REPORT NO. R-59

PERFORMANCE ASSESSMENT OF THE WATER REGULATION AND DISTRIBUTION SYSTEM IN THE CHISHTIAN SUB-DIVISION AT THE MAIN AND SECONDARY CANAL LEVELS

ZAIGHAM HABIB
MARCEL KUPER

JULY 1998

PAKISTAN NATIONAL PROGRAM
INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
LAHORE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Chishtian Sub-division, which is located in Southeastern Punjab near the Indian border, has a few typical agro-climatic characteristics. The region is semi-arid to arid and adjacent to the Cholistan Desert. Historically, these sandy plains have supported a civilization that benefited from three rivers -- Sutlej, Beas and Hakra. With the passage of time, the hydraulic regime of the area has changed, Hakra has been dried, the water rights of Sutlej and Beas were given to India in 1960, so that only the surplus flows of the Sutlej River during the flood season contribute to the surface supplies. About 60% of the cultivated area have half-yearly water rights. The other 40% of the cultivated lands are fed by a reservoir, Mangla, located 325 kilometers Northwest on the Jhelum River through three inter-river link canals.

Under these conditions, water supply to the area is influenced by many regulation locations, has a long response time, and a high variability factor. Even though the cropping intensities have been doubled during the last 50 years with the help of regular mining of the ground water, the crop yields are quite low as compared with similar systems in other countries.

The ground water quality in the area is of good to the moderate. Land characteristics of the sub-division are favorable for agricultural cultivation. Three main cash crops (cotton, rice and sugarcane) are grown in the area supplemented by a few minor crops, such as fruits, oil seeds and vegetables.

A low yield for most of the crops is normally linked with the unreliable water supply. And the performance of the water delivery and distribution system is identified as a primary area of concern.

Usually it is said that the canal system was working properly in the past. The necessary actions required for monitoring, evaluation and system's improvements have been provided in the recommended official procedures. This report documents these procedures and evaluates them in the current situation.

The general objectives of the system -- equity, reliability, timeliness and adequacy -- have been tested in the conjunctive water use environment using the traditional, as well as more recent, statistical indicators. A comparison of the indicators is presented for their given properties to provide necessary knowledge to the manager and other users.

Chapter One of the report presents concept of the irrigation system and the command area performance in a hierarchical supply base system.

The methodology and objectives of the study, boundaries of the selected processes, qualities of the indicators, and a brief description of the data used in this report is presented in Chapter 2.

Chapter 3 describes the hardware and software of the system. The managerial targets and system's qualities are presented by briefly describing the organizational setup, official rules for canal operations, water allocations, and the seasonal plus day-to-day target setting.

In Chapter Four, a serious effort is made to document and discuss recommended monitoring and evaluation procedures. The first part of the chapter presents the traditional definitions and purpose of each procedure and parameter. While in the second part, an existing data set is used to test if these procedures are still appropriate to assess the performance of a canal network at a sub-divisional level. Many interesting results are reported which indicate the worth of simple monitoring parameters if their meanings are properly understood and interpreted. The processes of the seasonal and local in situ planning, operations of the control structures, conveyance and water distribution are represented by *warabandi plans,* flow measurement accuracy, regime operations, relative tail supply conditions and the equitable supply ranges.

A range of indicators are presented in Chapter 5 to measure and represent equity, reliability, timeliness, adequacy, delivery performance ratio and the gross performance. Many ratios are used and compared for the similar processes. This analysis provides an insight into the potential of an indicator to represent a process and its merits for specific situations.

The results of Chapters Four and Five are further discussed and summarized in Chapter 6. The knowledge gained about each process is compiled by emphasizing the main factors contributing to the performance of the water delivery and distribution system at the level of a secondary canal system.

An account of different indicators in terms of their utility is provided to facilitate the user in understanding and selecting a relation for a particular application. The theoretical aspects of the indicator relations are not discussed in this report, but the inferences of each relation with reference to the boundaries set in the beginning of the season and the targets values of the involved parameters are briefly described. The strength and weaknesses of traditional indicators are reported with reference to the experience of this study.

A case study is presented to understand the factors and processes involved in the performance of a water delivery system, the information/knowledge provided by different indicators, and the potential of the traditional indicators for evaluating and managing the system.

FOREWORD

IIMI Pakistan has conducted a multidisciplinary research program from 1993-98 in the irrigation sub-division of Chishtian, commanded by a branch canal, Fordwah, and its fourteen distributaries. This area is located in Southeastern Punjab near the Indian border and has a few typical agro-climatic characteristics.

The agriculture related data -- land use patterns, cropping intensities and command area total water utilization -- were also measured by IIMI field staff with the help of local agencies. There is considerable hydraulic data that was collected in Chishtian Sub-division.

One of the major activities was to diagnose the physical and managerial aspects related to the performance of a water distribution system below the main canal level, which could provide insights to the irrigation managers for improving their system. For the monitoring and evaluation of canal operations, collaboration was launched with the Punjab Irrigation Department under the program called Decision Support Systems (DSS). The water measurement system was improved through a re-calibration of the structures and daily measurements of the gauges.

During 1994-96, IIMI Headquarters also provided funding for the performance studies of the irrigated agriculture, which was important in conducting the work presented in this report. This valuable contribution helped considerably in completing this investigation.

This report does contribute towards an understanding of the subject by providing a detailed performance analysis of the internal processes and a comparison of the traditional and contemporary evaluation techniques. Certainly, considerable field data was collected, much analysis completed, and the results provide interesting reading.

Prof. Gaylord V. Skogerboe, Director
Pakistan National Program
International Irrigation Management Institute

ACKNOWLEDGEMENTS

The authors thankfully acknowledge the efforts of the IIMI-Pakistan field teams of Hasilpur and Bahawalnagar, involved in the data collection of Chishtian Sub-division. We appreciate the support provided for the collection and checking of the official procedures and records by the divisional offices of the Irrigation Department and their local operational staff. These information and knowledge provided the opportunity to analyze the performance of water regulation and distribution systems in the Chishtian Sub-division.

The authors also wish to acknowledge the efforts of Mr. M. Samme Ullah for the management and processing of field data used in this study.

The authors are also grateful for Prof. Gaylord V. Skogerboe for reviewing the manuscript, his moral support and able guidance towards the completion of this report.

Finally, the authors would like to extend thanks to Mr. Muhammad Manshah for formating the report and taking a keen interest in its organization and compilation.

Zaigham Habib
Marcel Kuper

1. INTRODUCTION

1.1. BACKGROUND

In recent years, the performance of irrigation systems has become a growing concern for researchers, irrigation policy makers and donor agencies. Professionals belonging to different disciplines have addressed the issue at different levels of the irrigated agriculture system. Classically, the concept of performance for irrigation systems has been used in the sense of monitoring and evaluation of the irrigation facilities. This concept was especially relevant for the controlled, supply driven systems where the duties and targets of a manager have been defined with reference to the maintenance and operation of a canal network to deliver a pre-defined share of water. In these systems, the agriculture side was kept isolated from the irrigation side, mostly focusing on the canal water supply to the farmers. The growth of the agricultural economy, markets and population has increased concerns about overall productivity and sustainability of water resources. In the context of an agricultural production system, agronomists and agri-researchers started talking about the performance of canal commands in terms of cropping intensities, crop yields, availability of markets, etc..

Subsequently, performance assessment procedures developed in two directions: "the process evaluation approach" led to the selection and analysis of discrete parameters representing internal processes and the analysis of their specific behavior using statistical, or mathematical, analysis, while "the systems approach" led to the overall estimation of the productivity and sustainability of water and land resources.

Within IIMI, performance related studies have addressed the methodological, as well as practical, issues during the last few years:

- *Development of a performance framework (e.g. Murray Rust and Snellen 1993; Svendsen and Small, 1992, Molden 1997);*
- *Defining the irrigation (or irrigated agriculture) system, processes occurring in it, different actors involved and the objectives, targets and the measurement techniques (Abernathy 1987 & 1990; Chambers 1992, Murray Rust and Snellen 1993);*
- *Selection and application of performance indicators that allow a comparative analysis of the irrigation systems around the world (Abernathy 1991, Vender Velde 1991, Perry 1996);*
- *Review of Selected Literature on Indicators of Irrigation Performance (P.S Rao 1993); and*
- *Development of procedures to measure productivity, water availability and its sustainable utilization (Perry, Molden 1997, Seckler 1997).*

1.2. THE CONCEPT OF PERFORMANCE ASSESSMENT FOR LARGE-SCALE IRRIGATION SYSTEMS

The performance assessment work carried out in the last couple of years indicates the need to have gross measures of the performance on one side, and an understanding of the involved processes and managerial targets on the other. The later aspect is important in big supply-driven river and canal systems, like in the Indus Basin. The conveyance and water distribution canals in these systems are long and manually operated, canal supplies are not sufficient to fulfill crop demands, land holdings and the investment powers of the farmers vary in a big range, and agricultural practices critically affect the productivity. The water management activities are carried out at different levels of the systems, which influences conveyance and delivery efficiencies in a complex way.

The main issues to be addressed for the performance analysis of these systems are:

a) To identify discrete processes and responsibilities at the level of concern; and

b) To select easily measurable parameters whose statistical and mathematical characteristics could represent the desired function of the system.

