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THE DYNAMICS OF IRRIGATION SYSTEM PERFORMANCE

A Comparative Study of Two Secondary Canal Reaches in Mahi-Kadana, Gujarat

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IIMI

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

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We, the authors alone, are responsible for errors and omissions, which we hope to treat as pointers for further improvement.

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Introduction

BACKGROUND

THE DEVELOPMENT OF irrigation facilities has dominated agricultural and rural investment strategies in India for the last few decades. After independence, irrigation was given a prominent position among the national development plans. As a result, India developed an additional 34 million hectares (ha) of irrigated lands, bringing the total gross irrigated area to the current level of 68 million ha (Central Water Commission -- CWC 1988). In the Seventh Five-Year Plan (1985-90), investment in irrigation was scheduled to be more than US$10 billion. Nearly 75 percent of this investment was allocated to major- and medium-scale irrigation projects, and 25 percent to minor irrigation (surface water and groundwater) projects (Center for Monitoring Indian Economy 1986). In this plan, the State of Gujarat, where the current study site is located, was allocated the largest outlay for major- and medium-scale irrigation projects, approximating US$1 billion.

Despite these massive investments and the high priority given to irrigation, the general consensus is that in terms of performance the large-scale public irrigation systems have not met the expected standards. Returns on irrigation investment in terms of crop yields, farm incomes and cost recovery are disappointing. Average yields obtained under irrigation conditions while being more than double the amount of those obtained under rain-fed conditions (two tons per ha compared to 0.8 tons per ha for cereals), are nevertheless less than the yields obtained under irrigated conditions in other countries (World Bank 1991). Gaps are wide between the potential created and the potential realized. Only 55 percent of the potential was achieved in 1985/86 (Chambers 1988).

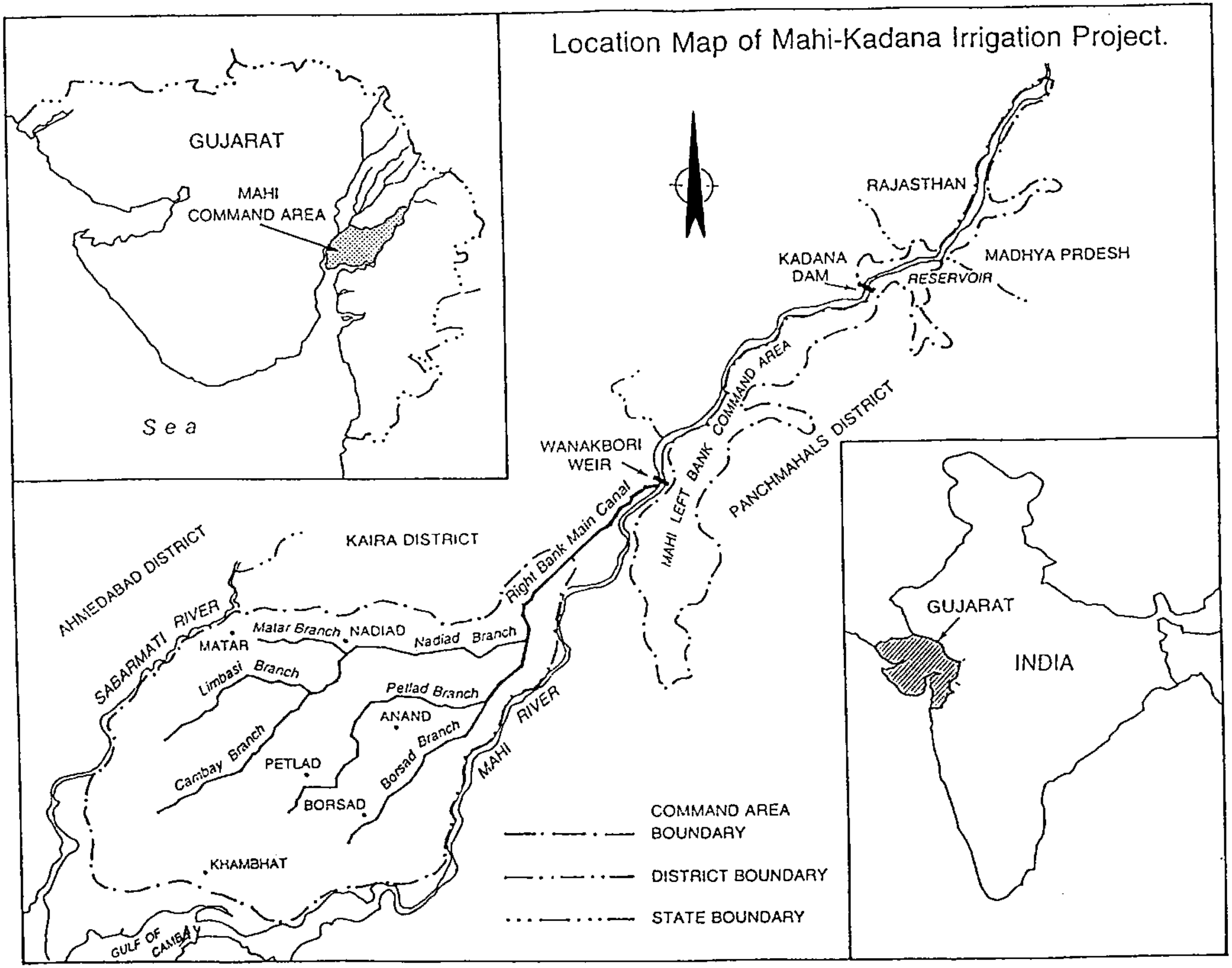
In many systems, the distribution of water is often inequitable, unreliable and inadequate. Ironically, deprivation in the tailreaches and waterlogging in the headreaches coexist in many systems. Approximately three million ha of irrigated land are estimated to be subject to waterlogging and/or salinization, though these conditions are not necessarily induced by irrigation. Despite this, there is scope for significant improvement. Diagnostic analysis focussing on the problems of critical performance can pin-point suitable reforms for improving the management, and hence the performance, of irrigation systems.

DEVELOPMENT OF THE MAHI-KADANA IRRIGATION PROJECT

The Mahi-Kadana Project is the largest irrigation project in the Western State of Gujarat in India, not including the Narmada High Canal Project (Figure 1). The Project was developed in two stages. In 1958, a diversion weir was constructed across the Mahi River at Wanakbori village in the Balasinor *taluk*[1] of the Kaira District. This allowed river flow to be diverted into the canal network without a storage facility upstream.

In the second stage, completed in 1978, a storage facility was created with the construction of the Kadana Reservoir in the Santrampur taluk of the Panchmahal District enhancing irrigation potential to 263,000 ha with a cultivable command area (CCA) of 212,000 ha.

Figure 1. Location map of the Mahi-Kadana Irrigation Project, Gujarat.



The command area comprises of two segments. The first (the major one), served by the Mahi Right Bank Canal (MRBC) covers seven taluks in the Kaira District. The second segment is the smaller Mahi Left Bank Canal (MLBC) covering two taluks in the Panchmahal District. The Wanakbori weir provides supplemental irrigation for the *kharif* crops. The Kadana Reservoir is designed to store and supply irrigation water for the winter and summer crops served by the Wanakbori System (Water Technology Center 1983).

ISSUES THAT NEED TO BE ADDRESSED

The Mahi-Kadana Project was designed to meet the water requirements of a gross cropped area of 260,000 ha, thus achieving an annual irrigation intensity of 121 percent solely through canal water sources.[2] On average, for the five years from 1985/86 to 1989/90, the gross canal irrigated area approximated 174,000 ha with a corresponding irrigation intensity of 72 percent.[3] Clearly, the achieved intensity of canal irrigation has not met the originally envisaged target levels.

The Mahi-Kadana Project Plan neither anticipated nor does it include irrigation from groundwater when calculating irrigation intensity or setting targets. The Water Technology Center (WTC) study, however, notes that the annual groundwater recharge in the command area is 1,333 million cubic meters (MCM). Although exact figures are not available, estimates suggest that an area equal to that irrigated by canal water (174,000 ha) receives groundwater.

It is apparent therefore that the cumulative impact of surface water and groundwater irrigation in the project is extensive. The WTC report also notes that the system has surplus water resources. It identifies the need for systematic conjunctive use in the command area. Regrettably, a discussion on operational issues is not included.

A recent analysis (taluk-wise) of water tables in the command area carried out by Shah (1988c), showed a potentially dangerous buildup of water table levels in the core command or the headreaches which are served mostly by canal water. But groundwater exploitation, which could act as a stabilizing factor, occurs mostly in the outer reaches or the tailreaches which are poorly served by canals. Therefore, the stability and the long-term sustainability of the system appears to be in jeapody.

Of serious concern then is the interplay of factors that are physical, institutional, social and economic, which contribute towards water control.[4] The question of whether the current process of surface water distribution and resultant utilization, i) between seasons and ii) in relation to groundwater, leads to the realization of potential productivity benefits in the command area, has not received adequate attention. Proper and reliable information on the extent of well irrigated and/or tubewell irrigated agriculture is lacking.

In order to address these issues, a fairly comprehensive examination of the performance of two secondary systems in the MRBC has been attempted. Primary data collection spans three cropping seasons -- kharif, *rabi*/winter and summer 1991/92.

EVALUATING THE PERFORMANCE OF MAHI-KADANA IRRIGATION PROJECT

Before attempting to evaluate the performance of an irrigation system, the criteria to be used must first be spelt out in terms of the broad, overall objectives laid down when the project was originally designed.[5] The purpose of harnessing the Mahi River and constructing the Kadana Reservoir was to increase agricultural productivity (and thereby substantially increase farm incomes) by providing an assured water supply to farmers. These objectives were to be realized by annual and seasonal planning, quantified targets and a set of operating rules.

Appraising operational performance requires the evaluation of the set targets. Since the implementation of system goals and seasonal targets is largely determined by the nature and quality of managerial inputs, any assessment of these inputs must necessarily judge managerial performance. Focusing on visible inputs and outputs, irrigation performance in this instance will be measured in terms of the water supply delivered and its consequences for agricultural production. The former can be characterized as the "means" and the latter as the "end" or the outcome.

RESEARCH OBJECTIVES

This effort is part of a broader study on *Main System Management* being conducted by the Institute of Rural Management (IRMA) and the Water and Land Management Institute (WALMI), in collaboration with the International Irrigation Management Institute (IIMI), Sri Lanka. Planning of water allocation, distribution, scheduling, and water in the main system, which act as externalities to the functioning of secondary and tertiary reaches, will be dealt with in greater detail in the main project.

This study deliberately focusses on *Microlevel Operational Performance* in water delivery and its impact on farm production. The impact is analyzed in two secondary systems through cropping patterns, irrigation intensities, yields, and agricultural incomes: according to i) location, ii) irrigation source and iii) farm size. To help understand performance, importance is also attached to i) assessing the nature and quality of managerial functions at the sub system level, ii) assessing the interaction of farmers with the system and their response to regulations, and iii) evaluating on-site operation of the canals. The case for redistributing canal water in the command area will also be examined and suggestions for optimal conjunctive use of both surface water and groundwater rationalized. Though the study is confined to two secondary canals, the analysis and suggestions for improvement are potentially applicable to the whole system.

The analysis will be conducted at two levels. For the location-based analysis which is the primary focus of this research, farm plots or fields were chosen as units in terms of the hierarchical structure of the hydraulic system. This was necessary as a single farm could have several parcels of land scattered in different tertiary blocks, with different water delivery patterns. When the emphasis shifts to studying economic performance by farm size and source of irrigation, the whole farm is treated as a single unit.

Performance criteria are set out in terms of agricultural productivity and equity. Also assessed are reliability and efficiency of water deliveries at the distributary level.

Production in agriculture is a function consisting of several factors such as land, labor, water and capital. For managers of irrigation systems, the productivity of water is of particular concern. In this study, the productivity of water is specified in terms of returns to an index of water availability. In the location-based analysis, plot-level data are used. On the other hand, in the analysis on returns on irrigation expenditure, data on the whole farm are used.

Equity in the context of water management relates to rights to water based on certain shared notions of fairness among water users. The difficulty is to agree on a basis for equality. In a demand-based system like the MRBC with little aggregate scarcity of water, should tertiary blocks and fields growing identical crops receive water in proportion to the area cultivated? For the purpose of this study, equity will be treated as equal access to a fair share of water for all users in the command. Its impact on crop and farm economy will also be examined.

RESEARCH APPROACH

Though there have been a number of studies on the performance of large- and medium-scale irrigation systems, few have considered irrigation as an enterprise where socioeconomic and technical processes interphase, and operate through a particular institutional framework. Conventionally, most multidisciplinary research simply provide different perspectives on the same problem and attempt to identify a common space in the different solution sets advanced. Irrigation research, however, requires an integrated approach tc the investigative process of identifying the issues involved, coupled with a basic understanding of the different disciplinary segments, in order to overcome the deficiencies of a segregated analysis.[6] This study strives to follow such an approach.

Infrastructure and Operating System

WATER AVAILABILITY AND WATER CONTROL CAPACITY

i) THE MAIN CANAL takes off from the right of the pickup weir at Wanakbori. The Kadana Reservoir, from which water is released into the Mahi River, is located 70 km upstream of Wanakbori, and has a storage capacity of 1,200 MCM. It is estimated that there is an 18-hour lag between the release of water at the head regulator at Wanakbori and the water reaching the tail of the distribution system.

ii) Based on an analysis of the hydrology of the Mahi River at the Kadana Dam, conducted by the Water Technology Center (1983), it is concluded that the reservoir fills by the end of the monsoon season every year with a probability exceeding 75 percent. There is, therefore, a good chance of having a full reservoir at the end of the kharif season, even after meeting kharif irrigation requirements.

iii) Fifty-six cross regulators are provided along the main and branch canals which enable a full supply to be maintained at these points. There is no need to wait for water to flow down from above. A number of escapes are available at the branch level to let out excess water and prevent overflowing.

iv) Conveyance structures are lined with concrete at the main canal and branch canal levels. Distributaries and hierarchical structures below are for the most part unlined, except for the initial stretch of certain minors and field channels. However, with the recent desiltation of canals, earth structures are in fairly good condition.

v) Distributary head regulators are calibrated and discharge is calculated based on the difference between the upstream and downstream water depth and the level of gate openings. Offtake points to the minors from the distributary are not generally calibrated. At places where they are, the calibrations are not clear.

vi) All outlets down to the tailreaches of distributaries are gated in concrete, and can be raised or lowered manually. Although gates are screw-bolted, it is not difficult to open or close gates.

vii) Outlets have a design capacity of 1 cusec (cubic foot per second) which is equal to 0.028 cumec with an average command size of 30 ha. The command size could be anything from 7 ha to 35 ha.

viii) Field channels, except in the salinity-prone Cambay region, cover most of the command area, and are extensive.

ix) Canal telephones are provided at control stations on the main and branch canals. These stations are connected to divisional and subdivisional offices.

x) At the subdivisional and sometimes at the sectional level, there are housing colonies in the same complex as the office premises. Therefore, day or night, communication between supervisory officers and field staff is possible.

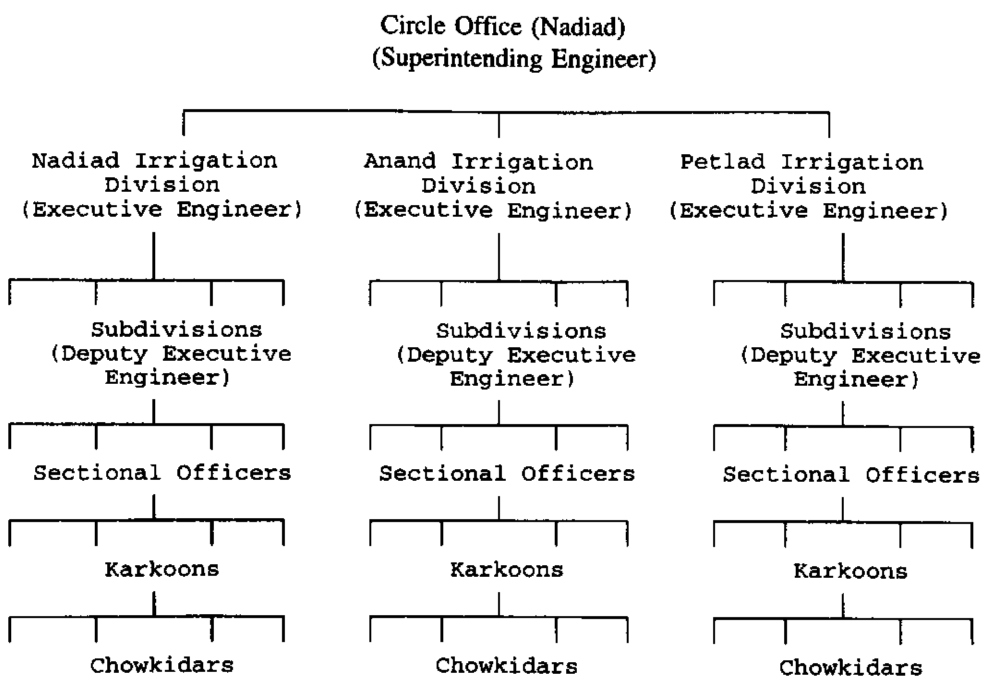
The physical system of the Mahi-Kadana can be described as "articulated" since the lowest level outlet serving less than 30 ha has an adjustable gate.[7] This system of water control permits adjustments in outlet gates in response to water levels in the distributary from above, and crop water needs from below, with sufficient flexibility to introduce rotations among outlets if necessary.

Thus, it is reasonable to describe the original capacity for water control in this system as fairly good, as it is designed for water deliveries much closer to crop water requirement than for the "warabandi" systems.[8] Some secondary canals, like the Borsad, though, seem to exhibit faults in design (more details would follow later).

Water availability does not appear to be a constraint to improving the performance of the system, unlike in many other systems in India, where total availability of water is often overestimated or is inadequate to serve the proposed command area.

ADMINISTRATION OF THE MAHI-KADANA RIGHT BANK CANAL (MRBC) SYSTEM

The organizational structure of the irrigation bureaucracy is as follows: The entire Mahi Canal Command Area of 212,000 ha comes under the management of the Mahi Irrigation Circle, headed by the Superintending Engineer. The command is divided into three irrigation divisions: Nadiad, Anand and Petlad, each headed by an Executive Engineer (EE). There is also a drainage division.



Each division has four to five subdivisions. Subdivisions come under the charge of a Deputy Executive Engineer (Dep.EE). Normally a Dep.EE is in charge of four secondary canals and relevant sections of the main and branch canal. The next official is the Sectional Officer, who may be a qualified Civil Engineer and who is usually responsible for one or more distributaries or minors. The allocation of area-to-be-irrigated targets and accountability for achievement stop at this level. Below the Sectional Officer are the field staff consisting of *Karkoons* or Work Assistants and below them the *Chowkidars* who are expected to maintain direct links with the farmers.

The area of jurisdiction of a Karkoon varies from 400 ha to 800 ha. He is in charge of the operation of minors. The area of control of a Chowkidar ranges from 75 ha to 350 ha. Chowkidars are posted at control points such as the offtake points of branch canals, distributaries and minors, and are required to monitor and adjust these diversion structures according to the instructions of the Supervisory Officers. Work Assistants are usually literate unlike the Chowkidars who are mostly illiterate. Prospects of promotion for these personnel are virtually nonexistent.

WATER ALLOCATIVE PROCEDURE

In order to determine whether the water control capacity is being effectively utilized, a description of the allocative mechanism and the operating procedures for water distribution is necessary. The plan document prepared at the Mahi Circle Office determines the inter- and intra-divisional seasonal targets of water to be supplied, and the area to be irrigated under each crop. This is matched with expected water availability. In estimating the area to be irrigated, past data on the area irrigated by canals for each crop, and for rotation periods within a season are taken into account. The total water requirement for the season is arrived at based on past years' data on cropping patterns, number of watering of each crop, and duty. When allocating water to the three divisions and the various subdivisions, demand is ignored and water is allocated in proportion to the CCA of each irrigation division and/or subdivision. Frequently, this process of allocation by CCA percolates down to the sectional level, wherever such targets are given.

The plan document is generally ignored in implementing release to the main branch canal and other offtakes further down. Release is usually based on the day-to-day indents placed through canal telephones. Furthermore, the plan document completely neglects to take into account soil characteristics, rainfall and groundwater irrigation.

OPERATIONAL CHARACTERISTICS OF SECONDARY CANALS

The "Shejpali" system is followed for water distribution in the Mahi-Kadana Irrigation System. This is a demand based system of water allocation. The system requires that farmers submit an application for water to the Chowkidar, a few weeks in advance of the cropping season and cultivation, and after the receipt of verification from the village *Talati* (village revenue official). The application forms contain information on land area and crop but do not contain information on the frequency and the duration of the irrigation supply. The available water supply, as allocated in the plan document, is then distributed among farmers after consolidating these indents at the sectional (distributary command) and subdivisional levels. Crop areas thereafter, become sanctioned for canal irrigation and form the basis for scheduled water deliveries at each outlet.

