IIMI Country Paper – India – No.1

Improving Irrigation Performance through the Use of Management Information Systems

Improving Irrigation Performance through the Use of Management Information Systems: The Case of Mahi Kadana, Gujarat, India

D. Hammond Murray-Rust, O.T. Gulati, R. Sakthivadivel
V. B. Prajapati and P.L. Shukla

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

WATER AND LAND MANAGEMENT INSTITUTE, ANAND, GUJARAT

Murray-Rust, D. H.; O.T. Gulati; R. Sakthivadivel; V. B. Prajapati and P.L. Shukla. 1994. Improving irrigation performance through the use of Management Information Systems: The Case of Mahi Kadana, Gujarat, India. Colombo, Sri Lanka: International Irrigation Management Institute. xix + 85 pp. (IIMI Country Paper — India — No. 1).

/ water management / water distribution / cropping systems / rotation / performance evaluation / performance indexes / data collection / databases / canal irrigation / Management Information Systems / India / Gujarat /

DDC: 631.7
ISBN: 92-9090-305-8

Please direct inquiries and comments to:
Information Office
International Irrigation Management Institute
P. O. Box 2075
Colombo
Sri Lanka

Illustrations on the cover depict the process of transforming field data into useful information for managers to use in the improvement of irrigation performance.

Contents

List of Figures

List of Tables

Foreword

IIMI'S COUNTRY PROGRAMS play a major role in dissemination of information and methodologies to national irrigation agencies so that they can make improvements in the way they manage irrigation systems. The staff based in IIMI's Headquarters in Colombo assist in this process by providing technical assistance to the various country programs. This India Country Paper represents a good example of collaborative activities between a national irrigation agency, IIMI's India Program and IIMI's Research Division over a period of several years using both project specific money provided by the U.S. Agency for International Development and the Ford Foundation and IIMI's core funds provided through the CGIAR.

The success or failure of such collaborative activities is in large measure determined by the degree to which national agencies are willing to identify their goals and objectives, and work together with visiting IIMI staff in making changes to existing practices in efforts to improve performance. The Gujarat Department of Public Works has shown exemplary cooperation in this project, from the level of Secretary to the Ministry of Public Works right down to the lowest level staff of the Mahi Kadana System. The degree of cooperation is perhaps best demonstrated by the willingness of staff involved in the project to end up doing things that had not been contemplated in the initial proposal. This flexibility of attitude has made the project easier to undertake, and much more enjoyable to participate in because there is a sense of working together in an adventure rather than merely plodding along a predetermined track.

A second factor in obtaining successful collaboration is that there is a frequent interchange of views on an incremental basis. Rather than trying to make wholesale changes that may meet with institutional resistance, a steady development of small changes with periods for determination of the comparative success or failure of each change and identification of the most appropriate next step keeps all participants fully involved and thus responsible whatever success is ultimately achieved.

The final aspect of the collaboration that deserves mention is that IIMI has, through this project, shown a capacity to bring ideas and experiences from other countries to help in addressing the concerns of the Mahi Kadana System. At the same time, the experience IIMI has gained in Mahi Kadana is used in developing and implementing other activities in India and elsewhere. This two-way international flow of information and ideas is what the CGIAR system stands for, and why IIMI was brought into existence in the first place.

Hammond Murray-Rust
Senior Irrigation Specialist
International Irrigation Management Institute

Acknowledgements

THIS PAPER COULD not have been prepared without the highest level of cooperation from the Gujarat Irrigation Department staff and the team at the Water and Land Management Institute (WALMI) at Anand.

The Irrigation Department has been extremely generous in providing almost instant access to discharge data in the main and branch canals. The lower-level staff have been diligent in taking daily readings of water levels, gate openings and discharges; although this is part of their duty, they have discharged that duty with interest and commitment. The same officers have also participated fully in the calibration activities with all the normal difficulties of extended field work under difficult conditions. The data provided by the chowkidars in the Red Books represent a great deal of effort on their part as well, while the entry of these data into the computer is a tedious task that has been done with great accuracy.

The WALMI staff have played an equally important role. The computer-based MIS package works extremely well. It has proved itself under field operation conditions, and it generates quick and accurate information. The generation of Main Canal Performance data to complement the field-level data presented here represents a significant step forward in the development of a comprehensive and useful database for planners, managers and researchers alike. The programs of calibration, training of staff in different tasks, and logistic and other support to the IIMI visitors have always been at the highest level. Without such cooperation none of this would have been possible.

Amongst our colleagues at IIMI particular thanks are due to Dr. Douglas Merrey for a thorough editing of this paper together with several insightful comments concerning the content and presentation.

O.T. Gulati
V.B. Prajapati
P.L. Shukla
WALMI
Anand,
Gujarat

D. Hammond Murray-Rust
R. Sakthivadivel

IIMI
Colombo,
Sri Lanka

April 1994

Summary

MANY COUNTRIES ARE facing the challenge of attempting to improve the performance of irrigation systems with fewer financial and human resources. Although there are a wide range of strategies for meeting this challenge, they almost all have one thing in common: the adoption of a management approach that includes a greater responsiveness to current and potential levels of performance. Typically, three elements of performance-oriented management are: better and more timely access to data, an improved capacity to process the data into meaningful information on performance, and a capacity to identify causes of less than desired performance and potential solutions.

This paper describes the development, introduction and use of an improved Management Information System in the Mahi Kadana Irrigation System in Gujarat, India. It represents the outcome of the first two phases of a collaboration between the Gujarat Irrigation Department, the Water and Land Management Institute (WALMI) at Anand, Gujarat, and the International Irrigation Management Institute (IIMI) which has its headquarters in Colombo, Sri Lanka. In undertaking this collaboration, each of the three elements of performance-oriented management has been addressed in a sequential set of activities.

The first phase of the project involved the modification of existing data collection procedures that made the collection and reporting of monitoring information more efficient and useful for lower-level managers. The primary innovation was the development of the "Red Book," a revised format for collecting information on farmers' cropping patterns, water use by source and other information to assist in the development of a faster billing system. Before this innovation was introduced, a complex system of ledgers was used to manually record each irrigation delivery to every farmer, and then the information was extracted from those ledgers to generate irrigation bills and calculate actual values for different performance indicators.

The Red Book enabled the information to be recorded in a systematic way by each outlet by the *chowkidar* (irrigation laborer), thus paving the way for computerizing the information collected. Although a very simple innovation, the Red Book provides the basis for all of the subsequent innovations because

it standardizes the way in which data are collected and reported. The first phase was successful in getting reactions from the different levels of Irrigation Department staff, and making appropriate modifications in light of inputs from field staff and the computer programmers involved in the second phase.

The second phase developed a computer-based Management Information System, known as the Mahi MIS, that can process the data quickly, combine them with regular discharge measurements taken by the Department, and generate a series of performance reports at the end of each rotational period (i.e., bimonthly) and at the end of each of the three seasons. A consolidated demand statement is also generated by the Mahi MIS to enable rapid production of accurate bills for farmers.

Training of Irrigation Department staff in the use of the data entry module proved that it was possible to convert the Red Book data into computer records at section level, and to do so with sufficient speed that performance results from one biweekly rotation period could be made available to managers within a few days of the end of that time period. This cut the reporting time of performance information from several weeks to a few days, and facilitated a real-time response to actual field-level conditions.

An example of a seasonal performance report for one section of the system is described in the report, illustrating the value of using the MIS package to simultaneously process both main-system data and tertiary-level data. All of the data and information provided in this seasonal report can be generated in a standardized format within the space of a few minutes. This means that managers can have a look at the performance of any part of the system as often as desired rather than having to wait until after the season is completed as was the case before the introduction of the Mahi MIS.

The result of the first two phases of the collaborative project is that the Red Book procedures have been adopted throughout the 212,000 hectare (ha) Mahi Project, and in a few other large systems throughout the State of Gujarat, while the Mahi MIS has been tested and implemented in Ode Subdivision under real operating conditions using the existing resources of the Department without relying on any special input. This tests the package under realistic, rather than controlled, conditions.

The third aspect of the collaboration is to use the available information to determine aspects of performance not currently included in the routine work of the Irrigation Department. The final chapter of this report examines several aspects of performance of the Mahi Kadana Irrigation System that can only be undertaken when both hydraulic and agricultural information can be analyzed together. The Mahi MIS provides the potential to look at performance in respect of such things as the operation of cross-regulators to achieve different objectives, the effectiveness of rotational irrigation innovations to achieve equitable and reliable irrigation water deliveries, and efforts of *karkoons* (work assistants) in achieving fair water distribution in distributary canals. This type of assessment also raises additional questions that cannot be answered immediately from the existing databases but which can form the basis for further work in subsequent phases of the collaboration.

The overall conclusion of the project to date is that it has been possible to introduce a cost-effective and practical management information system that addresses key concerns of the Irrigation Department staff at the Mahi Kadana. Given the nature of the data collection programs and the Mahi MIS, it is believed that it can be easily replicated in other locations, both in Gujarat and other States, and can provide the basis for more cost-effective and high-performing irrigation management.

CHAPTER 1

The Use of Management Information Systems (MIS) for Irrigation Managers

IRRIGATION PERFORMANCE IMPROVEMENT

A CONSIDERABLE AMOUNT of work has been undertaken in recent years on the problems of assessing irrigation performance, and how to develop suitable ways to get managers to respond better to actual conditions at field level. Improvement in performance of irrigation systems does not come easily or automatically. It requires a set of preconditions that must be in place to guarantee lasting and sustainable improvements. Among these are the identification of clear management objectives and associated operational targets, a system for monitoring actual field conditions, a process to store and retrieve useful information on performance levels, and a management framework that allows these performance data to be used in a program of improvement over a period of several years. A clear explanation of the entire process is given by Bos et. al (1994) and Small and Svendsen (1992).

The approach advocated by Bos and his colleagues, as well as by Murray-Rust and Snellen (1993) goes further than merely monitoring and evaluation: it also deals with the analysis of causes of different levels of performance. For such diagnostic and analytic approaches to be effective in real life, however, it is necessary to retrofit new techniques and approaches to existing monitoring practices rather than starting entirely from first principles: this avoids the risk of introducing new data collection programs that are alien to normal practices, and that fail to use the existing knowledge of managers with long experience.

The Mahi Kadana Irrigation System in Gujarat has provided an excellent opportunity to retrofit new techniques and approaches onto an existing monitoring package that while functional for managers needed some upgrading to meet challenges imposed by changes in the physical, social, economic and financial environments. A modern and efficient management information system, designated as "Mahi MIS" was selected as the entry point for the improvement package: plenty of data already existed and data collection programs were continuing, but the storage, processing, and retrieval of useful performance information constituted a slow and extremely tedious process relying entirely on manual entering and compilation of performance information.

THE DEVELOPMENT OF THE MAHI MIS PACKAGE IN THE MAHI KADANA, GUJARAT

This paper describes the steps taken to improve irrigation management in the Mahi Kadana Irrigation System in Gujarat, India in a collaborative project undertaken between the Irrigation Department of Gujarat, the Water and Land Management Institute (WALMI), Anand, and the International Irrigation Management Institute (IIMI) based in Colombo, Sri Lanka.

Chapter 2 describes the data collection procedures and management strategies that were used prior to the collaborative program. The Mahi Kadana follows a system of irrigation whereby seasonal water allocations are made at a macro level based on anticipated supplies, while at local level, discharges are adjusted to the requests of individual farmers by lower-level staff of the Public Works Department. It is clear that most of the necessary conditions for improving performance were already present: data collection programs existed, and there were mechanisms for processing those data to aid managers in identifying performance deficiencies. However, the procedures followed were laborious, and it was almost impossible to get timely feedback of actual performance levels to managers for them to make informed judgements about what to do next.

Chapter 3 looks at the initial interventions that were made in the first phase of the collaboration. These included a redesign of the basic data collection procedures at field level that enable a more systematic collection of data indicating which farmers obtained water at what time, what crops were grown on individual plots, and the overall efficiency of water application. The revised reporting arrangements were encapsulated in the "Red Book," the basic register of irrigation activities filled in by the *chowkidars* (irrigation laborers) who interact with farmers at outlet level, and report their irrigation requirements to the *karkoon* (work assistant, a field-level staff member of the Irrigation Department responsible for approximately 1,000 ha). Adoption of the Red Book enabled additional information to be included in the overall reporting upwards through the information channels, including improved knowledge of use of other sources of water than canal irrigation, and the actual dates on which water was applied to specific fields. This pilot data collection system, first used in the Kunjarao Section of Ode Subdivision, proved so successful that it has been adopted as the standard for reporting throughout the 212,000 ha of the Mahi Kadana and is being extended into other large irrigation systems throughout the State of Gujarat.

The second phase of the intervention focused on the development of a simple but functional management information system to more effectively use the information contained in the Red Book. The result is the Mahi Management Information System (Mahi MIS), a computerized information storage and retrieval system which has been used by staff of the Irrigation Department on a trial basis in Kunjarao since the 1993 kharif season, and which is now being extended to cover all of Ode Subdivision. The pilot use of the Mahi MIS has proved two important things: it has been able to be integrated directly into the normal working practices of the Irrigation Department insofar as the data entry and retrieval have been done by regular staff following training at WALMI, and it has been able to generate additional performance information from the same data already collected by the Department. This cost-effective and versatile facility is only possible because of the power of database management to sort information according to whatever criteria managers may specify.

The details of the Mahi MIS package and its utilization are described in Chapter 4 of this paper, while Chapter 5 provides an example of how performance assessment can be undertaken using the output from the Mahi MIS. One of its striking features is its versatility: originally, the Mahi MIS was expected to largely replicate (although with greater speed) data on existing performance indicators used by the Department; as it has developed, it can now also provide information on a far wider set of hydraulic and agricultural aspects of performance, and generate demand statements (irrigation bills) that meet the same standards as were previously undertaken manually. It is possible now to generate the demand statements within a couple of days after the end of each irrigation season rather than toward the end of the following season as was the case before the development of the Mahi MIS.

Because the package is designed in a generic manner, it is directly transferable to the remainder of the Mahi Kadana Irrigation System, and others which use the same reporting format. The final chapter of the paper looks at the potential for using this type of management information system in other systems and other States. With minimal modification to the computer package, it is possible to envisage a much wider adoption of the MIS: changes will depend on what objectives are used by agencies operating irrigation systems, and what type of data are collected in sufficient quantity to justify the initial investment of time to establish an effective basic database.

The joint Irrigation Department/WALMI/IIMI Project has additional objectives that, subject to normal approvals, will be carried out over the next couple of years. This could result in adding additional databases leading to the computation of far more performance indicators and in documenting the impact of using the improved MIS on performance. However, the present stage of development is more or less completed, and has resulted in a flexible and efficient management information system that can be used widely throughout the Mahi Kadana and other large systems in the years to come.

CHAPTER 2

The Mahi Kadana before the Introduction of MIS

SYSTEM OVERVIEW AND OBJECTIVES

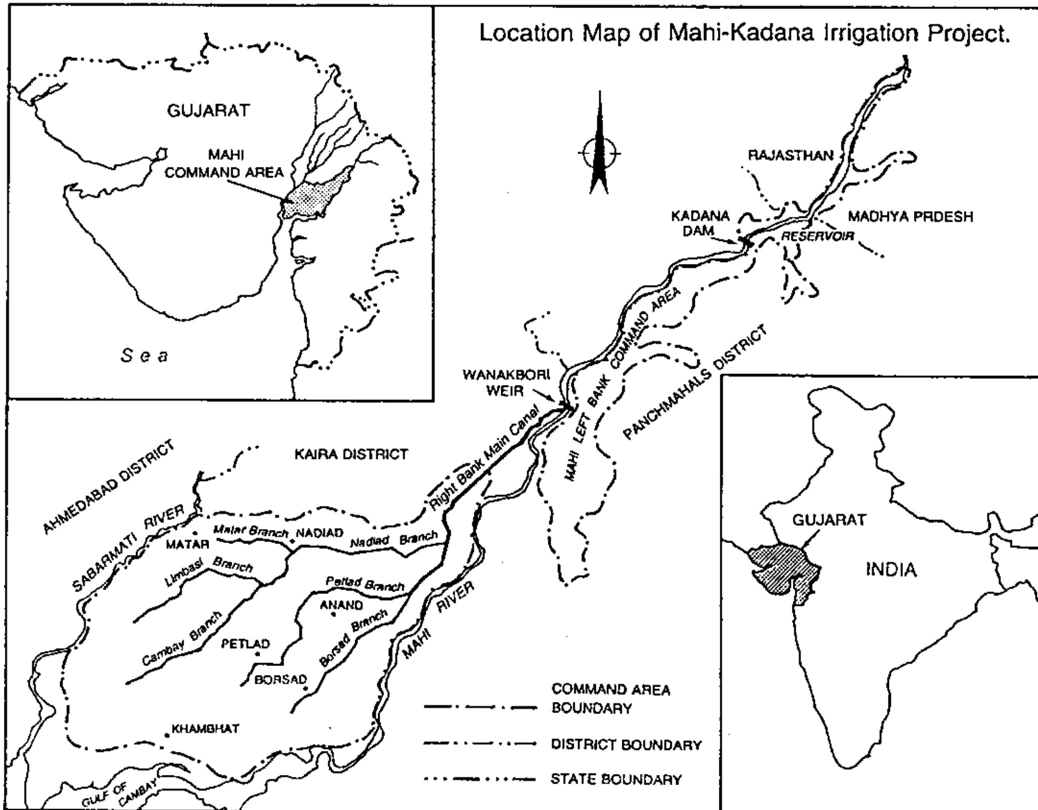
THE MAHI KADANA System (Figure 1) is situated in the State of Gujarat, India It has a total irrigable area of 212,000 ha making it the largest system in the State outside the Narmada Project. The Mahi Kadana System has been developed in two stages. The first stage comprised the construction of a pick-up weir across the Mahi River at Wanakbori in 1958. The second stage comprised the construction of a storage reservoir 90 km upstream of the Wanakbori Weir of the Kadana Reservoir, in 1978. The command area has been receiving perennial irrigation since then. The reservoir is filled almost every year during the kharif and at the end of kharif, so that the main canal system can receive its full design discharge of 7,000 cusecs (223.5 cumecs).[1] The main irrigation seasons are *kharif* (15 June to 15 November), *rabi* (15 October to 15 March) and *hot weather* (15 February to 15 June). During the rabi and hot weather, the command area is reduced as certain portions of the command area are not served with irrigation due to heavy clay soils causing poor land irrigability.

The system is designed to use canal water to irrigate a total of 260,000 ha during the three seasons. Presently, the total area irrigated by surface water is estimated at 200,000 ha comprising 100,000 ha in kharif, 50,000 ha each in rabi and hot weather. This is supplemented by extensive pumping of groundwater that enables a further 180,000 ha to be irrigated or a total annual

---

1 In this Report the units quoted reflect current practice in the Mahi Kadana. Area, yield and rainfall are normally measured in metric units, while discharges and water deliveries are normally expressed in imperial units. Some indicators, therefore, may be expressed in mixed units. The authors feel that it is best, at this stage, to maintain current practices although in the long run, and in international publications concerning this project, metric units should be used.

Figure 1. The Mahi Kadana System.



cropping intensity of 1.80. Groundwater usage is increasing due to favorable electricity tariffs, but there is a persistent rise in groundwater levels at many locations that is becoming a serious threat to production.

The cropping pattern is mixed. During the kharif season, between 90,000 and 100,000 ha of rice are cultivated, much of this in the heavy clay soils of the lower half of the system adjacent to the Arabian Sea. In water-abundant parts of the upper half of the system there is considerable rice cultivation, but tobacco and bananas are also widely cultivated on sandy loam soils. In the colder rabi season, wheat is widely grown, while tobacco planted in September comes ready for harvest in January or February. Heavy soils are frequently left fallow in this period. Other important crops are pulses, millet, and some sorghum.