To implement a diagnostic procedure for a specific study, an understanding and rationalization of the following needs to be done:

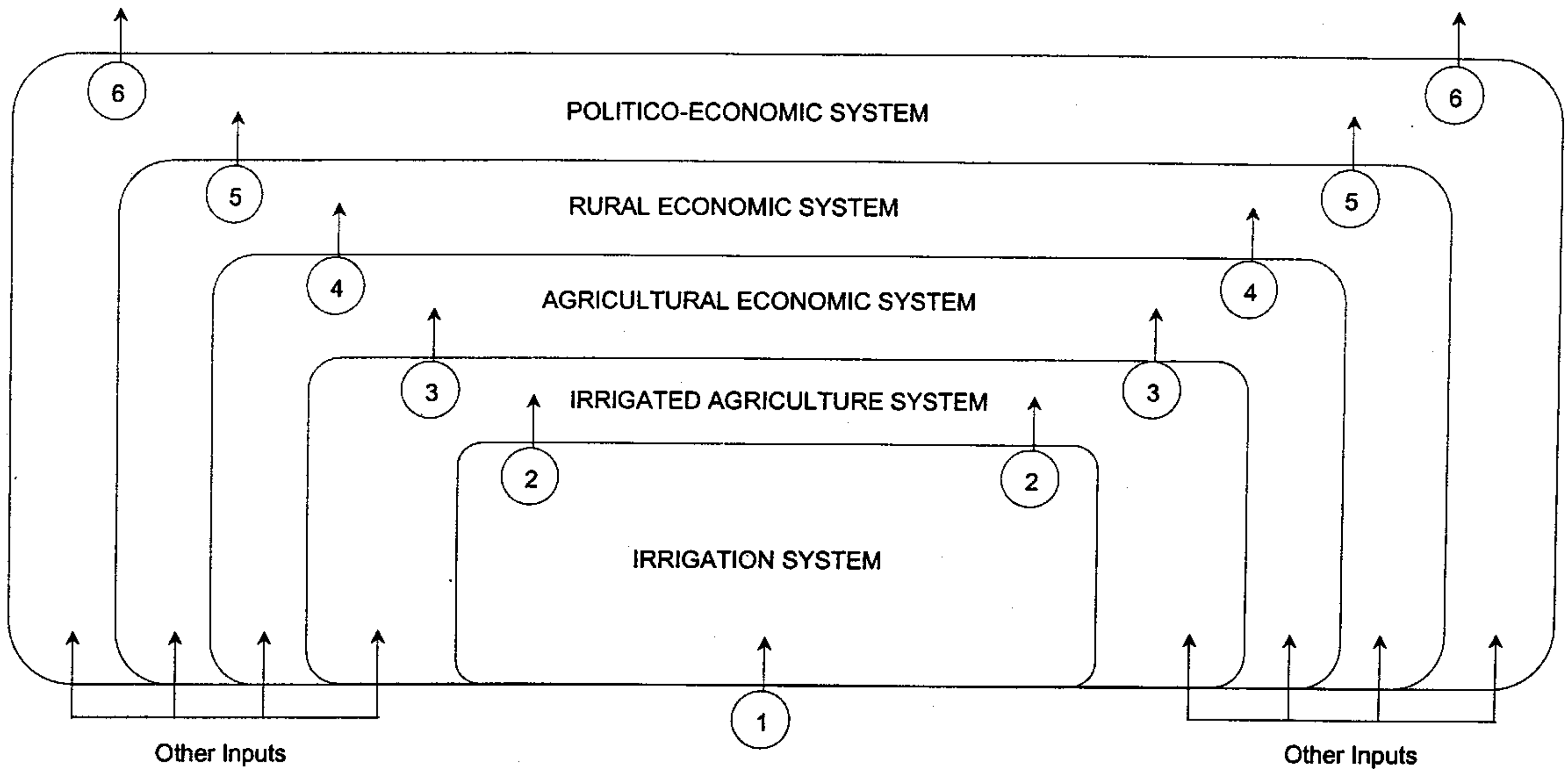
i. *boundaries and levels of a specific research domain;*
ii. *goals and targets of a particular activity or agency;*
iii. *the relation between system performance and management achievements;*
iv. *the role and relationship of different actors; and*
v. *interpreting original targets with reference to the prevailing situations.*

A wealth of literature is available on the framework, boundaries and targets of a process. Mostly, targets are defined by splitting and redefining them with reference to boundaries and objectives of a process, though the same language is not always spoken.

Conceptually, in this study, to link the target-oriented process of canal water deliveries and irrigation supplies with a broader system of agricultural production, the framework of Small and Svendsen, while the criteria and definitions of Ansoff and Abernathy, are used. The following paragraphs briefly explain these concepts.

Small and Svendsen (1992) presented a framework consisting of a nested hierarchy of the systems ranging from irrigation to the irrigated agriculture and then to the national level, which was further discussed by Hammond and Snellen (1993). This framework (reproduced in Figure 1) is taken as a starting point to understand the definition of performance by Abernathy (1989):

Figure 1. Inputs and outputs: Irrigation in the context of nested systems.



<u>Key to Inputs/Outputs</u>

1. Operation of irrigation facilities
2. Supply of water to crops
3. Agricultural production
4. Income in rural sector
5. Rural economic development
6. National development

Source: Small and Svendsen, 1992.

"The performance of a system is represented by its measured levels of achievements in terms of one, or several, parameters that are chosen as indicators of the system's goals."

This definition requires a clear identification of the tasks (objectives) with reference to the activities and actors. In the case of irrigation activity, there is a difference between satisfying the demands of the farmers and an efficient management of the resources, especially true for the water short systems. Hence, the criteria mentioned by Ansoff (1987) could be used to separate two types of targets. Ansoff says that from the viewpoint of society, the effectiveness of an organization's activities can be measured by two complementary criteria:

- *The degree to which organizational products/services respond to the needs of the customers; and*
- *The efficiency with which the organization uses resources in supporting their needs.*

The context of this study is a supply-based contiguous large-scale irrigation system, which is a part of a huge network of rivers and canals, as shown in Figure 2. The system has been very skillfully designed for the robust, minimum and manual operations. To face the network complexities, management complications have been avoided by defining step-wise, hierarchical and locally controlled operations of the system. The links of canal water supply with the production system is kept indirect.

Analysis of the irrigation system carried out in this report follows the design definition of the system. The current situation has been analyzed with reference to the original (defined at the design stage) targets and pre-defined goals of the system. Boundaries of the analysis (processes) and the system (hardware and software) have been clearly defined. The roles of different actors have been discussed only with reference to water management activities; hence, the management role of the irrigation agency is analyzed against their officially recommended duties and procedures. The relationships among different actors are not explored in this report.

This report is the first volume of a two series report, which presents a comprehensive performance analysis of water delivery system at a branch canal level in Chishtian Sub-division. Fordwah Branch Canal delivers water to fourteen secondary canals and eighteen direct outlets. In this area, IIMI-Pakistan has carried out a long-term research on many issues related to irrigation, conjunctive water management, salinity, sodicity, and the water-markets, as well as farmers practices from the main canal to the command area level (Pierre 1997, Kuper 1997). Large amounts of primary and secondary data collected in the sub-division are used for the performance analysis.

The second report is more focused on the aggregate processes of water accounting, land use and productivity at the level of the branch and distributary canal commands.

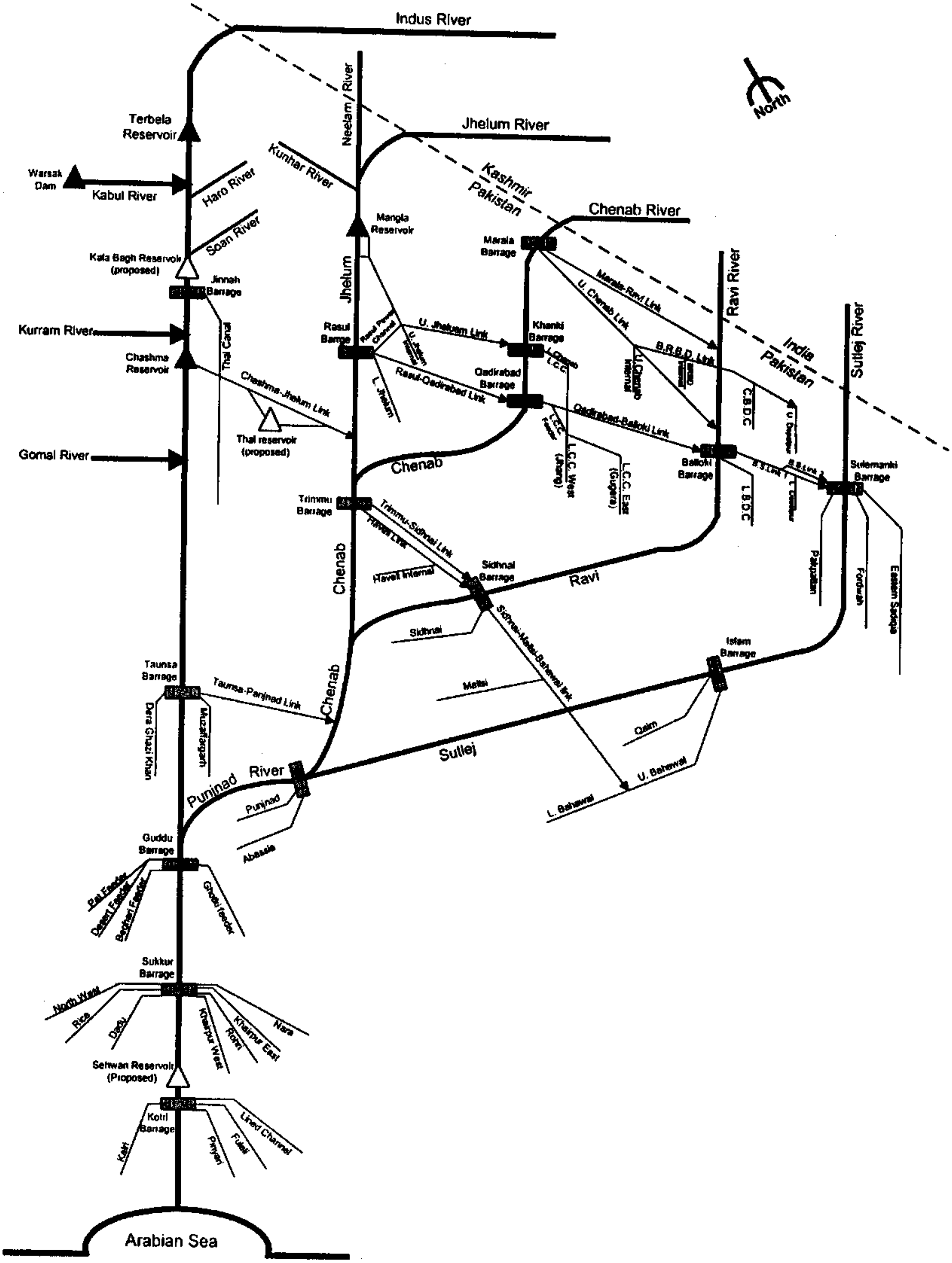


Figure 2. Schematic Diagram of Indus Basin Irrigation system.