In reality, on average only 30 percent to 40 percent of farmers apply for water prior to irrigation. Even those who do, usually do not apply at the beginning of the season as stipulated. Farmers who use water without applying are issued *panchnamas* or notices which certify the land area and their period of unauthorized irrigation. Such farmers are penalized by being charged one-and-a-half times the regular water rate. They also become ineligible to apply for water during the next season, although it is impossible to prevent farmers from helping themselves to canal water. Farmers have little incentive to pay water rates and a large portion of the assessed water charges remains unrecovered. Furthermore, tailreach farmers often do not receive water despite having applied for it. Unauthorized irrigation, therefore, accounts for the bulk of water deliveries.

Earlier, it was stated that the physical components of the system favored a flexible mode of operation with reference to the control of water. This technical aspect of water control, although important, is insufficient to secure maximum benefits from canal irrigation. The nontechnical aspect of water distribution should also be present.

In order to achieve a high degree of flexibility in operational procedures, the system needs to be demand oriented while promptly responding to the changing water requirements. Here, heavy reliance is placed on the ability of the lower-level irrigation staff, the Chowkidars and the Karkoons in promptly assessing water demand as new cropped areas come up. Daily, they report the area irrigated to the Sectional Officers, who in turn submit formal written reports on a fortnightly basis to the higher-level officers.

Measurement devices are usually absent below the distributary level and discharge assessments have to be made by eye. There are no fixed schedules for the operation of minors and outlets which are expected to operate as per farmer's demand. Decisions concerning opening and closing of sluices are made on an *ad hoc* and on a day-to-day basis.

Once the Karkoon reports the probable area to be irrigated to the Sectional Officer, the Sectional Officer computes the total water demand. This is computed employing a thumb-rule of a one-day cusec (defined as a discharge of one cubic foot per second flowing for 24 hours), or a 0.028 day cumec for every 2 acres (0.81 ha) of a single irrigation irrespective of crop and season. A one-day cusec normally irrigates 1 ha (2.27 acres) up to a depth of 6 inches. Allowing for a 50 percent conveyance loss (assumed by the Sectional Officers) from the distributary head to the field level, this is still well above the water requirement of even the most water consuming crop, i.e., rice.

Hardly any consideration is given to the question of what is to be done should the water supply fall short of that which has been prescribed. No formal or codified procedure has been developed to deal with how the water demand should be assessed for crop mixes, nor are there rotational procedures available that can be followed within the distributary during peak demand periods.

Canals are expected to operate at night, but there is no provision for overtime to be paid to the irrigation department staff. This is a sore point with lower level irrigation department staff and few find an incentive to operate the minors at night. As a result, sometimes, anarchic conditions prevail the following day. Canal operators attempt to reduce flow levels in the late afternoon (after 6:00 p.m.) during the rabi season by closing distributary, minor and subminor gates when there is less demand. Levels are reestablished the next morning.

Although Sectional Officers and Dep.EEs are expected to check 20 percent and 5 to 10 percent, respectively, of authorized and unauthorized irrigated areas, this is rarely done. By and large, supervisory staff visit canal sites only when canal breaching, or damage to physical structures occur, in order to handle repair and maintenance work. In fact, one Sectional Officer remarked that he had not visited any interior canal reach apart from the site of the head regulator, as it required a few kilometers of cycling and/or walking.

The Irrigation Department prepares information on the area irrigated for crops at the minor level, by aggregating the data provided by Chowkidars and Karkoons at the tertiary level. There are two reasons for the misreporting of data by the staff. On the one hand, it is not unusual for the staff to collect a partial amount of the actual revenue rates from farmers who indulge in "unauthorized irrigation" and in return, not issue panchnamas. On the other hand, there is pressure put on higher-level functionaries to inflate and redistribute the actual figures to bring them closer to target values. This produces anomalies between figures reported villagewise for revenue collection and those reported in terms of canal command areas.

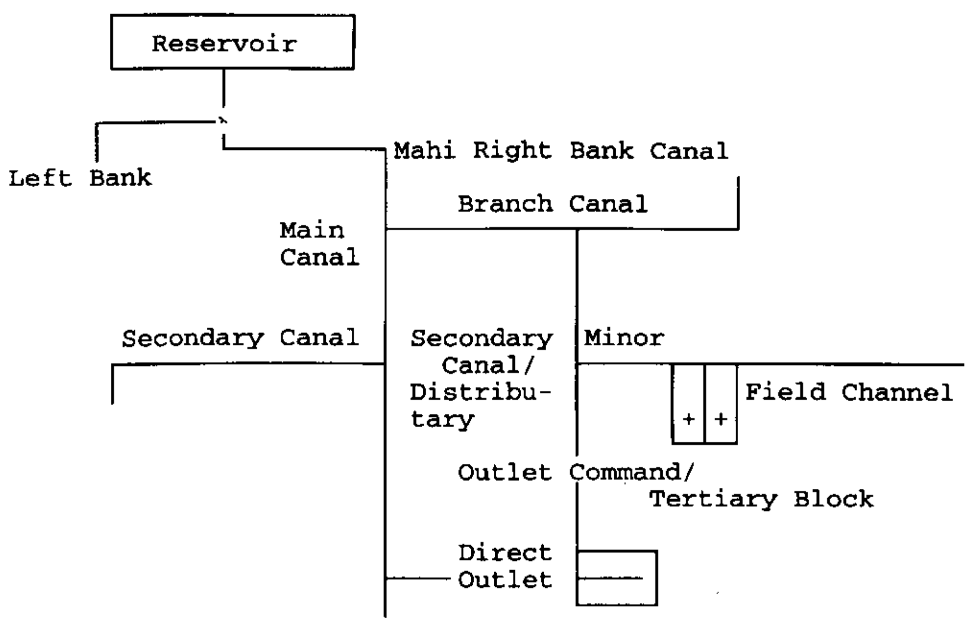
It is beyond the purview of this study to identify the extent of these discrepancies. It is best, therefore, to rely on secondary data, only in a descriptive sense and not in any analytical sense.

Methodologies

SAMPLE-SELECTION PROCESS

THE PATH OR route of irrigation water from its diversion at the pickup weir at Wanakbori through main and branch canals (six in number) to secondary canals or distributaries and eventually to farmers' fields is shown in a diagram (Figure 2). Note that distributaries offtake from both main and branch canals and that outlets are found both in the distributary and minors.

Figure 2. Schematic representation of the hierarchical structure of water distribution in the Mahi-Kadana Irrigation Project.



* Diversion Structure
\+ Farm Plot

The Mahi-Kadana Irrigation Project is a large project, and as such, it was necessary to represent the project by selecting distributaries for detailed analysis. The selection of two secondary canal commands was an important step in conducting research at the sub-system level.

Figure 3 illustrates the command locations. The Umreth Distributary located advantageously upstream of the system and taking off from the main canal has an impressive performance, with an annual canal irrigation intensity ranging from 140 to 190 percent. In contrast, the Borsad Distributary's performance (average annual canal irrigation intensity being around 40 percent) is low considering its middle level position in the system (Table 1). Senior irrigation department officials attribute this low performance to the topographical characteristics of the command area. However, apart from faults in the original canal design (see next section), operational failures and other factors appear to be more responsible for poor performance. While a few of these operational features were discussed in the earlier chapter, other issues shall be investigated in more detail later.

Table 1. Canal-irrigated area of sample distributaries/minors, 1985-90.

Sl.No.	Name of the Canal	Gross area irrigated and irrigation intensity of canals									
		1985-86		1986-87		1987-88		1988-89		1989-90	
		Area irrigated (ha)	Percent of CCA	Area irrigated (ha)	Percent of CCA	Area irrigated (ha)	Percent of CCA	Area irrigated (ha)	Percent of CCA	Area irrigated (ha)	Percent of CCA
I	Umreth :	2,600.43	140.20	3,461.72	186.64	3,256.03	175.55	3,187.19	171.84	2,957.72	159.47
(i)	SM 2/R (H)	130.01	155.09	164.44	196.16	172.51	205.79	163.98	195.61	182.93	218.22
(ii)	SM 5/R (M)	299.44	150.07	292.84	146.76	213.56	107.03	219.69	110.10	219.79	110.15
(iii)	SM 9/L (T)	98.81	79.69	218.00	175.81	118.89	95.88	125.59	101.28	112.14	90.44
II	Borsad :	1,270.60	41.71	1,681.56	55.20	1,596.55	52.41	1,372.81	45.07	1,481.45	48.64
(i)	SM 6/L (H)	195.56	63.76	239.38	78.05	224.34	73.14	140.82	45.91	187.63	61.18
(ii)	Vehra (M)	204.68	22.96	226.20	25.38	184.37	20.69	188.15	21.11	204.01	22.89
(iii)	Borsad D.O.	846.40	57.71	1,064.98	72.62	1,082.31	73.80	907.43	61.88	973.89	66.41

Source: Mahi Irrigation Circle (Nadiad, Gujarat).
Note: Figures refer to area irrigated through canals and do not include well-irrigated areas.

FEATURES OF SELECTED DISTRIBUTARIES

The selected distributaries have other features in addition to those described earlier:

i) The Umreth and the Borsad distributaries serve a command area of 2,532 ha and 2,393 ha, with a total canal length of 32.35 km and 24.48 km, and a design capacity of 128 cusecs and 62 cusecs (3.63 and 1.76 cumecs), respectively.

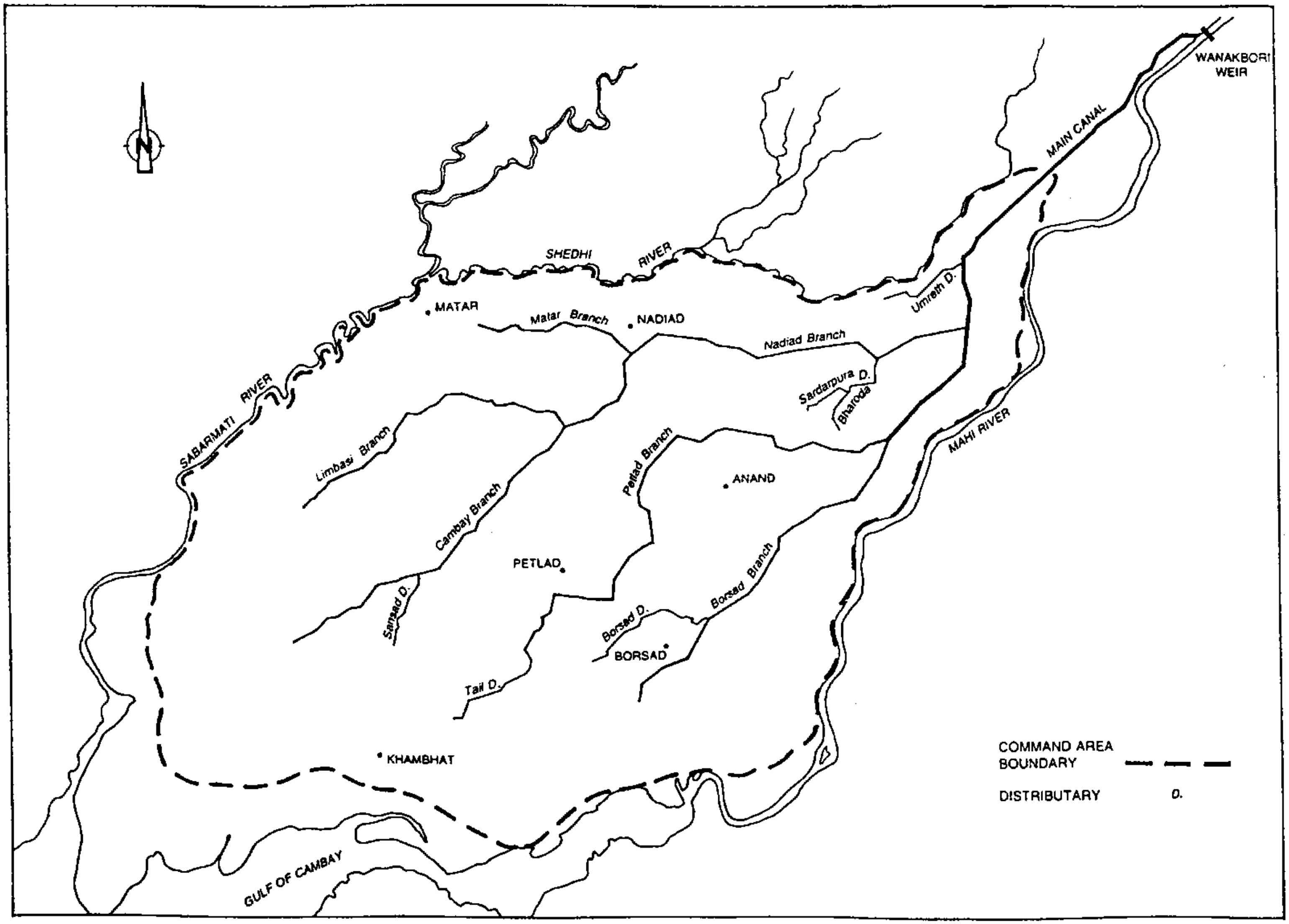
ii) The Umreth Distributary has 9 minors. Eighty percent of the area is commanded by these minors.

iii) In contrast, there are more direct outlets in the Borsad Distributary, but they command only 60 percent of the total CCA. This design feature reduces the capacity to control the water supply considerably. Small quantities of water release become especially difficult to control, and with reduced water control, less water is available to downstream users. The maintenance cost of direct outlets also becomes higher.

iv) The soil profile of the sample distributary commands vary from sandy loam to loam. Being permeable and at a comparatively higher elevation, they are well drained with a moisture holding capacity of 38 percent to 44 percent.[9] These soils are considered suitable for heavy and light perennials, and rice.

Minors located in the head, middle and tail reaches of the canal were selected from within the representative distributaries, since for the most part, there are significant differences in irrigation intensity between the head and tail in these distributaries. Three minors from the Umreth Distributary were selected. There are only four minors in the Borsad Distributary. The tail minor, Chuva is defunct, with its entire command area being irrigated by groundwater. In our sample selection of minors, two direct outlets in the tail were chosen in addition to two minors, to represent the distributary's lateral network.

Figure 3. The Mahi-Kadana Right Bank Canal Command Area.



For each minor, three sample outlets were chosen based on location. As far as *a priori* information was available, tail outlets irrigated exclusively by groundwater were avoided so as to focus on canal water distribution for plot-level analysis.

Within selected minors, the strategy was to take samples of farm holdings operating within the sample outlet commands, but situated at different points along the water course. This was done using minor and outlet command maps and records available at the Irrigation Department, and through personal observation of field conditions. Some plots selected initially on the basis of Irrigation Department maps, had to be rejected as they were found to be located in neighboring outlet commands. Where discrepancies occurred between area figures maintained in official records and those reported by farmers, a direct appraisal of the disputed plot was made to arrive at an acceptable figure. One hundred and thirty-four farm plots, 62 from the Umreth Command and the remaining from the Borsad were selected for the study. When dealing with cropping systems, the whole outlet command area was surveyed for the analysis.

In order to obtain sufficient samples of well-irrigated farms in carrying out the farm-level analysis by type of irrigation, fifteen farms located in the command of the Chuva Minor (the tail minor in the Borsad Distributary) were added to the original sample.

SURVEY METHODOLOGY

Before an assessment of sub-system performance can be made, hydraulic and agricultural data at the micro level must first be obtained. Two questionnaires were therefore designed: one to collect farm cultivation data, and the other to record observations of field watering and outflows. The former consisted of household and agricultural production data (with the emphasis on irrigation). Data collection for kharif and rabi was confined to the plot, while data collection for all three seasons (kharif, rabi and summer), included the entire farm. A qualitative section was added to include farmer experience with canal irrigation (in general) and water allocation (in particular). Farmers' perceptions of adequacy and reliability of water supplies also form a part of this section.

The period of primary data collection covers the agricultural year 1991/92. The question of how typical the three seasons studied were, can be analyzed in terms of rainfall patterns and its consequences for the cropping calendar. The southwest monsoon which provides 96 percent of the annual rainfall of the region was delayed in 1991/92. The effective on-set of the monsoon occurred on 20 July, with most of the heavy downpours occurring during the subsequent fortnight (Figure 4). The normal or mean date for the on-set of the monsoon was set by the WTC study at Anand (1983) as 1 July, based on rainfall data from 1943 to 1973. While the annual rainfall for 1991 at 644 mm was lower than the mean annual precipitation of 75 percent, the year was not categorized as a drought year.

Transplanting of kharif rice which usually begins towards the end of July, was put off by nearly a month and it staggered more than usual.[10] Farmers growing tobacco normally start planting early September. They were therefore not affected, but most of those following rice with wheat and a summer crop had to postpone agricultural operations.

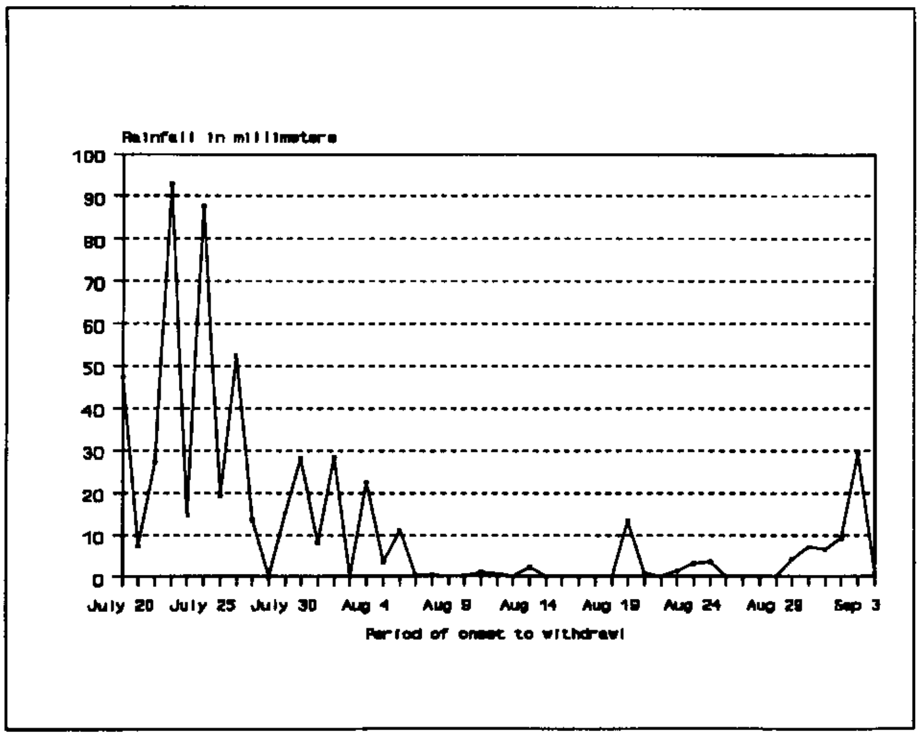
MEASUREMENTS OF WATER DISTRIBUTION

Discharge readings of the distributaries at zero level are taken every two hours by the Irrigation Department staff. The WALMI measurement team has been engaged in spot checking to make sure these data are accurate (within permissible error). These measurements can be converted into expressions of equity and reliability, by computing a ratio such as the Delivery Performance Ratio (DPR) and the Coefficient of Variation (CV). These can then be compared for different reaches within a system or for the same location over time. The DPR relates actual discharge to targeted discharge and is simple to calculate and use, if the data are available.

The CV (Standard Deviation/Mean [Std.Dev/Mean] * 100) measures the degree of stability or fluctuation in discharges and is therefore viewed as an indicator of reliability. The Area Irrigated per Day Cusec (AI/DC) gives an indication of the distributional efficiency of water and shows how well water is managed. The figure will vary depending on the crop (crop growth stage is also a factor), and the soil type that is being irrigated. The AI/DC should be higher for larger areas of permeable soils under water consuming crops and vice versa.

At the farm-gate level, attempts were made to obtain both subjective and objective indicators of water availability. Farmers were interviewed frequently to elicit data on dates and duration of irrigation. However, two problems were encountered. Since the main kharif crop is rice and the irrigation duration often extends for several hours, interruptions and obstruction to water courses by farmers unwilling to await their turn are not uncommon, especially during peak demand periods. Farmers are therefore not able to report the duration of each irrigation accurately. Furthermore, farmers are often under the impression that their response will influence water allocations in the future so that the possibility of a strategic bias cannot be ruled out. Responses gathered from farmers on adequacy and timeliness of water deliveries for the three seasons, though, have been quantified, and presented in the next chapter.

Figure 4. Daily rainfall variations during the southwest monsoon: Anand station (1991).



Note: Anand is located 20 km from the Borsad and 30 km from the Umreth canal commands.

Discharge measurements were also made at the field level every three days for each outlet using portable cutthroat flumes. Given that it was almost impossible to know in advance which farmers will receive water at a specific time, one had to literally follow the course of the water flow. Discharges vary considerably at different points in the same day, and due to supervisory constraints, measuring at each field level was ruled out. Besides, the diversion of flows by intermediary farmers reduced flows to the tail end. Water management under these conditions thus becomes a difficult task. This exercise revealed that differences in flows from head field to tail field vary from one outlet command to another, depending on the topography, number of intermediary fields, bifurcation, length, and condition of field channels.[11] Therefore, no meaningful quantification of these variables was possible.