A significant feature of the system is that it is operated under the "*shejpali*" system. This system is intended to match supplies and demand as closely as possible. Before each season, the total water resources are estimated, and the area that can be irrigated for the ensuing season determined based on the experience of previous years. Farmers, having been informed of the proposed cropping pattern, then make individual applications to receive irrigation water, and are given an application number indicating their sanctioned surface irrigated area and cropping pattern. This then entitles them to receive water on request during each of the rotation periods specified by the Irrigation Department. Normally, the main and branch systems run continuously, as do most distributaries, thereby leaving the task of matching supply and demand to the karkoon. He is supported by 4 or 5 chowkidars who are responsible for passing to him requests for water, and recording which farmers receive water for which crop during each two-week period. This information is subsequently used for billing purposes.

The overall objectives of this project are:

* to irrigate 260,000 ha annually from gravity supplies in a mixed cropping pattern;
* to match water supplies at the system head with the demand created by the actual cropping pattern; and
* to assess irrigation fees on the basis of crop and area irrigated as well as mode of irrigation, i.e., authorized or unauthorized and flow or lift.

SYSTEM DESIGN

There are no significant design constraints to achieving higher performance at the Mahi Kadana. The main canal system runs more or less at full supply level; there are 56 cross-regulators in the main and branch canals to control water levels when discharges are below the maximum, and control over water can be maintained into the head of every distributary, minor and sub-minor served by the main canal system.

The "articulated" nature of the system incorporates a capacity to control discharges down to the outlet level. Each outlet, serving approximately 30 ha, is provided with a screw gate to enable discharges of about 1 cusec (28.3 l/sec), and in many locations drop structures or small cross-regulators are provided close to outlet and sub-minor structures so that the appropriate discharge can be maintained. However, it is worth noting that invariably the sum of outlet capacities is always greater than minor or sub-minor capacity, which makes it basically impossible to operate all outlets simultaneously at 1 cusec; also most outlets are designed to draw 1 cusec even when the parent channel is operated at two-thirds of full design discharge, thus allowing head-end outlets to draw more discharge than the tail ones.

Measurement structures or rating tables exist for all offtakes (other than direct outlets) from the main and branch canal systems, making it possible to determine how much water is delivered to approximately each distributary (distributary commands vary from 665 to 7,665 ha). Normally, the water delivered to each karkoon beat, can be directly measured, except in larger distributaries where there are no measurement structures provided below the head regulator.

SYSTEM OPERATION

The operational pattern in the Mahi Kadana is complex. In the main and branch canals, wherever possible, water deliveries are continuous but are controlled to match the anticipated demand during each season. This requires a considerable degree of adjustment at the various cross-regulators, and at head regulators of canals served directly by the main system. It appears that there are few problems in maintaining constant water levels.

At secondary levels and below, however, some problems are observed. The chowkidar is supposed to inform the karkoon of which farmers want water during the next day or two, and the karkoon then has to work out a schedule of water deliveries that matches these demands to the available supplies. It is apparent that this matching is an ad-hoc process: there is no systematic schedule of which farmers will receive water, particularly when demand is high in the kharif season, and there is no capacity to ensure that deliveries are really at or close to the designed level of 1 cusec. The result is that water deliveries are not predictable and not very equitable.

Further, although farmers are expected to make applications for water before the season starts, they can still receive water without such an application if they are willing to pay a penalty of 50 percent cess on the standard water charges. Unauthorized irrigation (legal but without applications) now represents 60 percent of all irrigation: this means that demand is never really known until late in the season, and the procedure for matching the uncertain demand to supply becomes tenuous.

Maintenance in distributaries is moderate. The sandy loams in the upper portion of the system are susceptible to erosion, so that many secondary canals are much wider than designed, and it is hard to maintain adequate head upstream of offtakes. Many outlet gates are broken or missing, and this further undermines the capacity of karkoons to match supply and demand effectively.

IRRIGATION MANAGEMENT ORGANIZATION

The whole Mahi Right Bank Canal Project command area of 212,000 ha comes under the management of the Mahi Irrigation Circle, headed by a superintending engineer. There are three divisions under the Mahi Irrigation Circle, at Anand, Petlad and Nadiad, each headed by an executive engineer. The command area managed by each division varies between 70,000 and 80,000 ha. Each division has 4 to 5 subdivisions, each headed by a deputy executive engineer. The command area of each subdivision varies between 16,000 and 20,000 ha. The next official in the hierarchy is the section officer, who may have a diploma or degree in civil engineering. There are four to five section officers in each subdivision, and the jurisdiction of each section officer varies from 4,000 to 5,000 ha. The field staff below the section officer are known as karkoons and chowkidars. There are about 4 karkoons under each section officer, and under each karkoon there are 4 to 5 chowkidars, each of the latter usually managing 200 ha. The total number of operating staff in the project is given in Table 1.

The communication linkages are strictly hierarchical. The chowkidar is the interface between the farmers and agency officials. The lowest official in the hierarchy who can take a decision is the section officer. Decision with regard to water distribution below the distributary mainly rests with the section officer.

Table 1. Operational staff in the Mahi Kadana Project.

Level	Designation	Number	Area Managed (ha)
Project	Superintending Engineer	1	212,000
Division	Executive Engineer	3	70 - 80,000
Subdivision	Deputy Engineer	13	16 - 18,000
Section	Section Officer	60	4 - 5,000
Beat	Karkoon	220	1,000
Outlet	Chowkidar	1,100	200

PERFORMANCE INDICATORS FOR WATER DISTRIBUTION

Presently, Area Irrigated Per Day Cusec (AIDC) and number of waterings per season are used as performance indicators in the Mahi Kadana for water delivery and distribution efficiency. If the flow is continuous throughout the season, then AIDC is equivalent to the concept of duty. AIDC is computed based on daily flow. A hypothetical example is presented below (Table 2) for computing AIDC.

AIDC is also expressed as so many hectares/day-cusec. It can be computed per rotation and per season by averaging the value over the rotational and seasonal number of days. In addition, the number of waterings per season is also used as an indicator of water use efficiency, although this concept omits the measurement of depth per watering.

Given the logical structure of the administrative hierarchy within the Mahi Kadana, where administrative boundaries almost all coincide with hydrological units within the system, the use of performance indicators such as AIDC makes it relatively simple to determine performance both in terms of hydrological units and individuals responsible for irrigation management at each level in the hierarchy.

Table 2. Hypothetical example of AIDC computation.

Time of Day	Discharge (cusecs)	Discharge during the Interval (cusec-hrs)	Cumulative Discharge (cusec-hrs)
08:00-10:00	5	10	10
10:00-12:00	5	10	20
12:00-14:00	7	14	34
14:00-16:00	6	12	46
16:00-18:00	5	10	56
18:00-20:00	5	10	66
20:00-22:00	5	10	76
22:00-00:00	6	10	86
00:00-02:00	6	10	96
02:00-04:00	7	14	110
04:00:06:00	5	10	120
06:00-08:00	6	12	132

From the above table,

Day-cusec $= \frac{132}{24} = 5.5$

Area irrigated during this period with the above discharge = 11 acres.

AIDC (acres) $= \frac{11}{5.5}$ = 2 acres/day-cusec.

THE "SHEJPALI" SYSTEM OF WATER DISTRIBUTION

The irrigation management practices in the Mahi Kadana System are governed under the Bombay Irrigation Act, 1879 and the Gujarat Canal Rules, 1962 as amended from time to time. The distribution system, known as "Shejpali," is basically a demand-based system, in which each irrigator is expected to apply to the irrigation agency before the beginning of each season, stating the crop and area to be irrigated. Any irrigation taken from the canal system without prior and timely sanction is dealt with as unauthorized irrigation, for which the defaulting irrigator has to pay penal irrigation rates.

The farmers are expected to apply for irrigation on the prescribed form to the section officer. At the time of application, the farmer has to obtain a certificate from the *talati* (the Revenue Department for water tax collection) to the effect that there are no irrigation dues outstanding against him. Sanction of application for irrigation is communicated to the irrigator by the section officer on the prescribed form of the irrigation pass through the karkoon. Every time the irrigator takes water, he has to present his irrigation pass and obtain the signature of the chowkidar. Similarly, the irrigator has to sign the duplicate copy of the irrigation pass, kept by the chowkidar.

Any irrigation taken without prior and timely sanction, area irrigated in excess of the sanctioned area, and deviation from the sanctioned crop are dealt with as "unauthorized irrigation." The irrigator who takes unauthorized irrigation is called upon to sign a form known as *ekrarnama* (the Form of Admission), whereby he admits the unauthorized irrigation and agrees to pay the penal irrigation rates as decided by the competent authority. If the irrigator objects to signing the ekrarnama, then the full procedure of *panchnama* is followed, i.e., the signatures of *panch* or five witnesses are taken at the site according to the procedure laid down by the government, and panchnama is processed, and penal irrigation rates are charged.

Before finalizing the bills of irrigation charges, a 'demand statement' is prepared by the irrigation agency and exhibited in the village *chora* (a common meeting place of farmers in a village) for the purpose of information and verification by the irrigators. A notice is given declaring that a *kul rajuat* (a statement of verification) of the demand statement will be made on a specified date noted in the notice and the irrigators are called upon to make any representations in respect of the draft demand statement already exhibited. On the specified date, the section officer visits the village and listens to the representations, if any, by the irrigators. The draft demand statement may need some modifications in view of representations made by the irrigators, and after these corrections, the demand statement is finalized and processed for recovery.

The water requirement of the various canals is supposed to be assessed on the basis of the demand applications received. Farmers do not generally apply for water thinking that they will get rain and also some farmers are not eligible to get sanction because of previous years' dues. Moreover, the penalty is not high enough to make the farmers to apply for sanction in time. The farmers do not apply for irrigation within the prescribed time making assessment of irrigation water requirements impossible. Usually, the water requirement assessment is made based on the past performance of each canal system. At present, the normal ratio of authorized to unauthorized irrigation is 40:60. The date of receipt of application for sanction is invariably extended every year and every season for many reasons, thereby creating a complacence on the part of farmers for not applying for water in time. The whole process appears to be a vicious circle. The low demand leads to extension of the date, which in turn affects farmers' attitude and they do not apply in time, hence the low demand.

Also, because of the relatively high water rates, farmers delay applying for sanction in the hope of good rains. An important effect of this delayed application is "slippage" of the crop season, and hence reduced yields. The World Bank conducted an experiment in the State of Maharashtra of making the first irrigation free so as to set the planting dates earlier. It was very successful in increasing demand for water and yield (C. Perry, personal communication).

CANAL SEASONAL WATER ALLOCATION

a. The canal seasonal water allocation procedure starts from top to bottom. Based on past records as well as on the collective advice of the Command Area Development (CAD), the ID and the Department of Agriculture, provided through the "Project Canal Advisory Committee," the CAD Commissioner sets the area target for the three seasons (kharif, rabi and hot weather) and informs the Superintending Engineer (SE) (Operations). The procedure adopted by the SE for canal water allocation is explained below using an example of target setting for kharif 1990-91. The area targeted for this season is 85,000 ha. Based on the crop data of the previous years, the SE sets the following crop targets.

Crop	Area (in ha)
Perennial	4,270
Rice	68,380
Bajri-Jowar	500
Tobacco	9,570
Others	2,280
Total	85,000

b. Crop period assumed is 123 days from 16-07-1990 to 15-11-1990.

c. AIDC assumed at head regulator of the Wanakbori Weir = 2 acres/day-cusec.

d. Water utilization from the Kadana Reservoir at Wanakbori = 90 percent.

e. Overall efficiency of water supply = 40 percent. Therefore, an AIDC of 2 is equivalent to 125 mm at the field and requires 300 mm at the Wanakbori Weir.

f. Crop area coefficient: During kharif, because of the rainfall and cropping pattern, not every acre under a crop needs to be irrigated in each watering. Based on the previous waterings, the Mahi Kadana Project authorities have developed an area coefficient which varies from crop to crop and depends on the watering number (i.e., first, second or third watering and so on). Typical crop coefficients used at the Mahi Kadana are shown in Figure 2.

g. The total water requirement of a rotation of 16 days for different crops can be worked out according to the following formula:

Area under crop x area coefficient x water requirement.

h. The total water requirement in million cubic feet (mcft) is converted into day-cusecs by multiplying by 11.574. This quantity of water is utilized to irrigate the total number of days in that rotation. Here is an example.

   i. Suppose the total quantity of water required in a 16-day rotation period is 4,983 mcft.

   ii. The above quantity is converted into day-cusecs by multiplying by 11.574. This works out to 4,982 x 11.574 = 57,662 day-cusecs.

   iii. This means that 57,662 day-cusecs are to be drawn from the Wanakbori Weir in a period of 16 days (16-day rotation period).

   iv. Average daily withdrawal at the Wanakbori Weir

$$= \frac{57{,}662}{16} = 3{,}604 \text{ cusecs.}$$

   v. Deduct losses in the main and branch canals which according to Table 3 (p. 16) are 377 cusecs.

   vi. Water available for offtaking channels = 3,227 cusecs.

Figure 2. Estimated crop coefficients for rice, crops and tobacco for each rotation in the kharif season.

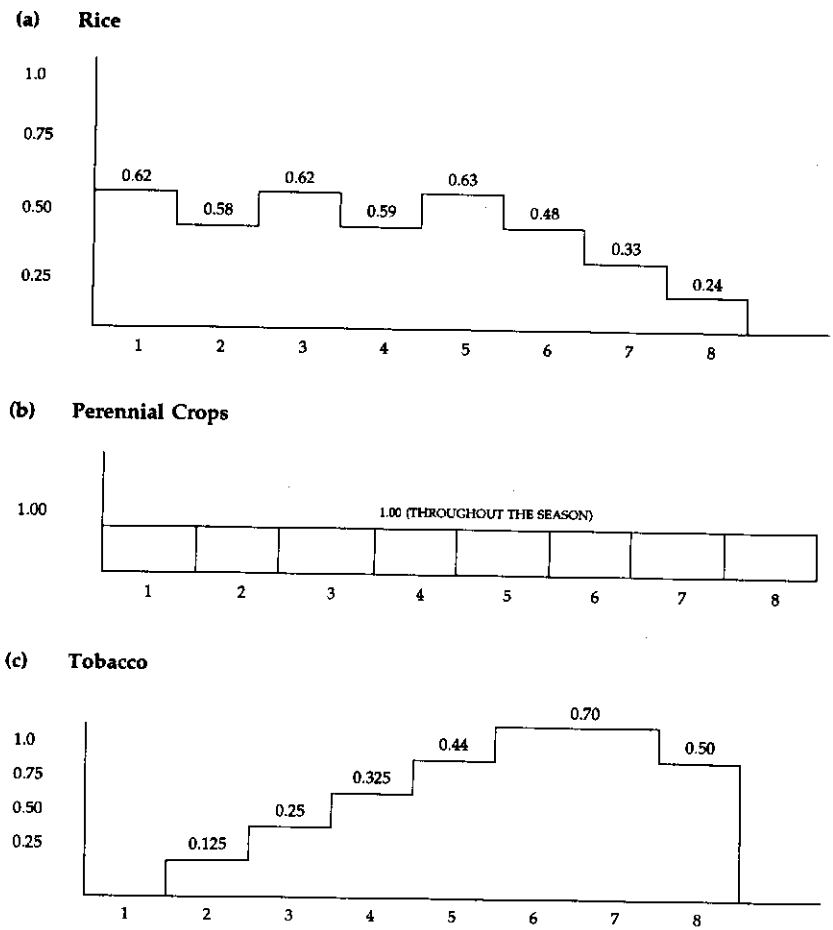


Table 3. Canal losses (cusecs): Canalwise and divisionwise.

Name of Canal/Branch	Nadiad Division	Anand Division	Petlad Division	Total
Main Canal	100	25	0	125
Nadiad Branch	35	0	0	35
Matar Branch	20	0	0	20
Cambary Branch	0	0	92	92
Lunibasi Branch	35	0	5	40
Pedlad Branch	0	33	4	37
Bersad Branch	0	28	0	28
Total	190	86	101	377

vii. The project authorities assume that this amount is available for a total cultivable area of 199,594 ha (this figure is based on actual area cultivated during the previous year).

viii. If the Nadiad Irrigation Division has a cultivable command area of, say, 55,657 ha, then water to be let into that division

$$= \frac{55{,}657 \times 3{,}227}{199{,}594} = 900 \text{ cusecs.}$$

ix. Losses in the main and branch canal in that division = 190 cusecs.

x. Total release for the Nadiad Division = 1,090 cusecs. Similarly, for the Anand Division and the Petlad Division the total discharges are 1,228 and 1,286 cusecs, respectively, totaling 3,604 cusecs.

A similar procedure can be used to allocate water between different canals based on proportional culturable command area (CCA) under each canal in that particular division.

It may be worth noting that while the total water requirement computation is based on the projected area of cropping pattern, the actual distribution of that water among different canals is based in proportion to CCA under each canal.

IRRIGATION REVENUE

Water rates are based on crops grown in the area. The government has fixed water rates for major crops as shown in Table 4.

Table 4. Seasonwise and cropwise irrigation water rates.

Season	Crop	Irrigation Water Rates per Hectare (in Rs.)
Kharif	i. Rice	110.00
	ii. Bajara, Jowar, Maize, etc.	40.00
	iii. Vegetables and Other Food Crops	60.00
	iv. Groundnut, Cotton	110.00
Rabi	i. Wheat	110.00
	ii. Gram	50.00
	iii. Vegetables	100.00
	iv. Other Rabi Crops	150.00
Hot weather	i. Hot Weather Bajara, Jowar	140.00
	ii. Hot Weather Groundnut	200.00
	iii. Hot Weather Rice	250.00
Two seasonal	i. Cotton, Beedi Tobacco	200.00
	ii Other Tobacco	250.00
Perennial crops	i. Sugarcane, Banana	830
	ii. Lucerne	570.00

The above water rates, effective since 1981, are meager compared to the agricultural development that has taken place due to irrigation. But farmers are reluctant to pay even this meager amount. It can be noticed from Table 5 that the percentage of recovery against the total demand has fallen from about 40 percent during 1974/75 - 1978/79, to about 30 percent during 1979-80; and 20 percent during 1987/88 - 1988/79. This is due to the previous years' huge outstanding amount. The total amount outstanding by the end of 1991-92 is as high as Rs. 95.15 million. Also, cost recovery is only about 2/3rds due for a given year, leaving aside outstanding dues; so arrears are increasing rapidly (see Table 5).

Table 5. Statement showing the position of irrigation recovery on the Mahi Right Bank Canal Project (in Rs.).

Sr. No.	Year	Outstanding amount at start of the year	Additional amount due to irrigation during the year	Total amount to be recovered	Total amount recovered during the year	Remission amount in the year	Outstanding amount at the end of year
1	1983-84	21456479	22442947	43899426	16175869	–	27723557
2	1984-85	27723557	23943100	51666657	18213512	1316767	32136378
3	1985-86	32136378	17816685	49953063	11495730	95569	38361764
4	1986-87	38361764	24602234	62963998	19437511	1569009	41957478
5	1987-88	41957478	22186148	64143626	13238118	–	50905508
6	1988-89	50905508	31945933	82851441	17358285	2301201	63191955
7	1989-90	63191955	27221386	90413341	17318037	–	73095304
8	1990-91	73095304	42231377	115326681	26043476	98152	89185053
9	1991-92	89185053	24869413	114054466	18884065	19658	95150743

METHOD OF INFORMATION GENERATION

The canal operation schedule along with the schedule for water application are decided by the superintending engineer in consultation with the Project Canal Advisory Committee, and due notification is made in local newspapers. The procedure adopted for preparing the seasonal water allocation schedule is explained below. The canal operation schedule is also communicated to each village *panchayat* (Council) through section officers and other field functionaries. Blank water application forms are distributed by the section officer, the karkoon and the chowkidar. The completed application forms are collected in the section officer's office and classified canalwise and villagewise. Thereafter, the details of landholding, holder's name and survey number are compared with the register of land records, to verify the identity of the irrigator. Based on this verification, the karkoon gives a certificate to the effect that the application has been "compared with register of land records and found correct." Then the applications are registered in the water application register, along with all relevant details, and water applications are sanctioned by the deputy engineer. A progress report of water applications received during each fortnight is prepared by the section officer and submitted to the deputy engineer. Irrigation passes are issued by the section officer for the sanctioned water applications, and a duplicate copy of these applications is maintained with the chowkidar. The daily irrigation done on any particular outlet in a chowkidar's jurisdiction is noted by him in a note-book as shown in Table 6.