2. METHODOLOGY

This section presents the setup of the study by giving a brief account of the objectives, boundaries of the present analysis, and the selection of indicators.

2.1. OBJECTIVES

- To evaluate the performance of canal water allocation and distribution system in the Chishtian Sub-division with reference to authorized water allocation, managerial planning, actual operations of the system, and land use.
- To investigate the gap between planned, available and delivered canal waters to the secondary canals of the Chishtian Sub-division with reference to inherited physical limitations and current management practices.
- To test the applicability of traditional performance indicators proposed at the design stage of the system to monitor and evaluate its performance.
- To apply and compare process-oriented internal indicators recommended and used by different researchers for the analysis of water delivery performance in the Chishtian Sub-division.
- To identify a set of *simple internal indicators,* which could be used to define and evaluate targets and procedures involved in canal water distribution at the secondary level, and subsequently provide better knowledge for water management activities.

2.2. BOUNDARIES[1]

In order to delineate the scope of the study, the following system boundaries[2] are proposed:

- The study is limited to the level of an irrigation sub-division consisting of a network of one branch and fourteen secondary canals. From an operational point of view, an irrigation sub-division is a basic unit of water distribution at the level, where transfer of responsibilities from the irrigation department to the users takes place. "*The maintenance of equitable distribution of supplies are very important in the case of distributaries where according to the present Punjab practice the further distribution is automatic*" (PWD, 1961).
- This report takes into account details of the management and distribution of water, while acquisition and application of water are grossly considered:

[1] See Small and Svendsen, 1992

[2] Small and Svendsen (1992) propose a definition of boundaries in terms of (1) functions performed by a system, (2) life processes of an irrigation system (design, construction, etc.), and (3) the geographic area.

- The characteristics of the irrigation network are discussed in detail, while the behavior of the distributary command area is considered uniform;
- The report focuses on the operation of the system, while the maintenance is not considered directly, but only its link with the operations is discussed whenever necessary;
- The study focuses on the irrigation agency as the main actor, while farmers are only mentioned as far as they influence water distribution; and
- Another limitation of this study is that the canal irrigation system has been monitored and evaluated extensively, whereas the ground water pumpage has been assessed based on the monitoring of sample command areas consisting of eight watercourses, along with a few surveys.

2.3. SELECTION OF INDICATORS

The irrigation agency that manages this system has traditionally used a number of simple indicators that help managers to improve operations at the main canal level, and target maintenance measures at the distributary level. *In this report, most of the water management related official indicators have been tested for the Chishtian Sub-division.*

In addition, statistical and analytical indicators proposed by different researchers have been applied to examine the water delivery, or operational and managerial efficiency, of the system. Some of these indicators are more important with respect to the system's overall objectives (like equity in supply based systems), while others are more informative about the functioning of the operating agency (like delivery performance ratio). A large set of indicators has been applied for the Chishtian Sub-division in order to have a comprehensive analysis, and finally, to identify an appropriate set of performance measures which could be used to supplement traditional indicators of the system. The performance indicators used in this study can be classified into five categories:

- traditional operational indicators (head and tail gauges, target discharge, operational rules);
- indicators related to the control functions of the agency and typical characteristics of the system (seasonal plans, authorized allocations, efficiency criteria for structures);
- indicators appropriate to address the performance of the system with reference to the targets of *equitable, adequate, timely and reliable* water supply to the farmers ;
- simple relations, or parameters, which could be used to evaluate a typical water delivery function of the system (total error term, delivery performance ratio); and
- the gross indices (six of Mao-Zi's indicators).

2.4. DATA ACQUISITION AND PROCESSING

The performance analysis carried out in this report has been supported by a three-year project in the area, which aims to improve water management and monitoring procedures carried out by the local irrigation agency. A data collection and transmission network has been established to monitor the water distribution network with the help of irrigation department staff. All discharge-measuring devices have been re-calibrated. The data on water levels and discharges (head and tail gauge) is conveyed first to the Sub-divisional Officer, Chishtian, who then transmits the data to the Divisional Office. A departmental custom is for these gauges to be handwritten in the official registers by the SDO in-charge of the sub-division, in order to reinforce the importance of the information. Monitoring and evaluation has been developed as a basic part of irrigation systems management. IIMI's involvement in data collection for Decision Support System Implementation has strengthened the existing monitoring of the system.

A summary of the data collection activities launched jointly by IIMI and the Irrigation Department are listed below.

- The Irrigation Department at three out of five cross-regulators, monitors discharges daily. In addition, discharges of 10, out of 14, distributaries were recorded daily. Since 1993, IIMI has supplemented this effort to collect water level and discharge data for all cross-regulators and distributaries. Official target discharges (indents) were obtained from the registers of the Irrigation Department. These indents are available for half of the distributaries.
- To supplement the daily flow data and operational patterns of the cross regulators, hourly measurements were taken for three weeks for all x-regulators and distributaries of the Fordwah Branch. This information includes upstream and downstream water levels, gate openings and the time of operation.
- Tail gauges in the sub-division are generally not collected by the Irrigation Department and were, therefore, monitored by IIMI staff with the help of farmers.
- Crop data have been collected by the Irrigation Department at the *Chak* level. This data has been supplemented by a two-year monitoring of eight sample watercourses and through a few comprehensive crop surveys.
- The Irrigation Department and IIMI jointly measured seepage losses during a training course in 1995.
- Branch and distributary structures have been calibrated by IIMI with the help of ID and International Sediment Research Institute, Pakistan (ISRIP).
- The topography of the branch canal and five distributaries has been monitored in detail, and more than once, for the calibration of a hydraulic model. The cross-sections in the selected canal reaches have been measured for all of the distributaries.

In addition to dynamic data that are collected on a regular basis, the following permanent records[3] of the Department[4] have also been obtained:

- seasonal operational plans, *warabandi* schedules for *Kharif* 94 to *Kharif* 97;
- longitudinal sections of the branch and distributary channels;
- outlet register consisting of design outlet parameters, authorized discharge and command areas;
- design data for all of the structures in the sub-division;
- distributary and watercourse boundaries;
- seasonal cropping intensities and pattern used for the revenue assessment; and
- history of the system.

The primary data collected by IIMI-Pakistan's field staff in Hasilpur and Bahawalnagar is extensively used for the current analysis.

[3] A complete description of all the records available is given in Rehman (1996).

[4] Records are available in the Sub-Divisional, Divisional and Circle offices. The records in the circle office were found to be better maintained and updated.

3. DESCRIPTION OF STUDY AREA

3.1. HARDWARE OF THE SYSTEM

The Fordwah and Eastern Sadiqia area is located in the southeast of the Punjab, and is confined by the Sutlej River in the north-west and the Indian border in the east (Figure 3). Commanding a gross area of 684,985 ha, 593,100 ha are culturable command. The irrigation system originally received its water from the Sutlej at the left abutment of Suleimanki Head works. After a treaty with India on the division of river waters, the Sutlej River only carries surplus flood waters into Pakistan during a couple of months. Hence, all main canals offtaking from Sulemanki are fed through a series of link canals. In the flood season, the water comes mainly from the Chenab River, while during the rest of the year, water is mainly derived from the Mangla Reservoir[5] (Figure 2).

Most of the main canals of the Punjab Province were designed in the late 19th and early 20th centuries as run of the river, continuous supply systems to distribute available river water to a large command area[6] through gravity canals. These systems overlaid earlier (smaller scale) irrigation facilities and extended into large hitherto for non-irrigated tracts ("labeled as crown waste land"). The Sutlej Valley Project was the last big project of the British Government, which was finalized in 1934 with the involvement of two rich Indian States, Bahawalpur and Bekanair.

The Chishtian Sub-division is a 67,000 ha hydraulic unit starting at 61 km of the Fordwah Branch (which off-takes from Fordwah Canal), flowing down to its tail at 113 km, and feeding 5 perennial and 9 non-perennial[7] distributaries (see Table 2). Also it supplies some 18 direct outlets. A schematic diagram is drawn in Figure 4. The present irrigation network has been operated since 1937, replacing and extending an old irrigation system developed and operated by the rulers of Bahawalpur State. The design concepts of the Indus Basin Systems was followed: to maximize irrigated area for low (70 percent) cropping intensities, and to split the system into perennial and non-perennial for optimum use of available water in *Rabi*. However, there have been some special characteristics of the system due to its location and the negotiated agreement between the British government and the two states involved (which are discussed in the next chapter).