For the rabi season, the field discharge measurement program was redesigned with the sole objective of understanding the degree of conveyance losses in the field channels.

Field conditions of rice crops receiving canal irrigation were monitored to get a better idea of water adequacy at the field level and also to account for the influence of topographical and soil variations on the soil moisture level. Every third day, the water status of the selected plots was noted and ranked as follows:

i) Soil dry/water shortage.
ii) Soil semi-wet/moderate or low shortage.
iii) Soil wet/saturated condition.
iv) Standing water.

Based on these observations, a Water Availability Index (WAI) was computed for each plot using a weighting procedure.[12] The period considered was late August to 20 October (54 days) with minor variations in actual dates according to location to account for different planting dates. The period covered the critical water sensitive phase of the rice plant, from the tiller completion phase to the flower completion phase (Michael et al. 1977). The weighting assigned was: the number of days in the first category, plus double the number of days in the second category, plus triple the number of days in the third category, and four times the number of days in the last category. The number of observations, based on an every third-day observation of the 54-day period is 18 (54/3). The minimum score would therefore be 18x1=18 and the maximum score 18x4=72.

After the WAI is calculated for each plot, it can be regressed against the distance from the outlet/water source to examine whether there is any secular decline in the index with increase in the distance from the water course. Further, the average WAI for head minors versus tail minors can also be calculated, as well as for distributaries as a whole, for the purpose of comparison. The WAI as an observational measure was applied to the rice crop for the kharif season. Since rice is the dominant crop in these areas during kharif, it was not unreasonable to concentrate our performance study on that crop. The WAI used as an analytical measure was found to be strongly correlated to rice yields (Wijayaratna 1986).

Our research extended the methodology used for estimating the adequacy of water distribution for rice, to the wheat crop during rabi, with suitable modifications, as variations in moisture content in wheat fields is not sufficiently visible to be assessable by the naked eye. Soil moisture was estimated by adopting what is known as the "touch and feel" method. This method enables technicians to make practical estimates on-field when decisions are necessary. The "feel" of a sample ball of soil from the field is tested for strength and then related to agreed descriptions representing the textural grade of the sample, to estimate soil-moisture deficiency or availability in percentage values.[13]

With these observations, a weighted index was constructed for wheat, closely paralleling that used for rice. While the "touch and feel" method has been used for evaluating water availability in the past, the development and application of a seasonal soil moisture index for nonrice crops is new in water management research.

These statistics in themselves are insufficient to determine whether physical system limitations, operational problems or sociopolitical and management problems are the cause of good and/or bad performance. That can only be identified through a thorough understanding of the system's operational features and farmers' behavior in the command area.

Farmer System Nexus[14]

RESPONSE OF FARMERS

FARMERS IN THE representative distributaries of the Mahi-Kadana System were interviewed to obtain their opinion on the operating procedures for water allocation and their assessment of performance. Their quantified responses are given in Table 2.

Table 2. Responses of farmers to queries on canal system functioning.

Query	No. of respondents		Percent of respondents by distributary					
	H.D	M.D	H.D.	M.D.	H.D.	M.D.	H.D.	M.D.
Water availability:	67	62	Adequate		Inadequate		Too much	
(a) Kharif			89.5	38.7	5.97	59.0	4.77	1.61
(b) Rabi			89.5	39.7	7.46	59.0	2.98	1.61
(c) Summer			88.0	37.7	8.95	60.0	2.98	1.63
Timeliness:	67	32	Timely		Untimely			
(a) Kharif			89.5	62.5	10.4	37.5		
(b) Rabi			92.5	63.5	7.46	36.6		
(c) Summer			98.0	65.6	8.95	34.3		
Reduction of cropping plan due to insufficient canal water	67	62	Yes		No			
			2.98	21.2	97.0	63.3		
Source of information on canal	67	32	+Other Farmers		Chowkidar		Other	
			44	34	33	63	--	20
Frequency of meeting with:	67	62	Low		Medium		High	
(a) Chowkidar			41	63	16	25	43	13
(b) Karkoon			47	81	37	13	16	7

Notes: H.D. = Head Distributary (Umreth).
M.D. = Middle Distributary (Borsad).
\+ = Groups are not mutually exclusive.

Irrespective of location, farmers were unanimous in their comment that the procedure for applying for canal water was tedious. Application forms required certification by the village *talati*; and he was often not available when required. Senior Irrigation Department Officials, on the other hand, complained that the date for submission of applications extend well into the middle of the season, causing problems in collecting dues. Farmers in the head distributary preferred flows to be continuous in the minors during kharif and felt that there was no necessity for any kind of rotation.

More farmers in the Umreth Command obtained information on canal operations from Chowkidars (63 percent), than from neighbors (34 percent), and nearly 60 percent described the frequency of contact with lower-level Irrigation Department staff as being high-to-medium. Complaints generally centered around the poor condition of the physical structures and the field channels.

Farmers from low-lying plots complained of leakage from the minors and irregular channel configuration contributing to water logging. They also complained of overflow from heavy rains during kharif. Ninety percent of the farmers described the water supplies as being adequate and timely during all three seasons. A few farmers in the head-end areas reported excessive irrigation, especially during the kharif season.

In the Borsad Command Area, 60 percent and 34 to 38 percent of the respondents reported inadequate and untimely flows, respectively, during all three seasons. Well irrigators were included in the sample reporting on adequacy but dropped out when querying the factor of timeliness. In fact, a smaller number of respondents categorized water flows as being untimely.

Upstream farmers of the Borsad Distributary were against any kind of rotation at the minor level. They said that the water flow was erratic and communication regarding the operational schedules of minors and outlets was inadequate. Dissatisfaction increased with regard to timeliness and adequacy of the water flow as one moved further down the water course. (Note: When questioned about the political pressure brought to bear upon the Irrigation Department, some farmers said that it was necessary for the active functioning of the canal during peak demand periods.)

Middle-reach farmers of the Borsad Distributary had several complaints regarding current operating procedures, or more accurately, regarding what they perceived as a lack of procedure. A greater number of respondents reported obtaining information on canal operations from other farmers (63 percent), than from Chowkidars (33 percent). Several farmers characterized the frequency of meetings with Chowkidars as low (63 percent). Twenty-five percent reported a medium level of frequency (once every 7 to 10 days). Meetings with Karkoons were even less frequent.

Farmers viewed the lower-level Irrigation Department officials as being concerned with paper work and the higher-level officers as being indifferent. They categorically stated that the main problem was the inability of the Irrigation Department to maintain proper flows in the lower reaches. They seemed inclined toward fixed rotations in the minors, if this enabled them to receive water during the critical growth period of the kharif rice crop. A few suggested a warabandi system of fixed schedules as one way to bring about equitable water distribution in the command area. Their understanding of warabandi, though, was confined to that of following rotations within outlets, and did not extend to farm-to-farm rotations.

Water wastage and hoarding due to uncertainty of flow upstream of the Borsad Distributary were blamed as the causes for the deprivation downstream. Complaints regarding weeds in the minors and in the field channels were universal.

INTERACTION WITH THE SYSTEM

In view of the inadequate operating procedures and the inability of the Irrigation Department field staff to enforce regulations, farmers resort to several different practices to gain control of water. These are given in Table 3.

The field investigations revealed that Chowkidars and Karkoons are usually not at sluice gates when water is required, so farmers are often compelled to operate the gates. Manipulation of physical structures along distributaries, minors and sub-minors by breaching and cross-bunding are also not uncommon during kharif. These interventions occur frequently during peak demand periods.

It was also surprising to observe a few farmers who had missed an earlier irrigation and late planters intervening to raise water levels when Irrigation Department staff closed the minor gates, even though demand was low at that time.

To reduce conveyance distance, farmers often construct *kutcha* or unauthorized outlets and lay pipelines direct to their fields. The more resourceful ones have in fact managed to establish mini water markets for the water pumped and delivered through these pipes. These farmers not only irrigate their crops, they also sell water to neighboring farmers at rates equivalent to that of well water.

Table 3. De jure rules and de facto operations of the secondary canals.

	De jure	De facto
1.	Applications/indents must be submitted to receive water	Unauthorized irrigation forms the bulk of the total irrigation.
2.	Farmers are not permitted to operate outlet gates or tamper with physical structures.	a) Headend and other powerful farmers open and close outlet gates at will.
		b) Cross regulators and minor gates are opened and closed by farmers at night. Minor gate rods are removed to obtain a low level of discharge, when minors are closed.
3.	Water conveyance structures (except for field channels) are not to be constructed except with special permission.	There is a proliferation of kutcha outlets, with direct pipelines laid to the fields.
	Obstructing water flow in distributaries and minors by farmers is illegal.	a) Farmers frequently resort to raising the canal water level by blocking a minor with obstructive material (including broken pieces of canal lining), and then irrigating through pipes or outlets, if located nearby.
		b) Minor beds are cut to take water directly to the fields.
4.	It is illegal to obtain water from an outlet of a different command.	Tailend farmers of a designated outlet, often resort to securing water from adjacent outlets.
5.	Field staff must inform farmers in advance about water canal closures.	Such decisions are usually made *ad hoc* and are often not communicated to the farmers.
6.	Field staff must maintain accurate outlet command area records and maps.	a) Outlet command boundaries and farm holding records change, but are not always updated.
		b) Chowkidars keep records of the area irrigated, duration, etc., mainly through guesswork.
		c) In some cases, farmers who irrigate without authorization are not issued panchnamas in return for gratis payments.
7.	Senior supervisory staff are responsible for visiting and assessing progress.	Responsibilities are often shirked. Adequate assistance and protection to lower level staff is not always provided.
8.	More than one irrigation per fortnightly rotation is not authorized.	Those who gain access to water deliveries resort to duplication of irrigation.

Night irrigation is more frequent during kharif. Quite often tailreach farmers have no option but to irrigate during night time; some even engage extra labor to do this. There is little night irrigation during rabi because water requirements are lower and the cold weather acts as a deterrent.

Staggered planting or late planting is to some extent responsible for water wastage. Where fields are uneven, in order to supply adequate water to the higher sections, farmers over-irrigate the lower patch. In headreaches where water is abundant, flooding and impounding of water to remove weeds is not uncommon and partly accounts for excess irrigation.

Farmers at the head who are in favored positions do not usually support attempts at reform by tailenders or others who may be interested. In this particular research area, though, even tailenders did not find it necessary to protest forcefully. The availability of groundwater and the presence of competitive water markets have provided an attractive alternative to canal water supplies.

Earlier, the degree of interference with water distribution in both the minors and the field channels during a single irrigation (which can run intermittently for several days), was discussed. It has also been noted that bribes are sometimes solicited for nonassessment of the area irrigated and the water supplied. These factors, coupled with increases in the cost of canal irrigation -- brought about by increasing monitoring charges and longer irrigation durations -- have contributed significantly to reducing farmer interest in obtaining canal water.

The complex network of social institutions which exploit and distribute groundwater has been extensively documented in Kolavalli and Chicoine (1987), and Shah (1988a, 1988b). Groundwater markets are more active in taluks located away from the head. They provide even smallholders with access to reliable water supplies.

Pumped water is supplied through a network of underground pipelines. A typical village in these areas will have 25 to 40 tubewells. In the study area, we found well water pumped in Borsad town being delivered to villages like Bochasan, located 5 km away. Water prices were fairly uniform within the region at Rs 15 to Rs 20 per hour for 20 to 25 hp wells. A detailed economic analysis of groundwater and conjunctive water use in the sampled farms of the command area is given in the section *Type of Irrigation and Production Behavior.*

Delivery Performance

THE ANALYSIS OF system operations and farmer behavior presented so far provides the framework for the following hypotheses on water distribution patterns. These hypotheses will be tested using statistical parameters and models.

(1) There appears to be a significant disparity in flow levels and reliability of water supplies between the two secondary canals. Untimeliness and irregularity were also reported in the Borsad Command Area.

(2) The spatial factor is a major determinant of the water supplies received by farm plots. Hence, the WAI should be strongly influenced by the position of the field in relation to the outlet head.

WATER DELIVERIES AT DISTRIBUTARY LEVEL

The Irrigation Department's data had to be relied on for discharge readings at the head regulators of the secondary canals. The WALMI team had carried out only a limited number of spot checking measurements using more accurate measuring devices. Unfortunately, for the Umreth Distributary, target figures on the area irrigated/unit water were unavailable. Comparison based on these criteria between the secondary canals, therefore, is impossible. Nevertheless, several inferences can be drawn from the figures that were available.

Kharif

During the first two rotation periods, canals were closed due to rains. Delayed monsoon rains also postponed water releases in the secondary canals, as evidenced through the skipping of planned rotations one and two (Table 4). In setting the formal targets, the irrigation authorities assumed that canal irrigation was the only source of water supply, although rainfall during this period is a regular occurrence. Rainfall was heavy from 20 July until 10 August, followed by a dry spell until the end of August (see Figure 4). While the Umreth Distributary started operating by 13 August, canal operations only began in the Borsad three days later.

The coefficient of variation (CV) of daily discharges within a rotation was fairly low for Umreth except in the fifth rotation, during which period it was higher (Table 4).

Data on the area irrigated by crop for the corresponding period during previous years not being available, it is difficult to explain this. Canal closure for the week beginning 29 August, coincided with moderate rainfall (Figures 4 and E-1). Discharge levels dropped by a cubic meter during the last week of September. Overall water levels were not low, and were maintained at higher levels before and after this period.

Table 4. Discharge-related statistics: Kharif 1991/92.

		Borsad				Umreth	
Rotation No.	Rotation period	Coefficient of variation of daily discharges (%)	Actual/ target ratio (DPR)	AI/DC Target	AI/DC Achievement acres	Rotation period	Coefficient of variation of daily discharges (%)
3	16-31 Aug.	16.13	0.93	1.85	1.01	08-28 Aug.	2.9
4	01-15 Sep.	45.50	0.20	1.79	1.53	06-21 Sep.	8.63
5	16-30 Sep.	9.43	1.05	1.74	1.58	27 Sep.-07 Oct.	13.86
6	10-14 Oct.	13.90	1.03	1.65	1.47	16 Oct.-01 Mar.	8.32
7	16-29 Oct.	31.10	1.26	1.84	2.04	--	--

Note: AI/DC = Area irrigated per day-cusec.

The CVs for comparable time periods for the Borsad Distributary are generally much higher, as is to be expected from a distributary located downstream. Since this distributary has a lower design capacity, it operates without a break between rotations. In contrast, there are seven days off between each rotation in the Umreth Distributary (Figures E-1 and E-2). As target figures were available for this sub-system, the DPR was calculated for each rotation period (Table 4). Since the canal was closed for nearly a week during the 3rd rotation due to breaches, both the average daily discharges and DPR were low while the coefficient of variation was high. The DPR was close to one (an ideal value) in the succeeding rotation periods.

The period beginning September to mid-October broadly corresponds with the critical water sensitive period of the rice crop. Moderate rainfall of 30 mm occurred during the last week before the withdrawal of the monsoon on 3 September (Figure 4). Discharge flows were nil from 5 to 8 September (due to canal closure), and reached design capacity (1.76 cubic meters/sec) around 20 September. Canal flows tapered off toward the end of the month and finally exceeded design capacity on 10 October. Thereafter, the CV which had been relatively low, moves up in the last rotation, with day-to-day fluctuations in discharges.

The irregularity of water deliveries is validated through this lag in water response to critical crop-water demand. Excess demand, even in the head reaches results from moisture stress which develops at an earlier stage of crop growth. This is the case even after the end of the monsoon, when there is sufficient time to assess the area under rice.

The area irrigated per day-cusec (AIDC) achievement figures also fall short of target figures. As pointed out earlier, target figures are set well above the normal crop water requirement (CWR) for rice crops in sandy loam soils. The target discharges and the area to be irrigated as discussed in the seasonal plan document do not reflect anticipated demand. Therefore, the delivery-performance ratio (DPR) is not a very meaningful figure. Even if discharge readings are accepted at face value, one cannot conclude from the DPR that canal operations are meeting targets and functioning efficiently.

Rabi

Despite lower than normal rainfall in the catchment area in 1991, the Kadana Reservoir reached its full capacity of 1,540 million cubic meters by mid-September.

A disruption in flows for 3 days occurred during the second rotation due to breaching and topping in the Umreth Distributary. Nevertheless, data on daily discharges for the Umreth and the Borsad distributaries reinforce the earlier finding that variation in flows is more in the case of the latter than the former (Figure E-3 and Figure E-4). The respective CVs also reflect the differences in flow fluctuations (Table 5). Discharge levels on an average are 0.5 cusecs lower than during kharif due to reduced water demand.

As rotations advance, progressive increase in daily flow variations are noticed in the case of the Borsad Distributary. While the Irrigation Department staff do not report target figures (target allocations frequently stop at sub-division level), flows are expected to remain stable during a specific rotation period. The DPRs for the Borsad Canal ranged from 0.51 to 0.69, reflecting, both the abstract target setting exercise and poor operational performance. Both distributaries are planned to operate on a 10 days on, 10 days off schedule. However, observing the varying intervals between the starting dates of rotations, it can be inferred that this is rarely adhered to. While there are fewer rotations but of longer duration for the Umreth Distributary, the practice is reversed for the Borsad Distributary.

Table 5. Discharge related statistics: Rabi 1991/92.

Borsad						Umreth	
Rotation No.	Rotation period	Coefficient of variation of daily discharges (%)	Actual/ target ratio (DPR)	AI/DC		Rotation period	Coefficient of variation of daily discharges (%)
				Target	Achievement acres		
1	16-27 Nov.	22	0.58	2.11	1.68	-	-
2	06-15 Dec.	20	0.69	2.11	2.27	05-15 Dec.	16
3	27 Dec.-05 Jan.	25	0.57	1.99	1.86	08-23 Jan.	19
4	16-26 Jan.	35	0.51	1.99	2.10	05-24 Feb.	28
5	06-16 Feb.	36	0.65	2.00	2.25	07-17 Mar.	15

Note: AI/DC = Area irrigated per day-cusec.

The area irrigated per unit water in the Borsad Secondary Canal is approximately 2 acres/day-cusec, an increase over the average kharif figure of 1.5 acres/day-cusec. These values match the expectation of less water required for the rabi crops.

FIELD WATER DISTRIBUTION

Kharif

The water availability index (WAI) is regressed by the distance between the canal-irrigated rice plot and the outlet head. Dummy variables are used for minors in the Umreth Distributary and a single dummy for the Borsad Distributary. Since there were only 13 canal irrigated rice plot observations in total for the latter, individual analysis has not been attempted for each minor.

The results are as follows:

WAI= 57.57 - 0.0037DISOUT + 8.46UMM + 4.33UTM - 12.04B (26.7)
(2.84)+++ (3.84)+++ (1.98)++ (4.70)+++
$R^2 = 0.50$

Note: DISOUT = Distance from outlet head.
B = Borsad.
UMM = Umreth Middle Minor.
UTM = Umreth Tail Minor.

Parenthetical values are two-tailed "t" statistics.
+++ and ++ are the significance at the 1 percent and the 5 percent level, respectively.

These results indicate that if a plot is located just adjacent to the outlet of the head minor, the WAI would be 58, whereas for a similar plot located in the middle and tail minors the WAI is higher by 8 and 4, respectively (Table 6). The comparable value of the WAI for a farm plot located in the head of an outlet in the Borsad Distributary is much lower at 45.

It cannot be claimed that these results represent the minors for all periods, however carefully the outlets have been sampled. Despite its location and the lower CCA it commands, the head minor has a lower WAI. This is primarily due to its higher elevation in the middle portion in relation to the other minors, which forces farmers to pump canal water to their fields with diesel engines.

The negative coefficient on DISOUT confirms the assumption that the WAI is inversely related to distance along the field channel. The WAI decreases by 3.7 units for every 1,000-feet increase in field channel length. While field channel length varies from one outlet command to another, the average tailend farm plot is located 1,500 to 2,000 feet from the outlet head. Thus, the expected WAI for such plots should be 5.5 to 7 units less than that for the headend plots. Spatial inequity in terms of less water being available to tailend farms is, therefore, a phenomenon common to even the head distributary.

Table 6. Water availability index (WAI) and location.

Name of Secondary Canal		Expected WAI at Outlet Head
Umreth	- Head	58
	- Middle	66
	- Tail	62
Borsad		45

No trends in the number of irrigations or the duration of irrigations between plots at different points along the water course were noticed. Views expressed in an earlier section with reference to obtaining accurate information on these variables must be kept in mind.

Rabi

Based on a set of sample readings taken at different points along three water courses belonging to the Umreth Distributary, conveyance losses were estimated. After allowing for errors in measurement (extreme observations were eliminated), on an average, a field located mid-way along the field channel could expect between 65 percent to 30 percent of deliveries as at the head of the outlet (Table A-1). These figures indicate that the normally assumed losses at the field level by Irrigation Department staff (30 percent) are low and suggest one possible reason for the lower efficiency of the area irrigated per unit water. These readings were taken when there was no diversion in flow.