Table 6. Details of daily irrigation to be recorded by the chowkidar in his note-book.

Sr. No.	Date	Outlet No.	Name of Irrigator	Survey No.	Area of Field Irrigated	Crop Irrigated	Pass No. or Ekramama No. (If available)	Signature of Irrigator

The above information is recorded by the chowkidar on a regular daily basis, for all irrigators who take water for irrigation. If a chowkidar is illiterate, he records the information with the help of fellow literate chowkidars or literate farmers. Each day during an irrigation season, the karkoon meets all the chowkidars in his jurisdiction at a predesignated place and time, either collectively or individually, and takes down all the information on irrigation from the chowkidars' note-books in his register of irrigation.

The flow observations are made at distributaries and minors/sub-minors directly offtaking from main and branch canals. The details of discharges into canals are maintained by a separate set of chowkidars who have been assigned to operate these flow-regulating and control structures. From the details of daily irrigated area and flow in any particular canal, water delivery efficiency, and AIDC (area irrigated per day cusec) are calculated, and fortnightly reports are submitted to the divisional offices by the section officers.

Based on the crop and area irrigated, and authorized and unauthorized irrigation, demand statements for revenue recovery from each irrigator are prepared canalwise and villagewise by the karkoon. The demand statements of revenue recovery, after due procedural approval, are forwarded to the recovery officer for recovery purposes.

SHORTCOMINGS OF THE PRESENT SYSTEM

The following are the major shortcomings in the system of information generation:

* In the present system, hierarchical information channels are utilized for information generation and transmission, but the information generation system at the level of chowkidar is not standardized. There are wide variations within the system for recording daily irrigation by the chowkidars. The information collected and registered at different levels in different registers makes it difficult and time-consuming to compile information for preparing reports.

* There is much overlapping, repetitive efforts for information recording and transmission. The same information is recorded both by the chowkidar and by the karkoon. If any irrigator takes, say, 12 waterings in a year, then the details like irrigator's name, survey number and area of landholding, which do not alter often, must be recorded 12 times by the chowkidar and the karkoon. Because of these overlapping and repetitive efforts, much time is wasted in collecting and recording information, leaving less time for irrigation management.

* The details regarding irrigators who take canal irrigation are collected and compiled. However, no information regarding farmers who are within the command area but who do not take canal irrigation, for some reason, is available. The details like area irrigated by wells, area having conjunctive use of canals and wells, fallow land, rain-fed agriculture, cropping pattern on well irrigation and rain-fed irrigation, and yield levels in the command of a particular outlet or canal are not available. Therefore, the identification of constraint areas for diagnostic and remedial measures is not possible for improving system performance.

* The routine irrigation checking required by the official procedure is very cumbersome, as all the information is available in scattered forms and places. In order to compare the information, sources like the note-book of the chowkidar, the water application register available with the karkoon and the ekrarnama register maintained by the karkoon need to be used.

* Because of the fragmented way of recording information it is difficult to find out from records whether the irrigator has applied for irrigation and has obtained an irrigation pass or whether ekrarnama has been done or not.

NEED FOR A NEW DATA COLLECTION SYSTEM

In the first phase of the IIMI-India research program, it was realized there was the need and importance of a new data collection system with improved data collection, recording and transmission procedures to:

* Mitigate the drawbacks of the present data-collection procedures and use of the information system.
* Collect total service area details to identify the constraints so that corrective remedial measures can be planned and implemented.
* Standardize the irrigation information system for the project so that with less effort more useful information on the project performance can be generated.
* Minimize the time factor required for information generation, collection, compilation and transmission at various levels of field functionaries so that they can devote more time to tackling the issues of irrigation management and have more contact with irrigators.
* Have a standardized data collection system which can be easily computerized for the purposes of data processing, preparing progress reports, analyzing irrigation performance, and issuing farmers' bills.

CHAPTER 3

Improving the Data Collection Procedure at Field Level

INTERACTION WITH FIELD-LEVEL OFFICIALS

THE DRAWBACKS OF the existing data collection procedure were highlighted during detailed discussions with field functionaries. To devise a new data collection procedure, intensive and informal discussions were held with the field functionaries to identify the information flows and channels. The data collected at each level, method of data collection, compilation and onward submission were analyzed intensively. Also the timing, quantity and type of information required at each level for daily irrigation management were studied by observing the routine working system. The lower-level field functionaries were interviewed and the following questions were asked:

* What kind of data do you collect and how do you collect?
* How do you compile the information?
* How do you submit the information to the next level in the hierarchy?
* What use do you make of this information in decision making for daily irrigation?
* Is all the collected information being used?

Based on such questions, it was possible to devise a data collection format which would satisfy information needs at all levels.

NEW DATA COLLECTION SYSTEM

The new data collection system has been designed keeping in view the fact that the basic unit of irrigation is the *chak* (field outlet, a gated structure serving about 30 to 40 ha). All information/data regarding irrigation and land utilization are generated at the level of the chowkidar. Subsequent information compilation and transmission are done keeping in view the information need at each level for decision making.

In the new data collection system, the outlet register (hereafter called the Red Book) is the basic unit of information. A separate Red Book is provided for each outlet to the chowkidar. The format of the Red Book is given in Table 7. The first 4 columns contain details regarding name of irrigator, survey number and area of landholding. The details on all irrigators within an outlet are taken from the register of land records, in sequential order as located along field channels. These details are entered in the Red Book at the beginning of each irrigation year.

The information entered into these columns of the Red Book can be used for one year or more as required. The remaining columns provide for the following details which the chowkidar can enter during the irrigation season:

* Irrigation application number;
* Ekrarnama number;
* Crop and area irrigated;
* If canal irrigation used, then the actual dates of irrigation; and
* If canal irrigation is not used, then whether well-irrigated, fallow or rain-fed.

At the end of each rotation, the chowkidar has to submit a fortnightly progress report of irrigation, in the format given in Table 8. Duplicate registers containing these formats are given to each chowkidar. At the end of each rotation, the chowkidar compiles the irrigation performance details from the outlet register in the progress report, and submits one copy of the progress report to the karkoon; a duplicate copy is kept by the chowkidar for reference. Similar progress reports for submission from the karkoon to the section officer, the section officer to the deputy engineer, the deputy engineer to the executive engineer, and from the executive engineer to the superintending engineer were also devised (Tables 9 [p.26] and 10 [p.27]). Similarly, progress reports to be submitted at the end of each season were also developed (Tables 11 and 12 [p.28]).

Table 7. Basic outlet register.

Name of canal: Name of section:

Outlet no.: Season:

Sr. No.	Name of Farmer	Village Survey No.	Area 7/12 (ha)	Application No.	Ekramama No.	Canal Crop	Irrigation Area (ha)	Rotation* 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Rotation 6	Rotation 7	Rotation 8	Well-Irrigated (ha)	Rain-fed (ha)	Crop	Fallow	Signature of Checking Officer
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

* Rotation refers to irrigation rotation and not crop rotation.

Table 8. Rotational progress report.

To be filled in at the end of each rotation (chowkidar to karkoon).

Season:

Name of chowkidar: Rotation no.: Date: To:

Sr. No.	Name of Canal	Outlet No.	Area Irrigated by Canal (in ha)						Total (in ha)
			Peren-nials	Wheat/ Rice	Cotton/ Tobacco	Jowar/ Bajri	Ground-nut	Other	
1	2	3	4	5	6	7	8	9	10

Table 9. Rotational progress report.

To be filled in at the end of each rotation (karkoon to section officer).

Season:

Name of karkoon: Rotation no.: Date: To:

Sr. No.	Name of Canal	Name of Chow-kidar	Area Irrigated by Canal (in ha)						Total (in ha)	Water Used (in day-cusecs)
			Peren-nials	Wheat/ Rice	Cotton/ Tobacco	Jowar/ Bajri	Ground-nut	Other		
1	2	3	4	5	6	7	8	9	10	11

The format of the progress report is such that each field functionary, on getting progress reports from all the immediate lower-level functionaries, can prepare his progress report in two ways:

* compile the information on canal basis (hydraulic unit); and
* compile the total information as received on the basis of administrative units.

During the irrigation season, whenever any field functionary desires to do field checking, it can be done on the basis of the outlet register, and necessary remarks can be made in the outlet register itself.

Table 10. Rotational progress report.

To be filled in at the end of each rotation (SO to DE/DE to EE).

Season:

Name of karkoon: Rotation no.: Date: To:

Sr. No.	Name of Canal	Name of Sn/Sdn /Dn	Area Irrigated by Canal (in ha)						Total (in ha)	Water Used (in day-cusecs)
			Peren-nials	Wheat/ Rice	Cotton/ Tobacco	Jowar/ Bajri	Ground-nut	Other		
1	2	3	4	5	6	7	8	9	10	11

Note: Sn = Section; Sdn = Subdivision; Dn = Division.

IMPLEMENTATION

The data collection format was designed after intensive discussions with lower-level field functionaries. The new data collection procedure was implemented in one section of the MRBC Project from the beginning of kharif-1991. Prior to the introduction of this new format, all the concerned chowkidars, karkoons and the section officer of the concerned canal were trained in detail on the new data collection format and the procedure for using it. Close monitoring was also maintained during the initial implementation period, to render assistance wherever needed. The data collection through the Red Book was operated for one year from kharif-1991 to hot weather-1992. At the end of one year, the concerned field functionaries were brought together and requested to explain their experiences with the new data collection system and make recommendations for implementing this system on a larger scale at project level.

Table 11. Seasonal progress report.

To be filled in at the end of the season (karkoon to section officer)

Year:

Name of karkoon: Season:

Sr. No.	Name of Canal	Name of Chow-kidar	Outlet No.	Actual Area Irrigated (in ha)						Total Irri. (ha)	Author-ized Irri. (ha)	Unauthorized Irri. (ha)	Water Used (in day-cusecs)	Well-Irri. (ha)	Rain-fed Land (ha)	Fallow Land
				Peren-nials	Wheat/ Rice	Cotton/ Tobacco	Jowar/ Bajri	Ground-nut	Other							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

Table 12. Seasonal progress report.

To be filled in at the end of the season (section officer to DEE, EE, SE)

Name of karkoon: Year:

Season:

Sr. No.	Name of Canal	Name of Chow-kidar	Actual Area Irrigated (in ha)						Total Irri. (ha)	Authori-zed Irri. (ha)	Un-author-ized Irri. (ha)	Water Used (in day-cusecs)	Well-Irri. (ha)	Rain-fed Land (ha)	Fallow Land
			Peren-nials	Wheat/ Rice	Cotton/ Tobacco	Jowar/ Bajri	Ground-nut	Other							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

RESPONSE OF FIELD-LEVEL FUNCTIONARIES

The response of field-level functionaries is outlined below:

a) Earlier the chowkidar had to write the name of each irrigator, survey number, area, crop and date, and had to get the signature of the irrigator, whenever the irrigator availed irrigation. Now he has to write only the actual date of irrigation. All other details like name, survey number, and area are to be written only once a year. This saves a lot of time and stationery.

b) The outlet register is prepared for each year and it lasts for one year. The actual irrigation performance of the outlet vis-à-vis culturable command area can be worked out easily, and water accounts and demand statements can be prepared quite quickly.

c) The total number of waterings availed by each irrigator in the outlet command is available immediately.

d) The errors in recording are minimized, and the actual observations regarding the date of irrigation, if not recorded, can be detected easily.

e) As the name and survey number of all irrigators situated in the canal command are written in a sequence, it is possible to work out easily the number of irrigators who have not irrigated and are yet to take irrigation.

f) All the information regarding land use pattern of any outlet in terms of area irrigated by canal, area irrigated by wells, area having conjunctive use, rain-fed agriculture, fallow land, crop pattern, etc., is available quickly and reliably.

g) Any concentration of well irrigation in a particular outlet may exist because of some constraints or inefficiency of irrigation. This system helps in identifying such concentrated well-irrigated areas, which can be diagnosed and suitable remedial measures worked out for improving irrigation efficiency.

h) The actual working days of each outlet in each rotation can be worked out from the outlet register.

i) In the earlier procedure, it was necessary to obtain the signature of the irrigator whenever he irrigated. Many times, farmers sent laborers to the field for irrigation, and it took much time to track down the landowner for his signature. As this has been done away with, it saves a great deal of time for the chowkidar.

j) If any irrigator takes water twice in a rotation, it can be easily detected from the outlet register.

k) It is also possible to detect from the outlet register, the names of irrigators who have not obtained their irrigation pass, or who have taken irrigation water but who have not signed the 'ekrarnama.'

l) In this outlet register format, the procedure of 'irrigation checking' or inspection becomes smoother and easier. 'Irrigation checking' is the procedure by which irrigation officers check some percentage of irrigated area to verify that all the details regarding irrigators who have taken irrigation (crop and area) have been correctly recorded for revenue assessment.

m) The periodical progress reports of irrigation performance can be prepared quickly and accurately. All the information regarding irrigation performance, from the outlet to the project, i.e., from the chowkidar to the superintending engineer can be compiled and transmitted in one day, for which four to five days were required earlier.

n) The new data collection system is flexible in operation. It can be easily computerized for data processing, preparing progress reports, doing analyses, and preparing demand statements and farmers' irrigation bills.

o) The field functionaries agreed that because of the new information system, they could collect all the relevant outlet information quite quickly, and the saving in time provided them more opportunity for making farmers' contacts and managing issues of daily irrigation management. Also, the data for all the irrigators, irrespective of whether irrigation is availed or not, were collected for the first time, and these provided them with new insights and opportunities for improving irrigation performance. This saving of one hour per karkoon for the working periods during a year would roughly amount to Rs. 1,000,000 – 1,500,000 per year at the project level, when converted into financial terms.

p) The field functionaries suggested that this new information system should be introduced at project level, as an official standardized system, with due training.

q) The data collection system will be quite helpful for monitoring and evaluation of the irrigation performance in terms of parameters like equity, reliability, etc., if data on water measurement are utilized.

The use of the Red Book led to two other changes: improved methods for chowkidars and karkoons to collect water-level and gate-opening data so that the hydraulic information could be better matched with the Red Book data; and the identification of the need to try to collect hydraulic information at karkoon beat level, not just at the head of each canal.

The new data collection system has been introduced in the whole Mahi Kadana Project from kharif-1992, with the help and consent of project officials. Efforts are being made to introduce this system in other projects of the State. The response to the new system has been quite encouraging from all levels.

CHAPTER 4

Processing Data to Make Them Useful for Managers

MANAGEMENT INFORMATION SYSTEMS comprise several different elements: they require an *easily accessible database* which stores information on performance in a convenient and efficient manner; they have to process the data to *transform them into useful information for managers;* and they require a *framework of objectives, targets and standards* that make use of that information in a positive way for improving performance. The Mahi MIS contains all three of these elements, each of which is described below.

CREATION OF EFFECTIVE DATABASES

The Mahi MIS uses a set of interrelated databases that contain different types of information. These databases are all in d-Base format, but are protected through a master program written in C language. The advantage of this approach is that each of the databases is kept within reasonable size, and can be individually updated and saved without having to access the entire information set.

Because of the varied nature of the output required by managers, it is necessary to develop a set of basic inventory databases that contain information that does not change seasonally. These databases are used as sorting mechanisms for the data pertaining to individual seasons.

Basic Inventory Databases

Several different basic information databases are used in the Mahi MIS. They represent the description of the system characteristics that will either not change at all, or will only need periodic updating. The following databases have been developed:

Canal Inventory Database. This gives a complete listing of all canals in the Mahi Kadana Irrigation system, classifying them by canal type (main, branch, distributary, minor, sub-minor), name and number of outlets. Each canal has a unique code number.

Outlet Inventory Database. Each outlet is classified with a unique code number in addition to its official serial number or name, and is identified by karkoon beat and section name.

Administrative Inventory Database. This contains details of each section, division, subdivision and the names of the current officers in each position.

Karkoon Beat Inventory Database. This gives each karkoon beat a unique number, together with the beat name, the name of the current karkoon, and the section in which the beat is located.

Village Inventory Database. This lists all villages, their names and serial numbers, the district, the *taluk* (subdistrict) and irrigated area in that village.

Farmer Inventory Database. This gives a complete listing of farmers, by outlet and canal, with names, survey numbers, area of each parcel, farmer account number, type of water permit, village, canal, beat, outlet name and number.

Crop Inventory Database. This lists all possible combinations of crop names, the relevant billing rate per hectare for normal irrigation, and the factors used to modify rates according to application dates, source of water and whether water was used once or more than once.

Although this represents a substantial amount of data input in the initial phase of the use of the Mahi MIS, only occasional updating is required. All of the data contained in these databases already exist and have to be used when preparing bills for irrigation water use at the end of each season. Because the work is currently conducted manually, it takes several weeks or even months to prepare bills for each village, the current basis for irrigation billing. The one-time investment in creating the main databases is clearly a long-term labor-saving activity, and will permit much more rapid processing of information.

Seasonal Databases

The seasonal databases contain records for the irrigation conditions experienced in each of the three seasons per year. The databases fall into two main categories: hydraulic and outlet level irrigation activities.

Hydraulic Database. The regular data from the Irrigation Department relating to water levels, gate openings and discharges are entered into a separate database. Where necessary, the database has the capacity to calculate discharges from the water level and gate opening data, although for major structures discharges are already determined through the use of rating tables. With the exception of two locations along the Bharoda Distributary, all these data represent the routine information collected by the Department and do not represent any departure from normal practice.

Outlet-Level Database. This database forms the primary storage of outlet-level data collected from the Red Book used at chowkidar and karkoon levels. At the end of each rotation, the Red Books are taken to the point of computer entry, and the information described under NEW DATA COLLECTION SYSTEM in Chapter 3 (p. 23) is entered. The entry is simplified in the form of a template so that once an entry has been established with the basic information, updating of area and crop irrigated can be undertaken for every rotation within a few minutes.

Because these files are large, containing several hundred or thousand records for each outlet or discharge measurement location, they are stored individually on diskettes. The total number of entries when the full project comes on stream will be on the order of 10,000 per day, thereby causing a huge storage problem. Moreover, there is insufficient storage capacity in typical computer systems to store large amounts of daily records, and it significantly increases processing time. This is the reason for storing outlet register data on individual diskettes.

System-Level Summary Database

A third database has also been established that provides a summary of performance in each season since 1958 when water from the Kadana Reservoir was first delivered into the conveyance system. This database has recently been published (Gulati 1994). These data are stored primarily in Lotus 1-2-3 files which facilitate easy updating at the end of each season and year. The summaries are of two main types, irrigation performance, and environmental data.

Irrigation performance summaries at system, branch and distributary levels report on area by crop, total hectare waterings, water used, irrigation intensity, number of waterings, AIDC and total duty, reported both seasonally and annually, area targets and achievements by subdivision, source of water used for agriculture, authorized and unauthorized irrigation, and revenue recovery and O&M expenditure.

Environmental data summaries deal with annual and monthly rainfall summaries for 16 locations in and around the system, depth to groundwater at system level, salinity levels, monthly discharge (yield) into the Kadana Reservoir, soil salinity distribution and soil pH.

This represents a very comprehensive and useful set of information for policymakers, planners and managers, and is worth updating periodically so that long-term trends in performance and environmental conditions can be tracked into the future.

EXTRACTING INFORMATION FROM THE DATABASES

The second component of an effective information system is the capacity to extract information from the database in a format that is useful to managers. The structure of the databases used in the Mahi MIS allows information to be extracted from each database to form reports of any nature because each individual database has a set of identifying codes that are used to sort and extract specific types of information. In the past, this capacity only existed in theory: it would have been possible to develop custom-made reports for any unit desired (e.g., by canal, outlet, village, subdivision), but it would have been a major task and extremely time-consuming.