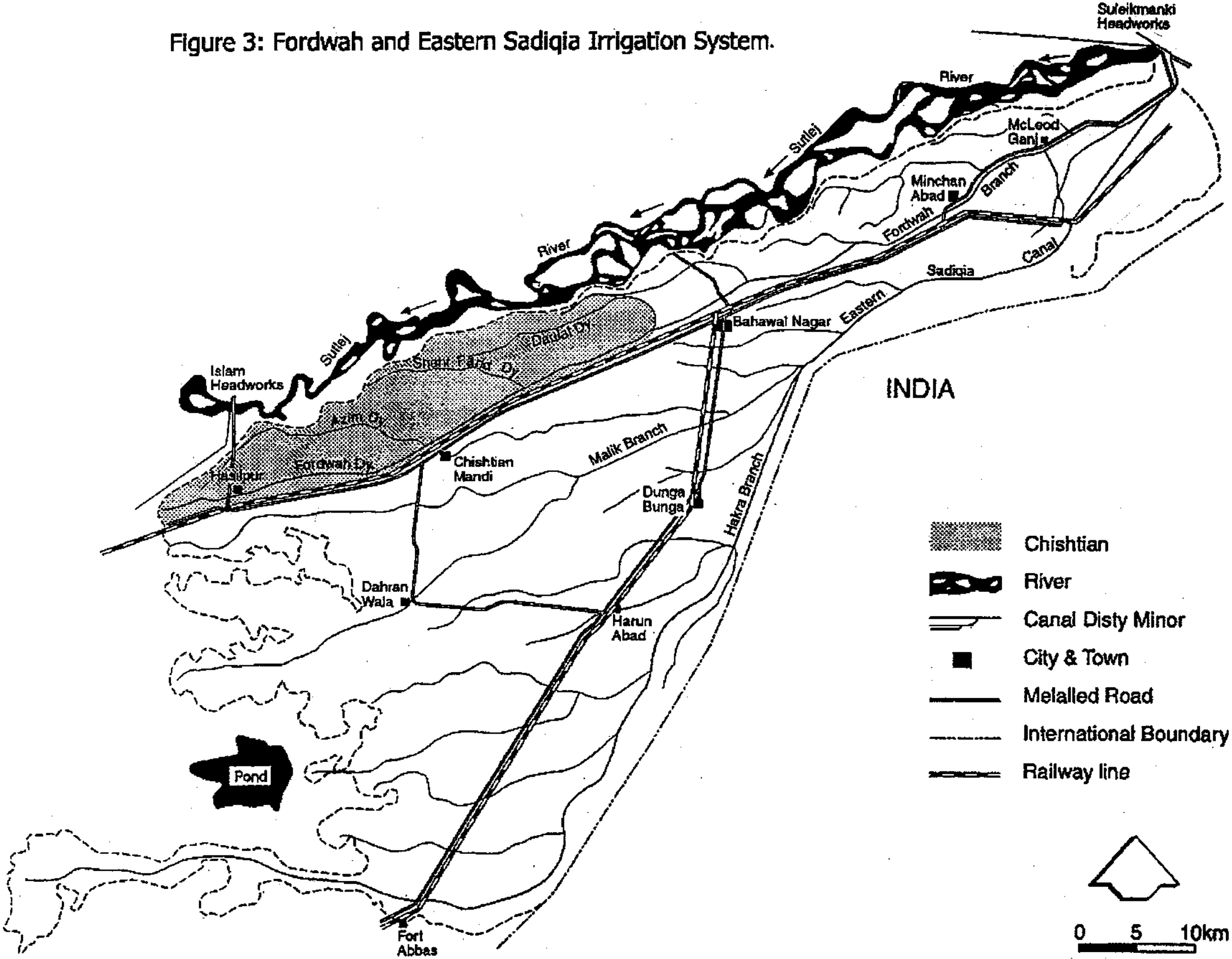
---

5 From the Mangla reservoir, water is diverted towards the Chenab river via the Jhelum river and the Rasul-Qadirabad link canal. From there, water is conveyed to the Ravi river via the Qadirabad-Balloki link canal, which feeds, amongst others, the Balloki-Suleimanki link canal.

6 Irrigation intensities were designed to be fairly low, in the range of 70-80 % over two cropping seasons, in order to maximize the area brought under command.

7 Non-perennial distributaries are entitled to water from 15 April to 15 October *(Kharif)*, while they will receive three "waterings" during *Rabi*, if supplies are available. A watering is defined as a full *warabandi* cycle for a given distributary.

Figure 3: Fordwah and Eastern Sadiqia Irrigation System.



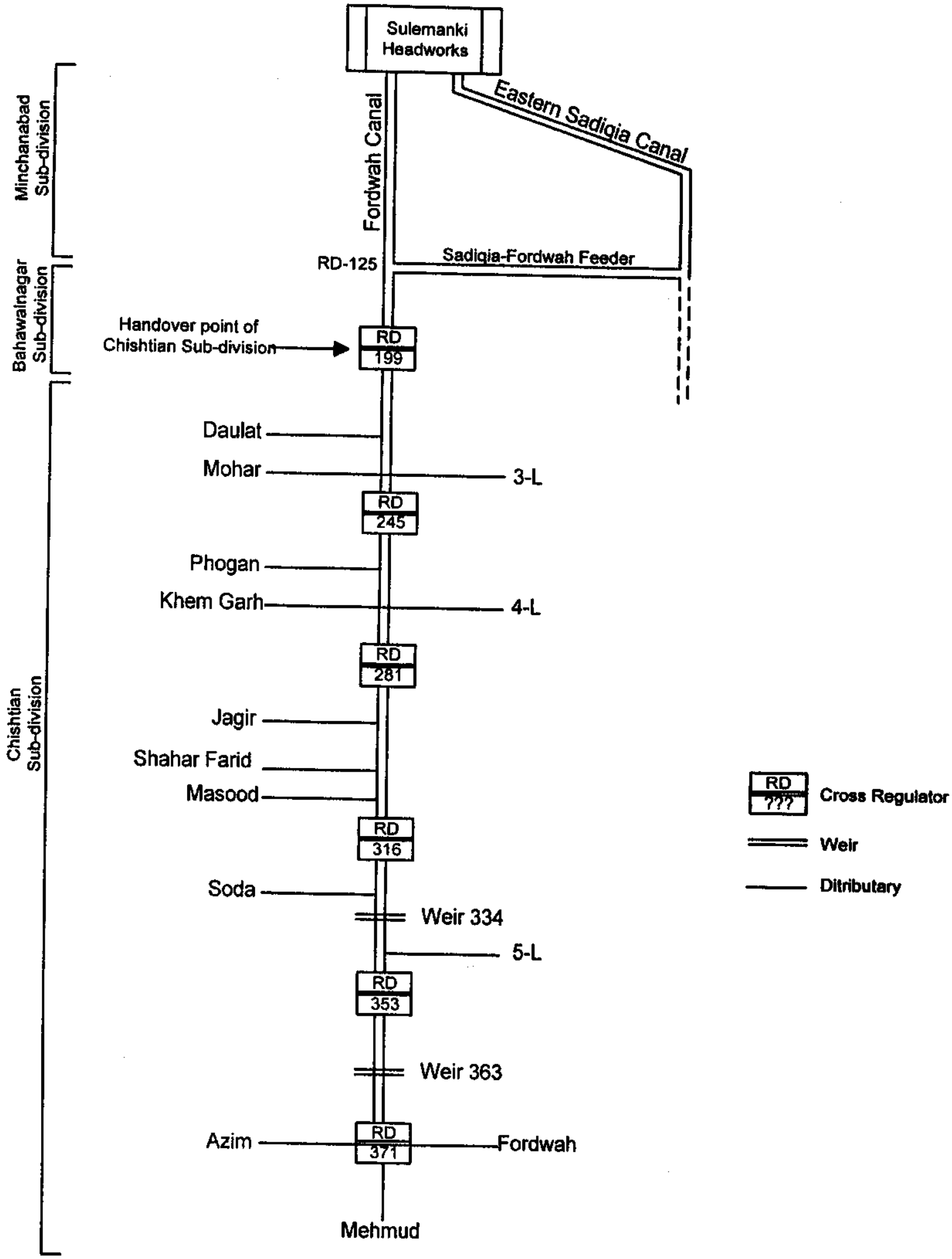


Figure 4. Physical Schematic of Chishtian Sub-Division.

The climate of the command area is semi-arid with annual evaporation (2400 mm) far exceeding annual rainfall (200-400 mm). The area is a part of the cotton-wheat agro-ecological zone of the Punjab, with cotton, rice and forage crops dominating in *Kharif*, with wheat and forage crops in *Rabi*.

3.2. SOFTWARE OF THE SYSTEM

The rules for regulating the canals and organizational setup of the Chishtian Sub-division are the same as elsewhere in the Punjab for that type of system. The water rights of the area are higher than the Punjab averages, as well as the percentage of perennial and non-perennial areas. The procedures, methods and directions outlined at the design stage remains the basic reference for surface water supply software at this level.

3.2.1. Organizational Setup

The management unit for the main canal is a Division, of which an Executive Engineer (XEN) is in-charge. A Division is also a basic irrigation unit for regulation and maintenance. A Division is further divided into two or three Sub-divisions. Normally, the sub-divisional staff takes care of a branch canal. Subsequently, Fordwah main canal is divided into three branch systems and three sub-divisions. Sub-divisional staff are responsible for monitoring and evaluation (M&E) of the branch canal, secondary canals and tertiary head works (outlet structures). In the Punjab, a branch is normally quite a long canal (about 61 kilometers in this case), and is further divided into sections, of which sub-engineers take charge, providing instructions to gate operators and O&M staff. The organizational chart of the irrigation setup is shown on the next page (Figure 5).

