reaches with abundance of water, flooding and impounding of water to remove weeds can partly account for irrigation beyond the economic optima.

Farmers at the head usually block any attempt at reform by the tail-end farmers. Besides, the concerted and consistent voicing of protests by the tail-enders has diminished because of:

1. Availability of groundwater and prevalence of competitive water markets.

2. Increases in effective cost of canal irrigation with increasing monitoring costs and necessary bribery charges, more so for small farmers.

3. With land holdings being relatively small in Kheda District and opportunity costs of own-labor and other inputs being more for water-intensive crops such as rice and banana, some tail-end farmers chose to grow tobacco or bajra.

Table 8. Farmers' responses to de Jure rules and de facto operations.

Sr No.	De jure rule	De facto operation
1.	Applications/indents are expected to be submitted for receiving water.	Unauthorized irrigation forms the major portion of the total irrigation.
2.	Farmers are not supposed to operate outlet gates or tamper with physical structures.	a. Head-end and powerful farmers open and close outlet gates at will, whenever water flows in minor/ distributary.
		b. Even cross-regulators and minor gates are opened/ closed by farmers in the night. Minor gate rods are removed to allow for low level of discharge, when minors are closed.
3.	Water conveyance structures, except for field channel, are not to be laid except with special permission.	There is large proliferation of *kutcha* outlets, with direct pipelines laid out to fields.
	Intervention in water flow in distributary/minor by farmers is illegal.	a. Farmers frequently resort to raising the canal water level by using and blocking minor with any obstructive material, (sometimes including broken pieces from canal lining) and then irrigating through pipes or outlets, if they are located nearby.
		b Cutting of minor beds, to take water directly to the field.
4.	It is illegal to obtain water from an outlet of different command.	With tail-end farmers of the designated outlet, this does happen.
5.	Field staff should intimate in advance about water delivery and canal closure.	Such decisions are usually made ad hoc and not often communicated to farmers.
6.	Field staff must maintain accurate command area records and maps.	a. Outlet command boundary and farm holding records may change, but are not always updated.
		b. *Chowkidar* keeps record of area irrigated, duration, etc. mainly on the basis of guesswork.
		c. In a few cases, *panchnamas* are not issued to farmers who actually irrigated illegally and *gratis*.
7.	Senior supervisory staff are responsible for visiting and assessing the progress in irrigation.	Responsibilities are often shirked. Assistance and protection to lower staff is also not adequately provided.

Overall, as mentioned earlier, the water delivery system of the Mahi-Kadana project relies on a high degree of flexibility in response to differing irrigation requirements for the mixed cropping in the command area, during any particular season. This is in contrast to the Warabandi system, where fixed schedules are rigidly adhered to, causing water scarcity for every user. Water availability is not considered a constraint in Mahi project with the existing storage capacity exceeding total water requirements. However, it appears, from an understanding of the farmers' experience in certain selected territory blocks, that adequate and reliable delivery of water is achieved in sections of the command area only through over-irrigation.

Over-irrigation at head reaches and low lying areas substituted for an organized and systematic operational approach to achieve more equitable water distribution in the command area. A resigned attitude of accepting these situations at the head and the tail of an irrigation command as an irremediable natural phenomenon is reinforced by neglect of physical structures downstream.

THINKING ABOUT IMPROVING PERFORMANCE OF MRBC

Irrigation performance has generally remained relatively poor after widespread and repeated physical improvements, extensive training efforts and attempts to elicit farmer participation (Vermillion 1991). In the MRBC, at least three experiments related to farmers' participation have been carried out. The first, was at Anklav Distributary by WALMI; the second, by IRMA staff and students, was in a village called Ashi; and the third is presently being implemented by WALMI in Sardarpura sub-minor of Bhorada Distributary. The Anklav intervention was capital-intensive, and extensive repair of distributary and water courses were carried out. A recent evaluation study suggests that while water use efficiency has increased, equity and other issues related to water use and management remain unresolved (Patel and Brahmhbatt 1991).