The Mahi MIS is designed to produce two types of output: routine reports that fulfill current reporting requirements at the end of each rotation (as indicated in Chapter 3), and a new set of reports that can be used to assess other dimensions of performance. Both reports are produced in the same manner: by writing specific algorithms for extracting, sorting, and writing specific tasks, with options to write the information to the screen, to a printer or to a new file. This task is facilitated because the length of each season and rotation is known in advance, making the normally arduous task of formatting output comparatively easy.

Typical of the routine reports that can be directly generated from the databases using the program are:

* seasonal area irrigated by each crop under each outlet;
* volume delivered in each rotation to each canal and beat;
* AIDC in each rotation by canal and beat;

* daily discharge at each measurement location;
* area irrigated in each rotation and total seasonal hectare-watering;
* source of water used in each outlet;
* hectare-watering by beat and by rotation; and
* generation of the demand statement for irrigation billing.

A second set of performance reports which reflect interest in a wider range of performance indicators than currently used by the Irrigation Department have been developed that look at some other performance indicators including:

* management of the main, branch and distributary canals and their interrelationships;
* water management within distributaries at the karkoon-beat level; and
* agricultural conditions at beat level.

These reports, which can be presented in the form of both tables and graphs, are discussed in Chapter 5. At present, they have to be generated from a spreadsheet program that imports data from the seasonal databases, but will be generated in the routine reports through the development of additional algorithms in the C language.

There are three obvious advantages of having such a computer-based information approach that provides the basis for effective and rapid decision making by managers at various levels in the system.

First, it is possible to determine performance in respect of hydraulic units such as outlet or canal; in terms of administrative units within the Irrigation Department such as karkoon, section officer or subdivision officer; and in terms of civil administration units such as village or even taluk. This enables managers to identify not only what performance problems are being encountered, but where necessary what action is required. Directly linking and integrating hydraulic and agricultural data using different boundaries are almost impossible using traditional manual methods.

Second, the performance reports can be generated at the end of each rotation and each season so that within-season performance assessment now becomes a realistic task. Manual systems do not normally have the capacity to respond to field-level performance before the end of the subsequent rotation: the processing capability of the Mahi MIS is such that remedial action can be greatly speeded up, and a clear picture of actual and expected performance can be built up incrementally after each rotation.

The third advantage is faster billing of farmers for use of irrigation water. With dozens of different crops, each with different billing rates, with variation in rates due to time of application for permission to use irrigation water, and remission for various extenuating factors, billing is a difficult task. However, the preparation of bills is now a simple task because all calculations and printing of the demand statement can be done within a couple of days of the end of the season, as soon as the data on the final rotation are entered into the computer at the Section office. The first test of the billing package showed that it was accurate, and that the output meets current legal requirements.

USE FOR PERFORMANCE IMPROVEMENT

It is worth noting that one of the important steps prior to performance assessment is to acquire information which is comparable across space and time. Once this is achieved and there is an installed capability to enter and retrieve information from the MIS, managers have at their disposal a powerful facility to assess current levels of performance, their trends, and the implications for future managerial decisions. This forms part of the overall framework for irrigation performance assessment described by several authors (Bos et al. 1994; Murray-Rust and Snellen 1993; Small and Svendsen 1992).

In general terms, managers of irrigation systems such as the Mahi Kadana have to make decisions of three different types, each of which requires a different set of information on performance. The Mahi MIS is designed to meet each of these three needs, as described below. An example of the description of performance is given in Chapter 5.

Operational Management

The focus here is on whether targets set for each irrigation period are being met, with particular reference to the hydraulic performance of the canal system and the technical staff employed to operate gates, control water levels and discharges, and report on field- level conditions. The Mahi MIS provides a capability to enter data, process it into useful information and retrieve performance reports for each rotation. Actions can thus be taken within the first few days of the subsequent rotation to improve those areas where lower-than-desired performance has been achieved.

Typical of the concerns that need to be addressed within the timespan of a rotation are the relationship between actual discharges and the cropping pattern established by farmers, equity of access to water, based on CCA by canal and beat, response to rainfall, and degree of variability of discharges within the previous rotation. With the move towards rotation in deliveries to individual canals during kharif, the need to monitor the actual implementation of this high-level rotational irrigation is very important.

Seasonal Planning and Allocation

The seasonal reports generated by the Mahi MIS give valuable information for use in planning for the same season in the following year (the marked differences between the kharif, rabi and hot seasons in respect of climate, crops and water availability mean that they require completely different plans). At one level, the evaluation is to determine the extent to which planned water allocations among different divisions and subdivisions, or among different canals, were accomplished, and accomplished with what degree of certainty and reliability.

Seasonal reports also show what farmers did with the water they received. In most systems, there is unlikely to be a dramatic change in the cropping pattern from one season to the same season next year. This means that water allocations by canal, and the responses to changes in evapotranspiration can be checked and modifications made where necessary.

It is also important to look at the spatial variability in water delivery and water use for the entire season in relation to objectives such as equity of access to water.

Long-Term Trends

The final evaluation is to identify what changes are occurring over time within the system. Two broad categories of interest are included in this type of analysis.

The first deals with the natural tendency to relax management inputs if no major problems are encountered. Typically, cropping patterns or demand for water do not change more than a few percent for the same seasons from year to year, but there may be a longer-term underlying trend that ultimately requires modification of water allocation at season or even rotational level. An example of this type of change is in the demand variation consequent on the adoption of short growing season rice or wheat varieties that change the overall shape of the evapotranspiration curve. By comparing similar data collected systematically over several years, the changes in both supply and demand can be identified. Other trends that can be identified are changes in equity of water allocation among canals: this can reflect loosening up of management inputs at key control structures, or reflect canal deterioration that slowly reduces the conveyance capacity of that canal.

The second set of trends are those relating to the impact of irrigation on the physical and socioeconomic environment. Data useful for such evaluation are already included in the compilation of historical performance data, such as depth to groundwater, groundwater quality, soil salinity, etc., all of which show whether or not the resources required for irrigated agriculture and/or the irrigation system itself are stable or unstable.

CHAPTER 5

Example of Performance Assessment, Kharif 1993

THE 1993 KHARIF season provided the first opportunity to undertake a detailed description of performance activities. Based on a combination of data on main and branch canal discharges and the outlet data collected in the Red Book by field-level staff, it has been possible to do a comprehensive evaluation of performance in the Kunjarao Section of the Mahi Kadana Irrigation System. Although the data are primarily those collected by the Irrigation Department, the methodology was jointly developed by IIMI and WALMI at Anand and the Irrigation Department.

A primary objective of this report is to demonstrate that, using existing data sets collected by different branches of the Irrigation Department, it is possible to effectively describe irrigation performance in respect of both water deliveries and agriculture. It is hoped that this type of report, although normally rather shorter, could be a routine exercise that results from the adoption of the Programmed Irrigation Monitoring and Evaluation (PRIME) Management Information System developed at WALMI by P.L. Shukla and O.T. Gulati. Because of the ease of developing simple reporting packages there is considerable scope for using them as part of regular management activities throughout the Mahi Kadana Irrigation System within a few seasons.

Following a description of the sources of data, the report describes performance at three levels of the irrigation system: the main and branch canal water delivery performance, the secondary-level water distribution performance, and agricultural performance.

The final part of this chapter makes a preliminary evaluation of the levels of performance obtained, and provides suggestions for overcoming some of the possible problems identified. The purpose of this paper is not to be critical of current management but to demonstrate how a description of performance achievements can be used in a follow-on stage if desired by system managers.

It must be remembered that, ultimately, performance requires the comparison of actual and target conditions, the targets reflecting the objectives set down by the operational agency itself. There is no great utility in imposing outside objectives and targets if there is sufficient capacity within the system to undertake this task.

SOURCES OF DATA USED

Almost all of the data used in this report are collected by the Irrigation Department as part of routine activities. Only two additional sets of discharge measurements initiated under the IIMI-WALMI collaboration have been included. As such, there is every possibility to replicate these reports in the future.

Main and Branch Canal Discharge Data

To understand the cause of variations in deliveries to distributary and other canals that offtake directly from the main and branch canal distribution system, it is important to look at the way in which the main system is operated. For analysis of the performance of the Kunjarao Section, data from five locations have been used, representing seven sets of discharge measurements. These are as follows:

Main Canal downstream of the Khakhanpura Cross Regulator
Head Discharge of the Nadiad Branch at the Khakhanpura Regulator
Discharge of the Nadiad Branch at Ch. 32,000
Main Canal downstream of the Devrampura Cross Regulator
Head Discharge of the Petlad Branch at the Devrampura Cross Regulator
Discharge of the Petlad Branch at Ch. 32,000
Discharge of the Main Canal at Ch. 222,000

Several times a day, in all of these locations the Irrigation Department takes readings of upstream head and gate openings, plus downstream head in those locations where gates may be subject to submerged flow. Based on the existing rating curves, the average daily discharge at each location is calculated and expressed in day-cusecs.

Although it is recognized that some rating curves may be outdated, the results indicate a considerable consistency between different measurement points and they are certainly indicative of actual conditions.

Secondary Canal Data

It is normal practice for the Irrigation Department to provide discharge data for all distributaries (50 cusecs or 1.41 cumecs) and minors (20-50 cusecs or 0.56-1.41 cumecs) that offtake directly from the main and branch canal systems. Offtaking sub-minors are not normally measured, nor are direct outlets, siphon tubes and pumps along the main canals.

In the Kunjarao Section there are only three measured offtakes from branch canals:

The Bharoda Distributary, offtaking from the Nadiad Branch

The Bhalej Minor, offtaking from the Nadiad Branch

The Tranol Sub-Minor, offtaking from the Petlad Branch

All three of these head regulators have been calibrated under the WALMI field activities, and routine data collection has been under way for some time.

To examine further the water management activities along the distributary, two additional discharge measurement locations were established as part of the IIMI-WALMI Project. The two locations are at the points where control of water passes from one karkoon to another, i.e., at about the 1,000-ha level. This area of responsibility is termed the karkoon beat. Until these measurement points were installed it was not possible to assess performance at the beat level. The two measurement locations are:

The Duck Bill Weir at Ch.9,780 along the Bharoda Distributary

The Ramp Flume at Ch. 20,000 along the Bharoda Distributary

There are three beats along the distributary. However, the karkoon responsible for the tail-end beat is also responsible for the Tranol Sub-Minor offtaking from the Petlad Branch. This makes it necessary to divide this beat into two parts for performance assessment purposes. Together with the karkoon serving the Bhalej Minor, it is possible to assess performance in five separate beats in the Kunjarao Section where there is reliable discharge measurement at the head of the beat.

Field-Level Irrigation and Crop Data

As part of the earlier IIMI-WALMI collaboration, the field-level data collection program has been systematized through the adoption of the "Red Book," as described in Chapter 3. Each chowkidar has a Red Book for each outlet under his oversight, with four to five chowkidars reporting to one karkoon.

Data included in the Red Book are farmers' names, billing numbers, plot numbers and plot areas (data that form part of the master database for the system), and then during each 15-day rotation the date of irrigation of each plot is recorded, together with the crop being irrigated. Additional information in the Red Book added in the past few seasons allows the chowkidar to note if there are other crops irrigated by wells, relying on rainfall, or land being left fallow. It is therefore possible to estimate the overall cropping pattern and intensity, the source of irrigation water, and the number of waterings for each crop.

The Irrigation Department uses the Red Book data for several purposes. One is the reporting of performance, particularly in respect of total area irrigated, number of waterings, and the area irrigated in each rotational period per day-cusec. It also provides the basis for the preparation of farmers' bills after each season, the rate depending on the crop type and area, the date of application for water, and on whether one or more waterings were taken. From a performance assessment perspective, these data have one slight drawback: it is not possible to distinguish between crops irrigated solely with canal water and those irrigated conjunctively using groundwater and canal water.

The Red Book data form the heart of the PRIME MIS system developed at WALMI. It is possible to generate a wide range of performance measures in addition to that normally computed by the Irrigation Department, and this report focuses largely on the additional information that can be extracted from the database.

DESCRIPTION OF PERFORMANCE IN THE KUNJARAO SECTION, KHARIF 1993

This section describes the performance achievements in the Kunjarao Section during the 1993 kharif season. It is based almost exclusively on the output from the PRIME MIS package, with some additional graphic presentations using the database files generated by the Mahi MIS in Quattro Pro. The performance data presented were discussed with agency staff, including the relevant subdivision officer and section officer to ensure that conclusions drawn from the data analysis were correct in respect of their own recollection of what had happened at various points during the season.

In future seasons, the performance output data and graphs will be generated almost immediately after the conclusion of the season, without relying on the long-term memory of operational managers.

Main and Branch Canal Performance

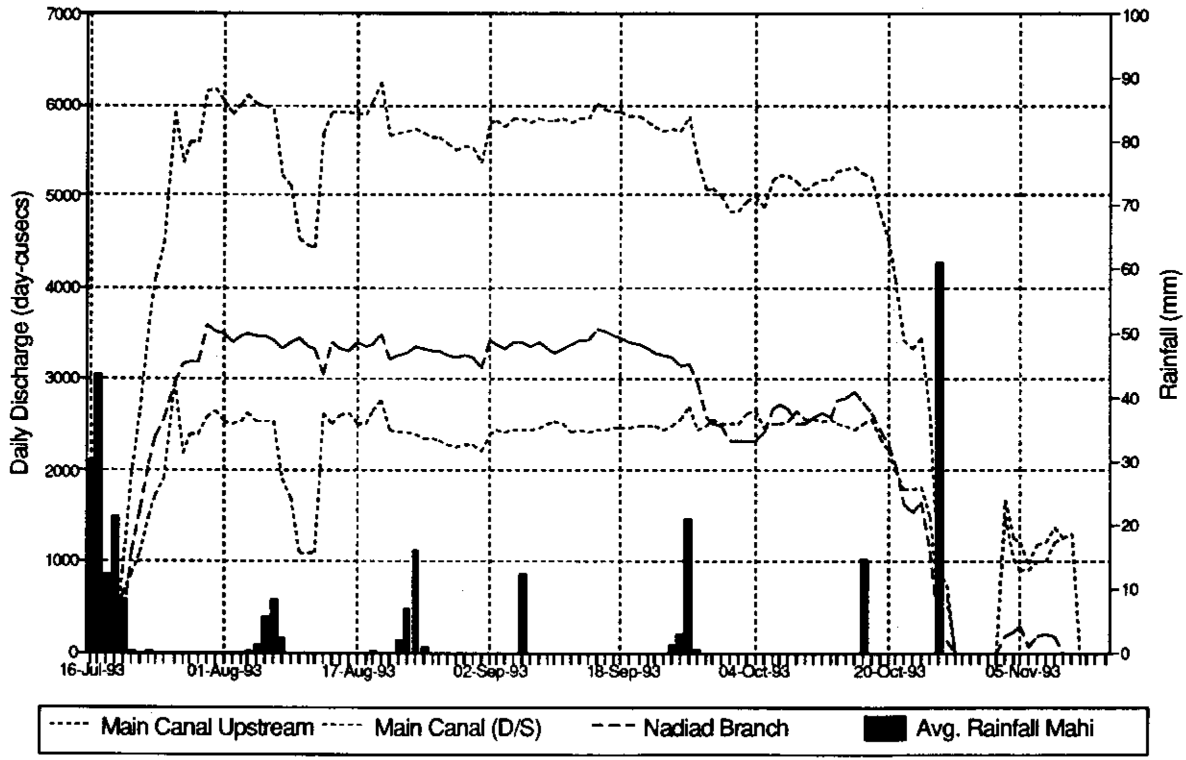
The kharif 1993 data indicate that the main and branch canal performance was favorable in terms of reliability and equity, the main operational objectives of the system at that level. Adequacy is not a concern at the main canal level: it is not possible to deliver water to all farmers in the kharif season because potential demand exceeds the actual canal capacity.

Operations at the Khakhanpura Regulator. Operations at the Khakhanpura Regulator (Figure 3) show that for most of the season discharges were very regular once the season was properly established. In the first rotation there were some heavy rains, and the entire system started operation after this heavy rain. For the Nadiad Branch, the discharge remained more or less constant until late September when it was reduced by approximately 500 cusecs. This reduction was the result of two factors: temporary gunny bags placed on the weir crest at Wanakbori to increase discharge into the main canal were washed away in a heavy storm, and demand at that time in some of the rice-growing areas was declining with the onset of harvesting. Even if the gunny bags had not washed away, it is said that discharges would have been reduced anyway. There is other evidence presented later to support this statement. A very interesting observation from the main and branch canal operations is that there is very little response of canal discharges to rainfall occurrences during the season.

The net result is a highly stable flow into the Nadiad Branch that provides ideal operational conditions at the head of offtaking canals. To overcome some design constraints, the regulator at Ch.32,000 along the Nadiad Branch has to be operated to maintain a water depth of 12.5' (3.81m) on the upstream side of the structure. This means that unless there are major changes in discharge in the Nadiad Branch, the canal will be at, or even slightly above, full supply level at this point. This operational rule has been developed so that there is sufficient operating head at the head regulators for both the Bharoda Distributary and the Bhalej Minor. It is therefore possible to say that at no time during kharif 1993 did the operation of the Nadiad Branch have any adverse impact on water conditions in those two canals.

The main canal shows a similar pattern, except that there was a sharp reduction of discharge for one week during the second rotation period (first half of August). The reasons for this are discussed below.

Figure 3. Water management at the Khakhanpura HR, the Mahi Kadana, kharif 1993.



In neither canal is there any evidence that discharges were changed in order to accomplish the rotational irrigation pattern being undertaken at the distributary level. There is also no significant evidence of response to rainfall at the regulator, on the assumption that adjustments to rainfall are made at local level rather than at main canal or branch canal level.

Operations at the Devrampura Regulator. This regulator shows a different operational pattern during the kharif season than at Khakhanpura (Figure 4). Two particular aspects need to be explained.

First, there was a closure of the Petlad Branch during the second rotation. This was stated to be due to the failure of a structure further downstream that required closure in order to undertake the necessary repairs. It is noteworthy that the discharge into the main canal downstream of Devrampura remained more or less unchanged during this closure, and that all necessary adjustments in discharge to account for the closure were made at the Wanakbori Weir. No other canal discharges were affected by the need to cope with this emergency, a clear sign that effective communication exists at main canal level.

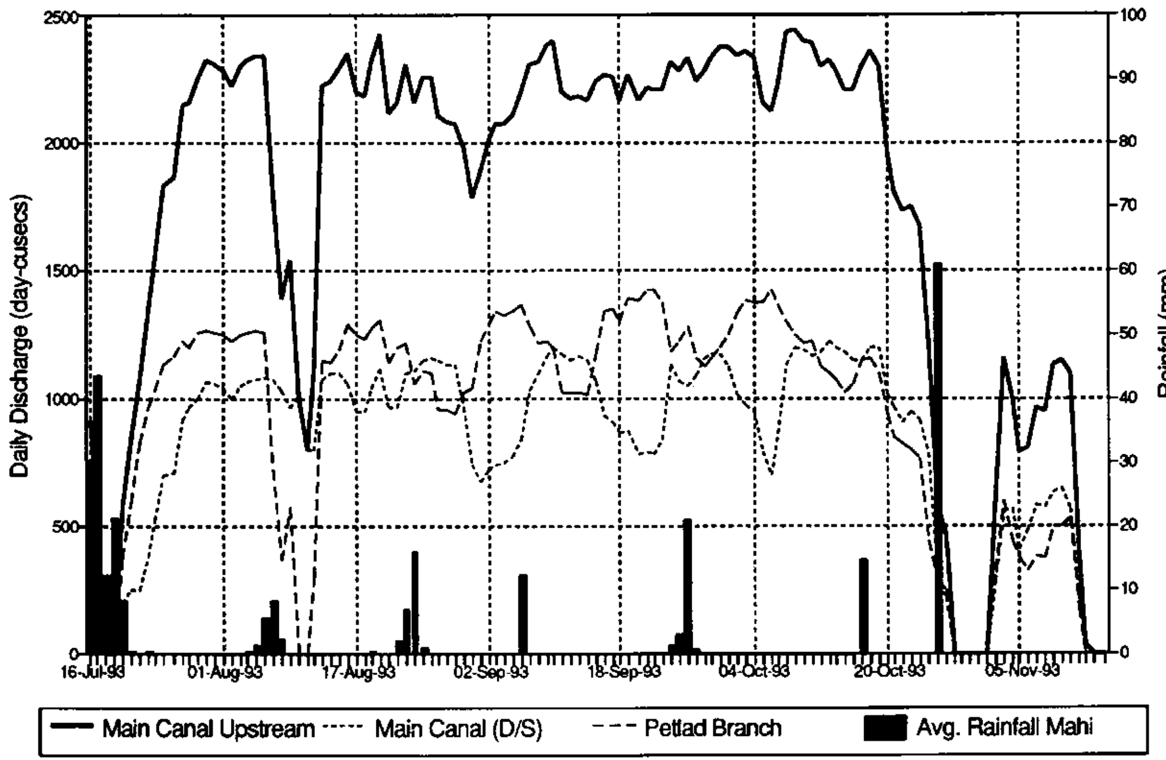
The second aspect of operation at Devrampura is that from the third rotation until the sixth rotation there is an alternation of peak discharges between the main and branch canals. The difference between peak discharge and lower discharge is between 400 and 500 cusecs, or some 30 percent of the maximum discharge for each canal. This appears to be in response to the implementation of rotations at distributary level where each canal was scheduled for closure for about four days during each rotational period.