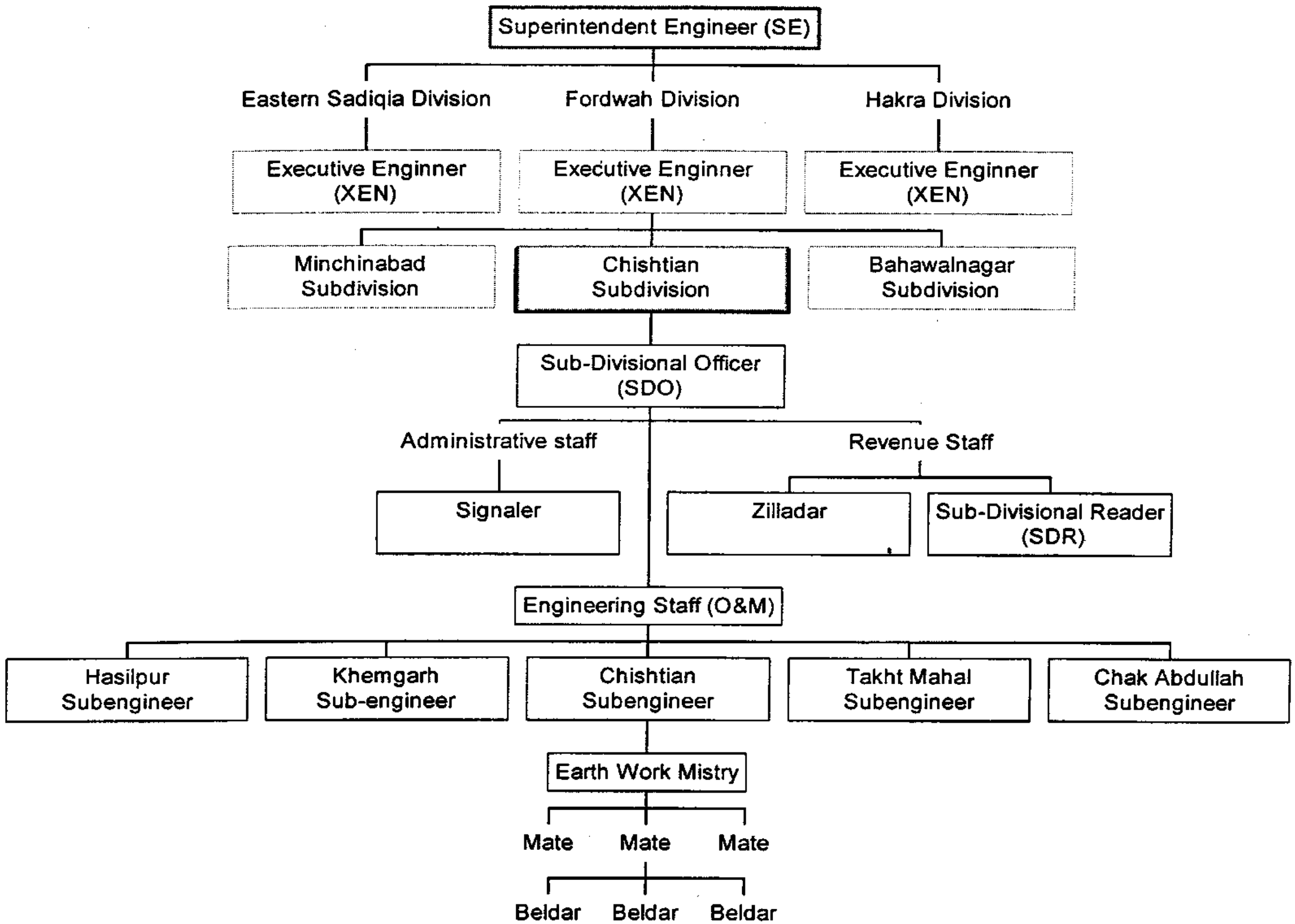
The hierarchy upstream of the Division is more administrative than managerial. Any modification in the system; sanctioning of new outlets, changes in water allocations or modifications in command area are allowed only under special conditions and with the approval of the higher offices. A Superintending Engineer is responsible for a circle office and a Chief Engineer for a zone office. The Punjab is divided into seven irrigation zones.

3.2.2. Official Rules for Canal Operations

In *Kharif*, the authorized discharge of Chishtian Sub-division is 36.4 m^3/s; while in *Rabi*, the authorized discharge is 12.7 m^3/second. Operations of the Fordwah Branch Canal for this discharge range infringes on the general concept of operations within the Indus Basin, where main and branch canals are always required to run at more than 70 % of their design discharge to avoid sediment deposition. In order to handle the *kharif* and *rabi* supplies properly, quite a large number of regulating structures[8] have been provided at the main and branch canal levels, as well as at the heads of distributaries, whereas only in rare cases, regulating structures have been provided below the distributary head regulator.

[8] These structures have either been provided with gates (e.g. gated orifices) or can be operated through vertical or horizontal stop logs (karrees).

Figure 5. Organizational Set Up of Chishtian Sub-division.



Once water is delivered to a distributary, the distribution of water depends on the physical state of the canal (conveyance efficiency), characteristics of the tertiary outlets *(mogha)* and the interference of the upstream users. Inside the tertiary unit, or watercourse, water is distributed following a fixed roster of turns, referred to as *warabandi*, in which one farmer will get the full discharge of a watercourse for a certain time period, depending on the amount of land he has.

Sediment has always been one of the main concerns of irrigation engineers in the Indus Basin. To ensure appropriate velocity, the canals were designed to operate under "regime flow", which means that their discharge should be near to full supply, preferably not going below 70%. The permissible range of 70% to 110% of full supply was given to accommodate fluctuations in supply from the source (rivers), as no reservoirs were provided. According to the regime theory, this range ensures a state of no silting/no scouring; within this range, all structures, specially ungated tertiary outlets, can acquire an equitable share of water and sediment. In the case of Fordwah, the regime theory cannot be followed for the branch canal during the *rabi* season when the canal flows are about one-third of the canal capacity.

3.2.3. Water Allocation

Water allocations to Fordwah and other Sutlej Valley canals were fixed in 1893-1920 after a long dialogue among involved parties (British Colonial Government, Bahawalpur and Bekanair States). To justify the demanded share, each party presented the maximum culturable command area under her jurisdiction, prevailing cropping patterns (irrigated by inundation canals) and the expected future water requirements. The water share was finally decided based upon a rather complicated criterion. Three basic parameters considered were ***availability of water in the Sutlej***, ***water use history of inundation canals*** and the ***maximization of profit from "crown waste land."*** The other factors taken into account were soil type, ground water quality, cost sharing by the involved parties and socio-political factors (Project document 1920, Gazette 1931).

The water allocation to the area was expressed in the seasonal *full supply factors* (same as the water duty), defined as the *"number of acres of culture-able command area to be irrigated with one cusec (ft^3 per second) of water"*. These factors were different for *rabi* and *kharif* and represent the water rights at the command area level. Table 1 shows water duties of all secondary canals during both of the seasons. The expected losses were assumed to be 20% in the secondary canals and were adjusted in the design discharges of the canals. The proposed cropping intensities were slightly higher than the Punjab average for that period (Malsi canal was used as an example with 23% cropping intensity in *kharif* and 30 % in *rabi*). Many committees[9] were formed between 1915 and 1920 to decide about the cropping intensities and water allowance. The water allowance at the watercourse level was computed using the following formula.

---

[9] The document, *"Sutlej Valley Project June 1920"* describes three project proposals prepared in 1913, 1917 and 1920. Only non-perennial supplies to the area were considered in 1913, about 20% of the area was provided with perennial supplies in 1917. The final project of 1920 includes the proposal for Bakhra Dam on the Upper Sutlej and 42% non-perennial supplies. A note prepared by H.W.M Ives, Chief Engineer Punjab (1920) briefs the recommendation of different committees and the water sharing propositions among three parties and the downstream concerns.

For each 1000 acres of C.C.A during *kharif*

Water Allowance = 1000/*Kharif* Full Supply Factor * Intensity/100

The authorized discharge during *kharif* and *rabi*, at the head of the secondary canals was fixed with the same formula, supply factors for both seasons, and the seepage losses.

During the last 70 years, small changes in the original water allocations have occurred at the local level because special allocations have been sanctioned for reclamation of salinity affected lands, for special food supply schemes (i.e. grow more food scheme), for gardens and for fish ponds. Some of the decisions taken at the basin level have also influenced the water availability in the system; two important such decisions are the Indus Basin Treaty with India, and the Water Apportionment Accord among the provinces.

Presently, seasonal cropping intensities are higher than 130 % in the Chishtian Sub-division (132% according the official records of ID, 1993-1995; and 150% according to IIMI survey, 1994). These cropping intensities have been achieved with the help of groundwater, pumped through a series of private tubewells. The average density of private tubewells is 6 per 100 ha in the Chishtian Sub-division, varying from 2 to 9 per 100 ha in distributary command areas.

Table 1. Design Characteristics of Fourteen Secondary Canals (Distributaries) of Chishtian Sub-division.

Name of Distributary	**CCA (ha)**	**Status**	**Design Discharge (m3/s)**	**Full Supply Factor**		**Water Allocation (l/s/ha)**	
				Khari	**Rabi**	**Kharif**	**Rabi**
Daulat	13570	NP	5.9	64	-	0.38	-
Mohar	1446	NP	1.1	50	-	0.49	-
3 L	1166	NP	0.7	64	-	0.38	-
Phogan	949	NP	0.5	50	-	0.49	-
Khemgargh	2032	NP	0.8	64	-	0.38	-
4 L	877	NP	0.5	50	-	0.49	-
Jagir	1604	P	1.1	75	58	0.42	0.42
Shahar Farid	10255	NP	4.3	64	-	0.38	-
Masood	3295	P	1.0	125	97	0.25	0.25
Soda Minor	4093	NP	2.2	50	-	0.49	-
5 L	357	P	0.1	125	97	0.25	0.25
Azim	12199	NP	6.9	50	-	0.49	-
Mahmud	813	P	0.2	125	97	0.25	0.25
Fordwah	14941	P	4.5	125	97	0.25	0.25

3.2.4. Seasonal Irrigation Scheduling

The Executive Engineer (XEN) of each irrigation division is supposed to prepare a seasonal water supply schedule with the help of all involved Sub-divisional Officers (SDOs) responsible for each component sub-division. These plans should indicate an expected flow hydrograph for each distributary in terms of time period and water supply preference. Historically, seasonal plans take into consideration water supply history and seasonal supply factors.

The gap between command area demand and canal water supply has interjected another factor in seasonal planning; a rotation (*warabandi*) has been introduced among, and within, three sub-divisions fed off the Fordwah Canal.