The total water requirement for the cropped period is estimated at 533 mm for kharif rice, higher than that of wheat (292 mm) and tobacco (393 mm), taking normal rainfall into consideration (WTC 1983). Water requirements for land preparation are included for rice, while residual moisture is considered sufficient for other crops. The broad guideline for irrigation intervals developed by the WTC study (ibid), recommends that wheat (dwarf) and tobacco be irrigated at 18 to 24 and 15 to 25 days intervals, respectively, and suggests a 2 to 4 days interval for rice, under rainless conditions. The actual requirements under different field conditions vary, especially where possibilities for water logging exist.

Nevertheless, it is evident that wheat and tobacco require a less number and duration of irrigations than rice. With a lowered demand for water, interference in tertiary block water distribution is also considerably reduced.

No significant functional relationship between the distance from the head of the outlet and the WAI (as in the case of canal-irrigated rice plots) was evident for sample plots of canal-irrigated wheat. This suggests that in the case of wheat, the location along the field channel does not have a bearing on the WAI.

Impact on Agriculture

CROPPING SYSTEMS, WATER CONTROL AND TYPE OF IRRIGATION

DATA PERTAINING TO cropping patterns in sampled outlet command areas are presented in Appendix B (Tables B-1 to B-6). A section of the same data on the area irrigated from different sources of water is represented in the Figures 5a-5d.[15]

Kharif

All outlet commands in the middle minor of the Umreth Distributary are irrigated by canal. However, in the head and tail minor commands, the area irrigated by canal decreases significantly as we move from the head to the tail outlets, dropping from 84 percent and 41 percent, to 12 percent and 15 percent of the respective CCAs (Figure 5a).

In the tertiary blocks in the tail minor 50 to 85 percent of the area is irrigated by well water either exclusively or conjunctively with canal water. It also appears that wherever canal water is available, rice is the preferred crop (Table B-1) except in parcels of land located at higher levels than the canal. Here, farmers usually grow tobacco and water is either pumped to fields using diesel motors or the land is irrigated by groundwater. Tobacco, unlike rice, requires regulated irrigation, therefore better water control is required to irrigate this crop. The area under perennials and bajra is negligible.

In the Borsad Distributary a large number of middle and tail outlets are nonfunctional (Table 7). Water deliveries do not go beyond the head reaches of the distributary and the minors. The tail minor Chuva is defunct. There are also a number of unauthorized or kutcha outlets (round-shaped breaches in canal walls) in the off-take minors of both secondary canals, in contrast to the pucca outlets (authorized concrete outlets). Pipes are laid directly to the fields in certain locations from these kutcha outlets. Often, kutcha outlets have capacities greater than one cusec discharge which is the design capacity of the *pucca* outlets. These outlet openings are sealed with mud, when not in use or during visits by high-level functionaries; so they "disappear" and "appear," according to necessity.

Consequently, water control by the Irrigation Department is poor. Besides, as discussed earlier, even at the peak of the season no systematic procedures are followed in rotating water flows within a distributary.

'The Borsad Distributary Command also has interesting sociopolitical features which influence water allocation. Most farmers in the head areas come from Borsad town and belong to the Solanki community, which although backward, is politically dominant. The middle villages of Vehra and Dedharda, and the tail village of Debassi consist mostly of Patels, Parmars and others. Whether the original canal design was influenced by the presence of the Solanki community is not known. Some farmers from this community, with large landholdings in two outlet commands in the head minor, have been able to prevent canal water from reaching these outlets by influencing the Irrigation Department staff and intimidating other farmers.

Solanki farmers have invested in tubewells and need a sufficient number of buyers of water from their tubewells. However, with the proliferation of tubewells further downstream, the groundwater market has become so competitive that even the Solanki tubewell owners have been forced to lower water prices. Concern with obtaining canal water has thus lost some of its importance.

Table 7. Count of authorized/unauthorized outlets.

Distributary	Name of minor	Design discharge	Outlets authorized functional	Nonfunctional	Kutcha outlets
Umreth	SM 2R(Head)	4.70	5	-	6
	SM 5R(Middle)	19.50	13	-	10
	SM 9L(Tail)	15.10	12	-	8
Borsad	SM 6L(Head)	7.95	6	6	4
	Vehra Minor (Middle)	19.20	11	13	5
	Direct outlets		54	13	16

Table B-2 in Appendix B gives the outlet area irrigated and the crop distribution by location. The proportion of the area irrigated by canal in the head minor decreases progressively from the head outlet towards the middle and tail outlets: 65 percent, 6 percent and 0 percent, respectively (Figure 5b). The area under rice also declines relatively. It can be observed that 50 percent of the middle outlet command is well irrigated and that most of the area in the tail outlet command, is rain-fed. Here, bajra is grown (Figure 5b and Table B-2). Six out of nine farmers growing bajra crops have nonagricultural, off-farm jobs as their primary occupation. With the nonavailability of canal water, the choice of bajra which requires relatively less labor and other inputs seems rational.

Rice, the main crop in the Vehra Minor (middle minor) Command, is irrigated by canal water or well water or both. The upper reaches of the head outlet of the Vehra Minor gets water almost at will, whereas in the tail section, conjunctive use with well water becomes necessary even for the same crop (Figure 5b). Outlet gates are in a state of disrepair due to leakage from the minor, and consequently, there is always excess water which remains undrained. Severe water logging occurs in and around the headend of the outlet command area in the middle outlet, again due to leakage. In addition, there is stagnant rain water with field channels below farm level, and very irregular channel configurations with a number of bifurcations. Water flow from field channels is almost nil in the tail of this outlet command. Only 30 percent of its area is irrigated by canal water while nearly 50 percent of the command area of the middle and tail outlets are irrigated by groundwater (Figure 5b).

In the tail outlet of the Vehra Minor, there is a tank in which topping often occurs during the monsoon. The erratic water flow in the minor, presents a picture of lax and unregulated water distribution. Cultivation practices reflect a fair degree of indifference during the kharif season.

Lift irrigation from canals is practiced in the headend of the tail direct outlet 1. Canal water is delivered into a defunct well through underground pipes and then pumped out and sold at groundwater market rates of Rs 15/hour (for a 20 hp motor). Tail direct outlet 2 has tobacco grown in its command area and is irrigated by well water (Figures 5b and Table B-2). Canal water has not reached this outlet for several years.

Rabi and Summer

A substantial area cultivated during kharif was left fallow in both the distributary commands. Farmers growing early summer crops often leave the land fallow during rabi. It can be observed that the two outlets MM and TM in the Umreth Distributary, with a higher proportion of fallow area (Figure 5c) have 55 to 60 percent of the area under summer crops. It is also instructive to note that similar to the pattern during kharif, the outlet commands of the middle minor of the Umreth Secondary Canal have higher percentages of canal irrigated area than the outlets of the other minors (Figure 5c and Table B-3). Again, tail minors are primarily irrigated by well and/or tubewell water. Tobacco is included in both seasons, since it is usually planted during mid-kharif and extends up to the end of the rabi season, receiving canal irrigation during both seasons. During the break in canal irrigation between the two seasons in November, some farmers supplement it with well water and some conjunctive use can be observed on this account. Additional area is brought under tobacco cultivation during rabi. This is a superior variety to the one grown during the mid-season of kharif. Wheat is the other main crop which has replaced part of the kharif area under rice for the rabi season.

No pattern in summer canal irrigation or well irrigation is observed in relation to outlet location (Table B-4). Apart from bajra and groundnut, nearly 50 percent of the summer canal irrigated area is found to consist of summer rice. Almost all examples point to a situation of rice lock-in. Water-logging resulting from excess water supplies during previous seasons prevents field drainage to such an extent that farmers are left with no alternative but to grow rice.

In the Borsad, the typical head-tail phenomenon of water distribution can be clearly seen. The head tertiary block of the head and middle minors are primarily irrigated by canals (96 percent and 58 percent of the total irrigated area, respectively). The remaining canal irrigated area is negligible (Figures 5d and Table B-5). Where well water irrigation is predominant in these areas, wheat and tobacco followed by mustard form the bulk of the hectarage. Farmers put in more effort to improve field channels to regulate outflows for the rabi crops than they do for kharif rice. Bajra and some groundnut are cropped in summer (Table B-6)

The proliferation of unauthorized kutcha outlets in both canal commands suggests the extent of deterioration in the de facto control of water supply by the Irrigation Department. In both distributaries, the commands of the minors at the head receive comparatively less water than the middle ones, as shown by the differences in the area irrigated by canal. Factors such as uplying lands in the former, and community politics in the latter are largely responsible for this. The lower distributary of the Borsad has less gross area irrigated by canal; nevertheless, it exhibits a more diversified cropping pattern due to better water control provided by lift irrigation.

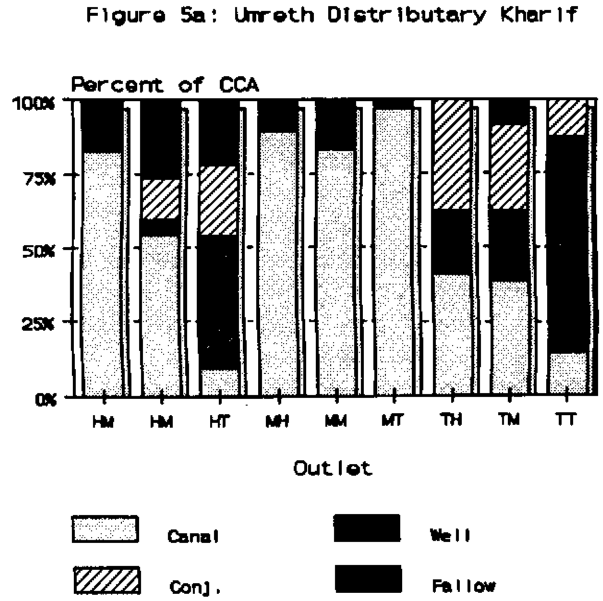
Rice is found to be irrigated with canal water, or well water, or both. The first method is more predominant in the Umreth Distributary Command and the latter two, in the Borsad Distributary Command. Farmers have found tobacco, and to a lesser extent mustard, to be increasingly attractive and remunerative and have replaced areas under rice and wheat with these crops. In fact, farmers with lowlying lands and fields which remain flooded continuously experience the most difficulty. They have the minimum of options in determining cropping pattern, and securing adequate benefits from inputs. They are interested in growing commercial crops (like tobacco) even in head reaches, provided the nature of the water supply allows such a choice. Less water but better delivered, especially in the head reaches, might therefore be a welcome change. On the other hand, farmers in uplying lands who are forced to pump canal water to their fields by hiring diesel engines, besides paying half the charges for canal water, are relieved from the hazard of water logging which often results from excess canal supplies.

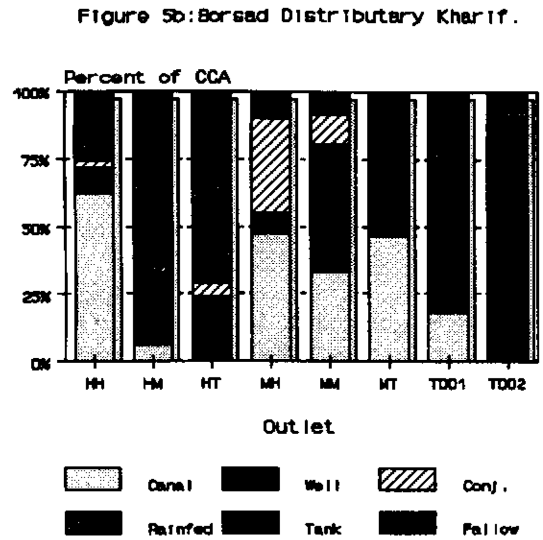
CROP PRODUCTIVITY BY LOCATION

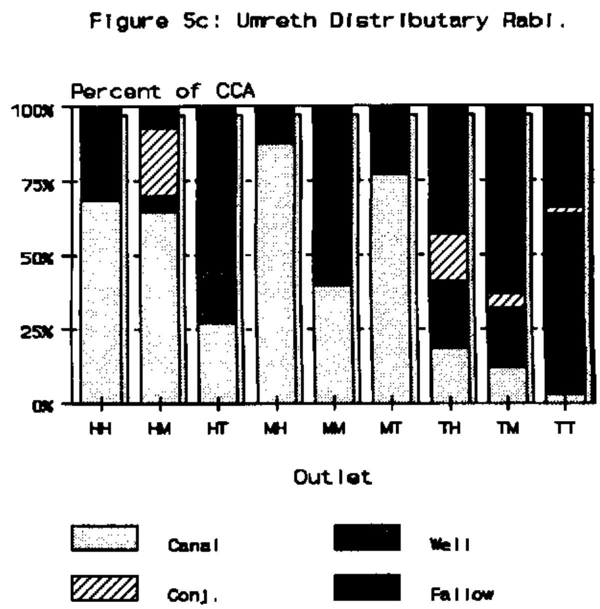
Kharif

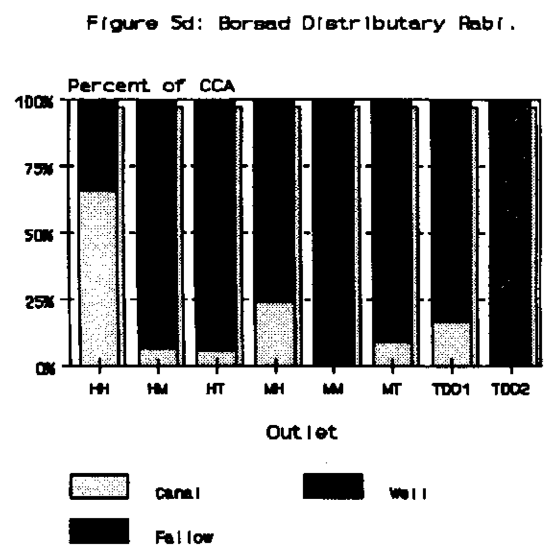
The previous section gave figures for crops grown under irrigation for all farm plots in the selected outlets, irrespective of whether they were part of the sample. Among the selected farm plots in the Umreth Distributary, almost all came under canal irrigation, with 80 percent of plots under rice and the remaining under tobacco.

Figure 5. Proportion of CCA of irrigated outlet, by type of Irrigation: 1991/92. (The first and second letters of X-axis labels refer to positions of the minor and the outlet, respectively.)









Note: H = Head. M = Middle. T = Tail. Conj. = Conjuntive. CCA = Cultivable Command Area.

In the Borsad, 25 percent of the selected farm plots came exclusively under canal irrigation and cultivated rice (Table 8). Here again the predominant crop in well irrigated and conjunctive irrigated areas (48 percent of the total sample) is rice, followed by bajra and tobacco. These figures more or less conform to the pattern of crop distribution for all outlet commands discussed in the previous section. An examination of Table 8 does not reveal any linkage between differences in the average WAI and use of nitrogen/ha with yield/ha between the head, middle and tail minors, as normally expected.

Increase in operational costs has a positive relationship with increase in yields per ha. What is interesting, though, is that the Borsad Distributary, despite a lower average WAI has an average yield approximately 450 kg per ha higher than comparable canal irrigated rice yields in the Umreth Distributary. Besides, well-irrigated and conjunctive-irrigated plots also show higher yields (3,100 kg) in comparison to canal-irrigated rice.

Table 8. Mean input/production indicators for rice, by location and type of irrigation.

Type	Location	No.of Farm Plots	Average WAI	Average Nitrogen (Kg/ha)	Average Total Operational Cost (Rs/ha)	Average Yield (Kg/ha)
Canal	Umreth (80%)	68	53	134	2,813	2,473
	H.M.	22	49	154	2,591	1,995
	M.M.	22	57	110	2,658	2,372
	T.M.	24	54	139	3,158	3,003
Canal	Borsad (25%)	13	38	160	3,741	2,944
Well/Conj.	Borsad (43%)	26	-	167	3,581	3,001
Canal Avg.	(Total)	81		138	3,159	2,549
Well/Conj. Avg.	(Total)	30		169	3,431	3,100

Note: H.M. = Head Minor. Avg. = Average. M.M. = Middle Minor.
T.M. = Tail Minor. Conj. = Conjunctive.
Parenthetical values are percentages of the total sample plots of a particular distributary command.

This could be accounted for, partly, by the greater flexibility and the more timely scheduling allowed by groundwater irrigation. Irrigating rice using groundwater costs almost seven times more than irrigating with canal water, so that farmers endeavor to make optimal use of the water. Canal irrigation charges are fixed per unit of land for the same crop and irrigation costs have been excluded from the total operational costs. The value of family labor is also not considered in computing costs.

Rabi

During this season as during kharif, the impact of variation in canal water deliveries is evident in terms of the canal irrigated area and the cropping pattern (refer previous section). Sample plot figures of the area under different crops are also representative of the figures for all outlet commands that were given earlier.

No significant differences are found in the WAI and neither do patterns of relationship between input and cost differences and production become visible with respect to location (Table C-1). Recalling that WAI does not appear to be related to the distance along the field channel; this suggests a fairly uniform level of water distribution for canal-irrigated wheat. Actually, the number of observations are rather limited since less wheat in comparison to rice is irrigated with canal water.

Given the variations in soil fertility, input applications, cultural practices and topography, trying to establish a relationship with mean values will not be sufficient. Productivity has to be specified with regard to a particular factor of production such as land, water, nitrogen, etc. In this study, productivity is illustrated in terms of returns to soil moisture conditions and a few interrelated variables.

PRODUCTION FUNCTION ANALYSIS

Earlier, there was evidence of a lax operating mechanism at the tertiary level and above with excessive flooding and inadequate drainage in several areas, particularly for kharif rice. It was also apparent that poor management on the part of the Irrigation Department, leakages in physical structures, land gradient and the actions of farmers themselves were responsible for the conditions which resulted in the loss of water control.

Irrigation beyond crop water requirements with its subsequent negative impact on crop productivity, also deserves consideration. A logical expression of production behavior should be tested for both positive and negative returns to the WAI for rice. Since all fields do not have independent irrigation inlets and drainage facilities, the practice of field-to-field irrigation is not uncommon. In plots which are water logged, farmers' use of inputs such as nitrogenous fertilizer, which can be leached by flooding, deserves attention.

Farmers are able and willing to follow better water management practices such as flood control, for the rabi season crops like wheat and tobacco, which they perceive as being water sensitive. It is useful to recall that water releases in the monsoon season during kharif (in addition to normal rainfall), are markedly higher than during rabi. It appears unlikely that field moisture conditions would cause declining yields in wheat.

A quadratic equation is used to capture the production relationship as it does not impose such strict restraints as many other functional forms. It does not presuppose zero yields when nutrient applications or any input level is zero. Besides, it subsumes the linear functional form (Griffin et al. 1987). It also permits data to be tested for changes in the sign/direction of the marginal product. Unlike the Cobb Douglas or the Power function, it allows for both a declining and negative marginal productivity. A *maxima* for total output is also defined. These features of the quadratic function are consistent with known input-output agronomic relationships (Heady and Dillon 1961).

Since we do not have data on the actual quantum of water applied to each plot, the proxy variable WAI is used. The index is constructed in such a way that it increases with the number and quantum of irrigations a plot receives, and reduces with increase in soil moisture stress. Nitrogen is the other variable included with the cropped area.

The complete functional form for these two resources and an additional linear term for farm plot size can hence be written as:

$$Y = b_0 + b_1W + b_2N - b_3W^2 - b_4N^2 + b_5WN + b_6A$$

Note: Y = yield/ha. W = WAI. N = Nitrogen in nutrient kg/ha. W^2 = Squared WAI. N^2 = Squared N. WN = Interactive term of WAI and N. A = Farm plot size (ha).

The estimated regressions are given in Table 9.

Table 9. Estimation of production function for rice.

	WAI	WAI^2	N	N^2	WN	A	Constant	R^2	Adjusted R^2
With N^2	220.08++	-1.87++	27.32+	-0.01	-0.35+	824.73++	-4819.0	0.28	0.23
Eq (1).	(2.648)	(2.48)	(1.83)	(0.38)	(-1.93)	(2.54)	(-2.09)		
Without N^2	224.27	-1.87	22.75++		-0.38+	816.76++	-5223.7	0.28	0.22
Eq (2).	(2.4)	(-2.42)	(2.57)		(-1.87)	(2.50)	(-2.047)		

Note: ++ Significant at the 5 percent level.
+ Significant at the 10 percent level.
Parenthetical figures are two-tailed "t" statistics.

In Eq (1), the term N^2 is insignificant, as there is a slight decrease in the adjusted R^2 with its introduction which indicates that this variable is not adding anything of explanatory value. Our range of observations for N (with mean = 143, and S.D. = 54) also suggests that there are hardly any farmers applying excessive nitrogen per ha, to cause diminishing returns to that factor. This variable was therefore left out and the equation re-estimated (Eq. 2). It is reassuring to note that all coefficients except the WN term are significant at the 5 percent level and also have the expected signs. The R^2 is rather low. However, it must be noted that yield and nitrogen are in per ha terms, and that variation in productivity (yields per ha), rather than production (yield per plot) is examined here. In the latter case, the farm plot size variable would have contributed to a high R^2, by capturing the variation in production across farm plots.