It is not immediately clear why it is necessary to modify the discharges at this high level in the system unless there were major changes in demand in certain canals. Nevertheless, the pattern of rotations appears to have been relatively predictable so that there should have been little uncertainty over whether each of the two canals would be at the higher or lower level.

Secondary Canal Operations

Two types of analysis were done at this level of the conveyance system: examination of the relationship between branch canal discharges and individual offtakes, and analysis of discharges and water consumption in each beat.

Figure 4. Water management at the Devrampura HR, the Mahi Kadana, kharif 1993.



Relationship between Branch Canals and Offtaking Canals. It is possible to look at the relationship between upstream and offtake discharges at each of the three head regulators in the Kunjarao Section. This gives a method of determining whether the way in which the branch canals are operated significantly affects offtake canal performance.

The Bharoda Distributary has an operational pattern significantly different from that of the Nadiad Branch (Figure 5). There are several periods of closure of the distributary that do not reflect changes in the upstream conditions, a clear sign of independent management of the distributary canal. However, it is also clear that the overall demand pattern in the distributary, indicated by the peak discharges, is generally matched by the water available in the Nadiad Branch. During the first few rotations, the Nadiad Branch was carrying an additional 500 cusecs due to the gunny bags placed at the Wanakbori Weir. If this 500-cusec flow is subtracted from the total discharge, the pattern of flow in both canals is almost identical. They show a particularly close relationship in the sixth, seventh and eighth rotations, showing that there are deliberate reductions in discharge into the system as a whole as the distributary demand decreases.

During this season, a new policy of operating the distributary canals was introduced. According to this policy, distributaries will be operated at full supply level for a period of 12 days during each rotation of 16 days and kept closed for the remaining 4 days. The Bharoda Distributary was closed for two reasons. In the first two rotations, it appears that closure was caused by heavy rainfall (Figure 6). Rainfall probably was the main reason for the extended closure in the seventh rotation. However, in rotations 4 to 6 the *new policy* of distributary canal closure adopted in this season seems to have been effected and this appears to be the main reason for these actions.

Figure 5. Discharges in the Nadiad Branch Canal and the Bharoda Distributary Canal, the Mahi Kadana, kharif 1993.

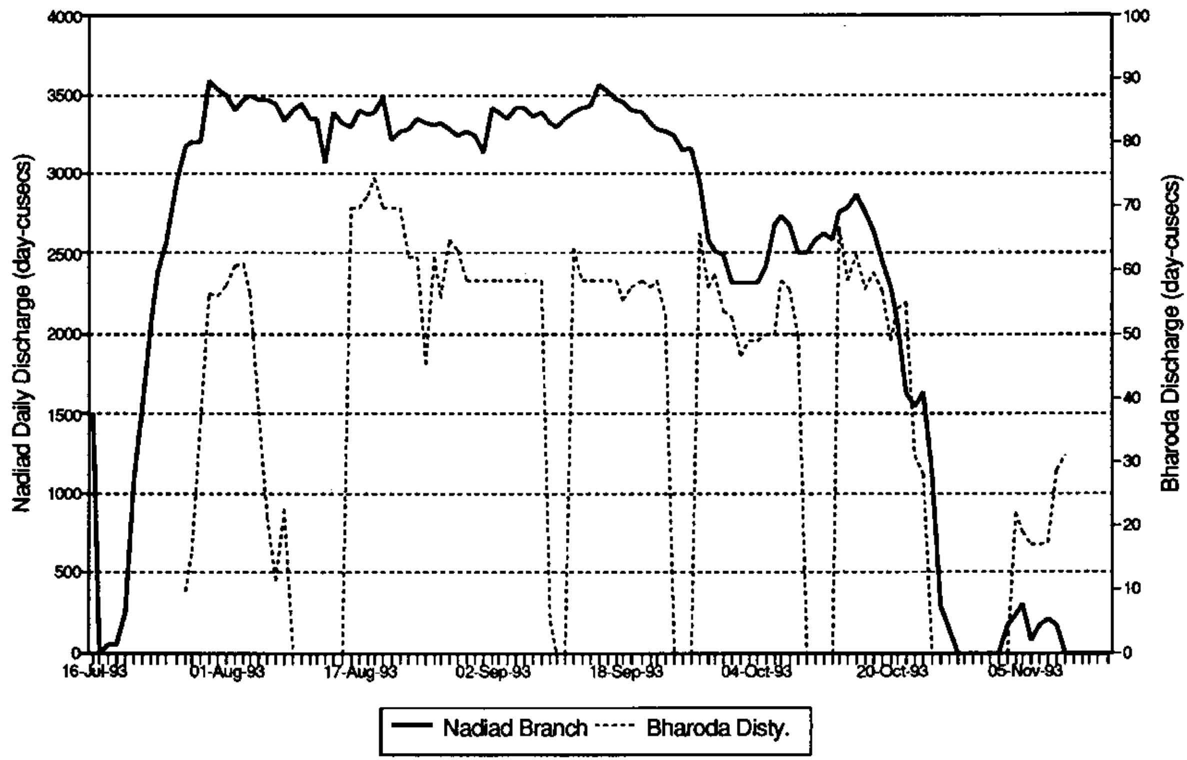
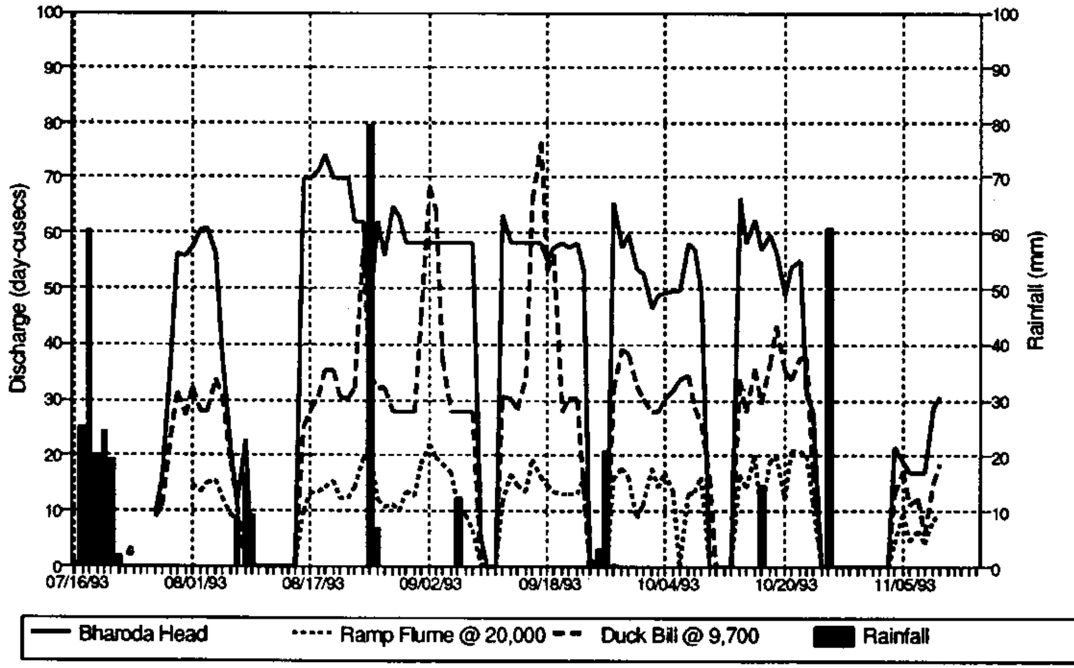


Figure 6. Daily discharges, the Bharoda Distributary, Ode Subdivision, kharif 1993.



The Bhalej Minor shows essentially the same pattern, although there are some small differences (Figure 7). There was an additional closure at the end of the second rotation that did not occur at Bharoda, the reasons for which are not clear as no rainfall occurred at Anand close to that period (Figure 8). There was a more marked decline in discharge after the fourth rotation, going from a maximum of about 40 cusecs down to 20 cusecs in the second half of the season. It appears possible that because the Bhalej Minor is close to the cross regulator at Ch. 32,000 it was able to take advantage of the additional 500 cusecs being delivered along the Nadiad Branch. In all other respects, the operations are similar to those in Bharoda.

The Tranol Sub-Minor shows rather more differences in operation at the head regulator (Figure 9). There is much more variation in the discharge into the canal on a short-term basis compared to the other two canals in the section, and there is a much clearer and steady overall decline in water deliveries during the season, presumably in response to decreasing demand for irrigation.

The breaks in deliveries in the second rotation were due to the structural damage further downstream in the Petlad Distributary, which also appears to have been associated with heavy rainfall (Figure 8). There was also a closure in the third rotation which was not seen in the other two canals. This may have been due to rainfall, or it may have been the start of the rotational closure program.

In terms of the rotational closure program, two things are noteworthy. First, there was no closure in the sixth rotation in this minor although both Bharoda and Bhalej showed a closure in this period as per the scheduled closure. This suggests that the rotational closure program was not always strictly implemented. Second, the pattern of closures at Tranol does not exactly match the variations in discharge found in the Petlad Branch. Admittedly, Tranol is only a small canal, taking only about 1 percent of the total discharge in the Petlad Branch but it suggests there is a need to ensure that the rotational closure program is coordinated between branch and offtaking canals.

Operations between Karkoon Beats. The addition of two measuring points at the boundaries between karkoons along the Bharoda Distributary made it possible to compare water delivery performance between five beats in the Kunjarao Section.

Figure 7. Discharges in the Nadiad Branch Canal and the Bhalej Minor, the Mahi Kadana, kharif 1993.

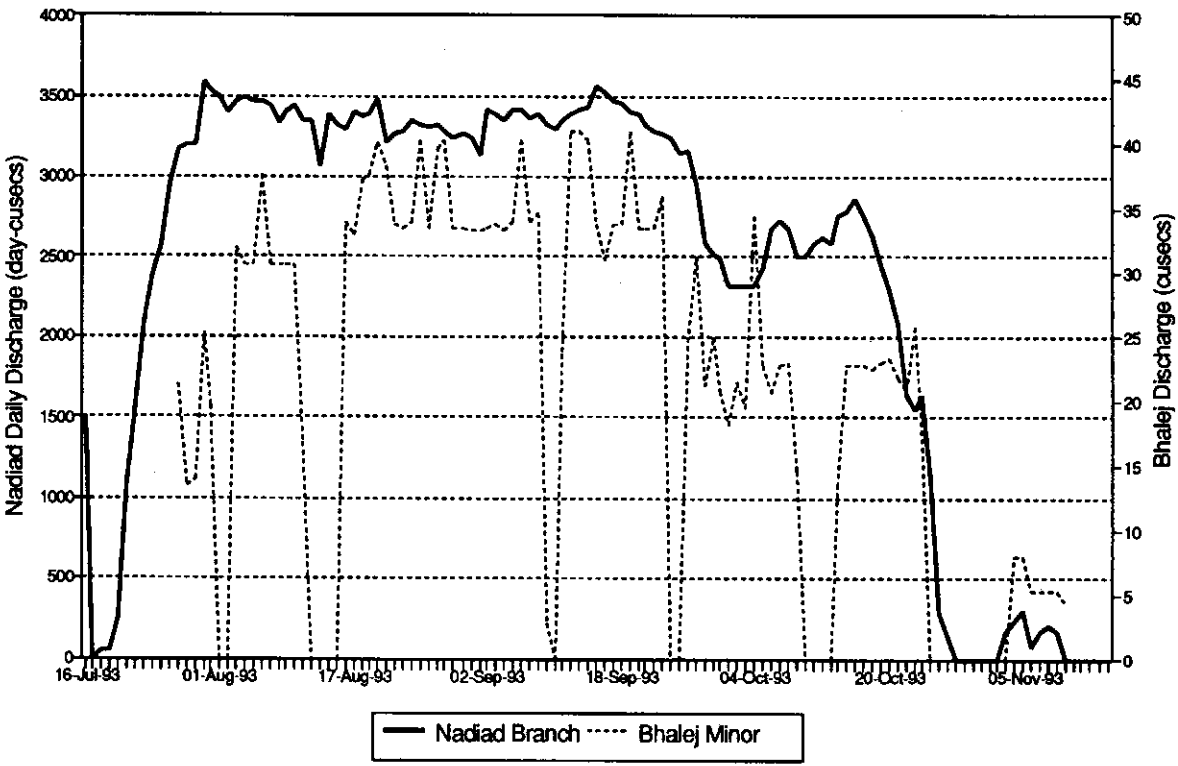


Figure 8. Daily discharges, Bhalej and Tranol, Ode Subdivision, kharif 1993.

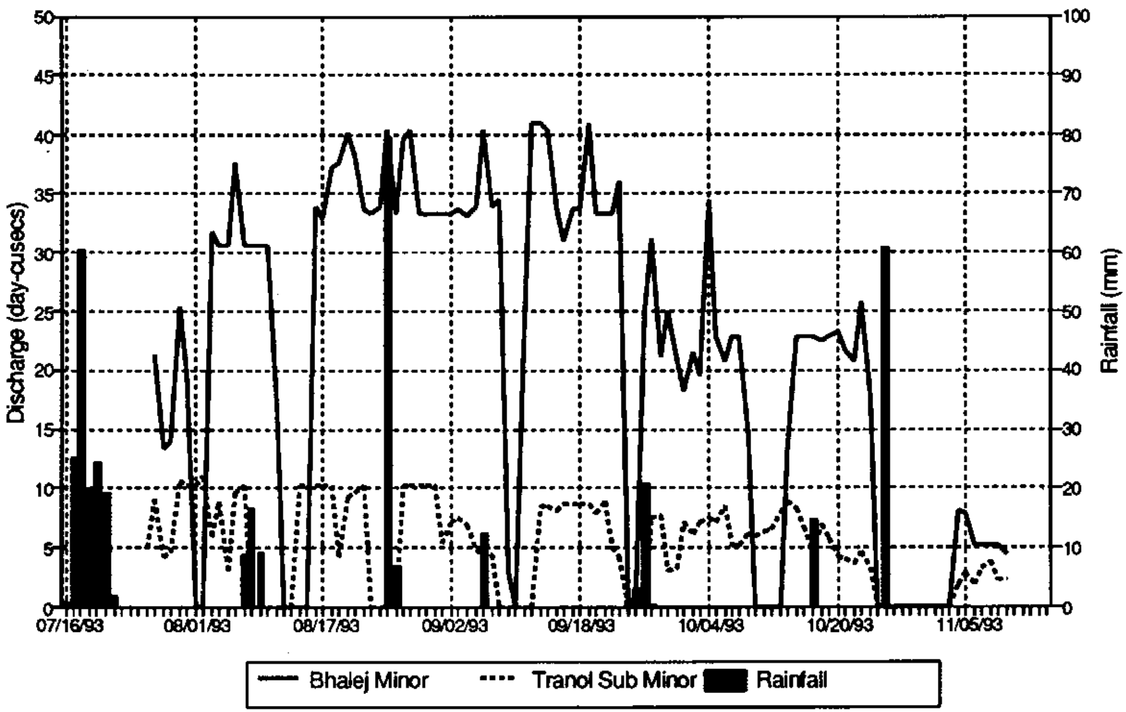
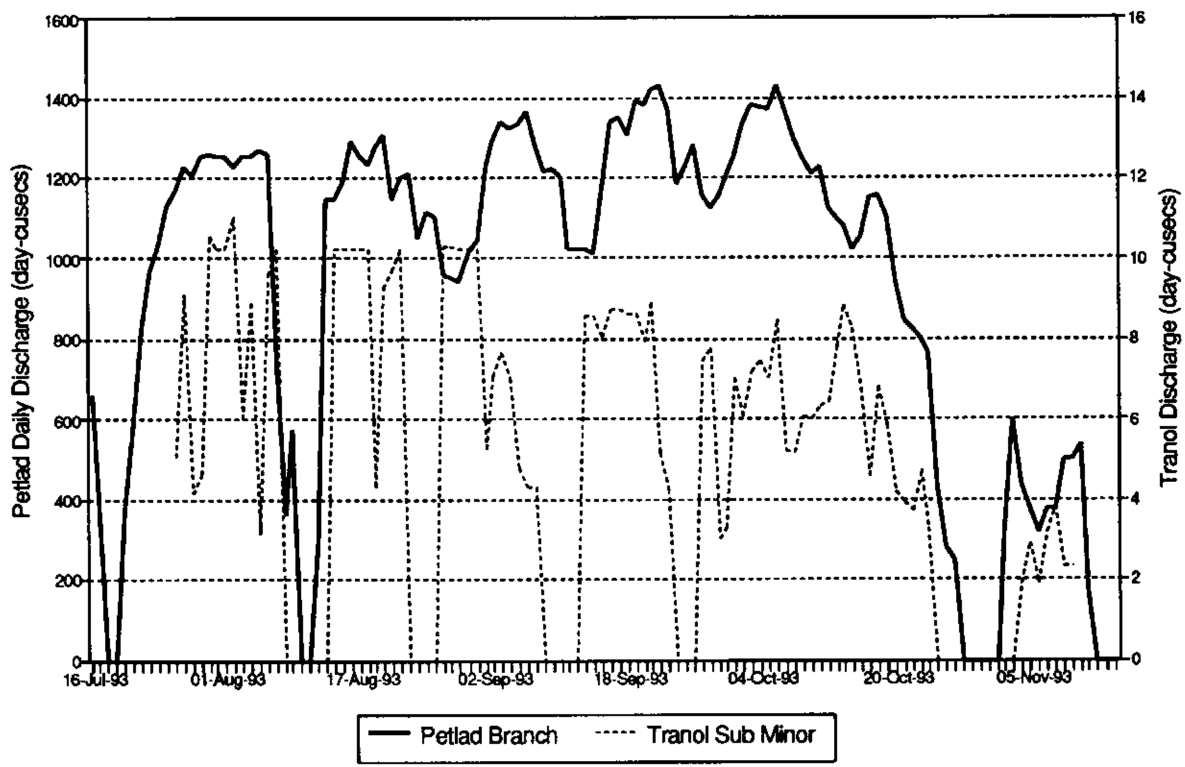


Figure 9. Discharges in the Petlad Branch Canal and the Tranol Sub-Minor, the Mahi Kadana, kharif 1993.



Analysis of the discharges at the head of each beat along the Bharoda Distributary reveals further insights into the way in which water distribution occurs at the secondary level (Figure 6 [p.51]). For the most part, as would be expected, the discharge decreases along the distributary. However, on three occasions there was a significant increase in discharge recorded at the duck bill weir at the head of the middle beat, and similar but smaller increases in discharges into the tail beat.