The Ashi experience was equally discouraging. As long as the intervention agency, IRMA, was directly involved, the canal water reached the tail end of the minor. A society was formed and registered under the Societies Act and once IRMA withdrew from the project, the supply of water became erratic. The farmers neither got water at the proper time nor in adequate quantity. As a result, they became disillusioned. The third project at Sardurpura sub-minor is still at the formative stage. If it succeeds, it will be a least-cost intervention. The main drawbacks in all these projects are: (a) it takes considerable time for the intervening agency to make an impact and seek farmers' participation, and (b) the supply of a sufficient quantity of water was assured in all the three cases but it is unlikely that this assurance can be fulfilled to the whole of the MRBC command.

Inspite of these reservations, we are in favor of including farmers' organizations in canal system management. It should be mentioned at the outset that all the three experiments conducted in the MRBC, although related to farmers' participation and organization, did not aim to empower farmers. The conditions for their participation were not created. Above all, these experiments sought to enlist farmers' participation using moral persuasion rather than a business approach. As a result, when the intervening agency withdrew, the system collapsed.

Government line-agencies are normally centrally funded organizations which operate from the top, following standard administrative procedures. They tend to maximize budgets and staff. Budgets, staff advancements, salaries and benefits are not normally related to management performance. Line-agencies are generally accountable only to other government institutions and do not have an economic market for their "outputs." The result is a proliferation of standard procedures and hierarchical controls. Staff performance, to the extent that it is evaluated, tends to be based not on producing outputs, but on conformity to higher authorities regarding the use of inputs (Rainey 1983). The existence of low and fixed salaries which are not related to performance outcomes creates a condition often leading to corrupt practices. Management behavior is often constrained by rigid regulations and is based more on top-down quotas and plans than on dynamic field conditions and demand for services. Therefore, there is a need to search for alternative institutional options which can be (i) replicated cost effectively and (ii) have incentives to manage in such a way as to achieve good performance.

In order to identify an alternative institutional option, one needs know strengths and weaknesses of the present system. The strengths of the present system are: (i) fairly good water control capacity through physical component of the system, (ii) enough water in the reservoir, and (iii) relatively small transmission losses in the main and branch canals. The weaknesses are: (i) badly managed minor and outlet structures, (ii) increasing water table on head reach of canal system, (iii) poor revenue realization and huge overdues; even operational costs are not covered; and (iv) the system does not have any mechanisms to address farmers' concerns and grievances. We, therefore, recommend that privatization of canal systems at secondary level would improve the performance.

PRIVATIZATION OF CANALS AND SPATIAL ALLOCATION OF WATER

Consider a contract between the Irrigation Department and a private agent, whereby the agent bids and purchases a certain volume of water per annum from the department. A supply range is determined based on total water availability in the reservoir, system design and maintenance of desirable water table in the specific command areas. The inter-temporal and spatial allocation of water is left to the purchaser of rights for delivery of water.

A model of demand and supply of water with a profit maximizing agent as supplier of water to farmers is presented here to examine the impact on optimal area commanded, water stock utilized and water charges.

A monocrop, and one-period model of an irrigation system with water supplied from a source point in a canal are assumed. Farmers are located at different points in the canal at a varying distance, say x, from the water source. Let F (x) be the total volume of source water sent to a farmer located at x and f (x) the net water received after conveyance losses.

Then $F(x)\, h(x) = f(x)$ - (6)

Where $h(x)$ is conveyance efficiency and $h(o) = 1$, $0 \leq h(x) \leq 1$

Assuming water as the only input in the production process and all farmers as homogenous, the agricultural output is given by the function f (x); then MVP (Marginal Value Project) at farm level.

$= MVP_f = Pf'(x)$ - (7)

Where P is output price

$MVPs = pf'(x)$ - (8)

From (6), taking first order conditions of Equations (6), (7) and (8)

$MVPs = pf'(x) = pf'(x)\, h'(x) = MVP_f\, h'(x)$ - (9)

That is, the MVP at the farm level is a decreasing function (due to conveyance losses) of MVP at the source.