The purpose of a rotational plan is:

- To provide full supply discharge to each sub-division for the maximum duration according to a pre-defined preference order. This situation occurs when the main canal is operated at a discharge lower than its design/authorized discharge, or the accumulated authorized discharge of the offtakes is more than the authorized discharge of the main canal; and
- To supply sufficient water (requested as indent by SDOs) to different components of the system during high demand periods, in case this accumulated indent is consistently higher than the canal capacity.

Both of these situations occur in Fordwah Canal (i.e., supply is less than design discharge) and the indent of offtakes is higher than the capacity of the main canal. Hence, the seasonal rotational plans are essentially required to set a preference roster for the secondary system. These plans should be available at all levels of water management and should be well publicized for the knowledge of the users.

3.2.5. Target Setting for Day-to-day Operations

The seasonal plan provides only guidelines for water deliveries to canal commands. Supplies are often different from seasonal target discharges (this difference should not be too much if the historical pattern is correctly envisaged), upon which the irrigation officer in charge of the head works needs to readjust the target for the main and secondary canals. This adjustment is carried out at all levels. Other reasons for a change in the target could be lower demand due to climatic conditions, or actual crop water requirements.

The target discharge (called indent) of a sub-division should consider water demands of farmers within the canal capacity constraints of the system. According to its definition, indent represents an influence of cropping pattern, crop calendar, climatic conditions and operational limitations. The indent discharge should be given with corresponding water levels and a specification of time for when indent should be met. The higher limit for indent is 120% of the design discharge, which allows maximizing day-to-day demand within the capacity limit of the canal.

For day-to-day real time operation of the distributaries, indent represents targets, but the operations follow the supply hydrograph as well. The following operational rules guide the SDO and his staff in distributing canal supplies.

- Supplies to distributaries should be more than 70 % of the design discharge in order to avoid siltation, but should not exceed 120 % of the design discharge, except in emergencies.
- The main canal must be safeguarded at all costs; if necessary, at the cost of breaches in distributary canals.
- Supplies to a distributary should be ensured for at least one *warabandi* cycle at the watercourse level (7 days) plus one day, allowing for discharge variability when changing the rotation.
- The tail of a distributary should receive a 1-foot depth of water supply, and a manager must ensure that all watercourses in a distributary are served.

4. TRADITIONAL MONITORING, EVALUATION AND PERFORMANCE ASSESSMENT

4.1. RECOMMENDED MONITORING, EVALUATION AND REGULATION PROCEDURES

The Irrigation Departments are responsible for the irrigation network at the provincial level including rivers and flood control structures below the reservoirs. The jurisdiction of the department is broad based and has been comprehensively defined and legally protected. The responsibilities of the department related to the water distribution can be categorized as:

1. *Allocation, regulation and distribution of river and canal water at different levels according to authorized and defined rules;*
2. *Up-keep and maintenance of all irrigation and engineering works below the reservoirs; and*
3. *Assessment of water rates, cropped areas and land revenue.*

To achieve these tasks, the agency is responsible to perform certain management duties followed by control procedures and actions. Most of the action-oriented activities carried out in the department are termed as Operation and Maintenance (O & M) procedures. While, the observation-oriented activities are termed as Monitoring and Evaluation (M&E) procedures, recommended to ensure a good performance of the system. At different levels of the system, the M&E procedures should be followed to achieve given O&M tasks. The recommended M&E can be taken as the traditional performance assessment process leading to the necessary control functions by the management.

The maintenance and revenue collection related activities are not a subject of this report, but it is not out of place to mention that the major responsibilities of divisional and sub-divisional officers revolving around these two tasks. The PID staff is responsible for maintenance up to the head of tertiary outlets, while farmers maintain watercourses below that level. Apart from the responsibility for O&M, Provincial Irrigation Departments are also entrusted with the assessment of water rates and land revenue. Based on the assessment of PID, farmers are charged a fixed amount of money per season for a specific crop they are growing, irrespective of the amount of water that has been delivered.

To carry out the first two tasks of the above list, three type of actions are desired:

- i) *Follow given operational rules to control a water management function as per given operational criteria;*
- ii) *Monitor, record and upkeep the desired values of parameters (gauges, levels, canal sections); and*
- iii) *Monitor and maintain the desired technical functioning of an irrigation device.*

A summary of the recommended parameters and procedures, and their targeted values and standards, is given in Table 2.

Table 2. Traditional Monitoring and Evaluation Procedures and Parameters Recommended at a Branch Canal Level.

M & E Procedure or Parameter	Reference Value or Criteria	Frequency of Observation or Action	Location
Seasonal Operational plan	- Design discharge - Regime operations - Equitable distribution	Seasonal for 10-daily average supplies	- Divisional & sub-divisional offices for planning. - Regulating structures along main canal for implementation
Gauge (reading) and discharge (computed)	- Authorized gauge - Design or authorized discharge - Rating table of each structure for gauge-discharge relation	Hourly during the day	- Regulating points - heads of the main and branch canals
		Twice a day (morning and evening	- Cross regulators - Heads of big distributaries
		Once a day under normal conditions	Distributary head regulators
Tail gauge	1 foot	Once a day, once in two days	distributary tail
Discharge table	Gauge-discharge relationship	Once a season Once a month	All structures
Canal cross-section	As per approved drawing	Once a year	Distributary
Outlet efficiency	Authorized range of H_d / H_u	Once a month	Watercourse inlet
Modularity of a structure	$H_d / H_u > .75$	Once a month	Every structure
Working head of the outlets	Value in outlet register	Once a month	Watercourse inlet
Canal cross-section	As per approved drawing	Once a year	Distributary
Silt intake		- Once a day in flood season - Based on XEN decision	- Main canal head reach - Problematic section of main, branch or secondary canal
Rain-fall		Continuous measurement	- One or more gauges based upon rain pattern

The activities related to the management and operation of water distribution system can be put into three categories.

Water management practices evaluated against recommended procedures and output parameters

These practices are to ensure a fair conversion and distribution of available water supply from an upstream node to the connected downstream nodes. Seasonal planning in the form of a *warabandi* roster is the first step followed by a recommended set of operations. Clear rules exist to design and implement a rotation. The priority roster must be defined in a way to deliver higher than 70% of the design discharge for the maximum period and let each section equally suffer, but for much smaller periods as possible.

Parameters monitored to target real time operations against a reference value

Most of the parameters relate to a real time (hourly or daily) monitoring of water distribution and delivery functions of the surface water supply system. The activities need to be performed under M & E consist of direct readings of gauges against a given reference value. An action needs to be taken if an unjustifiable inconsistency exists between these two values. The parameters related to maintenance, canal capacity and safety of the physical system are usually monitored after a reasonable time interval and restored to the original (authorized) value like watercourse head structures checked monthly and canal cross-sections taken yearly.

Technical functioning of the physical network

The objective is to maintain the discharge measuring ability and equitable distribution capability of each structure from the primary to the tertiary level. The targeted values of these functions are either a head-discharge relationship (rating table) of an individual structure or a ratio of these relations at the upstream and downstream points of a node (efficiency of the outlets). From a SE to the local operator are responsible to take action within a month in the case of malfunctioning physical structures.

4.2. PERFORMANCE ASSESSMENT USING TRADITIONAL MONITORING AND EVALUATION APPROACH OF THE IRRIGATION DEPARTMENT

The procedures and parameters discussed in the previous section are tested for two crop seasons to evaluate the performance of the water delivery system in the Chishtian Sub-division. Since the study focuses on performance of the branch canal and distributaries, the outlet indicators have not been calculated, but briefly discussed to make a proper reference. The silt intake cannot be evaluated since these data are no longer collected by the irrigation agency.

Officially recommended monitoring and evaluation procedures are used to evaluate the following indicators:

- *Seasonal water delivery plans;*
- *Head gauge and discharge;*
- *Modularity of a structure;*
- *Tail gauge;*
- *Outlet behavior; and*
- *Canal cross-sections.*

4.2.1. Seasonal Water Delivery Plans of Fordwah Division and Chishtian Sub-division

The operations of the Sutlej Valley Canals on low supply were expected at the design stage of the system. The Manual of Irrigation Practices Punjab, 1963, exclusively discusses the special operational requirements of these canals [10]. So, a need to have proper seasonal and inter-seasonal planning at different operational levels of the system had always been envisaged at this particular node of the Indus Basin due to historical water shortages, particularly before the introduction of reservoirs and link canals.

The convention of preparing a *warabandi* schedule for three irrigation sub-divisions of the Fordwah Canal exists for the *kharif* season. No plan exists for the *rabi* season because 60% of the system is non-perennial and does not get any water in *rabi*. The operational plans for *kharif* suggest a preference order to operate three sub-divisions on a rotational basis. The shortage at the head of each sub-division is further handled within the sub-division by the local SDO, who, nevertheless, needs an approval from the XEN for the implementation of his plan.

Before 1994, a formal operational plan does not exist for the Chishtian Sub-division. However, an informal rotation among big distributaries existed. In 1994, IIMI helped the local SDO to introduce a weekly rotational plan for the sub-division, which was approved by the department.

The *warabandi* plans of Fordwah Division and Chishtian Sub-division are analyzed for their comprehensiveness and ability to provide guidelines for equitable operations.

4.2.1.1. Warabandi Programs for Fordwah Main Canal, Bahawalnagar Division

Warabandi schedules for 1994 and 1995 are shown in Table 3 and Table 4, respectively. The shaded section, Table 3(B), is the rotational schedule for the Chishtian Sub-division. This plan was prepared by the local SDO in collaboration with IIMI in 1994. The XEN

[10] The manual was first published in 1943 and reprinted by Irrigation Branch of Public Works Department, Government of West Pakistan, in 1963. The section 10.4 of the manual mentions the operation of Sutlej Valley Canal at 55% of the design discharge, which is termed as "the normal discharge" for the non-perennial canals.

Table 3. *Warabandi* schedule for *Kharif* 1994 from 16/04/1994 to 15/10/1994.