It appears that on at least two of these occasions it had rained, and it is assumed that upper-end farmers and chowkidars had closed sub-minors and outlets, allowing the unwanted discharge to pass further along the canal. When there is no significant rainfall, these sudden increases in discharge at the duck bill weir do not occur, and there appears to be a relatively rational water distribution pattern.

Towards the end of the season, in rotations six, seven and eight, there appears to be less demand in head-end areas because a higher percentage of water passes to the middle and tail beats. However, there is no significant decrease in overall water delivery into the head of the Bharoda Distributary as the water demand decreases.

Water deliveries to all beats in the Kunjarao Section can be assessed in the same manner using the same data, plus data for the Bhalej Minor and the Tranol Sub-Minor. It is therefore possible to assess the fairness of water distribution to all of the five beats in the Kunjarao Section.

Figure 10 shows the water delivered in day-cusecs for the entire kharif season. However, these data do not account for the CCA or irrigated area in each beat, and need to be adjusted accordingly.

Figure 11 shows the total water deliveries to each beat expressed in relation to the overall CCA. These data show that there is relatively little variation in water delivery, although there are big differences between each rotation as is expected from the overall pattern of water deliveries. These data show clearly that, despite the large differences in size between the different beats in respect of CCA, and therefore the different discharges involved, there is still a highly equitable distribution of water to the head of each beat.

Figure 10. Rotational deliveries, Ode Subdivision, the Mahi Kadana, kharif 1993.

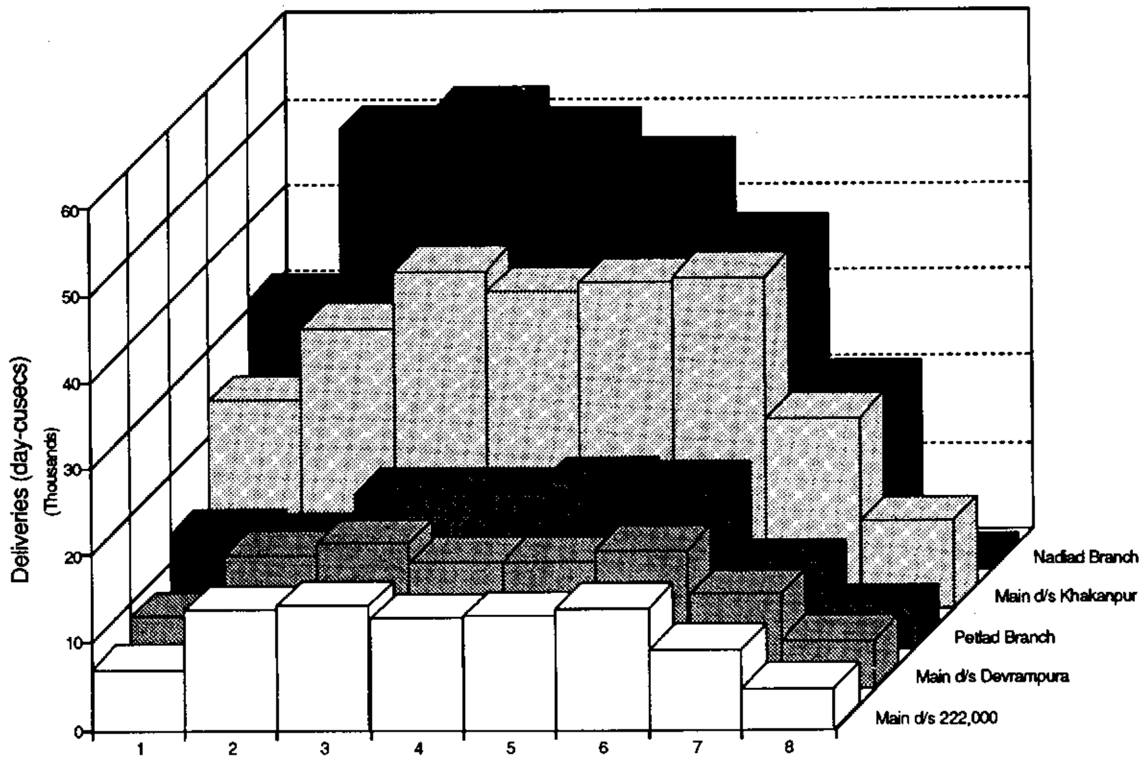
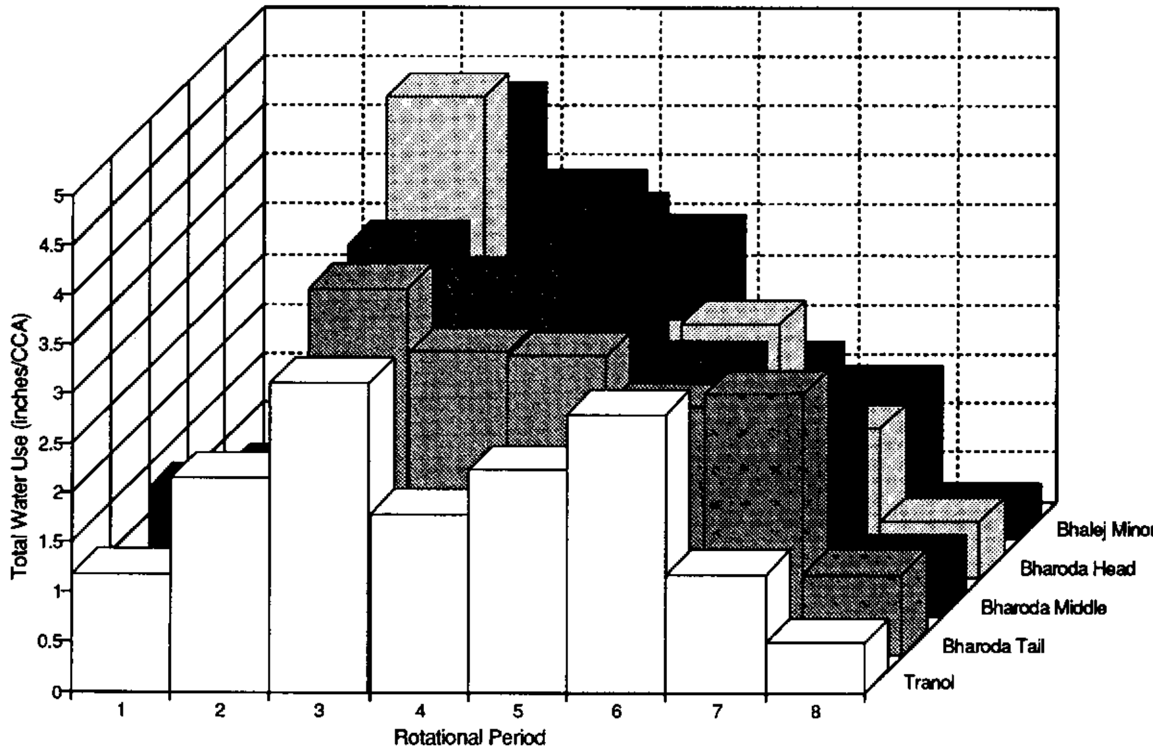


Figure 11. Water use in each rotation, all beats in the Kunjarao Section, kharif 1993.



It is clear, however, that the water in each beat is used very differently. Figure 12 shows that water deliveries to the surface irrigated area (i.e., the CCA less the areas using well water, rainfall and fallow) are less equitable. The head and middle beats of Bharoda use the most water per irrigated area, while Tranol uses the least per irrigated area. The Bharoda tail beat and the Bhalej Minor show an intermediate situation. To understand this better it is necessary to look at the tertiary and agricultural data collected from the Red Books.

Tertiary-Level Water Delivery and Agricultural Performance

Although the analysis of water delivery at main, branch, distributary and beat level reveals a considerable amount of information about the way in which the canal system is operated, it does not say very much about the agricultural consequences of these operations. For this, it is necessary to incorporate the information included in the Red Books at outlet level.

Before discussing agricultural performance, one point has to be stressed. In the Red Books, the area classed as irrigated may use not only surface water but also groundwater. The classification of land using well water means that no surface water is used. This means that the relationships between performance in the irrigated area and the water delivered through the canal system are not exactly comparable. Nevertheless, some interesting observations can be made.

Cultivation Method and Cropping Patterns. The Red Book information allows different cultivation methods to be calculated by canal, beat or any other unit. Figure 13 shows that there are major differences between the five beats in the way in which farmers practice agriculture.

Along the Bharoda Distributary, the area irrigated within a beat is almost the same (220-250 hectares) irrespective of the total CCA of the beat. This is true also for Tranol, even though the CCA is much less than in any other beat. This suggests that along the Bharoda Distributary, farmers use more well water for irrigation independently of canal water, while toward the tail there is much less area where well water is used alone. The absence of further information makes it impossible to determine whether there is a higher degree of mixing of canal water and well water in tail-end areas.

Figure 12. Water use in each rotation, all beats in the Kunjarao Section, kharif 1993.

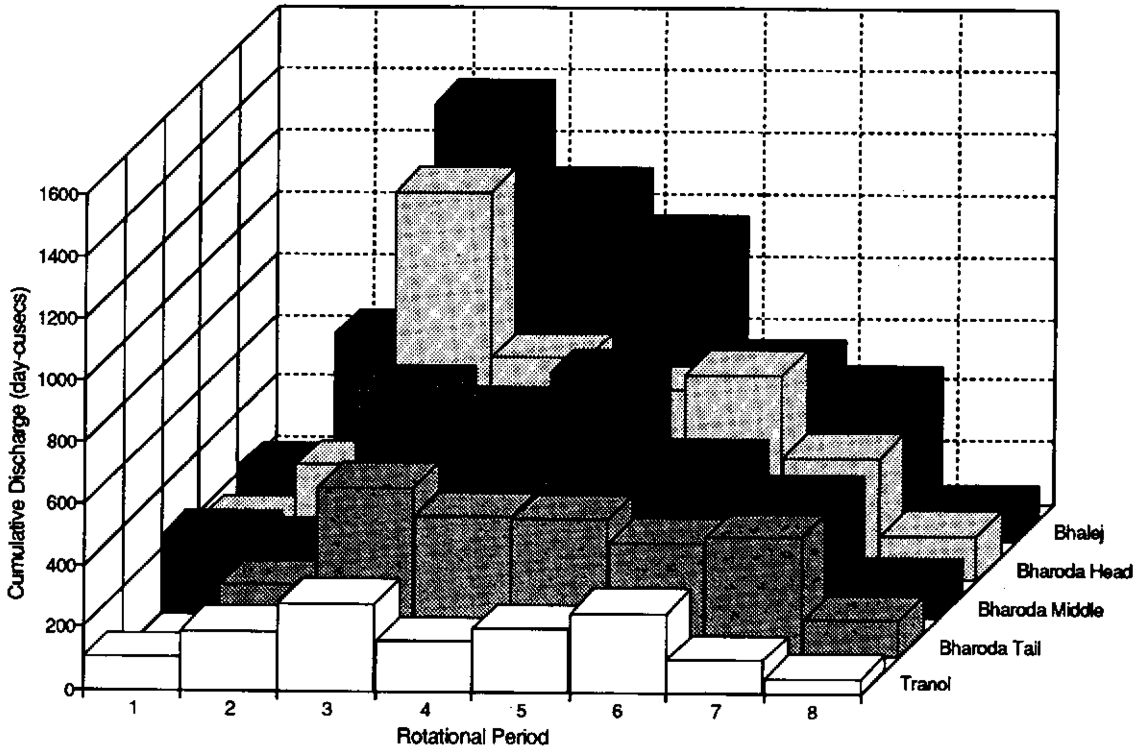
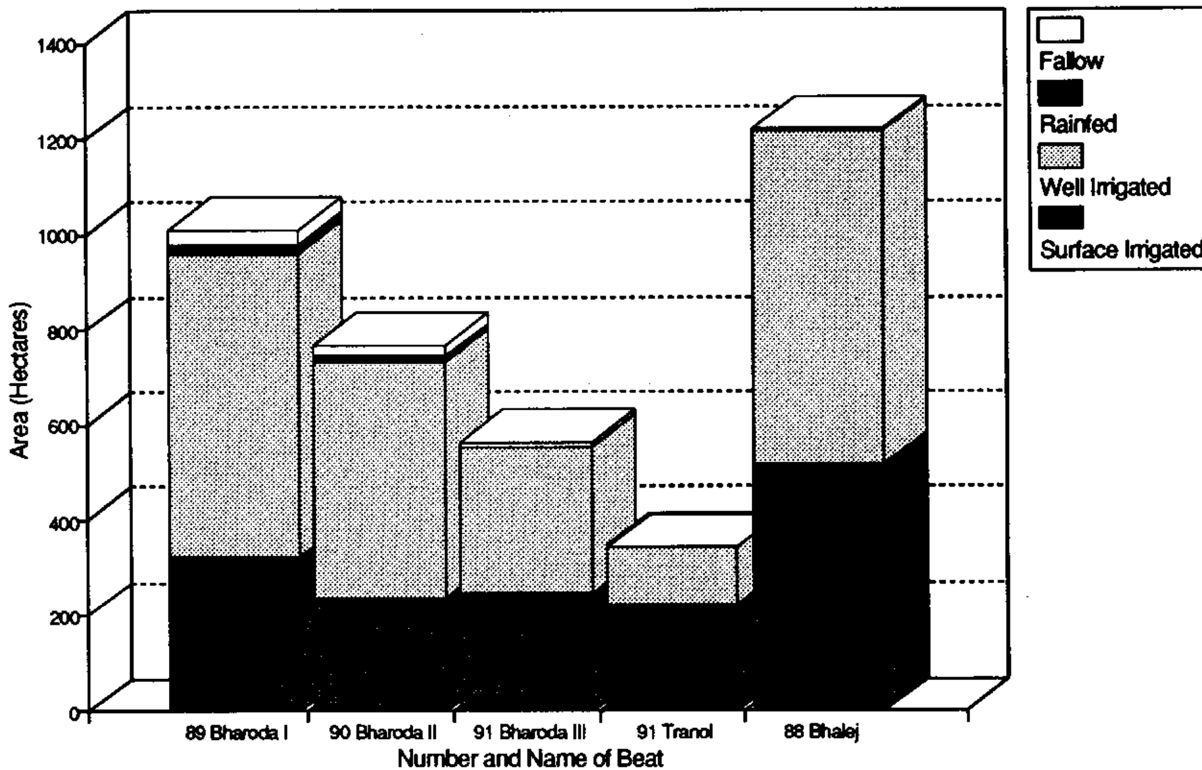


Figure 13. Irrigation source, all beats in the Kunjarao Section, kharif 1993.



When expressed as percentages of CCA (Figure 14), the irrigated area is smallest in the head and middle beats of the Bharoda Distributary, with only about 30 percent of all land being irrigated. The tail-end beat shows an increase to 40 percent, while Tranol shows as much as 60 percent of the CCA is irrigated. The Bhalej Minor shows a pattern that is more or less identical to the tail beat of the Bharoda Distributary, with some 40 percent of the total CCA being classed as irrigated land.

The cropping patterns also show some differences between the different beats (Figure 15). Tobacco is the dominant crop, followed by rice. Perennial crops are unimportant, while only Tranol shows any significant fallow. The high proportion of tobacco and rice means that it should be relatively easy to determine demand throughout the season once the cropping pattern has been established.

AIDC and Number of Waterings. These are the two performance indicators used on a regular basis by the Irrigation Department.

AIDC (area irrigated per day-cusec) is a measure of how much land is irrigated with a single watering, although it does not include any information on conjunctive use of surface water and groundwater. The data presented in Figure 16 show that AIDC values for all five beats are very similar, suggesting no significant differences within the Section.

The pattern of the AIDC values between different rotations shows a general increase from low values in the first two rotations, and then steadily increasing in each successive rotation. The explanation for this is that as demand (both crop and overall aggregate demand) slowly decreases after the peak demand of July and August, farmers can use the same quantity of water to irrigate more land. This is consistent with both a slow decline in the evapotranspiration as temperatures moderate, and the slowly decreasing demand as crops start to mature and thus require less water.

It is also clear that the average AIDC value for the whole season (Figure 17) does not give a particularly clear picture of the variation in AIDC between rotations. While all beats show more or less the same average (the Bharoda middle beat shows the lowest AIDC value), the difference between the beginning and the end of the season is very much larger.

Figure 14. Irrigation, all beats in the Kunjarao Section, kharif 1993.

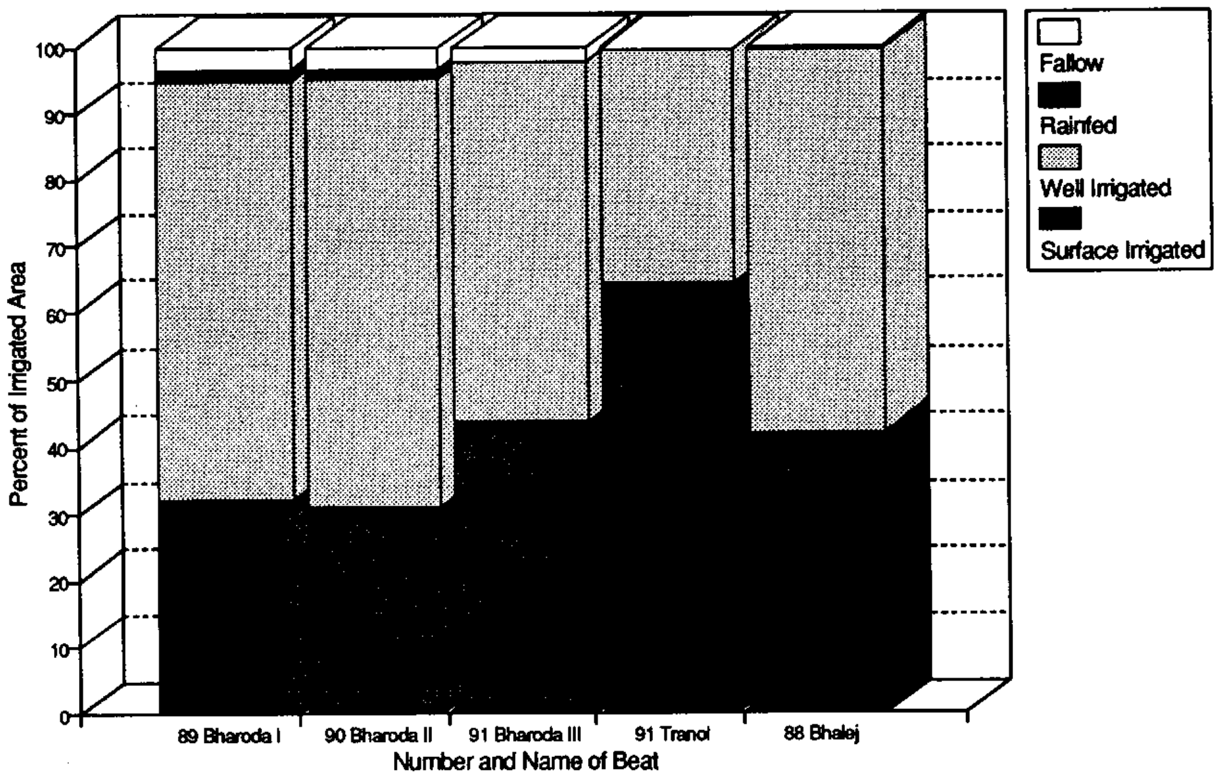


Figure 15. Irrigated cropping pattern, all beats in the Kunjarao Section, kharif 1993.