Now for an operational project with a fixed capacity,

C (W) is the short-run total cost function - (10)

Since supply of (W) water is fixed in the short run, $C'(W)$, is the marginal cost of distribution/allocation which includes maintenance of fields, channels, outlet gates, and monitoring of water delivery at farm level. $C'(W)$ increases with increase in distance; equating the marginal cost with marginal benefit according to of profit maximizing,

$MVPs = MVP_f\, h'(x) = C'(W)$ for each individual farmer - (11)

That is, for optimization, the MVP at source should be equal for all farmers. However, the MVP at farm level decreases with distance from the source. The optimal water supply W will also be determined by the above condition.

If the agency were to price water in terms of marginal cost of water delivery at farm level, then it will have to charge tail-end farmers more for same/less water delivered.

Now, given that (a) there are economies of scale in minor canal operation within the efficient boundary given by the allocation rule in Equation (11) and (b) water scarcity is certainly not a problem in canal water supply, the purchaser of water rights would be able to supply water to the tail end as long as MVP > than C' (W).

The issue of differential water pricing still remains. First of all, transaction costs of enforcing different water charges based on location would, in all likelihood, lead to uniform water pricing by the agent within the efficient boundary of command area. Besides, uniform water charges also serves the purpose of full cost recovery, and efficient water allocation. However, farms at head end will, in effect, be subsiding farmers at tail end for water delivered at source.

A substantial improvement in performance over the irrigation bureaucracy management of the secondary command area can be expected in terms of the following:

a) Canal water prices would increase from the current subsidized rate; the upper limit would be the well water/tubewell price. Increase in canal water price would result in more water-use-efficient cropping, especially in the core command area, where currently canal water is cheap, abundant, and reliable (see Appendix for the cost of irrigation by different sources).

b) Incentives for both canal operators and farmers to avoid wastage due to leakages and over-irrigation, and thereby reducing waterlogging in low lying areas.

c) A reduced supply at the head reaches and higher water charges would encourage the development of groundwater potential and activate water markets in these areas, where water tables are rising dangerously. A balanced conjunctive usage in the overall command area is certainly a desirable goal.

d) Lift irrigation is practiced in farms located higher in relation to the canal and those in proximity to the drains. The costs of lift irrigation are high, since both canal water charges and energy costs of operation are included. With more competitive canal water pricing, rationalization of lift irrigation charges is bound to follow.

e) Last, but not the least, is improved revenue collection for the State Government, which is suffering from poor cost recovery in canal irrigation projects.

There are enough indication that private investment will not be lacking for the improvement of field channels and water courses. For example, in Borsad Distributary, there are many farmers who, for different reasons, have invested in pipes and water channels to lift water from the distributary. They irrigate their own crop and sell water to their neighbors and charge rates almost equal to tubewell water prices.

The extent of such investment is shown in Table 9. It could be seen that the first seven farmers who are located at the head of the distributary have made significantly higher investments than others located downstream. Therefore, the Irrigation Department will only be required to ensure that a proper supply is maintained at offtake points of minors and sub-minors.

*Table 9. **Private investments in pipes and water channels in Borsad Distributary.***

Particulars	Total	First Seven
No. of farmers	14	7
Average size of the pipe	9"	9"
Total length of the pipeline (in feet)	20,200	17,000
Approximate total expenditure (at current prices)	173,450	146,000

Doubts, however have been raised about the efficacy of privatization of secondary canal systems, on the following grounds:

i) In order to prevent farmers from operating the system as they feel like and as they seem to do at present, the private manager will have to develop better controls and a means of implementing his controls.

ii) The private manager will have to try to collect his fees in a system where many farmers refuse to pay fees; collection cost may be high and if the manager has to rely on the legal system, and he may find it uneconomic to collect fees.

iii) The length of contract is also important. For example, if contracts are sold annually, the private manager has no motivation to undertake any regular maintenance. Further, such contracts might be used to exploit others.