Discharge in cusecs	***GROUP A***	***GROUP B***		***GROUP C***
	984	484		1041

Group C = Chishtian sub-division
Total discharge + losses = 2727 cusecs

Split of Group C for the Internal rotation	
C1=	334 cusecs
C2=	293
C3=	411
Total	1038

DATE		**Preference Order**						
		1ST	2ND	3RD		1ST	2ND	3RD
04/16/94	04/23/94	A	B	C		C1	C2	C3
04/24/94	05/01/94	C	A	B		C3	C1	C2
05/02/94	05/09/94	B	C	A		C2	C3	C1
05/10/94	05/17/94	A	B	C		C1	C2	C3
05/18/94	05/25/94	C	A	B		C3	C1	C2
05/26/94	06/02/94	B	C	A		C2	C3	C1
06/03/94	06/10/94	A	B	C		C1	C2	C3
06/11/94	06/18/94	C	A	B		C3	C1	C2
06/19/94	06/26/94	B	C	A		C2	C3	C1
06/27/94	07/04/94	A	B	C		C1	C2	C3
07/05/94	07/12/94	C	A	B		C3	C1	C2
07/13/94	07/20/94	B	C	A		C2	C3	C1
07/21/94	07/28/94	A	B	C		C1	C2	C3
07/29/94	08/05/94	C	A	B		C3	C1	C2
08/06/94	08/13/94	B	C	A		C2	C3	C1
08/14/94	08/21/94	A	B	C		C1	C2	C3
08/22/94	08/29/94	C	A	B		C3	C1	C2
08/30/94	09/06/94	B	C	A		C2	C3	C1
09/07/94	09/14/94	A	B	C		C1	C2	C3
09/15/94	09/22/94	C	A	B		C3	C1	C2
09/23/94	09/30/94	B	C	A		C2	C3	C1
10/01/94	10/08/94	A	B	C		C1	C2	C3
10/09/94	10/15/94	C	A	B		C3	C1	C2

XEN's Note:

- According to the program, first preference will be for 8 days.
- The XEN Fordwah Division will be in-charge of the rotational schedule.
- The supply for the third preference group will depend upon the availability of water
- There could be any change due to shortage, or excess, of water.

Table 4. Warabandi schedule for *Kharif* 1995 from 16/04/1995 to 15/10/1995.

GROUP A	Discharge in cusecs		***GROUP B***		A+B		A+B+Losses+ highland canals
	984			1038	2022		2535
A1=	416		B1=	334			
A2=	284		B2=	286			
A3=	272		B3=	418			
FROM	**TO**	**PREFERENCE**		**INTERNAL SEQ. OF 2ND PREFERENCE**			
		1ST	2ND	1ST	2ND	3RD	
04/16/95	04/25/95	A	B	B1	B2	B3	
04/26/95	05/05/95	B	A	A1	A2	A3	
05/06/95	05/15/95	A	B	B2	B3	B2	
05/16/95	05/25/95	B	A	A2	A3	A2	
05/26/95	06/04/95	A	B	B3	B1	B1	
06/05/95	06/14/95	B	A	A3	A1	A1	
06/15/95	06/24/95	A	B	B1	B2	B3	
06/26/95	07/04/95	B	A	A1	A2	A3	
07/05/95	07/14/95	A	B	B2	B3	B2	
07/15/95	07/24/95	B	A	A2	A3	A2	
07/25/95	08/03/95	A	B	B3	B1	B1	
08/04/95	08/13/95	B	A	A3	A1	A1	
08/14/95	08/23/95	A	B	B1	B2	B3	
08/24/95	09/02/95	B	A	A1	A2	A3	
09/03/95	09/12/95	A	B	B2	B3	B2	
09/13/95	09/22/95	B	A	A2	A3	A2	
09/23/95	10/02/95	A	B	B3	B1	B1	
10/03/95	10/12/95	B	A	A3	A1	A1	
10/13/95	10/22/95	A	B	B1	B2	B3	

Note (a):

Sadhoo, Dona, Naushehra, Bonga , 2-L Distributaries are not included in *warabandi* due to high level, total Q =139

Note (b):

- At the tail of Fordwah Canal (head *hadiwala*), the supply between Fordwah Branch and Macleod Gang Branch will be divided as 13:87.
- If the supply of Macleod Gang Branch at the head is full, then supply at the tail of Mecloud Gang Branch, Heirwah Branch and Fordwah Branch will be divided as 38:62; in case of shortage, if the distributary will be less then 50%, the other will get full supply for 10 days, and then the first one will get full supply for the next 10 days. SDO (Minchanabad) will be responsible for this.
- XEN will be in charge of the rotational schedule. The SE of Bahawalnagar is authorized to effect any change in the program due to excess, or shortage, of water.
- In the second preference group, in case of less supply, distributaries will be closed from left to right in internal sequence. For example, the second group from 16/4 to 25/4 will be dated in case of shortage; first Mahmud Distributary, then Azim Distributary, and last Fordwah Distributary will be closed.
- The dates when *darbari* will be closed will not be used at Karyan RD 72500/Fordwah .
- There should not be any unnecessary heading up.

for the Fordwah Canal approved this program, which was officially adopted for *Kharif* 94. However, in *Kharif* 1995, the XEN prepared a more comprehensive program for the Fordwah Canal system, which includes the internal planning of subdivisions. The plan for 1995 was again adopted in *Kharif* 1996 and 1997.

A recommended practice is to divide a group of canals under rotation into three equal sub-groups to ensure that when the parent channel is operated at 70% of the authorized supply, two of the sub-groups could get their full share. This effort aims to operate a group of canals at the second preference near to the design discharge, while the group at the third preference could be closed.

The rotational plan for *Kharif* 1994 (Table 3) gives a brief account of the preference roster. The document is lacking in the required comprehensiveness of a seasonal plan, because details of the system and operational instructions are not provided along with the proposed schedule. The given information can be summarized as:

- The plan provides a weekly preference order for rotation among three groups of the secondary canals. Names of the distributaries in each group are given but their respective sub-divisions are not mentioned.
- The net discharge involved in rotation is 2727 cusecs, that is, 673 cusecs less than the design discharge of the Fordwah Canal. The seasonal plan does not explain the reasons for keeping 20% of the discharge out of rotation.
- Three groups involved in rotation do not possess an equal total discharge; Group B is half of Groups A and C.
- Some of the secondary canals of the first two sub-divisions do not participate in the rotation for reasons not given; on the other hand, all of the distributaries of Chishtian Sub-division have been placed in Group C, including weir-type head regulators, which practically, could not be closed.

The briefness of the seasonal plan indicates that it is a reference for the manager only and not directly linked to the implementation side. Technically, the grouping procedure of the secondary canals can cause difficulties in the fair distribution of the shortages or excesses.

Group B, which possesses only one-sixth of the total discharge, will be more sensitive to the supply fluctuations and to the priority roster as compared to the two other groups. All of its distributaries will stop getting water when the shortage at the head of Fordwah will be still lesser than 30%; on the other hand, a 20% higher indent for the group during 1st preference can be satisfied by only 3% more discharge in the main canal. In case of a 30% shortage at the head, another group needs to be operated along with Group B, hence its operational significance is less than the other groups. Normally, there is a tendency for small groups to become "privileged sections".[11]

---

[11] The supply pattern of Group B is not monitored in detail and analyzed in this report. The field information about the comparative operations of the sub-divisions indicate that this section is a privileged section which is mostly not included in rotation.

A different approach was adopted in 1995, when the preference setup was changed and a more comprehensive plan was given that provides some explanation of the adopted practices which could be summarized as:

- A proportional share of 13% is fixed for the first branch of the Fordwah Canal, Macleod-Ganj Sub-division, under all conditions -- shortage or excess. A simple plan of operation is given for two minor canals at the tail of Macleod Branch.
- *Warabandi* is planned between two groups of the secondary canals each having three sub-groups. A part of the system from the first two sub-divisions is excluded from the main *warabandi*, and the remaining secondary canals are categorized as Group A, while the whole third sub-division is considered as Group B.
- Five secondary canals of 139 cusecs are kept outside the rotation schedule due to their physical conditions. All of these high level canals are in the first sub-division.
- A fixed priority order (from left to right) to close the canals of Group B is given with an example from the tail section. This instruction is inline with field practice, but does not provide conditions for the proportional distribution of the shortages.

The plan indicates an interesting shift from the approach of 1994. More responsibility has been put on the Groups, which are still three with a change in the constitution of the first two groups. At the main canal level, the operational arrangements have been simplified by using two criteria at the same time, the criteria of proportionality for the Macleod Branch and rotation for the rest of the system. A switch on/off type of operations within Groups A and B in fact leads to more planned operations within the sub-groups. One of the assumptions is that all canals of the three sub-groups of each group can take the maximum supply according to the indent of the local SDO, during the first preference. This can happen under ideal physical conditions of the branch canal and the secondary canal head regulators.

From the management point of view, the rotation proposed in 1994 seems more for the minimization of the gap between demand and supply for the group in the first priority, while the rotation of 1995 is more for the proportional distribution of water shortages.

4.2.1.2. Planned *Warabandi* versus Actual Supply in *Kharif* 1994

The actual supply pattern of the Chishtian Sub-division (Group C) is compared with the rotational plan (of 1994) and the demand and supply records of the department to check the implementation side. The actual discharges measured by IIMI and the data recorded by the Irrigation Department are used for this analysis.

As per rules, Fordwah Branch (Group C) should get 100%, or more, discharge during the first preference, higher than 70% in the second preference, and possibly zero discharge in the third preference. The 8-days targeted and the actual discharges of Fordwah Branch are shown in Figures 6A and 6B.