While some correlation exists between the independent variables, it does not suggest harmful collinearity.[16] The positive term on plot size indicates increasing crop productivity per ha in larger plots, that is increasing returns to scale with land.

The negative coefficient on the interactive (WN) term is unexpected, as water and nitrogen are generally regarded as complementary inputs.[17] However, with negative marginal productivity for the WAI, as denoted by the correct sign for the squared WAI term, a negative or zero interaction may also exist. Besides, at lower levels of the WAI (below 45), no significant correlation is found between the WAI and nitrogen. The correlation becomes negative and significant only at higher levels of the WAI.

From the estimated regression, the marginal physical product (MPP) of the WAI (the WAI is an approximate estimate of seasonal soil moisture conditions) can be obtained by taking the first derivative of the production function. (MPP = 220.08 - 2 (1.89 * WAI) - 0.35 N). The MPP here is not a constant and varies with the level of input, although the rate of variation is constant. By keeping nitrogen and other excluded variables and inputs at the mean level, the optimal level of the WAI (assuming zero marginal costs for water), is estimated and shown in Figure 6. This is the point where the total output is also maximized. Any increase in the WAI beyond 46, causes a decline in absolute yields, and therefore constitutes the zone of inefficiency in water utilization.[18]

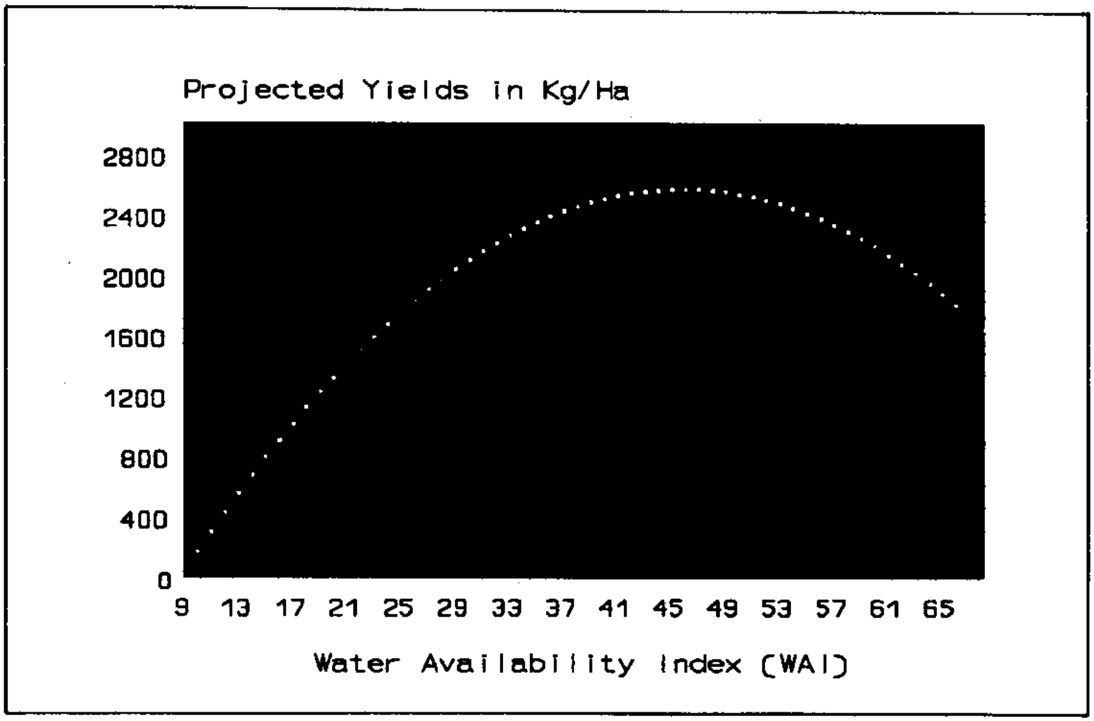
The average WAI and the corresponding projected yields per ha for the two distributaries are shown in Table 10. The number of farm plots exhibiting excessive soil moisture is also given. In both the Umreth and the Borsad canal commands, the hypothesized grain yields for the average WAIs are below the maximum potential, although ironically, this is due to exactly opposite reasons. In the case of the former, it is caused by over irrigation, while in the latter case it is due to a certain amount of water deficiency. For the Umreth, a majority of the sample farm holdings in all three minors fall into this category.

Table 10. Water use efficiency and production for rice.

Name of canal	Average WAI	Projected yield kg/ha	Farm plots with WAI > 46	
			No.	% of Total
Umreth:	53.73	2,435	53	79.10
H.M.	49.13	2,542	15	68.20
M.M.	57.17	2,326	18	81.80
T.M.	54.13	2,435	20	87.00
Borsad:	37.50	2,448	2	15.40

Note: H.M.= Head Minor.
M.M.= Middle Minor.
T.M.= Tail Minor.

Figure 6. Production relationship for kharif rice between water availability index and yield.



A note of caution should be added here. As some factors of production such as labor, capital expenditure, etc., are not components in the estimated production function and since some of them complement included variables, this function is better described as a partial production function. The projected yields are not in reference to an optimal mix of all input combinations and are therefore lower than the actual observed yields. Nevertheless, since the idea is to examine the relative impact of spatial distribution of water (or its proxy variable) on crop productivity, the characterized production relationship is adequate.

The optimal WAI as constructed here should also not be regarded as a practical guide for scheduling irrigations and determining ideal soil moisture regimes; rather, it should be regarded as an aggregated field moisture index for the entire season. It is useful to identify and compare areas of over- and under-irrigation.

WAI AND WHEAT PRODUCTIVITY

The computed WAI for canal irrigated wheat plots has been regressed on yields to examine whether any relationship is apparent. The variation in the independent variable WAI is not sufficient to cause diminishing returns on the yield (kgs per plot); so the simple linear form is the most appropriate in this case. The estimated model is:

Yield = - 3461.43 + 54.68 WAI + 1644.94 Plot Size
(9.45)+++ (2.17)++ (5.9)+++
$R^2 = 0.72$

Note: +++= significant at the 1% level.
++ = significant at the 5 percent level.
Parenthetical figures are two-tailed "t" statistics.

The positive coefficient on the WAI indicates that returns to additional canal irrigation are likely to be productive and that water utilization is not inefficient. Note that yields vary considerably depending on the size of the plot. The significant coefficient for that variable means that an additional unit of land under wheat produces 1,645 kg. Much of the explanatory power of the equation comes from using plot size as an independent variable. Correlation is of the order of 0.50 between the variables WAI and plot size, and does not indicate a serious multicollinearity problem.

Type of Irrigation and Production Behavior

THE AVAILABILITY OF groundwater and a competitive market mechanism to distribute it, has provided both an alternative to canal irrigation and a supplementary source of irrigation to many farmers who had previously been deprived of canal water in the command area. (Farmers are also reluctant to organize themselves on this account.) Conjunctive use of water also reduces risks associated with sole dependence on the canal water supplies.[19] Evidence from an analysis of cropping patterns in tertiary blocks shows that gross cropped area figures are as high downstream of the canal command as in the upper reaches. Groundwater irrigation also provides greater flexibility in fixing quantum and scheduling of irrigations; the potential for a better response to irrigation investment and higher farm returns is strong. This section will address the issue of the significance of the relative impacts of surface water and/or groundwater on agricultural production in the represented command areas.

CLASSIFICATION AND CHARACTERISTICS OF SAMPLE FARMS

Farms are classified based on the size and type of irrigation. The distribution of landholdings is given in Table 11. The total sample size is 133. The average holding size for farms is 1.69 ha.[20]

Besides using canal water, most farmers in the MRBC either buy well or tubewell water from other farmers or from state operated tubewells. Well owners are few in number and seven were identified in this sample. Conjunctive farms number 35 percent of the sample. These include farmers using well water to grow additional crops and/or those supplementing canal supplies with well water for the same crop. The average conjunctive use farm has approximately 38 percent of the gross cultivated area under canal irrigation and 47 percent under well irrigation. The remaining 15 percent receives water from both sources, suggesting the extent of the inadequacy of canal water supplies for the same crop and land parcel.

Farm size shows an interesting trend with reference to the type of irrigation. The average farm size for canal-irrigated farms (1.58 ha) is close to the sample average (1.69 ha). Around 75 percent of farmers fall into the marginal and small categories.[21]

Corresponding figures for well-irrigated farms and conjunctive-use farms show that these farms are 0.6 ha below and above the sample mean, respectively (Table 11). In proportion to total sample representation, a lesser number of well-irrigated farms (2) and more conjunctive-irrigated farms (19) are observed in the middle to large farm groups.

The sampling procedure did not explicitly consider farm size as a criterion in farm selection. Whether these trends are anomalies arising due to this procedure is not clear. It may be surmised that larger farmers with a number of scattered holdings in different locations have a greater need for irrigating conjunctively, in order to facilitate decisions on crop choice and water management for the entire farm.

Table 11. Distribution of landholdings.

Farm size category (ha)	Canal No.	Well No.	Conjunctive No.	Total No.
Below 1	25	19	14	58 (43.6)
1-2	15	14	13	42 (31.0)
2-3	8	0	7	15 (11.3)
Above 3	4	2	12	18 (13.5)
All farms	52 (39.1)	35 (26.3)	46 (34.6)	133 (100.0)
Average farm holding	1.58	1.07	2.28	1.69

Note: Parenthetical figures are percentages of the total sample.

CROPPING PATTERN AND CROPPING INTENSITY

Examining the hectarage of crops irrigated by different types of irrigation highlighted patterns outlined earlier in the analysis of cropping systems. Canal-irrigated and conjunctive-use farms have on the average 33 percent of the gross irrigated area under kharif rice while the figure is much lower (14 percent) for solely well-irrigated farms (Figure 7). The converse is true for summer bajra, a crop which requires far less water than rice. Wheat occupies 21 percent of the gross cultivated area of canal-irrigated farms, 12 percent of conjunctive-use farms with a negligible area under well-irrigated farms. The trend is reversed for tobacco, a water use efficient crop with high returns.

As water charges for well and tubewell irrigation are much higher than for canal irrigation, farmers' choice of crop is strongly influenced by the water requirements of each of these crops. Annuals such as sugar cane and banana are found only in isolated instances. Groundwater sources are not adequate for these crops and farmers using canal water prefer to grow multiple crops, rather than a single perennial crop.

Cropping intensity (CI) is found to be higher in canal-irrigated farms (Table 12). However, two factors require consideration. Large variations in cropping intensity across farms may reflect inequalities in canal water supplies. The range of variation is low in other farms, indicating stability in cropping patterns. The other aspect is that, since well-irrigated and conjunctive-use farms often switch to longer duration crops such as tobacco, which is grown across two seasons, the cropping intensity needs to be adjusted accordingly to double the weightage for such crops. When this is done, the cropping intensity of both conjunctive-use and well-water irrigated farms increase, and the differences are not significant.

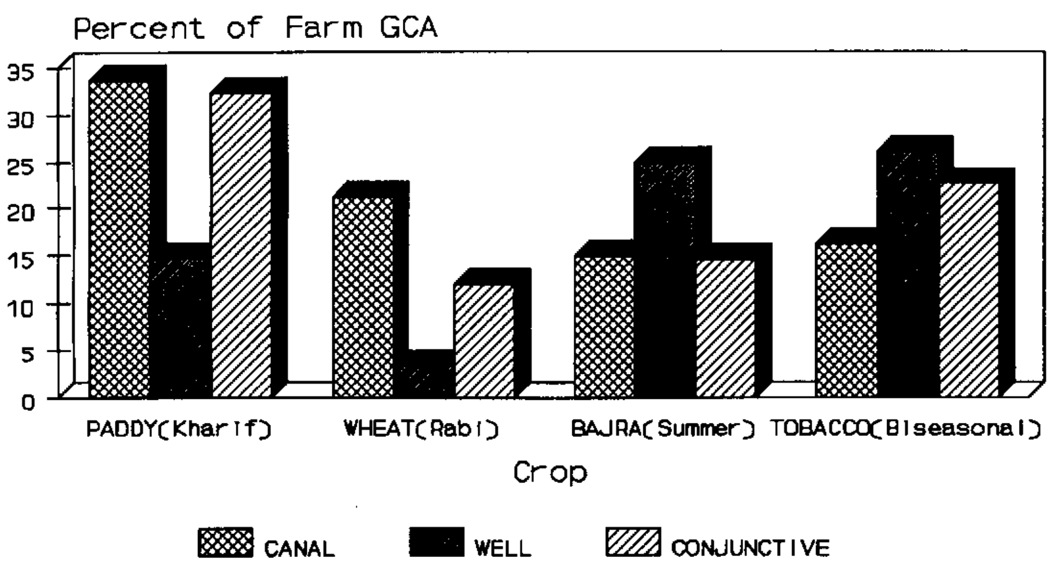
The cropping intensity, adjusted or otherwise, is observed to have an inverse relationship with farm size (Table 13). This result is in line with evidence from other studies in this region (Kolavalli 1986) and elsewhere in India (Sen 1964; Narain 1980). Smaller farmers generally make more optimal use of the resources they command (such as land and family labor), being more directly involved in agricultural operations than larger farmers.

Table 12. Cropping intensity (CI), by type of irrigation.

Parameter	Canal		Well		Conjunctive	
	Mean	CV	Mean	CV	Mean	CV
CI	2.35	0.30	2.13	0.38	1.80	0.33
Adj. CI	2.58	0.71	2.70	0.36	2.33	0.34

Note: CI = Cropping intensity. Adj. = Adjusted.
Source: Average figures for each category -- Farm Survey 1991/92.

Figure 7. Average proportion of each crop area in the GCA of farms, by type of irrigation: Farm Survey 1991/92.



Note: Gross Cultivated Area (GCA) and Gross Irrigated Area (GIA) are the same.

Table 13. Cropping intensity by farm size.

Parameter	Farm size category (ha)							
	Below 1		1-2		2-3		Above 3	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
CI	2.55	0.67	1.97	0.37	1.71	0.30	1.31	0.41
Adj. CI	2.87	0.62	2.42	0.32	2.10	0.28	1,79	0.35

Note: CI = Cropping intensity. Adj. = Adjusted.
Source: Average figures for each category -- Farm Survey 1991/92.

Marginal farms record a cropping intensity of 2.5, but also display more variation in CI across the farms, implying that all farms in that group are not able to maintain a high degree of intensity in cultivation. Arguably, this may be due to a comparatively restricted ability to purchase nonfixed factors of production.

PRODUCTION COSTS AND RETURNS

Table 14 presents a summary of the economic parameters of performance. Production cost I includes all "out of pocket expenditure," plus family labor computed at prevailing wage rates, and costs of usage of owned farm assets such as tractors, drought power and wells or tubewells, etc., again computed at market rates. Production cost II includes all costs except irrigation expenditure. Returns I and II correspond to production costs I and II. The latter is viewed as a better indicator of economic efficiency, since canal water charges are flat rates and unlike groundwater charges do not reflect demand and supply conditions for water.

Table 14. Production costs and returns, by type of irrigation.

I.Type	Gross returns	Total production cost I	Total production cost II	Irrig-ation costs	Net returns I	Net returns II	Returns/ unit cost I	Returns/ unit cost II
Canal	18,984.18	10,263.46	9,808.15	455.31	8,720.72	9,176.02	1.84	1.95
Well	24,210.04	13,175.36	11,288.75	1,886.61	11,034.68	12,921.29	1.84	2.15
Conjunctive	21,012.05	11,336.95	10,299.75	1,037.20	9,675.10	10,712.30	1.85	2.04

Source: Average figures for each category -- Farm Survey 1991/92.

In comparison to canal-irrigated farms, well-irrigated farms demonstrate higher production costs but also give higher gross returns and net returns (I and II). Well-irrigated farms also appear to be highly commercialized, investing more and earning more. Conjunctive-use farms are placed in an intermediate position in both costs and returns. Over the years, average irrigation expenditures have more than doubled for conjunctive-use farms and quadrapuled in the case of well-irrigated farms, in comparison to farms receiving only canal water. However, the greater water supply flexibility and control provided by well water is an important factor in improving the productivity of other interdependent inputs such as fertilizer and labor, yielding higher returns than canal irrigation, besides increasing the quantum of application of these inputs. Further, cropping patterns involving longer duration crops also increase the overall level of inputs.

Differences in net returns II between canal-irrigated and well-irrigated farms are substantial, around Rs 3,700 per ha. When irrigation costs are included though, they narrow down to Rs 2,300. Significantly, average returns I (gross returns/total production costs I) work out the same for all farm groups (1.8). As indicated, canal-irrigated farms incur lower irrigation costs and the productive potential of this investment is less compared to farms using groundwater. Taken together, this implies that farmers in all categories adjust the overall employment of inputs (given the constraints or flexibility associated with a particular type of irrigation), to secure an optimal rate of return in the region of 1:1.8. When irrigation costs are excluded, significant positive differences in average returns are observed wherever well irrigation is used.

Gross returns increase with decrease in farm size as do production costs I and II (Table 15). Outlay on irrigation does not appear to be significantly different across farms of different sizes except for the medium size. All 15 medium sized farms were only found in the canal-irrigated and conjunctive-use categories, accounting for the lower outlay.

Small and marginal farms exhibit a higher degree of cropping intensity (adjusted or otherwise); consequently, larger production costs and values of production are not surprising. Average returns I and II are uniformly stable across farm size categories.

Table 15. Production costs and returns for farms of different sizes.

Farm size (ha)	Gross returns	Total production cost I	Total production cost II	Irrigation costs	Net returns I	Net returns II	Returns/ unit cost I	Returns/ unit cost II
Below 1	22,423.20	11,956.31	10,854.79	1,101.52	10,466.89	11,568.41	1.88	2.06
1-2	20,816.51	11,378.96	10,311.41	1,067.55	9,437.55	10,505.10	1.83	2.01
2-3	19,757.81	10,591.54	9,855.36	736.18	9,166.27	9,902.45	1.86	2.00
Above 3	18,326.48	10,337.87	9,357.29	980.57	7,988.61	8,969.19	1.77	1.96

Source: Average figures for each category -- Farm Survey 1991/92.

FARM RETURNS TO IRRIGATION EXPENDITURE

A Cobb-Douglas or a geometric function is used to correlate irrigation expenditure (IRRCOST) and the gross value of production (GROSSVAL) for all three seasons for which data was collected (Table 16). Landholding is the other variable. This function assumes a constant ratio of input mix. Since canal irrigation rates are fixed according to farm size and crop, it is an appropriate functional form. Also, a lesser degree of freedom is exercised in estimating in a Cobb-Douglas model. This is useful, since the number of observations in each category is limited.

Table 16. Regression analysis of returns to irrigation expenditure.

Model (Y = Log GROSSVAL)	Intercept	Log IRRCOST	Log landholding	R^2
Canal Irrigation Farms	8.120+++ (10.22)	0.283+++ (3.10)	0.597+++ (5.12)	0.75
Well Irrigation Farms	6.593+++ (5.36)	0.452+++ (2.83)	0.482++ (2.71)	0.66

Notes: +++ => Significant at the 1 percent level.
++ => Significant at the 5 percent level.
Parenthetical figures are two-tailed "t" statistics.

The equations are estimated in log form; the estimates for conjunctive-use farms were not significant. Problems of multicollinearity were detected, which occur in most cross-sectional studies of this nature and which can inflate the standard errors of the coefficients. However, the degree of multicollinearity was not severe for the regression models of the other two categories. The correlation coefficient of irrigation cost to farm size for the two models that are presented above were of the order of 0.75, and in the case of the conjunctive-use model, it was 0.85. Good estimates have been obtained, as supported by the "t" statistics. An alternative simple regression procedure dropping the farm size variable and using the log GROSSVAL/HA with the log IRRCOST/HA variables, gives similar coefficients for the irrigation cost variable, lending credibility to the robustness of the estimates.

The coefficients of irrigation cost and landholding are elasticities of irrigation expenditure and land (hectare) with respect to the gross value of production. Gross revenue in well-irrigated farms show a far superior response to irrigation outlays than canal-irrigated farms. A proportionate change in the value of total production, per unit proportionate change in irrigation cost is more in the case of the former. For instance, a 10 percent increase in irrigation expenditure for well water (Rs 190) over average levels should yield a 4.5 percent increase (Rs 1,090) in gross returns; whereas, a similar increase of 10 percent (Rs 46) would produce a 2.8 percent increase (Rs 573) in gross returns for canal water.

From the estimated regression coefficients, the marginal value products (MVPs) were computed. The MVP is B_1Y/X, where Y and X are average values of the gross revenue and irrigation costs, respectively. Since irrigation costs were much higher in well-irrigated farms than in those using canal water, the MVP which explains the return to Rs 1 investment in irrigation is Rs 11.50 in the case of the former, almost double that of the return, Rs 6.50, obtained in the latter case. However, as farms using groundwater show more responsiveness to the proportionate increase in irrigation expenditure (refer last paragraph), they can be categorized as more efficient users of approximately the same volume of water.