CONCLUSIONS

In this paper, an attempt has been made to understand the operating mechanisms of the MRBC in Gujarat. It appears that the physical conditions of main and branch canals are fairly good; operation plan and water delivery schedule are prepared on the basis of different criteria and there is inconsistency. Water availability is not a limiting factor. However, we observed several shortcomings in system management: (i) revenue realization does not cover even operational expenditure, (ii) Irrigation Department does not have any control over water distribution below distributary level, (iii) there is no effective system to redress farmers' grievances, (iv) the system depends too heavily on lower level functionaries for demand collection and water distribution, and (v) the water table is rising alarmingly at the head reach of the canal. The main problems in regard to farmer participation were found to be of: (i) scaling up, and (ii) assurance of a abundant supply of water. It has been suggested that privatization of canal systems at secondary level would improve: (i) spatial distribution of water, (ii) parity between canal and tubewell irrigation costs, (iii) better conjunctive water management, and (iv) revenue realization.

Appendix 1

UMRETH DISTRIBUTARY

CROP DISTRIBUTION BY SOURCE OF IRRIGATION

Sr. No.	Name of the Minor/Outlet	Total CCA	CANAL Rice ha	CANAL Tobacco ha	CANAL Others ha	CANAL Total ha	WELL Rice ha	WELL Tobacco ha	WELL Others ha	WELL Total ha	BOTH Rice ha	BOTH Tobacco ha	BOTH Others ha	BOTH Total ha
1	HEAD SM 2R:-	110.97												
(i)	H.O.	7.63	6.01	0.20	0.20	6.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(ii)	M.O.	12.60	4.68	1.81	0.35	6.84	0.00	0.65	0.00	6.65	0.00	1.81	0.00	1.81
(iii)	T.O.	18.17	1.72	0.00	0.00	1.72	7.40	0.00	0.70	8.10	2.75	1.61	0.00	4.31
2	MIDDLE SM 5R:-	308.03												
(i)	H.O.	12.61	2.02	9.23	0.00	11.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(ii)	M.O.	14.39	10.19	2.14	0.00	12.33	0.00	0.38	0.00	0.38	0.00	0.00	0.00	0.38
(iii)	T.O.	12.36	10.29	1.74	0.00	12.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	TAIL SM 9L:-	226.67												
(i)	H.O.	33.58	11.37	3.31	0.00	14.68	0.61	7.01	0.00	7.62	10.27	3.27	0.00	13.54
(ii)	M.O.	16.01	6.22	0.00	0.00	6.69	0.52	3.18	0.00	3.70	4.16	0.55	0.00	4.71
(iii)	T.O.	34.08	4.96	0.00	0.00	4.96	5.77	18.42	0.00	24.19	4.30	0.00	0.70	5.00

Appendix 2A

BORSAD DISTRIBUTARY

OUTLET :- H.O. MINOR - HEAD MINOR

SOURCE	RICE	CROP TOBACCO	CROP BAJRA	CROP OTHERS	CROP TOTAL	% OF CCA
CANAL	11.57	0.00	0.00	2.61	14.18	0.69
WELL	1.56	0.33	0.00	0.33	2.22	0.11
RAIN-FED	0.00	0.00	3.00	0.37	3.37	0.16
BOTH	0.63	0.00	0.00	0.00	0.63	0.03
TOTAL	13.76	0.33	3.00	3.31	20.40	0.99

Appendix 2B

OUTLET :- M.O.

SOURCE	C R O P RICE	TOBACCO	BAJRA	OTHERS	TOTAL	% OF CCA
CANAL	2.06	0.00	0.00	0.15	2.21	0.07
WELL	7.78	2.68	3.94	2.60	17.00	0.50
RAIN-FED	0.00	0.00	*G'nut 5.92	0.00	5.92	0.17
BOTH	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	9.84	2.68	9.86	2.75	25.13	0.74

Appendix 2C

OUTLET :- T.O.