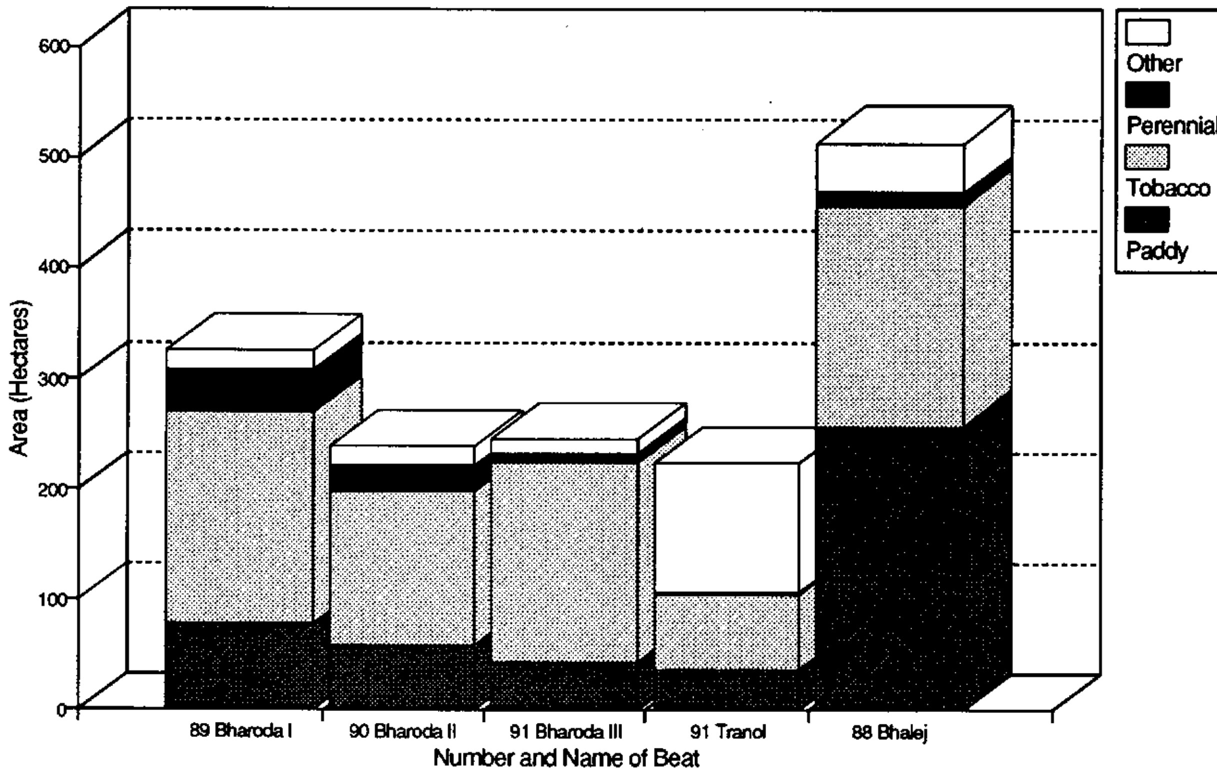


Figure 16. AIDC and number of waterings, all beats, the Kunjarao Section, kharif 1993.

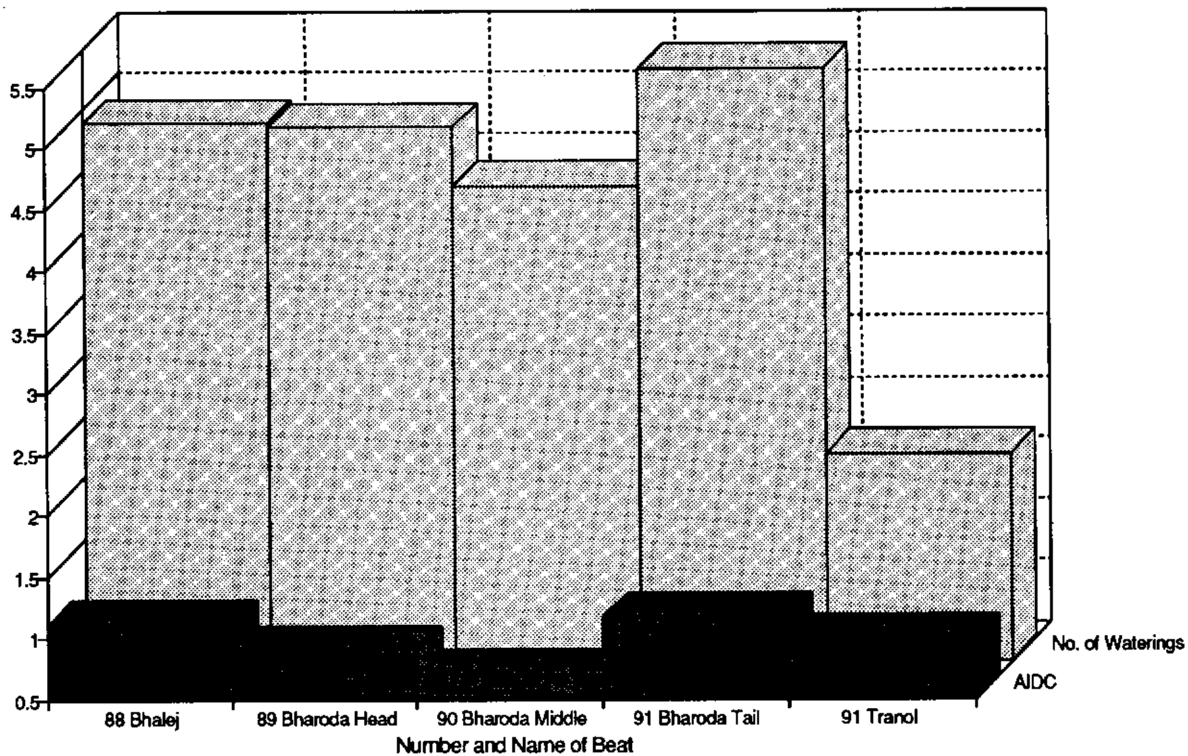
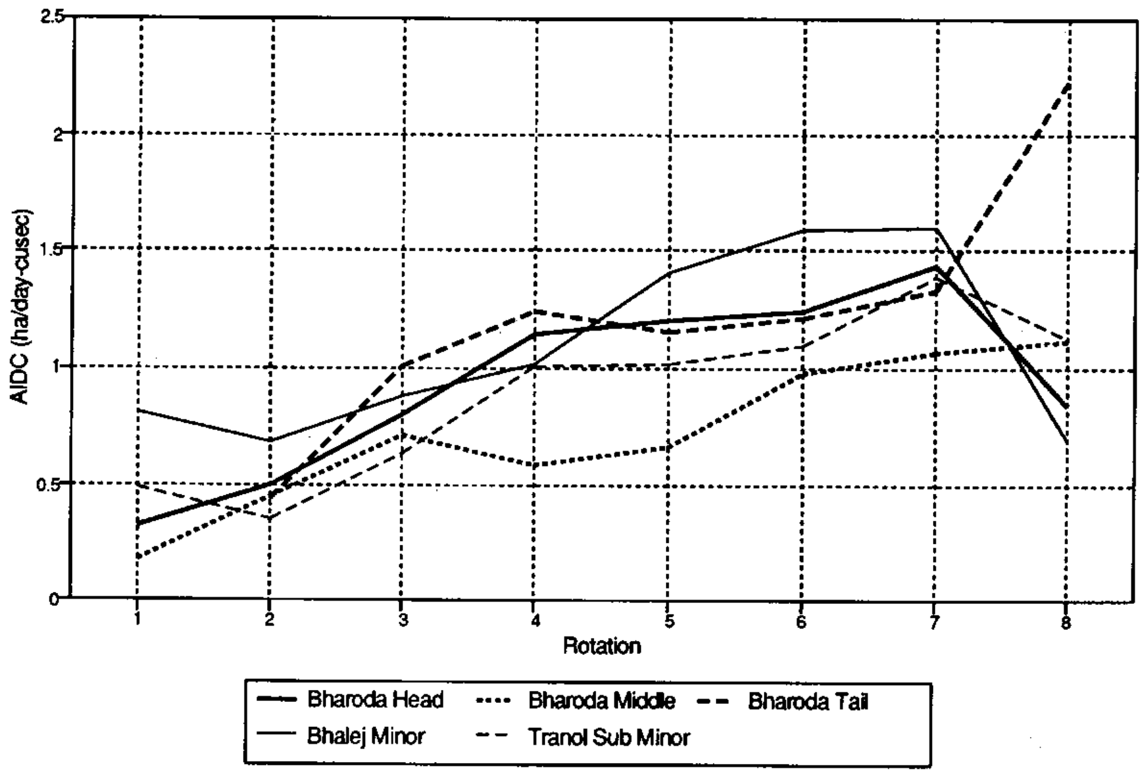


Figure 17. AIDC by rotation, all beats in the Kunjarao Section, kharif 1993.



Finally, it is interesting to see that the number of waterings is more or less uniform, except in the Tranol Sub-Minor. Typically, each beat uses about five waterings during the season, suggesting that there is a significant decrease in requirement of water during the season. The reason for this low value for Tranol cannot be explained with the data at hand.

CHAPTER 6

Future Opportunities for Using the Mahi MIS Package

THE ESTABLISHMENT AND utilization of MIS packages provide opportunities to examine aspects of performance that were not previously possible, or extremely difficult and time-consuming. The use of the MIS package with the 1993 kharif season data from the Kunjarao Section of the Mahi Kadana System provides a strong basis for identifying several aspects of current performance that can be further improved using the data and computer technology currently available to the Irrigation Department in the Mahi Kadana.

Actual performance described in the previous chapter was primarily concerned with the indicators used by the Irrigation Department. However, additional issues and areas of improvement are described in this chapter where existing data are used, and the potential of MIS is illustrated to examine a much wider range of parameters than is currently the case. As experience in the use of the MIS is gained, then there will be additional areas that can be examined.

MANAGEMENT ACTIVITIES AT THE MAIN AND BRANCH SYSTEMS

In general, the main and branch canal systems appear to have been operated in a manner that is both consistent with overall plans, and achieving goals of equity and reliability. In many respects, it performs better than expected, and certainly better than many systems of comparable size in other states and countries. However, four concerns arise from the evaluation of the data set for the kharif 1993 and the longer-term data set for the entire Mahi Kadana System.

Rotational Irrigation at Distributary Canal Level

The first is concerned with the new system of rotational closure program implemented at the distributary level which is additional to the rotational program carried out at the outlet level. The distributary-level program aims at reducing the total number of days of water delivery to canals offtaking from the main and branch canal systems, but ensuring that when they are operated, discharges are at or close to full supply so as to provide adequate driving head to the tail end. The 1993 data suggest that different things are happening in different canals.

The optimal type of rotation program is where the total discharge "saved" by closing individual canals should be uniform throughout the entire rotation period so that the total demand into the canal remains uniform. The discharge entering the main or branch canal does not then need to be modified during the rotation period. Limited data available suggest that this objective has been achieved in the Nadiad Branch. Both the Bharoda Distributary and the Bhalej Minor were included in the rotational closure program but the discharge in the Nadiad Branch remained uniform. This suggests that when the Bharoda and Bhalej canals were flowing fully other canals further downstream must have been closed. Conversely, when the Bharoda and Bhalej canals were closed other canals must have been opened. If this is in fact the case, it suggests that the Nadiad Branch and its offtakes have been effectively and efficiently operated.

At the Devrampura Regulator, however, the rotational closure program was also reflected in the branch and main canal discharges, with a clear cycle of increasing and decreasing discharges between the two canals. Given the size of the CCA served by each canal, it is perhaps odd to find the discharges changing by as much as 30 percent in each part of the cycle. It would be interesting to see if it is possible to modify the closure program so that the discharge into both the main canal and the Petlad Branch stays as constant as possible. This could be done by selecting distributaries of similar size along each canal and making a program that shares the overall quantity of water among them.

The second aspect of implementing rotations at a major regulator is that it takes some time to get water levels to stabilize. The data suggest it takes two to three days out of each week to balance out the fluctuations. If main canal and branch canal water levels fluctuate too much it merely increases the work load for the gate operators: it is not that it is impossible to adjust to the fluctuations, but in general, management is easier if the range of variation of water levels is minimized. As a consequence, it is generally recommended to attempt to maintain stable discharges in the main and branch canals, and modify the operational program at distributary level to keep demand more or less uniform for each major canal.

Achieving Equity of Water Distribution at Major Regulators

Data for the period 1989-1992 at Khakhanpura show some differences in the relative equity of water distribution between the Nadiad Branch and the Main Canal continuation. Figure 18 shows there is a very large difference in percent of water allocated between the two canals in different seasons. The obvious explanation is that there are different areas irrigated along each canal in different seasons.

By comparing, therefore, the percent of land irrigated along each canal and the percent of water allocated to each canal, a picture of overall equity of water allocation is obtained (Figure 19).

In the kharif seasons, the Nadiad Branch irrigates between 60 and 70 percent of the total area commanded by the Khakhanpura Regulator, with the main canal receiving the other 30-40 percent of land. However, Nadiad only receives 55-60 percent of the water, meaning that it gets rather less than its equal share, while the main canal continuation gets rather more. These differences could be because of differences in cropping pattern, rainfall pattern, soil type, etc., or because of the way the water is being divided among different canals, but this unequal distribution needs to be verified to assure managers that water distribution is being properly carried out in that season.

In the rabi and hot seasons, Nadiad only irrigates 30 to 50 percent of the total area below Khakhanpura. In three of the past four rabi seasons, Nadiad got less water than would be expected, but in the two hot seasons it got rather more than expected. The reasons for these variations need to be verified: it may be that they truly reflect the expected cropping pattern, but if they do not then there is an opportunity for improved water distribution. Further, if the MIS is used effectively, it is possible to determine the actual cropping pattern as early as the third rotation in each season, and make any necessary adjustments to discharge to reflect the actual conditions rather than assumed ones. This is a clear example of the possibility of moving towards a more real-time response to actual conditions.

Figure 18. *Water allocation, the Khakhanpura Regulator, seasonal percentages, 1989-1993.*

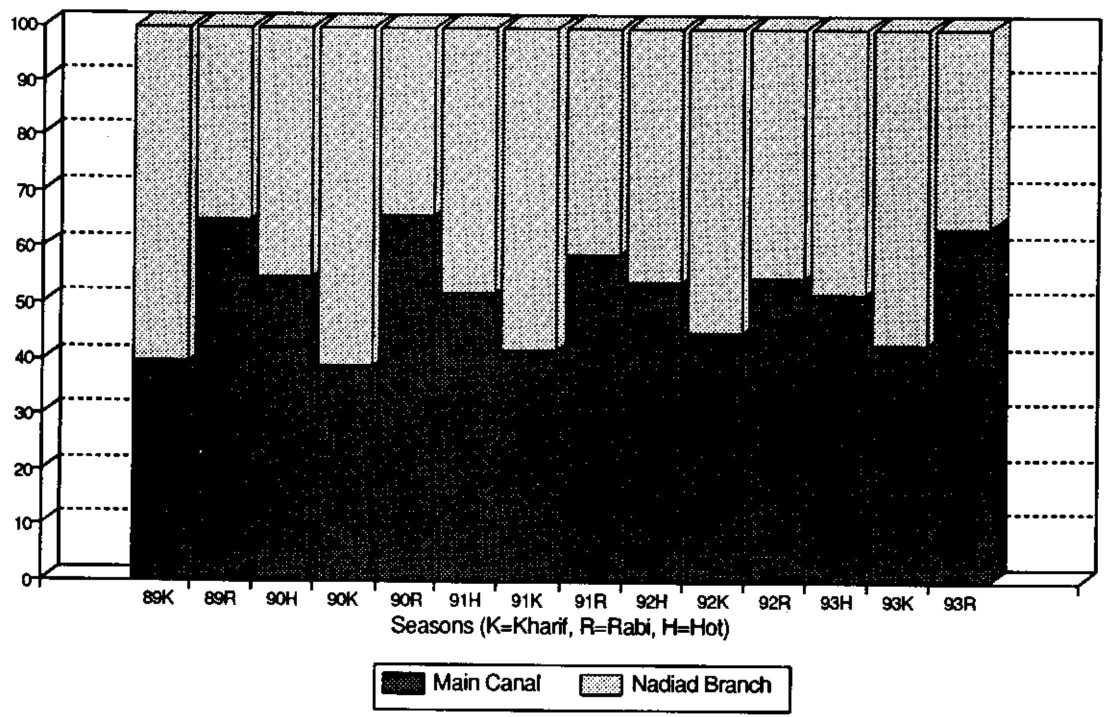
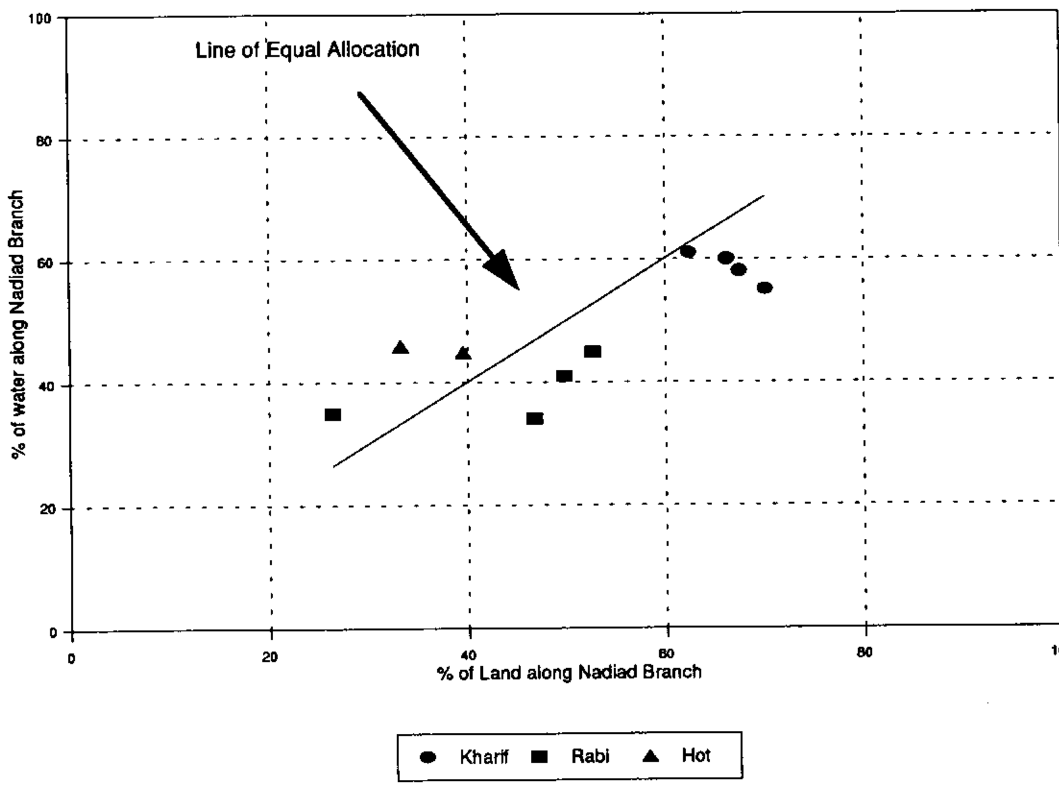


Figure 19. Equity of water allocation, the Khakhanpura Regulator, 1989-1992.



Variability of Discharges

Variability, measured here by the coefficient of variation (CV) of discharges in each rotational period, is one indicator of the reliability of water deliveries to lower portions of the system. Figure 20 shows the CV of discharges in the four canals served by the Khakhanpura and Devrampura regulators. The early part of the kharif season shows relatively high variability because of lack of initial demand from farmers during the period of land preparation and crop establishment, and because of fairly widespread rainfall. By the third rotation, however, discharges have stabilized to a significant extent, and remain low until the final couple of rotations when demand is much less.

As would be expected, the CV is highly dependent on the overall volume of water delivered in each rotation. If canals are run at or close to full supply, then the CV will automatically be low. This was the situation in the third to sixth rotations apart from the unexpected reduction in discharge in the Petlad Branch caused by the closure so that repairs could be made to a damaged structure. As total volume drops the CV rises, in an almost linear fashion (Figure 21). This strongly indicates that if canals are to be run at lower than 70 percent of design discharge, cross-regulation to maintain upstream head is essential, and there is a need to consider effective implementation of rotations among smaller canals to maintain proper hydraulic conditions.