Since canal water costs are fixed for a unit of land, the variation in expenditure is due to the cropping pattern of individual farms. The response to irrigation outlays, therefore, refers to changes in farm output value due to the adoption of a more productive crop mix with respect to water than to the revenue increase caused by an additional unit of irrigation for the same crop.

Summary and Conclusion

THE PURPOSE OF this study has been to critically examine the operational features and the interplay of factors in the Mahi-Kadana System responsible for the current process of surface water distribution, and to ascertain whether such a distribution and resultant utilization i) interseasonally, and ii) in relation to the abundant groundwater available, can result in a realization of the overall productivity benefits of the project command. The specific objective was to analyze the performance of two representative secondary canals in terms of water deliveries and its impact on farm production, with particular reference to location and to well and/or tubewell use in irrigated agriculture.

The study has produced some methodological innovation. It has succeeded in developing and applying a seasonal moisture index for wheat, on the lines of the one constructed for rice which analyzes spatial distribution and the productivity of irrigation water application.

In summarizing the evidence that has emerged, the discussion is conducted with reference to certain characteristics of the entire system.

EXISTING SYSTEM OF WATER DISTRIBUTION

A distinguishing feature of this system is that it enjoys an abundant water supply. There is little variation in aggregate water supply, unlike in many other systems in India which suffer from water scarcity. The water control capacity in terms of the hierarchical networks of physical structures is "fairly good;" and the system is designed for upstream control and is "articulated" to the lowest level. The impact of this project on agricultural production in the command has been extensive, with approximately 175,000 ha of gross area each under canal and well irrigation. Benefits, however, have stemmed primarily from the abundant water availability, the project size, and the magnitude of the investment rather than from efficient and productive management of the system.

The planning process for allocating targets of the area to be irrigated and the water to be supplied is a meaningless exercise. For the Shejpali System of water distribution to be effective, farmers' demand for water should be known in advance of the season. Applications for water are few though, and the deadline for submission of applications is invariably extended. Unauthorized irrigation forms the bulk of canal irrigation. Farmers also report that the application procedures are tedious. In addition, there is no incentive to pay duty, as the mechanisms for penalizing illegal users of water are weak and ineffective.

The system, expected to perform on demand, becomes dependent primarily on the ability of the lower-level officials to respond to the differing irrigation requirements necessary for the mixed cropping in the command area. The operation of minor gates is not known a day in advance and even distributary rotations do not necessarily follow fixed schedules, even after the withdrawal of the monsoon rains. Night irrigation is more prevalent during the kharif season than during rabi. While the lower-level functionaries are expected to perform their supervisory duties during the night, they are not paid overtime. Duties assumed by the canal officers are uniform irrespective of crop or season, and the area figures reported as irrigated are often manipulated. Areas irrigated by well and/or tubewell are ignored and rarely visited by even the lower-level functionaries.

Faced with lax operating conditions, farmers often gain access to and control of water by tampering with infrastructural installations such as cross regulators, and also by erecting cross-bunds and breaching the minors. They also construct kutcha outlets with pipes laid direct to the fields, either individually or in loose cooperation with other farmers, if they find their fields too distant to be adequately served by regular outlets. Such structures are numerous in both canal commands. Duplication of irrigations within a single rotation, by those located favorably and by those who can operate outlet gates at will, are not uncommon. Water control by Irrigation Department staff is thus reduced, resulting in frustration among some farmers and connivance among others.

Since both farmers and the Irrigation Department seem resigned to accept head and tail situations in an irrigation command as an irredeemable natural phenomenon, physical structures downstream are neglected. The system is thus no longer articulated in the manner it was originally designed.

Discharge flows in the head and downstream distributaries reveal disparities in both flow levels and variation between flow levels. Water lag during the early stages of the critical growth period of kharif rice also creates excess demand later in the lower distributary. On the basis of the secondary data provided, irrigation efficiency in terms of the area irrigated per unit water appears to be low. This is more so during the kharif season. The impact of differential water deliveries between secondary reaches and tertiary blocks is visible in terms of the proportion of CCA irrigated by canal and the cropping patterns.

It is not always, though, that minors at the head of the distributaries receive more water: topography, community problems, etc., can reverse the situation. However, by and large the head reaches, especially the head outlet commands receive more water than lower down, where conjunctive and well water use often predominate. Field-level conveyance losses are also greater than the assumed values, and could be one of the determinant factors for low efficiency levels.

Significant differences were also observed between minor commands and within outlet commands with reference to the availability of field moisture. The field moisture index is inversely related to location of plot in the field channel, and indicates an inequitable supply of canal water within the outlet command, especially in the case of kharif rice.

The original design features of the Borsad Distributary (such as too many direct outlets) make management tasks more difficult. The presence of a dominant community-owning tubewell system in some tertiary blocks has also interfered with water releases downstream. Nevertheless, despite flaws in the water distribution system, the experience of farmers in certain selected tertiary blocks and its substantiation by statistical results indicate that an adequate and reliable supply of water is achieved in parts of the command area, but this is achieved only through over irrigation. Over-irrigation in upstream commands, head areas and within tertiary blocks and lowlying areas, is substituted for an organized and systematic operational approach to more equitable water distribution, particularly during the kharif season.

The higher canal irrigation intensity of the Umreth Distributary and portions of the Borsad Distributary can be attributed to this phenomenon rather than to superior management. Deprivation of canal water irrigation has not paupered farmers in the Borsad Command. The availability of groundwater supplies and the presence of a competitive groundwater market has provided them with an attractive alternative supply of irrigation water.

IMPACT ON CROPS AND CROP PRODUCTION

The analysis of cropping systems reveals clearly that rice, wheat and summer bajra are grown with canal or well irrigation; tobacco is only grown with lift irrigation (well or canal); and kharif bajra is almost invariably grown under rain-fed conditions. While rice is by far the major cultivated crop during kharif, particularly in the upper reaches of the minors in both the upper and middle distributaries, the latter exhibited a more diversified cropping pattern largely due to superior water control made possible by lift irrigation.

Tobacco, and to a lesser extent, rabi mustard have gained popularity with the farmers. Even farmers in head reaches are willing to grow tobacco, provided proper water control can be achieved. Wherever uplying lands necessitate the pumping of water from canals, tobacco is the preferred crop. Such lift irrigation allows better regulation and control of canal water flows, although adequacy and timeliness depend on flow levels in the minor.

Despite incurring additional costs for lift irrigation, farmers are protected against excess flooding, with consequent water logging. (This suggests that the costly levelling of land in head reaches by the command area development authorities could potentially do more harm than good.) Farmers, whose fields are flooded continuously suffer as their choice of crop and input use is restricted. Water logging is so severe in some cases that farmers are forced to grow rice even in summer. Less water, better delivered, is the required reform method for certain commands.

Locational differences per se do not account for differences in agricultural productivity. A partial production function analysis of a proxy variable for the cumulative seasonal soil moisture condition of rice yields clearly implied that there was considerable wastage in the utilization of water with adverse effects on production. In the selected samples in the Umreth Secondary Canal, fields irrigated beyond the required maximum were in the majority.

Cropping intensity, on average, is greater in canal-irrigated farms (but less consistent) than in conjunctive-use farms, but when adjusted for crop growth period over seasons, the differences are not particularly significant. Small farmers cultivate land more intensively than farmers of larger plots, incur higher costs and reap higher gross and net returns. Farmers owning larger farms appear to rely more on conjunctive irrigation than small farmers. The importance of the effective control of irrigation water and flexibility of water supply, to farm incomes is reinforced by results which clearly demonstrate that both gross returns per ha and net returns per ha are significantly higher in well- and conjunctive-irrigated farms in comparison to canal-irrigated farms, despite irrigation costs which are 3 to 4 times higher. Farms using groundwater, therefore, invest more and earn more, suggesting that on the whole, they tend to be more commercialized than farms using only canal water. Nevertheless, the rationale for allocating farm input expenditure appears to be oriented towards securing an average rate of returns (gross returns to total production costs), which is uniformly consistent across farms using canal water or groundwater or both. Gross revenue in well-irrigated farms responds better to proportionate changes in irrigation expenditure, although additional value from the same amount of expenditure is higher in canal irrigation.

REFORMING DISTRIBUTION PATTERNS: BALANCING CONJUNCTIVE USE

There needs to be a reconsideration of the established practice of providing more irrigation during kharif than during rabi. The evidence indicates that efficiency in water utilization was disappointingly low for kharif rice on a number of farms, whereas the productivity of wheat during rabi can be improved with more irrigation.

The analysis suggests that *redistributing canal water supplies both between and within sub-systems from over-irrigated commands to areas receiving low canal water supplies and/or to conjunctive- and/or well-irrigated areas, would maximize the overall long-term economic benefits from irrigation in the command area.*

Limits to crop productivity in terms of returns to water have been reached and exceeded for the dominant kharif crop -- rice -- in the command of the Umreth Distributary, but opportunities for improving yields with increased water supplies exist in the command of the Borsad Distributary. Clearly, the current pattern of water distribution is inequitable.

Further, since a major portion of the latter command relies entirely on groundwater irrigation, pumping costs may be reduced by recharging with more canal water supplies. In addition, it could exert downward pressure on prices charged in the water markets, giving marginal farmers greater access to these markets. Since, returns under groundwater-irrigated agriculture are also superior to those obtained under exclusively canal-irrigated conditions, this needs to be sustained by allowing recharge of the aquifers.

These arguments are strengthened by Shah's insightful analysis (1988c) on the trend of water table movements. The study found that the capacity of the aquifers to absorb rainfall and canal seepage in the Thasra Taluk (where the Umreth Distributary is located) has nearly reached saturation point, whereas investment in wells "picks up momentum in those areas which are poorly served by canals (and therefore poorly recharged), where it may result in over exploitation of the aquifer."

Further, the same study reports that canal water releases during the kharif season raise the water table twice as much as releases during the rabi and summer seasons, and recommends augmenting canal water supplies during the latter seasons at the cost of the kharif season to reduce the buildup of water tables in the head reaches.

The imperative to attain *a spatial and an inter-temporal and interseasonal balance in conjunctive water use* is crucial and urgent, from the standpoint of economic efficiency, equity and sustainability of irrigated agriculture in the MRBC Command Area. Efforts at improving irrigation management through eliciting farmer participation also needs to evolve within the framework of bringing the spatial dimension into conjunctive use. To quote Burt (1964a,b), Dasgupta (1986) and Shah (1988c), conjunctive use is viewed as the optimal use of both canal water and groundwater resources, by treating the entire canal command area as a watershed.

ACHIEVING BETTER DISTRIBUTION

A mechanism for pricing water can be used as a tool to improve the allocative efficiency of irrigation water in crop production, especially in the headreach command areas where water is cheap and abundant. Also, some degree of parity has to be brought about between canal water price and well water charges. Not only are canal water charges low, farmers generally avoid paying duty as well. But raising canal water prices alone will not be adequate. An effective mechanism for recovering dues is equally vital.

In addition, the credibility of system operators must be boosted through improved water deliveries and redressing of farmers' grievances, if users are to be persuaded to pay more for canal water. There must also be incentives to avoid wastage of water caused by leakage, the poor condition of field channels and over-irrigation. This will also reduce water logging in lowlying areas.

A meaningful seasonal plan, based on forecasted information on crop cultivation and past data, monsoon rainfall, the differential water requirement of each crop, soil characteristics, and incorporating conjunctive water use is essential. At every level, the absence of an implementable plan makes it extremely difficult to assess performance.

Rational guidelines for assessing crop water requirements and for calculating duties -- depending on the crop and its growth stage -- have to be set out. Rotational procedures within the secondary canal reaches should be attempted on a planned basis; currently during critical peak demand periods, decisions to close or open minors are made on an *ad hoc* basis. Proper information on area and the crop irrigated by groundwater within the jurisdiction of a Chowkidar or a Karkoon is absolutely necessary when making decisions on water allocation.

An important factor that needs consideration is the possible utilization of existing organizational resources for the purpose of managing conjunctive use of water. This will mean closer coordination of the activities of the Canal Irrigation Management Department and the Groundwater Resources Development Corporation, which monitors water table movements and which also undertakes the setting up of public tubewells.

It appears unlikely that the current institutional structure for canal management will be able to address all the problems along the lines suggested, nor can we expect a radical overhaul of managerial operations from top to bottom. Yet, there is receptivity to the idea of devolving canal management at the minor level and to reducing physical and administrative control.

Earlier, the burden placed on lower-level functionaries with reference to actual system operations and constraints in the planning and regulatory mechanisms were pointed out. The evidence highlighted the inability of irrigation officials to control water supplies at the tertiary and field levels, and quantified the extent of disparity in water distribution. The role of irrigation officials, at best therefore, can be the ensuring of reliable and adequate water deliveries at the off-take points of the minors and the monitoring of patterns in canal water and groundwater use.

The reforms so far include experimentation with farmer participation in the MRBC at the secondary level and below. In pilot projects, where farmer organizations function and/or at places where canal repairs are undertaken, "superior" performance is achieved often at the expense of other parts of the system.

A Dep.EE cited a case where the official in charge of a "model" secondary canal demanded larger and earlier releases of water to that canal command, creating scheduling, allocation and other problems elsewhere. The cost of such interventions, in terms of the resources and time involved raises serious doubts regarding the sustainability and replication of these models.

Nevertheless, these experiments demonstrate that the mobilization of farmers has a reasonable chance of succeeding at the main and secondary levels. Certainly, the availability of alternate sources of irrigation has acted as a disincentive in bringing about farmer participation. It is also true that none of these experiments have really empowered farmers to manage systems.

As previously stated, farmers either individually or in informal cooperation with each other, do invest in pipes and water channels and in lift irrigation from canals, and have shown enterprise in selling this water at tubewell water prices to other farmers. The potential for exploiting this kind of entrepreneurship or organizing farmer cooperatives to advance the overall benefits of canal irrigation in the canal command area through contractual agreements remains to be explored.

End Notes

1 A collectorate or administrative subdivision comprising an Indian revenue district.

2 Irrigation intensity is defined as Gross Irrigated Area/Cultivable Command Area (CCA) expressed in percentages, i.e., the proportion of gross area that is irrigated in a year to the available irrigable area. When the specific term "canal irrigation intensity" is used, the gross area irrigated from canals alone is considered and areas exclusively irrigated by groundwater are not taken into account.

3 Source: Mahi Irrigation Circle, Nadiad, Gujarat.

4 It is true that secondary canals like the Borsad suffer from technical faults in the original design and construction, which make water control more difficult. As detailed later, other factors, particularly neglect on the part of irrigation management has further compounded the problem.

5 Murray-Rust (1992) broadly defines three important categories of irrigation management performance: output performance, operational performance and performance in setting of objectives.

6 The Water Technology Centre Study (1983) on MRBC which contains an exceptional amount of technical information is a good example of overemphasis on disciplinary specialization in irrigation research (Chambers 1988). The other drawback of this study is that it confines its description of the system to how it is "expected to function" in contrast to how it "actually does."

7 Wade (1990) details the features of different sets of physical structures in relation to different regimes of water control and their capacity for meeting managerial objectives of water allocation. With this framework in mind, the Mahi-Kadana System can be described as providing for upstream control (cross regulators are located even in the tail), while allowing for flexibility in tertiary-level water distribution.

8 "Warabandi" is the system of water distribution practiced extensively in the northwestern regions of the Indian subcontinent (including the Punjab Province in Pakistan), where canals are designed and regulated to allow constant discharges through ungated outlets. Each irrigator is allocated water by turn according to a predetermined schedule specifying the day, the time, and the duration of supply, in proportion to the size of his landholding in the outlet command (Malhotra 1982). The idea is to make water distribution equitable and to minimize administrative tasks in canal operation.

9 Refer Appendix D, the section on Land Irrigability Classification in MRBC and the accompanying map.

10 Although the water level of the Kadana Reservoir was low prior to the monsoon rains, the potential existed for a single irrigation, followed by two or three more with replenishment from the Panam Dam in Madhya Pradesh. But concern about not being able to meet the full irrigation requirement for the whole season prevented senior ministry officials and chief irrigation executives who were monitoring the situation from releasing water for rice transplanting until 5 August, after the heavy monsoon rains (Buch, Director of WALMI, Anand Personal Communication 1991). Ironically, canal water was not made available at a time when the need for irrigation was becoming critical.

11 Earlier, research on the Mahi-Kadana found significant variation in flows at the field level. Reduced control over irrigation water application had resulted in over-irrigation of some fields and under-irrigation of others. (Water Management Synthesis Project -- WMSP, 1983).

12 A method for assessing farm water status and computing soil moisture stress for rice was developed by Wijayaratna (1986). His method was based on earlier concepts engendered by Wickham (1974), and others. This study follows this earlier method with the exceptions given below:

i) The water status of the rice fields was recorded every day in that research program; in the present study, water status was noted once every third day. Resource and supervisory conditions precluded the former procedure; the viability of the constructed index, though does not appear affected on this account. It must be noted that the normal recommendation for judging soil moisture condition in the field is between 1 to 3 days after irrigation (FAO, Irrigation and Drainage Paper 1984).

ii) The earlier work double weighted observations for the reproductive stage in relation to observations for the vegetative phase. Such a demarcation was not made in this study, which considered the identified phase as uniformally critical in terms of water stress.

iii) The classification of soil moisture condition in the former study was as follows: (1) severe shortage (soil cracked), (2) moderate shortage (soil dry), (3) soil wet (no standing water), (4) standing water (shallow) and (5) deep flooding, respectively. The first two categories are redefined in the current study as follows: Since a soil-cracked situation was not encountered, the first category became soil dry and a new intermediate second one (between wet and dry conditions) was defined as soil semi-wet, and characterized as moderate shortage of water. The remaining categories are identical in both studies.

iv) In the former study, the starting dates for recording field observations differed according to variation in the planting dates of individual farm plots. As far as this study is concerned, planting dates differed broadly by location but remained more or less uniform within a particular location. Therefore, though dates for recording water status were adjusted by location, they were not adjusted by each farm plot or to correspond to the specific period of crop growth. In areas where wells and tubewells proliferate, water from these sources are sometimes used to raise the nurseries of rice seedling before this can be done in other places.

The following are planting dates across and within locations for the sample plots and the crop-growth period for which field observations were made:

Canal	Planting dates		Period of field observations	
		Month-Days (mm-dd)	Dates Beginning	(mm-dd) End
Umreth	SM 2R	07-27, 28	08-28	10-20
	SM 5R	07-24, 25	08-25	10-18
	SM 9L	07-25, 26	08-26	10-19
Borsad	SM 6L	07-22, 23	08-23	10-16
	Vehra	07-23, 24, 25	08-24	10-17
	D.O.	07-21	08-21	10-14

The hybrid rice strains cultivated during the kharif season were of 110-115 days duration, such as Gujarat-4, Jaya and G-17. Therefore, there was a problem in identifying different critical stages according to variety.

13 In practicing the "touch and feel" method, the basic textural group is first determined (i.e., sandy loam to loam soils in this particular command area). Then a handful of soil is sampled using an instrument known as an auger. Soil is tested for strength by squeezing it firmly three or four times to check whether it crumbles or retains its shape. If it forms a ball, then it is tossed five times in the air about 30 cm high and caught, to see whether it breaks or remains intact. If it breaks the ball is denoted as "weak" and if it remains intact, as "strong". Then a ribbon of soil is made by rolling it between forefinger and thumb to see whether the soil sticks to the thumb. The results of these tests are then compared with the following description:

Available soil moisture	Feel or appearance of soil (for sandy loam soils)
0-25 percent	Dry, loose, flows through the fingers.
25-50 percent	Appears to be dry, will not form a ball.*
50-75 percent	Tends to ball under pressure but seldom holds together.
75-100 percent	Forms a weak ball, breaks easily, will not stick.
100 percent	Upon squeezing, no free water appears on (field capacity) soil, but wet outline of ball is left on the hand.

* A ball is formed by squeezing a handful of soil firmly.

Source: Irrigation Practice and Water Management, FAO, Irrigation and Drainage Paper, 1984.

The water status of the sample plot for that particular day is then ranked from among the four categories listed above. Once this is done, the number of observations in the first category is multiplied by 1, those in the second category by 2, in the third category by 3 and in the fourth and fifth by 4 (as they are close or equal to field capacity) in order to compute the weighted WAI index for the season. As observations were made every third day for a 70-day period, total observations numbered 23 (69/3). The minimum score is therefore 23x1 and the maximum 23x4 which equals 92. The period covered the broadly critical growth stage of the crop from the crown root initiation stage (20 to 25 days after sowing), to the milky stage (90 to 95 days after sowing) for dwarf wheat varieties, as defined by Michael (1978) and FAO guidelines (Doorenbos et al. 1986). Where planting dates differed, the observation periods on moisture status were appropriately modified, to make them field-plot specific.