SOURCE	C R O P RICE	TOBACCO	BAJRA	OTHERS	TOTAL	% OF CCA
CANAL	0.00	0.00	0.00	0.00	0.00	0.00
WELL	2.29	0.00	0.67	3.64	6.60	0.24
RAIN-FED	0.00	0.00	17.91	1.11	19.02	0.69
BOTH	1.39	0.00	0.00	0.00	1.39	0.05
TOTAL	3.68	0.00	18.58	4.75	27.01	0.97

Appendix 2D

OUTLET :- HEAD MINOR - MIDDLE

SOURCE	CROP: RICE	TOBACCO	BAJRA	OTHERS	TOTAL	% OF CCA
CANAL	4.65	0.00	0.00	0.00	4.65	0.36
WELL	0.00	1.04	0.00	0.00	1.04	0.08
RAIN-FEB	0.00	0.00	0.00	0.00	0.00	0.00
BOTH	6.36	0.00	0.00	0.00	6.36	0.50
TOTAL	11.01	1.04	0.00	0.00	12.03	0.94

Appendix 2E

OUTLET :- MIDDLE

SOURCE	CROP: RICE	TOBACCO	BAJRA	OTHERS	TOTAL	% OF CCA
CANAL	8.58	0.00	0.00	0.00	8.58	0.31
WELL	7.69	3.92	0.71	0.00	12.32	0.44
RAIN-FED	0.00	0.00	1.67	0.00	1.67	0.06
BOTH	2.80	0.00	0.00	0.00	2.80	0.10
TOTAL	19.07	3.92	2.38	0.00	25.37	0.91

Appendix 2F

OUTLET :- TAIL

SOURCE	RICE	TOBACCO	BAJRA	OTHERS	TOTAL	% OF CCA
	C R O P					
CANAL+TANK	12.85	0.00	0.00	0.00	12.85	0.47
WELL	12.56	0.00	0.00	0.00	12.56	0.45
WELL+TANK	0.85	1.00	0.00	0.00	1.85	0.07
BOTH	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	26.26	1.00	0.00	0.00	27.26	0.99

Appendix 2G

TAIL DIRECT OUTLET 1

SOURCE	RICE	TOBACCO	BAJRA	OTHERS	TOTAL	% OF CCA
	C R O P					
CANAL (LIFT)	4.75	1.70	0.00	0.49	6.94	0.24
WELL	8.77	4.73	0.00	2.89	16.39	0.56
RAIN-FED	0.00	0.00	0.94	0.00	0.94	0.03
TANK (PUMP)	2.52	0.00	0.00	0.00	2.52	0.09
TOTAL	16.04	6.43	0.94	3.38	26.79	0.91

Appendix 2H

TAIL DIRECT OUTLET 2

SOURCE	RICE	TOBACCO	BAJRA	OTHERS	TOTAL	% OF CCA
	C R O P					
CANAL	0.00	0.00	0.00	0.00	0.00	0.00
WELL	0.00	17.03	0.00	1.59	18.62	0.97
RAIN-FED	0.00	0.00	0.58	0.00	0.58	0.03
BOTH	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.00	17.03	0.58	1.59	19.20	1.00

Appendix 3

COST OF IRRIGATION FOR VARIOUS CROPS IN RUPEES PER HECTARE, BY SOURCE

Crop	All Cases*	Canal and Well*	Well Only*	Canal Only**
Rice	491	366	696	110-125
Kharif Bajra	959	-	750	40
Kharif Tobacco	709	644	750	75
Cotton	968	743	1216	200
Wheat	715	421	863	110
Rabi Tobacco	743	510	899	125
Potato	647	504	719	100
Summer Bajra	778	775	779	200
Groundnut	609	521	942	100
Banana	1,687	1,484	2,169	830

Sources: * S Kolavalli "Economics Analysis of Conjunctive Use of Water: The Case of Mahi-Kadana Irrigation Project in Gujarat."
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