The data suggest that during the period of peak demand, discharges are high and variability very low. Clearly, there are opportunities to improve the reliability of discharges in both the beginning and end portions of the season either by tightening up on rotational practices, or by ensuring that when canals are operated they are operated at discharges at least 70 percent of full design capacity. Managers should expect that canals only operate below this discharge level when there are clear reasons for doing so, and have to be able to justify this operational situation whenever it occurs.

Figure 20. Variability of deliveries, Ode Subdivision, the Mahi Kadana, kharif 1993.

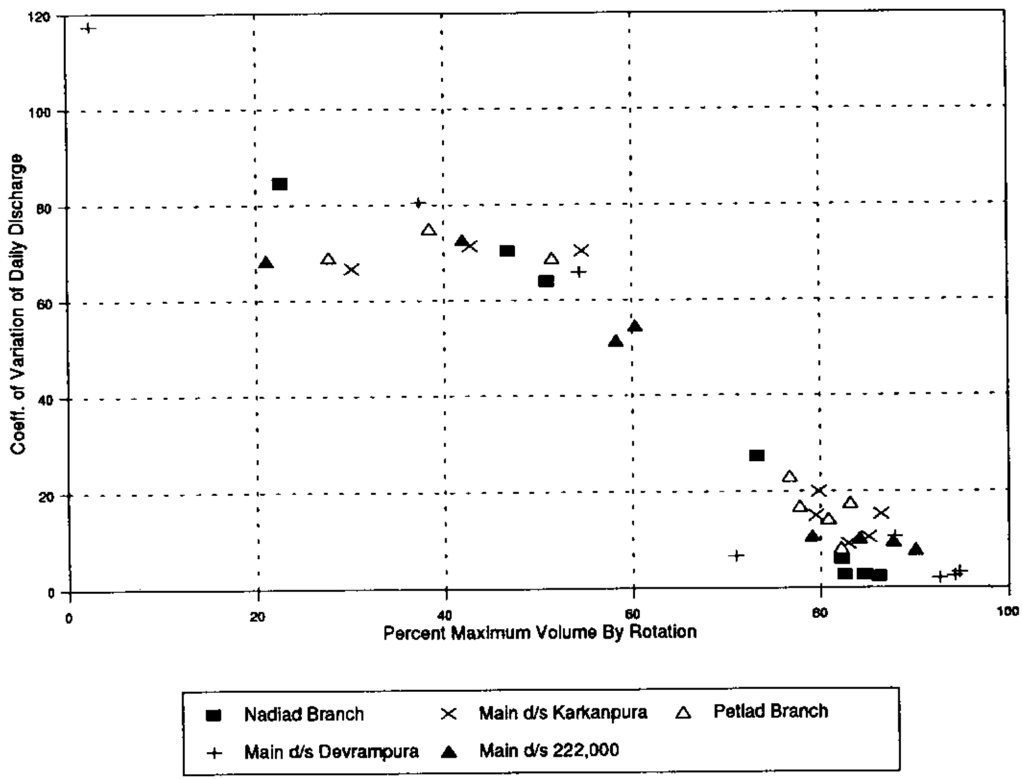
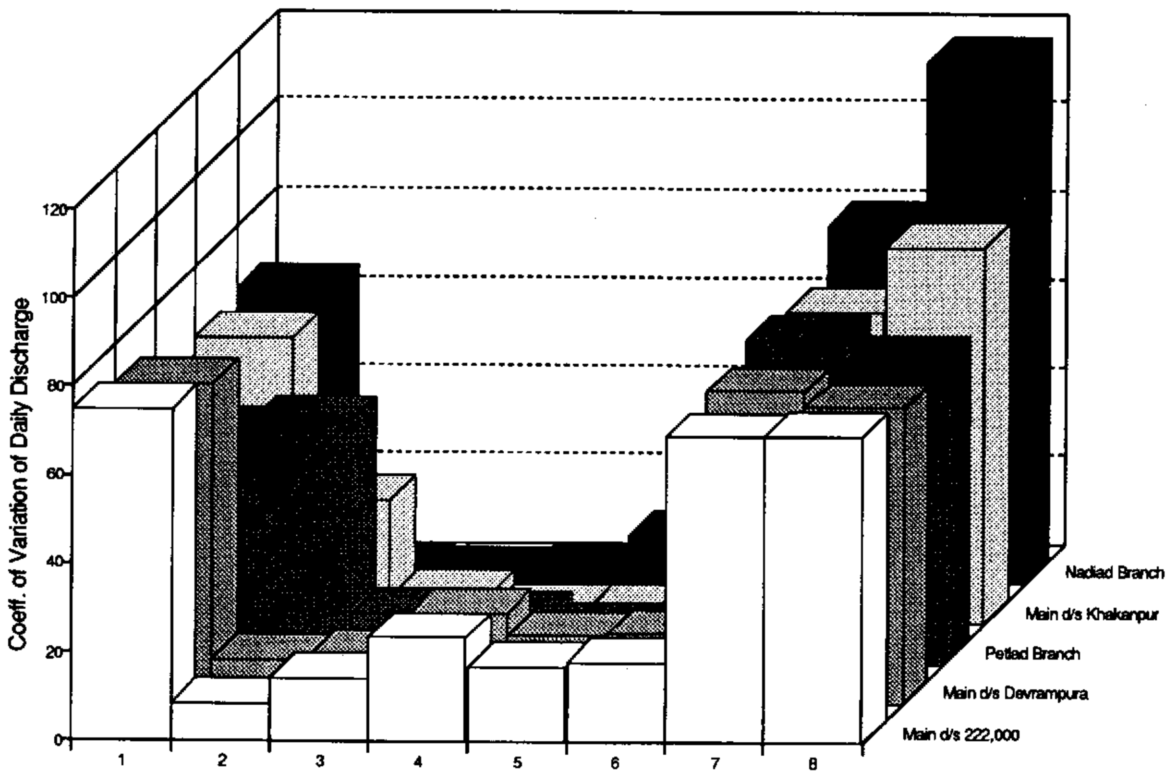


Figure 21. Variability of deliveries, Ode Subdivision, the Mahi Kadana, kharif 1993.



Checking Planning Assumptions of Water Utilization

At the system level, the overall estimate of water use is 2 acres/day-cusec (0.8 ha/day-cusec), with an assumption of about 40 percent efficiency down to field outlet level. With the data at hand these assumptions can be checked. Field-level values of AIDC in Kunjarao range from 0.5 to 2.5 ha/day-cusec, rising steadily from low values in the first rotation to high values at the end of the season. By studying these changes, the problem of staggering of cultivation could be addressed by ensuring that water deliveries to areas reaching satisfactory levels of AIDC are reduced, permitting downstream areas to get more water earlier in the season and thus speed up land preparation and reduce staggering. The results suggest three items for consideration in future performance assessment activities.

First, AIDC values appear to reflect changes in evapotranspiration rates as much as they reflect system-level response to demand. At the beginning of the season, the evapotranspiration is very high, and thus farmers have to concentrate irrigation over a smaller area. As crop water demand decreases with decreasing temperatures, the same volume of water can be spread over a wider area. It requires more analysis to determine whether a high value of AIDC really reflects good management or is merely a response to evapotranspiration.

Second, AIDC is only a good indicator of performance if there is full accounting for any groundwater use. If groundwater is used for irrigation, it must be accounted for in the total water utilized if the area data include land irrigated using both surface water and groundwater supplies. This appears to be the case in the Mahi Kadana, so that the AIDC figures reported suggest a higher level of efficiency of use of surface water than is actually the case: the current situation looks at only surface water delivery, but the cropping data include some areas that do use groundwater to supplement the surface deliveries. This is an area for further study, and one that the Irrigation Department should include in routine monitoring activities.

Third, there is little evidence of actual response to the measured AIDC values. Although the AIDC values exceed the values assumed in overall seasonal planning, there is no evidence of any systematic reduction in discharge to keep AIDC values at or close to the target values. While AIDC may be useful for overall seasonal water allocation processes, the data suggest that a discharge-based targeting process would be more useful at this stage in the development of the Mahi Kadana System.

MANAGEMENT ACTIVITIES AT THE SECONDARY CANAL LEVEL

The performance data can be used to examine existing management practices at secondary level and see if there are ways to make them more efficient in future seasons.

Variation in Operating Rules for Head Regulators of Distributaries

There are a number of differences in the way in which the three distributary head regulators included in the program were operated. These include differences in the response to rainfall, the length of time that canals are closed during the rotational closure program, and the number of closures themselves. It is quite possible that these are legitimate differences based on the individual differences between the canals themselves (area, crops grown, soil differences, etc.). However, it is desirable to see whether a clearer set of operating rules could be developed for each head regulator. The variations noted are not enormous but if the reasons for the differences can be understood this will help make it easier to have a more systematic program of water management.

There are some differences in the variability of daily discharge among the different regulators. While some fluctuations are inevitable, it is the responsibility of the gatekeeper to try to keep the discharge as constant as possible to provide stable water conditions for farmers during a rotation period. While some of the fluctuations may be due to upstream water-level changes beyond their control, there is little evidence that this is a serious problem in Kunjarao. There is more evidence that fluctuations are due to gate operations. Again, there is no evidence of a serious problem, but a better understanding of why discharges fluctuate as much as they do in some of the canals would be useful.

A final issue is that the rotational closure plan must be coordinated between branch canals and offtaking canals. At the Tranol Sub-Minor there does not appear to be a clear relationship between the branch canal water-level fluctuations and the timing of the closures of the Tranol Sub-Minor. As an isolated case, the variation in flow in the Petlad Branch caused by the operation of the Tranol Sub-Minor is hardly noticeable (about 1% of total discharge from Petlad goes to Tranol); however, if the same thing is happening in larger offtaking canals, the effect on discharge further downstream would be dramatic, and tail-end areas might end up with more uncertain water supplies than was the case before the implementation of the rotational closure plan.

The purpose of this analysis is to ensure that if canals are going to be opened and closed, the schedule needs to be carefully worked out and carefully implemented to avoid unnecessary confusion among water users.

Water Sharing between Beats

In general, there is very little difference in the water allocation among the different beats, especially when expressed in terms of water delivery in proportion to CCA, which is the prime indicator of equity. Water use in terms of actual irrigated area represents farmer response to water deliveries and is outside the immediate control of the Irrigation Department staff.

There are some differences in water use among the different beats. AIDC values are consistently lower in the middle section of Bharoda compared with all other beats. The reasons for this might be examined: they could be due to design, they could be due to measurement errors of discharge at either the duck bill weir or the ramp flume, or they could be due to social reasons. From a research perspective it would be interesting to see the actual causes of the differences.

The overall equity along the Bharoda Distributary seems very high. Tail-end areas do not seem to be particularly disadvantaged, although they do get less water per CCA than the head and middle beats. As the present data set only covers one season, it would be interesting to conduct a survey of farmers in tail-end areas, plus some representative farmers in head and middle beats, to see if they have perceived any significant differences in water supplies during 1993 in comparison with the past (the farmers must be given the chance to suggest their own explanations for any changes rather than being given a predetermined list of possibilities; an open-ended questionnaire is preferable in this instance).

A second possible opportunity for a survey of farmers (the two could be combined) is to try to determine some of the causes of the differences in crop type by source of water observed between the five beats. Questions that could be included in this study are: "why does the tail end of Bharoda irrigate a higher percentage of CCA compared to head and middle beats?" and "why do the head-end farmers have a higher proportion of perennial crops?" The answers to these questions are useful to managers because they help to see what the relationships are between irrigation deliveries and farmer crop choices.

Variation in Water Deliveries

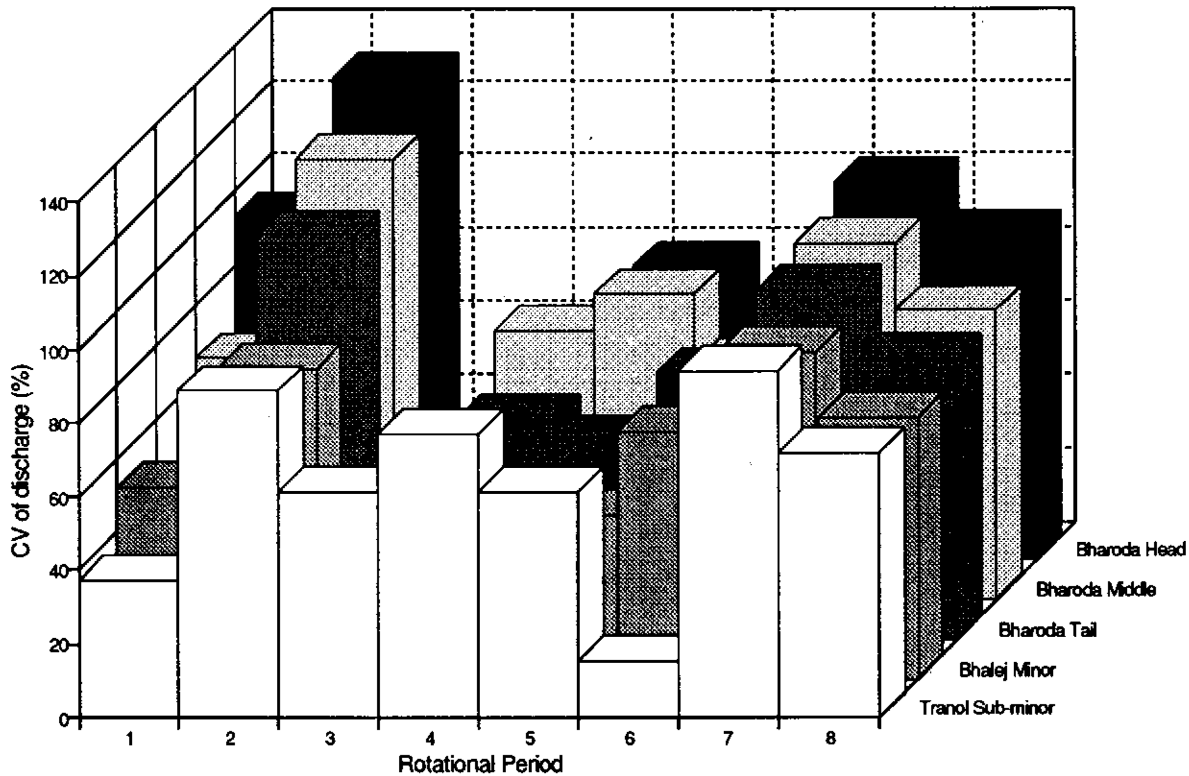
As would be expected, the variations in discharges in smaller canals are larger than those in the main and branch canals. However, a surprising element of performance in the Bharoda Distributary is that there is comparatively little increase in CV between the three beats as one moves downstream (Figure 22). This is in contrast to the conventional wisdom that tail-end portions of canals suffer disproportionately: if inflow into a distributary varies but head-end farmers take a constant volume, then it would be normal for CVs to increase downstream. The lack of significant increases in variability along the Bharoda Distributary suggests that there is indeed some degree of effective sharing of water between beats, and that head enders do reduce some of their water use when less water is available for all. The MIS provides a good opportunity to repeat this analysis as the database increases to ensure that similar levels of equity are achieved in other sections.

Communication between Karkoons

The Bharoda Distributary provides the opportunity to look in more detail at how information is passed up and down the canal. There are several instances where it appears that head-beat farmers do not want water because of rainfall, and therefore close off outlets or sub-minors. As a result, more water is delivered to middle and tail beats which also may not require the water. By presenting data from the MIS in such a format, several management questions are identified that could lead to further improvements in performance into the future: typical of these questions are "what are the communication processes that are required to reduce overall discharge into a canal when farmers do not wish to use all of their share of water?" and "how can discharges be managed so as to avoid downstream problems such as breaches or overtopping when head-end farmers do not require their full share of available discharge?"

Similarly, it is clear that towards the end of the kharif season, head-end farmers gradually reduced their demand but the discharge into the distributary did not get reduced in the same proportion. The result was a big increase in overall water deliveries to farmers in middle and tail beats, and it appeared to take some time to make adjustments at the head regulator. These communication processes are important to be studied because they give a

Figure 22. Coefficient of variation discharge, beats along the Bharoda Distributary.



good indication of how improved matching of supply and demand could be accomplished in the future.

Use of AIDC Values

There is not much evidence of response to the actual AIDC values for each rotation. All of the five beats show remarkably similar values for AIDC in any given rotation, and they all show the same pattern of starting at a low value and ending the season with high values.

This trend suggests that, in the first two rotations, farmers need a lot more water per unit area to get land preparation and soil water replenishment completed. Once they have accomplished this, they can use the same volume of water to irrigate more land. As demand drops further due to decreased evapotranspiration it should be possible to reduce discharges: an AIDC value of 2.5 ha/day-cusec is roughly equal to 40 mm/day, suggesting a lot of water wastage even allowing for losses, while an AIDC of 0.5 ha/day-cusec (about 8 mm/day) does not really meet tertiary-level conveyance losses, evapotranspiration demand and percolation losses.

The second aspect of AIDC is that although it is reported as a seasonal average, the actual variation is far greater than the average. This means that while the average may be useful for gross planning purposes, it is not very useful in reflecting actual performance within the season. In the case of Kunjarao, the average AIDC is about 1.0 ha/day-cusec in all beats or 15 mm/day for irrigated areas including all losses, higher than the overall estimate at system level, but with significant periods below this value early in the season.

It may therefore be useful as the program expands to see if there can be better estimation of the periods of lower and higher AIDC values in different canals so that overall discharges can be planned accordingly. The current data appear to suggest that there is a response to changing demand in the second half of the kharif, but the response at the distributary lags behind this, and the response at the branch lags behind further still.

DISSEMINATION OF THE PACKAGE

The Mahi MIS package has to date been adopted in one Section of the Mahi Kadana Irrigation System. It has been a deliberate policy to introduce the package systematically within the normal working conditions of the Irrigation Department. This means that the use of the Red Book, the transfer of Red Books to the section office for data entry into the computer by the Irrigation Department staff, and the production of performance reports have been validated at the lowest level of the administrative hierarchy. Moves have already been initiated to replicate this process in the other four Sections of the Ode Subdivision during the 1993-94 rabi season to fully test its efficacy at subdivision level.

There is no doubt that the package has been highly acceptable to all of the users within the Irrigation Department which intends to extend it to the rest of the Mahi Kadana. The location of computers is important: they must be close enough to the field so that there is a prompt and efficient flow of information upwards with the Red Books, and downwards with revised operating instructions. Too much centralization will not be a good strategy unless the computers can be linked into a network.

Beyond the Mahi Kadana, there are many opportunities for adoption. In its present form, it is clearly designed to support the shejpali system of irrigation practiced throughout Gujarat. With the continued support of both the Irrigation Department and WALMI, there is every reason to be optimistic about Statewide adoption of the package over a period of several years.

One pitfall often encountered in MIS development is the incapacity to accommodate conditions that are different to those in the initial site of development. However, because of the consistent effort to make the databases and the overall computer programming generic in nature, the package can be speedily adapted for use where there are other forms of data collection. The major changes required are in the data entry templates (the Mahi MIS data entry is designed to make entering of Red Book data extremely simple), and some of the interfacing of the different databases. The bulk of the work has already been done, and there is no doubt that with technical inputs from the original designers, quick modifications to suit the needs of other States would be easy to accomplish.

References

Bos, M.G., D.H. Murray-Rust, D.J. Merrey, H.G. Johnson and W.B. Snellen. 1994. Methodologies for assessing performance of irrigation and drainage management. Irrigation and Drainage Systems (in press).

Gulati, O.T. (Ed.). 1994. The Mahi Right Bank Canal Project: Performance details. Mahi Kadana Irrigation Circle, Nadiad, Gujarat, India.

Murray-Rust, D.H. and W.B. Snellen. 1993. Irrigation system performance assessment and diagnosis. (Joint publication of IIMI, ILRI and IHE.) Colombo, Sri Lanka: International Irrigation Management Institute.

Perry, Chris. 1994. Personal communication.

Small, L.E. and M. Svendsen. 1992. A framework for assessing irrigation performance. Working Paper on Irrigation Performance 1. Washington, D.C.: International Food Policy Research Institute.