The following lists the variation in planting dates across sample plots and the corresponding variation in observation periods:

Planting date (MM-DD-YY)		Observation period	
		Beginning	End
12-18-91		01-06-92	03-13-92 to
12-27-91	to	01-15-92	03-12-92

Soil moisture should be checked to about the depth of the crop root, which varies from crop to crop. The depth of the root of wheat crop varieties grown in this region is about 90 cm, which should ideally be the depth to which the soil auger should penetrate. In this study, though, soil samples were taken 60 cm below the surface. Normally, an irrigation in sandy loam soil wets 60 cm in 40 minutes and 90 cm in approximately 50 to 55 minutes. The time differences in duration of depletion is also small (FAO 1984). The degree of error is therefore not likely to be significant on account of soil sampling at less than the full root depth. However, future applications of this methodology are needed to test its robustness and viability under different conditions.

The most common wheat varieties (hybrid) adopted were Sonalika, Tundi and Lok-1, all with a crop duration of 110 to 120 days.

Note that two investigators with degrees in agriculture were trained to enhance their "feel" in actual field conditions to ensure consistency and accuracy of judgement. The training was conducted by an agronomist at the Water and Land Management Institute, Anand.

14 Much of the discussion in this section draws on an earlier version of an identically titled section in a paper presented by Ballabh et al. at the India-IIMI Collaborative Workshop in New Delhi (February 1992).

15 The resident field staff gathered this data through direct surveys and enumeration. Therefore, the information should be more reliable than that obtained from the Irrigation Department.

16 One method of detecting multicollinearity when there are three or more variables is by using the inverse of the correlation matrix. The diagonal elements of such a matrix are called variance inflation factors $(VIF)_i$. VIFs are calculated by taking the inverse value (-1) of $(1-R^2_i)$, where R^2_i is the R^2 from regressing the ith independent variable on the rest of the independent variables. The highest R^2_i produced by following this procedure for the rice production function was 0.23. The VIF_i therefore is $(1-0.23)^{-1}=1.3$, a low value, much below 10, the rule-of-thumb indicator of severe multicollinearity (Kennedy 1992).

17 The study on the Gal Oya Left Bank in Sri Lanka found, that farms with lower WAI applied larger amounts of fertilizer (Murray-Rust et al.). Chambers (1988) explains this by suggesting that in a field-to-field irrigation situation, excessive flooding of water could result in the leaching of nutrients. Consequently, over-irrigated farms may apply less amounts of nutrients.

18 Lest these results contradict the accepted conventional practice of a continuous impounding of water as a prerequisite for maintaining rice yields, there is sufficient evidence to suggest that rice can grow under near-saturation or alternate wet and dry conditions without sacrificing yields (Ghani et al. 1992).

Withholding water applications and/or field drainage at certain stages of growth, instead of continuous submergence or water suppression during critical phases (flowering phase) have also been reported to positively effect the yield components by producing a higher number of panicles/m^2. A study based on field trials in sandy loam soils shows that maximum yields for the Sona variety of rice were obtained with conditions of soil saturation between initiation and the maximum tillering crop phases, followed by a submergence of 5 cm up to the milk ripening stage, over complete submergence or saturation for all growth phases (Moturi 1977). The rate of nitrogen uptake was also found to be superior in the former rather than in the latter case.

Lysimetric studies for rice have also revealed an inverse relationship between depth to water tables and irrigation requirements for obtaining high yields (Singh and Sharma 1983). This indicates that shallow water-tables as those existing in particular headreaches in the Mahi-Kadana require a less number of irrigations.

A recent study on the economic impact of land degradation in Pakistan's Punjab Province found that excessive canal irrigation and fertilizer use per hectare has tended to promote land degradation through water logging and salinity. Tubewell irrigation, on the other hand, by reducing the water-table and rainfall by washing and leaching salts from the soil decrease land degradation (Usman 1991). The study concludes that land degradation has strong negative effects on rice yields and rice production.

19 In this study, the term "conjunctive use" refers to "joint or supplemental use" of groundwater and canal water on a farm holding. Optimal management of renewable resources such as groundwater basins, however, necessitates the viewing of the whole command area as a single watershed. For a conceptual discussion on some of these issues, see Shah (1988b). For a detailed empirical study on the economics of conjunctive use in farms, refer Kolavalli (1986). In the latter study, a comparison is made between conjunctive farms and canal irrigated farms in the Kheda District. The benefits of conjunctive use include the capacity to cultivate crops of a longer duration with higher and more stabilized levels of annual gross production. The section on farm-level economic performance in the present study adds to that literature by adding farms solely irrigated by well water into the overall analytical picture.

20 For the rest of the analysis in this chapter, the sample size for a particular category may be referred from Table 11.

21 The initial selection of farm plots was based on location in the canal. Nevertheless, the sample distribution has turned out to be broadly representative of taluk population statistics.

Appendix A

Conveyance Losses in Field-Channel Water Distribution

Table A-1. Estimates of conveyance losses in field channels, middle minor and Umreth Distributary.

Head outlet. Table 1a.

Sr. No.	Date of measurement	Discharge measured at Head (50 ft)	Middle (838 ft)	Tail (1,531 ft)	Difference in discharge H-M (788 ft)	M-T (693 ft)	Conveyance loss H-M For 1,000 ft	Conveyance loss M-T For 1,000 ft
		Cusecs					Percent	
1	07/12/91	0.85	0.60	0.37	0.25	0.23	37.32	55.32
2	08/12/91	0.91	0.66	--	0.25	--	34.86	--
3	09/12/91	0.85	0.60	0.50	0.25	0.10	37.32	24.05
4	10/12/91	0.66	0.41	--	0.25	--	48.07	--
5	12/12/91	0.79	0.60	0.37	0.19	0.23	30.52	55.32
6	13/01/92	0.90	0.71	0.47	0.19	0.24	26.79	48.78
7	20/01/92	0.55	0.41	0.29	0.14	0.12	32.30	42.23
Total		5.51	3.99	2.00	1.52	0.92	247.20	225.69
Average		0.79	0.57	0.40	0.22	0.18	35.31	45.14

Middle outlet. Table 1b.

Sr. No.	Date of measurement	Discharge measured at Head (363 ft)	Middle (838 ft)	Tail (1214 ft)	Difference in discharge H-M (475 ft)	M-T (376 ft)	Conveyance loss H-M For 1,000 ft	Conveyance loss M-T For 1,000 ft
		Cusecs					Percent	
1	09/12/91	0.66	0.41	0.32	0.25	0.09	79.74	58.38
2	11/12/91	--	0.41	0.37	--	0.04	--	25.95
3	07/02/92	--	0.21	0.18	--	0.03	--	37.99
4	10/02/92	0.50	0.32	0.26	0.18	0.06	75.79	49.87
5	18/02/92	1.31	0.89	--	0.42	--	67.50	--
Total		2.47	2.24	1.13	0.85	0.22	223.03	172.19
Average		0.82	0.45	0.28	0.28	0.05	74.34	43.05

Tail outlet. Table 1c.

Sr. No.	Date of measurement	Discharge measured at Head (99 ft)	Middle (865 ft)	Tail (1,525 ft)	Difference in discharge H-M (766 ft)	M-T (660 ft)	Conveyance loss H-M For 1,000 ft	Conveyance loss M-T For 1,000 ft
		Cusecs					Percent	
1	07/12/91	0.83	0.55	0.44	0.28	0.11	44.04	30.30
2	08/12/91	0.96	0.66	0.41	0.30	0.25	40.80	57.39
3	09/12/91	0.41	0.32	0.21	0.09	0.11	28.66	52.08
4	17/01/92	0.60	0.41	0.25	0.19	0.16	41.34	59.13
5	18/01/92	0.55	0.36	0.25	0.19	0.11	45.10	46.30
6	21/02/92	0.41	0.25	0.18	0.16	0.07	50.95	42.42
7	09/03/92	0.89	0.60	0.36	0.29	0.24	42.54	60.61
Total		4.65	3.15	2.10	1.50	1.05	293.42	348.23
Average		0.66	0.45	0.30	0.21	0.15	41.92	49.75

Discharges (flow rates) were measured using cutthroat flumes at certain pre-identified head, middle and tail points of the main field channel after blocking the bifurcations in each outlet command. The distances are measured from the beginning of the field channel. Assume that the flow is from point a to point b, a distance of D feet and the discharges measured are X and Y at these two points respectively. Then, $((X-Y)/D) * 100 = CL$ is the conveyance loss as a percentage of X for a stretch of D feet. The conveyance losses in percentages can be calculated for 1,000 ft = $(CL/D * 1{,}000)$. An average field channel has a length of 1,500-2,000 feet, so the CL for 1,000 feet would represent the figure for approximately a middle located farm plot.

Appendix B

Cropped Area of Outlets Irrigated by Type of Irrigation

Data on the cropping pattern for the entire command area of sampled outlets, gathered by field investigators.

Table B-1. Cropping pattern by location and source of irrigation for Umreth Distributary: Kharif 1991.

Sr. No.	Crop	Type	Head minor						Middle minor						Tail minor					
			H.O.		M.O.		T.O.		H.O.		M.O.		T.O.		H.O.		M.O.		T.O.	
			Area in—																	
			ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
CCA			7.63		12.60		18.17		12.61		14.39		12.36		33.58		16.01		34.08	
1.	Rice	Canal	6.01	100	4.68	100	1.72	14	2.02	100	10.19	100	10.29	100	11.37	51	6.22	57	4.96	33
		Well	--	0	--	0	7.40	62	--	0	--	0	--	0	0.61	3	0.52	5	5.77	38
		Both	--	0	--	0	2.75	23	--	0	--	0	--	0	10.27	46	4.16	38	4.30	29
		Total	6.01	100	4.68	100	11.87	100	2.02	100	10.19	100	10.29	100	22.25	100	10.90	100	15.03	100
		% of CCA	78.77		37.14		65.33		16.02		70.81				66.26		68.08		44.10	
2.	Tobacco	Canal	0.20	100	1.81	42	--	0	9.23	100	2.14	85	1.74	100	3.31	24	--	0	--	0
		Well	--	0	0.65	15	--	0	--	0	0.38	15	--	0	7.01	52	3.18	85	18.42	100
		Both	--	0	1.81	42	1.61	100	--	0	--	0	--	0	3.27	24	0.55	15	--	0
		Total	0.20	100	4.27	100	1.61	100	9.23	100	2.52	100	1.74	100	13.59	100	3.73	100	18.42	100
		% of CCA	2.62		3.89		8.86		73.20		17.51		14.08		40.47		23.30		54.05	
3.	Others	Canal	0.20	100	0.35	100	--	0	--		--		--		--		--		--	0
		Well	--	0	--	0	0.70	100	--		--		--		--		--		--	0
		Both	--	0	--	0	--	0	--		--		--		--		--		0.70	100
		Total	0.20	100	0.35	100	0.70	100	--		--		--		--		--		0.70	100
		% of CCA	2.62		2.78		3.85		--		--		--		--		--		2.05	
	Total	Canal	6.41	100	6.84	74	1.72	12	11.25	100	12.33	97	12.03	100	14.68	41	6.22	43	4.96	15
		Well	--	0	0.65	7	8.10	57	--	0	0.38	3	--	0	7.62	21	3.70	25	24.19	71
		Both	--	0	1.81	19	4.36	31	--	0	--	0	--	0	13.54	38	4.71	32	4.30	13
		Total	6.41	100	9.30	100	14.18	100	11.25	100	12.71	100	12.03	100	35.84	100	14.63	100	34.15	100
		% of CCA	84.01		73.81		78.04		89.21		88.33		97.33		106.73		91.38		100.21	

Notes: H.O. = Head Outlet. M.O. = Middle Outlet. T.O. = Tail Outlet. CCA = Cultivable Command Area.

Table B-2. Cropping pattern by location and type of irrigation for Borsad Distributary: Kharif 1991.

Sr. No.	Crop	Type	Head minor						Middle minor						Direct outlets			
			H.O.		M.O.		T.O.		H.O.		M.O.		T.O.		D.O.1		D.O.2	
			Area in															
			ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
CCA			22.86		35.1		27.73		13.42		27.87		27.61		29.34		20.68	
1.	Rice	Canal	11.57	84	2.06	21	--	0	4.65	42	8.58	45	12.85	49	--	0	--	--
		Well	1.56	11	7.78	79	2.29	62	--	0	7.69	40	12.56	48	8.77	55	--	--
		Both	0.63	5	--	0	1.39	38	6.36	58	2.8	15	--	0	--	0	--	--
		Canal (L)	--	0	--	0	--	0	--	0	--	0	--	0	4.75	30	--	--
		Well+Tank	--	0	--	0	--	0	--	0	--	0	0.85	3	--	0	--	--
		Tank (p)	--	0	--	0	--	0	--	0	--	0	--	0	2.52	16	--	--
		Total	13.76	100	9.84	100	3.68	100	11.01	100	19.07	100	26.26	100	16.04	100	0	--
		% of CCA	60.19		28.03		13.27		82.04		68.42		95.11		54.67		0.00	
2.	Tobacco	Canal	--	0	--	0	--		--	0	--	0	--	0	--	0	--	0
		Well	0.33	100	2.68	100	--		1.04	100	3.92	100	--	0	4.73	74	17.03	100
		Both	--	0	--	0	--		--	0	--	0	--	0	--	0	--	0
		Canal (L)	--	0	--	0	--		--	0	--	0	--	0	--	0	--	0
		Well+Tank	--	0	--	0	--		--	0	--	0	1.00	100	1.70	26	--	0
		Tank (p)	--	0	--	0	--		--	0	--	0	--	0	--	0	--	0
		Total	0.33	100	2.68	100	--		1.04	100	3.92	100	1.00	100	6.43	100	17.03	100
		% of CCA	1.44		7.64		0.00		7.75		14.07		3.62		21.92		82.35	
3.	Bajra	Canal	--	0	--	0	--	0	--		--	0	--		--	0	--	0
		Well	--	0	3.94	40	0.67	4	--		0.71	30	--		--	0	--	0
		Rain-fed	3.00	100	5.92	60	17.91	96	--		1.67	70	--		0.94	100	0.58	100
		Total	3.00	100	9.86	100	18.58	100	0.00		2.38	100	0.00		0.94	100	0.58	100
		% of CCA	13.12		28.09		67.00		0.00		8.54		0.00		3.20		2.80	
4.	Others	Canal	2.61	79	0.15	5	--	0	--		--		--		0.49	13	--	0
		Well	0.33	10	2.60	95	3.64	77	--		--		--		2.89	75	1.59	100
		Rain-fed	0.37	11	--	0	1.11	23	--		--		--		--	0	--	0
		Canal (L)	--	0	--	0	--	0	--		--		--		0.49	13	--	0
		Total	3.31	100	2.75	100	4.75	100	--		--		--		3.87	100	1.59	100
		% of CCA	14.48		7.83		17.13		--		--		--		13.19		7.69	
	Total	Canal	14.18	70	2.21	9	0.00	0	4.65	39	8.58	34	12.85	47	0.49	2	0.00	0
		Well	2.22	11	17.00	68	6.60	24	1.04	9	12.32	49	12.56	46	16.39	60	18.62	97
		Both	0.63	3	0.00	0	1.39	5	6.36	53	2.80	11	0.00	0	0.00	0	0.00	0
		Rain-fed	3.37	17	5.92	24	19.02	70	0.00	0	1.67	7	0.00	0	0.94	3	0.58	3
		Canal (L)	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	12.66	46	4.75	17	0.00	0
		Well+Tank	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1.85	7	1.70	6	0.00	0
		Tank (p)	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	2.52	9	0.00	0
		Total	20.40	100	25.13	100	27.01	100	12.05	100	25.37	100	27.26	100	27.28	100	19.20	100
		% of CCA	89.24		71.60		97.40		89.79		91.03		98.73		92.98		92.84	

Notes: CCA = Cultivable Command Area. H.O. = Head Outlet. M.O. = Middle Outlet. T.O. = Tail Outlet. D.O. = Direct Outlet.

Table B-3. Cropping pattern by location and type of irrigation for Umreth Distributary: Rabi 1991/92.

Sr. No.	Crop	Type	Head minor H.O. ha	Head minor H.O. %	Head minor M.O. ha	Head minor M.O. %	Head minor T.O. ha	Head minor T.O. %	Middle minor H.O. ha	Middle minor H.O. %	Middle minor M.O. ha	Middle minor M.O. %	Middle minor T.O. ha	Middle minor T.O. %	Tail minor H.O. ha	Tail minor H.O. %	Tail minor M.O. ha	Tail minor M.O. %	Tail minor T.O. ha	Tail minor T.O. %
CCA			7.63		12.60		18.17		12.61		14.39		12.36		33.58		16.01		34.08	
1.	Wheat	Canal	4.69	100	6.50	100	3.32	50	0.52	100	4.43	100	6.29	100	2.64	40	1.82	90	--	0
		Well	--	0	--	0	3.26	50	--	0	--	0	--	0	1.69	26	--	0	3.77	89
		Both	--	0	--	0	--	0	--	0	--	0	--	0	1.96	30	0.20	10	0.45	11
		Canal(L)	--	0	--	0	--	0	--	0	--	0	--	0	0.27	4	--	0	--	0
		Total	4.69	100	6.50	100	6.58	100	0.52	100	4.43	100	6.29	100	6.56	100	2.02	100	4.22	100
		% of CCA	61.47		51.59		36.21		4.12		30.79		50.89		19.54		12.62		12.38	
2.	Tobacco	Canal	--		1.65	32	1.62	100	10.56	100	1.02	73	1.25	100	3.39	28	--	0	1.00	6
		Well	--		0.65	13	--	0	--	0	0.38	27	--	0	5.86	49	3.18	85	16.99	94
		Both	--		2.89	56	--	0	--	0	--	0	--	0	2.81	23	0.55	15	--	0
		Total	--		5.19	100	1.62	100	10.56	100	1.40	100	1.25	100	12.06	100	3.73	100	17.99	100
		% of CCA	--		68.02		8.92		83.74		9.73		10.11		35.91		23.30		52.79	
3.	Others	Canal	--		--		--		--		0.24	100	2.00	100	--	0	0.15	100	--	0
		Well	--		--		--		--		--	0	--	0	--	0	--	0	--	0
		Both	--		--		--		--		--	0	--	0	0.49	100	--	0	0.30	100
		Total	--		--		--		--		0.24	100	2.00	100	0.49	100	0.15	100	0.30	100
		% of CCA	--		--		--		--		1.67		16.18		1.46		0.94		0.88	
	Total	Canal	4.69	100	8.15	70	4.94	60	11.08	100	5.69	94	9.54	100	6.03	32	1.97	33	1.00	4
		Well	--	0	0.65	6	3.26	40	--	0	0.38	6	--	0	7.55	40	3.18	54	20.76	92
		Both	--	0	2.89	25	--	0	--	0	--	0	--	0	5.26	28	0.75	13	0.75	3
		Canal(L)	--	0	--	0	--	0	--	0	--	0	--	0	0.27	1	--	0	--	0
		Total	4.69	100	11.69	100	8.20	100	11.08	100	6.07	100	9.54	100	19.11	100	5.90	100	22.51	100
		% of CCA	61.47		92.78		45.13		87.87		42.18		77.18		56.91		36.85		66.05	

Notes: H.O. = Head Outlet. M.O. = Middle Outlet. T.O. = Tail Outlet. CCA = Cultivable Command Area.

Table B-4. Cropping Pattern by Location and Type of Irrigation for Umreth Distributary: Summer 1991/92.

Sr. No.	Crop	Type	Head minor H.O. ha	Head minor H.O. %	Head minor M.O. ha	Head minor M.O. %	Head minor T.O. ha	Head minor T.O. %	Middle minor H.O. ha	Middle minor H.O. %	Middle minor M.O. ha	Middle minor M.O. %	Middle minor T.O. ha	Middle minor T.O. %	Tail minor H.O. ha	Tail minor H.O. %	Tail minor M.O. ha	Tail minor M.O. %	Tail minor T.O. ha	Tail minor T.O. %
			Area in																	
CCA			7.63		12.60		18.17		12.61		14.39		12.36		33.58		16.01		34.08	
1.	Ground nut	Canal	0.40	100	1.46	100	0.50	15	--		3.30	100	1.61	100	6.13	78	0.80	23	--	
		Well	--	0	--	0	2.80	85	--		--	0	--	0	0.34	4	0.54	16	--	
		Both	--	0	--	0	--	0	--		--	0	--	0	1.40	18	2.14	62	--	
		Total	0.40	100	1.46	100	3.30	100	--		3.30	100	1.61	100	7.87	100	3.46	100	--	
		% of CCA	5.24		11.59		18.16		--		22.93		13.03		23.44		21.61		--	
2.	Bajra	Canal	0.59	100	1.18	100	--		0.80	100	4.45	100	0.50	100	--		1.35	75	--	0
		Well	--	0	--	0	--		--	0	--	0	--	0	--		--	0	--	0
		Both	--	0	--	0	--		--	0	--	0	--	0	--		0.44	25	1.30	100
		Total	0.59	100	1.18	100	--		0.80	100	4.45	100	0.50	100	--		1.79	100	1.30	100
		% of CCA	7.73		9.37		--		6.34		30.92		4.05		--		11.18		3.82	
3.	Rice	Canal	0.35	100	--		--		--		0.15	100	0.70	100	4.38	100	2.83	67	3.62	52
		Well	--	0	--		--		--		--	0	--	0	--	0	--	0	--	0
		Both	--	0	--		--		--		--	0	--	0	--	0	1.38	33	3.35	48
		Total	0.35	100	--		--		--		0.15	100	0.70	100	4.38	100	4.21	100	6.97	100
		% of CCA	4.59		--		--		--		1.04		5.66		13.04		26.30		20.45	
	Total	Canal	1.34	100	2.64	100	0.50	15	0.80	100	7.90	100	2.81	100	10.51	86	4.98	53	3.62	44
		Well	--	0	--	0	2.80	85	--	0	--	0	--	0	0.34	3	0.52	5	--	0
		Both	--	0	--	0	--	0	--	0	--	0	--	0	1.40	11	3.96	42	4.65	56
		Total	1.34	100	2.64	100	3.30	100	0.80	100	7.90	100	2.81	100	12.25	100	9.46	100	8.27	100
		% of CCA	17.56		20.95		18.16		6.34		54.90		22.73		36.48		59.09		24.27	

Notes: H.O. = Head Outlet. M.O. = Middle Outlet. T.O. = Tail Outlet. CCA = Cultivable Command Area.

Table B-5. Cropping pattern by location and type of irrigation for Borsad Distributary: Rabi 1991/92.

Sr. No.	Crop	Type	Head minor H.O. ha	Head minor H.O. %	Head minor M.O. ha	Head minor M.O. %	Head minor T.O. ha	Head minor T.O. %	Middle minor H.O. ha	Middle minor H.O. %	Middle minor M.O. ha	Middle minor M.O. %	Middle minor T.O. ha	Middle minor T.O. %	Direct outlets D.O.1 ha	Direct outlets D.O.1 %	Direct outlets D.O.2 ha	Direct outlets D.O.2 %
			Area in															
CCA			22.86		35.1		27.73		13.42		27.87		27.61		29.34		20.68	
1.	Wheat	Canal	9.51	97	1.04	14	--	0	3.25	100	--	0	0.67	46	1.32	19	--	0
		Well	0.33	3	6.41	86	4.93	100	--	0	4.38	100	0.80	54	5.52	81	--	0
		Total	9.84	100	7.45	100	4.93	100	3.25	100	4.38	100	1.47	100	6.84	100	--	0
		% of CCA	43.05		21.23		17.78		24.22		15.72		5.32		23.31		--	
2.	Tobacco	Canal	--	0	--	0	--	0	--	0	--	0	1.85	12	2.71	23	--	0
		Well	--	0	1.84	100	2.12	100	2.35	100	13.94	100	13.66	88	8.99	77	20.24	100
		Total	--	0	1.84	100	2.12	100	2.35	100	13.94	100	15.51	100	11.70	100	20.24	100
		% of CCA	--		5.24		7.65		17.51		50.02		56.18		39.88		97.87	
3.	Mustard	Canal	1.31	100	0.47	6	0.35	3	--	0	--	0	--	0	0.93	22	--	0
		Well	--	0	7.85	94	11.13	97	--	0	--	0	0.28	100	3.38	78	--	0
		Total	1.31	100	8.32	100	11.48	100	--	0	--	0	0.28	100	4.31	100	--	0
		% of CCA	5.73		23.70		41.40		--		--		1.01		14.69		--	
4.	Maize	Canal	1.48	85	--	0	0.91	43	--	0	--	0	--	0	--	0	--	0
		Well	0.26	15	--	0	1.19	57	--	0	0.93	100	--	0	1.93	100	--	0
		Total	1.74	100	0.60	100	2.10	100	--	0	0.93	100	--	0	1.93	100	--	0
		% of CCA	7.61		1.71		7.57		--		3.34		--		6.58		--	
	Others	Canal	2.77	100	0.79	17	0.40	15	--	0	--	0	--	0	--	0	--	0
		Well	--	0	3.77	83	2.33	85	--	0	0.21	100	--	0	1.79	100	--	0
		Total	2.77	100	4.56	100	2.73	100	--	0	0.21	100	--	0	1.79	100	--	0
		% of CCA	12.12		12.99		9.85		--		0.75		--		6.10		--	
	Total	Canal	15.07	96	2.3	10	1.66	7	3.25	58	0	0	2.52	15	4.96	19	0	0
		Well	0.59	4	19.87	87	21.7	93	2.35	42	19.46	100	14.74	85	21.61	81	20.24	100
		Total	15.66	100	22.77	100	23.36	100	5.6	100	19.46	100	17.26	100	26.57	100	20.24	100
		% of CCA	68.50		64.87		84.24		41.73		69.82		62.51		90.56		97.87	

Notes: H.O. = Head Outlet. M.O. = Middle Outlet. T.O. = Tail Outlet. CCA = Cultivable Command Area. D.O. = Direct Outlet.

Table B-6: Cropping pattern by location and type of irrigation for Borsad Distributary: Summer 1991/92.

Sr. No.	Crop	Type	Head minor H.O. ha	Head minor H.O. %	Head minor M.O. ha	Head minor M.O. %	Head minor T.O. ha	Head minor T.O. %	Middle minor H.O. ha	Middle minor H.O. %	Middle minor M.O. ha	Middle minor M.O. %	Middle minor T.O. ha	Middle minor T.O. %	Direct outlets D.O.1 ha	Direct outlets D.O.1 %	Direct outlets D.O.2 ha	Direct outlets D.O.2 %
			Area in															
CCA			22.86		35.1		27.73		13.42		27.87		27.61		29.34		20.68	
1.	Ground nut	Canal	0.44	100	0.18	7	--	0	2.41	100	1.46	76	6.36	84	0.69	56	--	0
		Well	--	0	2.37	93	--	0	--	0	0.46	24	1.20	16	0.55	44	--	0
		Total	0.44	100	2.55	100	--	0	2.41	100	1.92	100	7.56	100	1.24	100	--	0
		% of CCA	1.93		7.27		--		17.96		6.89		27.38		4.23		--	
2.	Bajra	Canal	5.20	100	2.64	66	--	0	2.39	100	--	0	--	0	--	0	--	0
		Well	--	0	1.37	34	1.27	100	--	0	0.50	100	--	0	--	0	--	0
		Total	5.20	100	4.01	100	1.27	100	2.39	100	0.50	100	--	0	--	0	--	0
		% of CCA	22.75		11.43		4.58		17.81		1.79		--		--		--	
3.	Rice	Canal	--	0	--	0	--	0	1.06	0	0.69	0	1.93	0	--	0	--	0
		Well	--	0	--	0	--	0	--	0	1.13	0	--	0	--	0	--	0
		Total	--	0	--	0	--	0	1.06	0	1.82	0	1.93	0	--	0	--	0
		% of CCA	--		--		--		7.90		10.12		6.99		--		--	
	Total	Canal	5.64	100	2.82	43	0	0	5.86	100	2.15	51	8.29	87	0.69	56	0	0
		Well	0	0	3.74	57	1.27	100	0	0	2.09	49	1.2	13	0.55	44	0	0
		Total	5.64	100	6.56	100	1.27	100	5.86	100	4.24	100	9.49	100	1.24	100	0	0
		% of CCA	24.67		18.69		4.58		43.67		15.21		34.37		4.23		0.00	

Notes: H.O. = Head Outlet. M.O. = Middle Outlet. T.O. = Tail Outlet. CCA = Cultivable Command Area. D.O. = Direct Outlet.

Appendix C

Mean Input/Production Indicators for Wheat by Location

Table C-1. Mean input/production indicators for wheat by location and type of irrigation.

Location		No. of farm plots	Average WAI	Average nitrogen nutrient kg/ha	Average total operation costs Rs/ha	Average yield kg/ha
Umreth	H.M.	18	66.96	172	2,706	2,137
	M.M.	14	67.90	161	2,885	2,221
	T.M.	3	69.50	181	2,242	2,191
Borsad		8	65.16	136	2,888	1,941

Notes: H.M. = Head Minor.
M.M. = Middle Minor.
T.M. = Tail Minor.

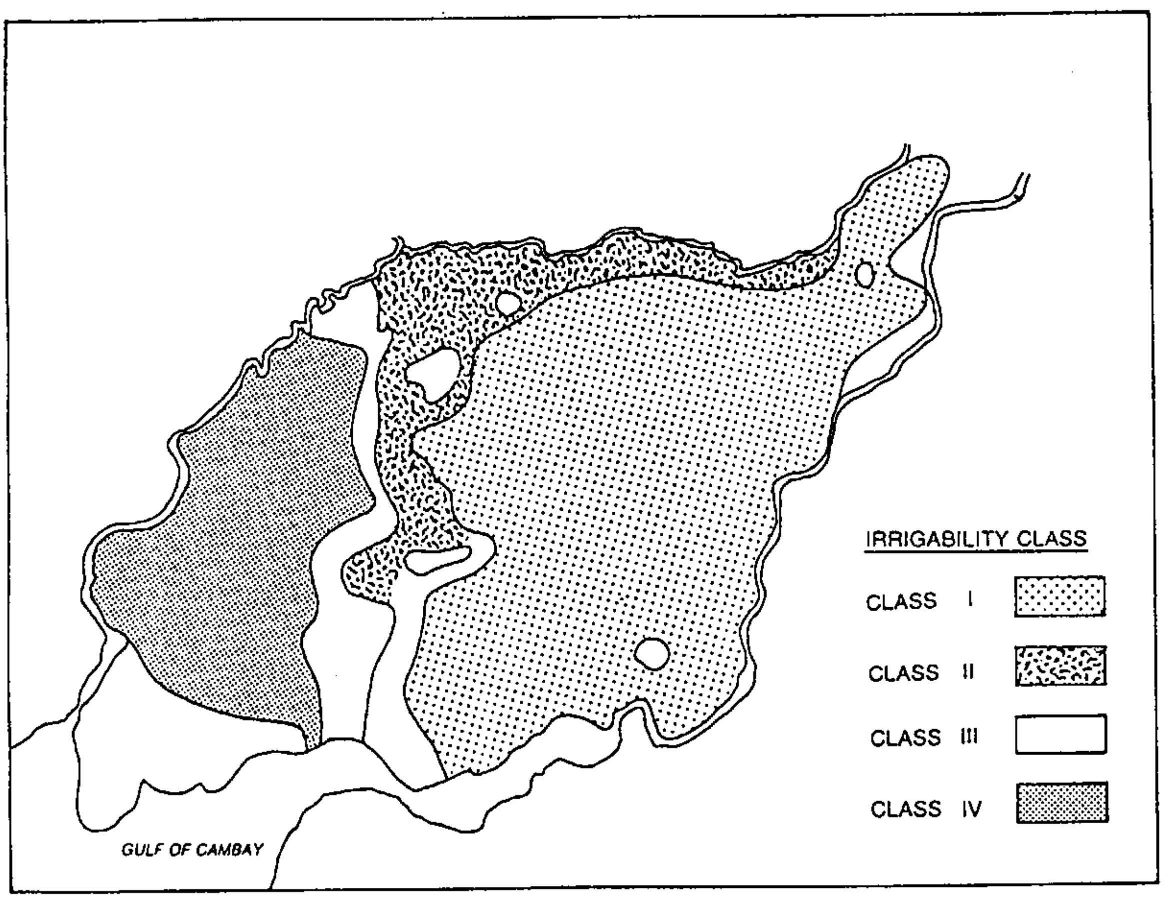
Appendix D

Land Irrigability Classification in Mahi-Kadana Project Area

Physiographically, the command area of the Mahi Project falls under the flood plains of the Mahi River. The soils in MRBC have been classified in to the four Land Irrigability Classes. Soils vary from sandy loam to loam and soil texture, from medium to coarse occur in the eastern portion of the command area. These soils are inherently permeable and well-drained and are classified under Land Irrigability Class-I (Figure D-1). The soils become deeper and darker in color towards the west, are moderately drained, but have salt problems in certain areas and come under Classes II and III. Further west, the Class IV soils are deep black and clayey, with moderate to poor drainage, and are affected by salinity problems (WTC 1988).

Around 51 percent and 31 percent of the total command area are covered by Class I and Class IV soils, respectively. Both the selected distributary commands also fall under Class I. Class IV soil commands represent different technical problems in the form of intensive drainage cum reclamation and have not been considered suitable as irrigable areas to be represented. The remaining Classes II and III have less command area and are not represented either. These are some limitations of this study.

Figure D-1. Land Irrigability Classes in the Mahi-Kadana Right Bank Canal Command Area.



Appendix E

Water Deliveries at the Heads of Distributaries

Figure E-1. Daily discharge variations: Umreth Distributary (Kharif 1991/92).

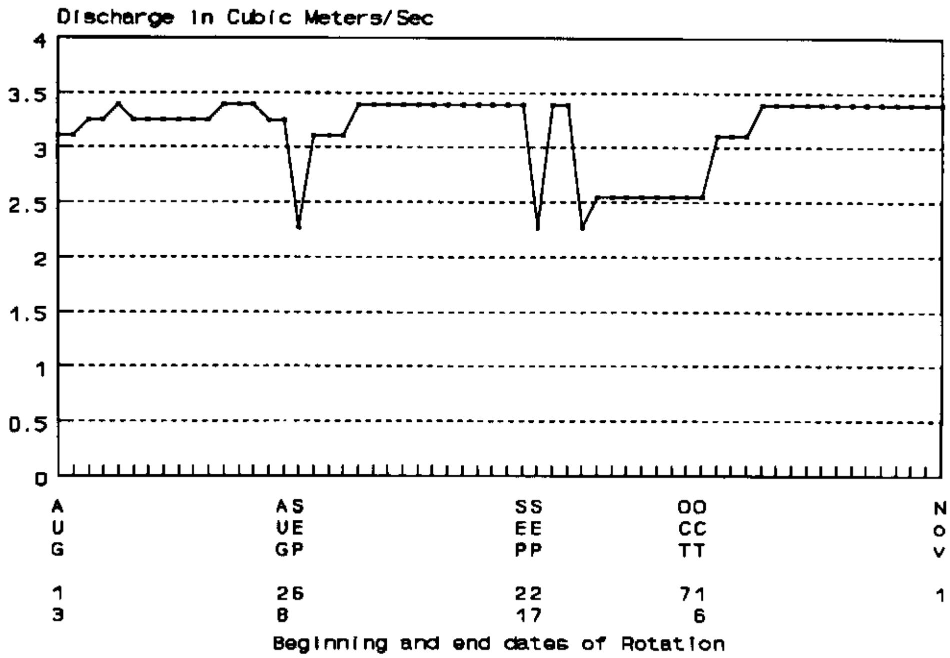


Figure E-2. Daily discharge variations: Borsad Distributary (Kharif 1991/92).

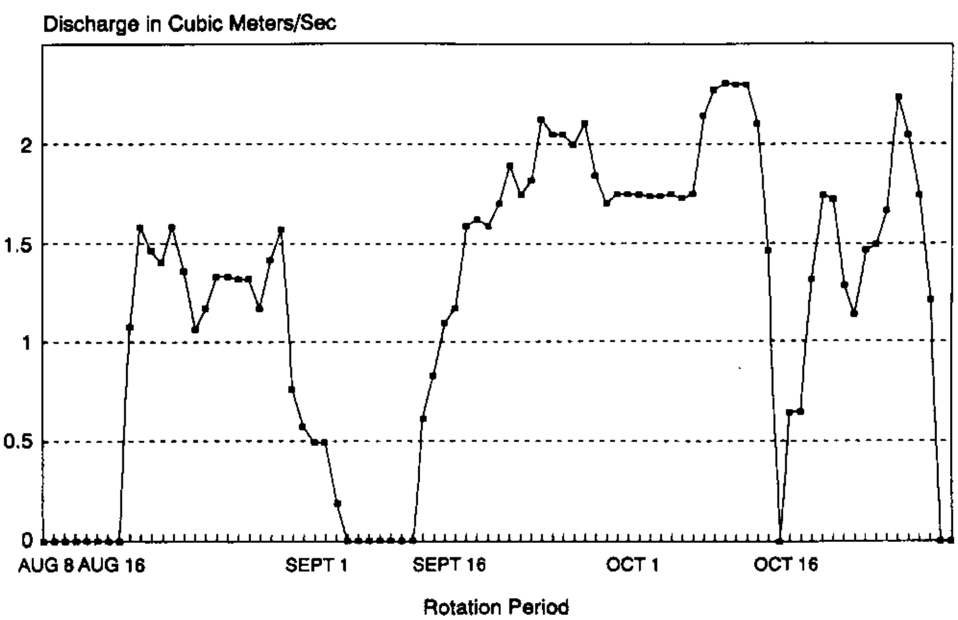


Figure E-3. Daily discharge variations: Umreth Distributary (Rabi 1991/92).

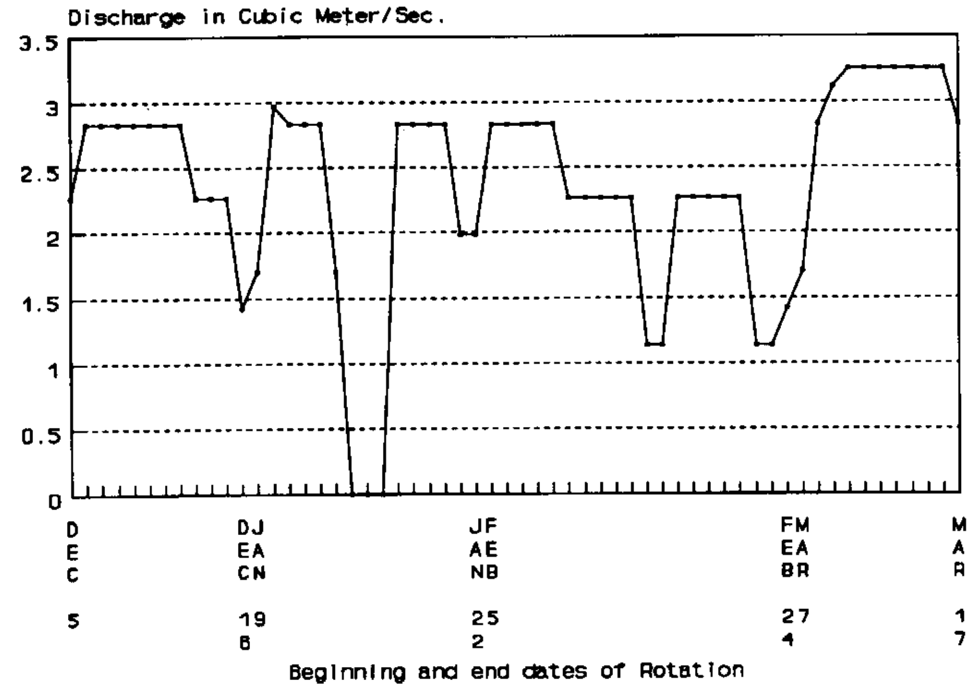
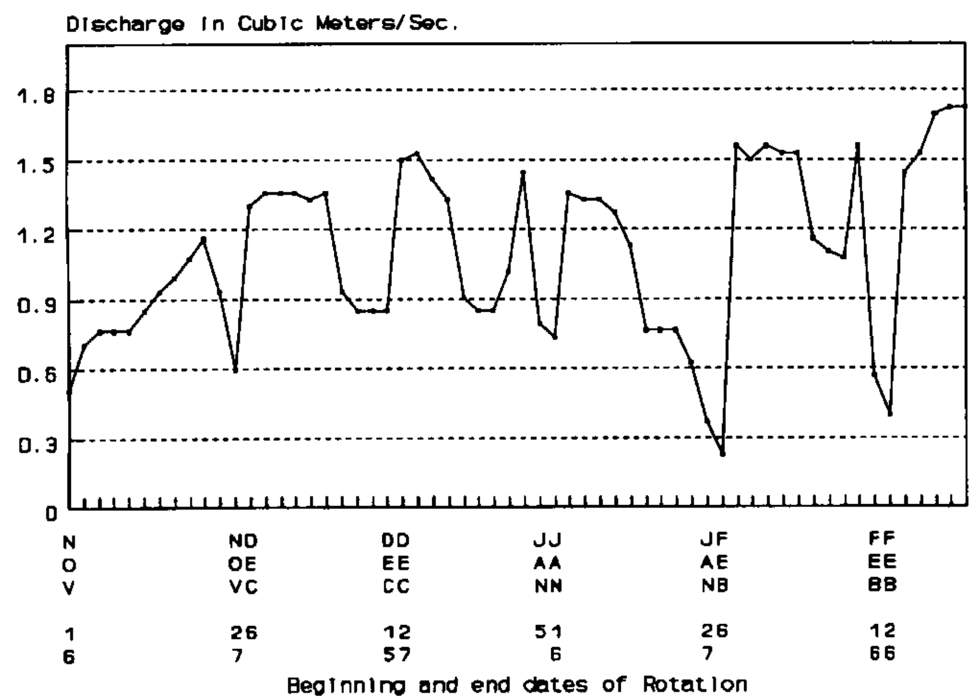


Figure E-4. Daily discharge variations: Borsad Distributary (Rabi 1991/92).



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