Figure 6A, shows that no defined preference pattern is obvious from the actual flow hydrograph. The water shortage is a permanent feature but not very severe quantitatively. The sub-division receives higher than 70% discharge most of the time but never more than the design discharge. However, the variability of flows is quite high and inflow into the sub-division remains fluctuating most of the time. The two low supply periods in April and August are during the rains, when there was either a low demand, or supplies were lowered for safety purposes.

Figure 6B shows the seasonal planning, indent of the SDO (short term planning) and the supply recorded by the local staff of the Irrigation Department. Interestingly, demand is not much different from the supply according to the ID register, but both are much higher than the seasonal target and still far away from any weekly plan. According to this information, the shortage expected by the seasonal planning is not there, so, the seasonal plan is not very valid as an operational guideline. The short term planning does not follow any weekly roster, system is more frequently operated but finally the supply match very well to the indent.

If the information provided by Figure 6 are true, a mis-match of the targets exist between the seasonal planning and the short term planning. No operational pattern is proposed by the short-term planning, which is the main weak aspect of the regulation at the secondary canal level.

4.2.1.3. Internal *Warabandi* of Chishtian Sub-division

Information from the operational staff and field data spanning several years indicate that not very well defined operational procedures exist within the sub-division. However, an operational-protocol does exist, which is implemented in case of emergencies like rain, or a breach, and for the day-to-day local operations during low water supply, or high water demand periods.

Everyone is active in the case of emergency; the telegraph office of the sub-division receives messages from the XEN and SDOs of the upstream and downstream sub-divisions, the sub-engineer checks the gauges, and local operators take prompt actions to protect/save their sections. Sometimes problems occur, but more due to communication than operational inefficiencies.

During normal low demand periods, only gate-operators are responsible for operation. Sometimes, they have to rotate two or more distributaries at their nodes; mostly, they have established preferences, they know the physical limitations of the canals more than anyone else and usually they have 'practical operational setups'[12]. During the high

[12] It is important for researchers to understand 'practicality of the things' when suggesting modifications based upon their very precise analysis. For example, even the farmers of two big distributaries which are operated alternatively do not mind if a much smaller channel at the same location always gets water.

Figure 6A. Seasonal Planning, Indent and Actual Supply at the Head of Chishtian Sub-division.

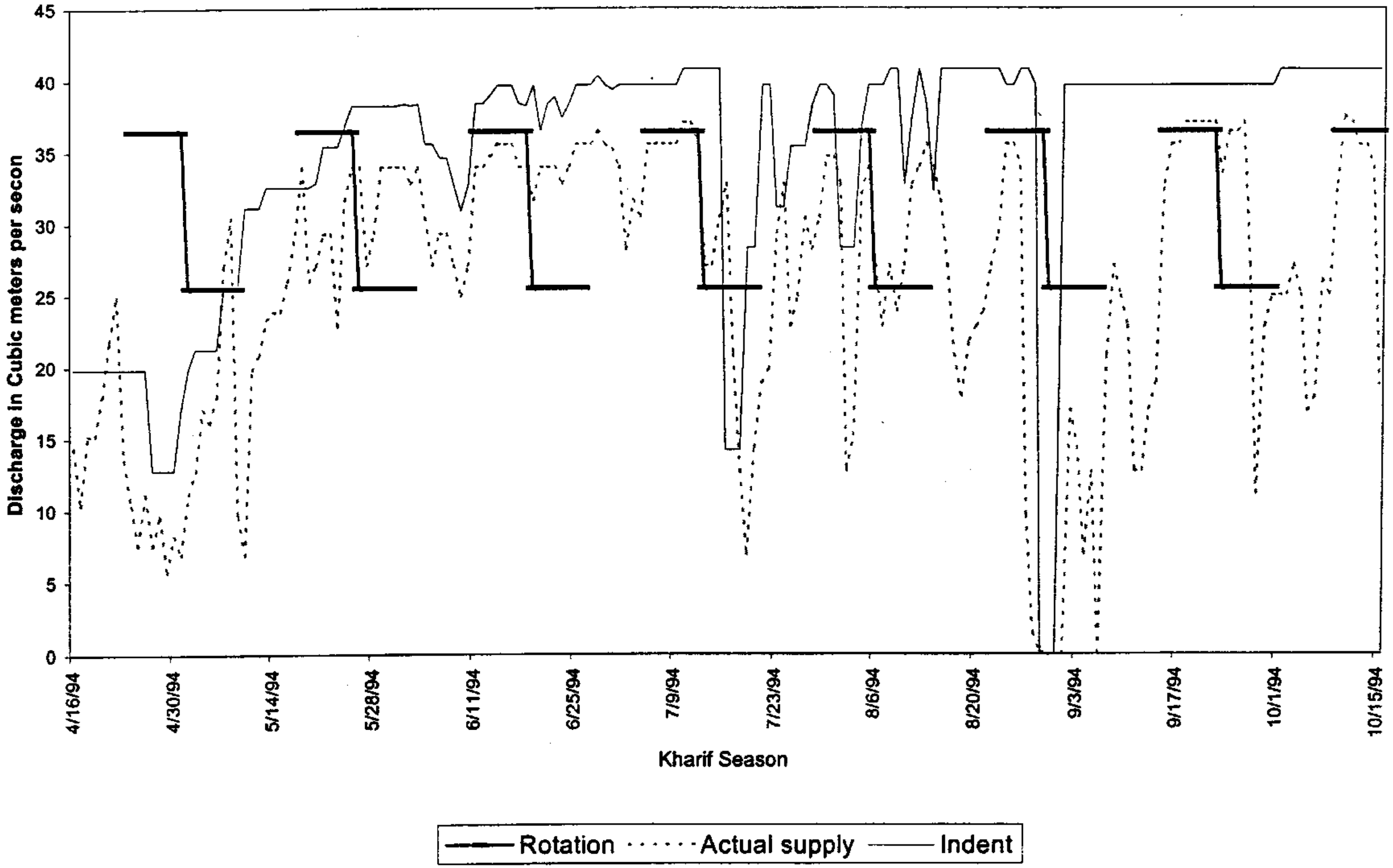
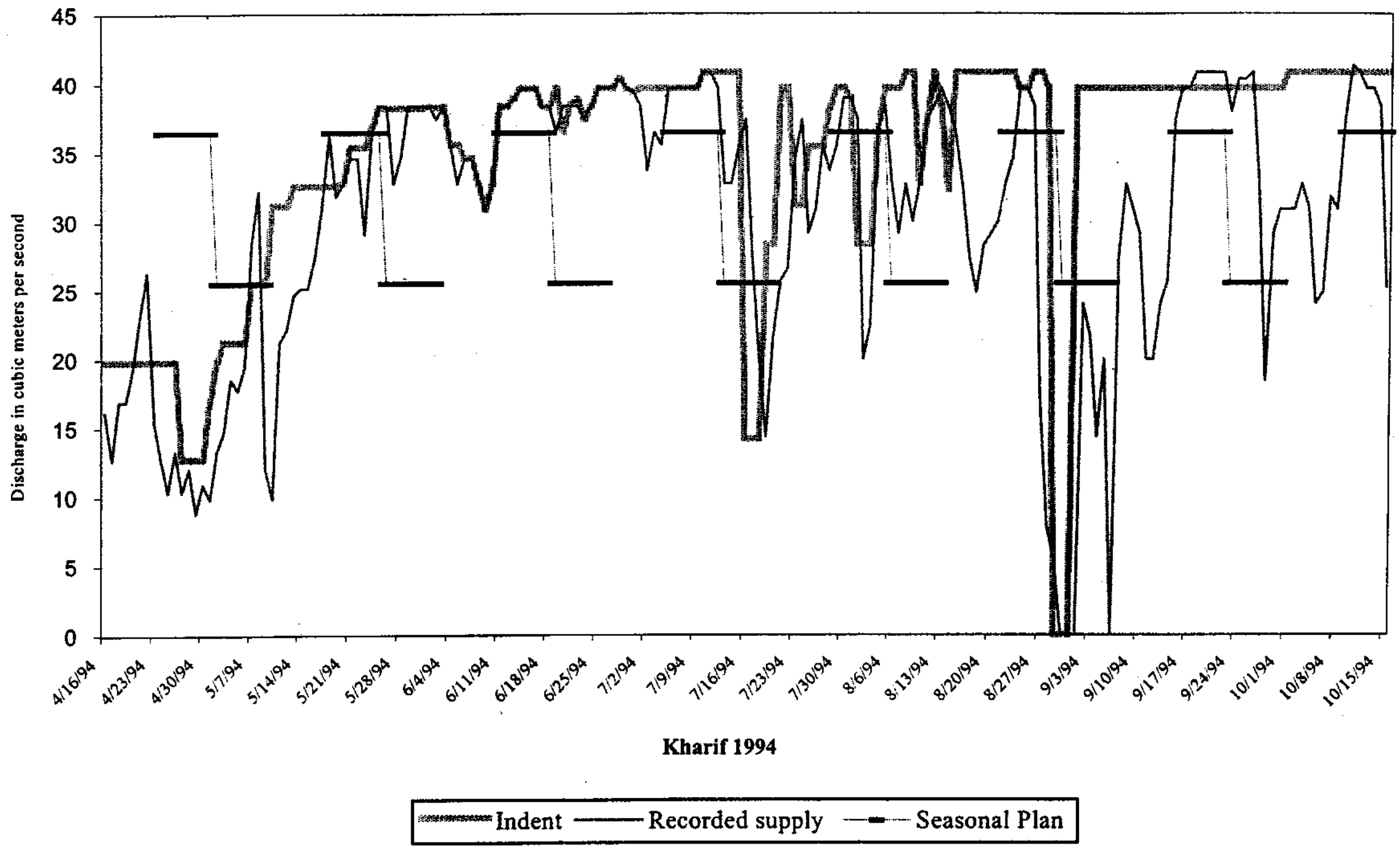


Figure 6B. Delivered Discharges by Irrigation Departmenmt versus the Seasonal Target.



demand periods, operational orders are issued from all higher staff from the level of the Sub-engineer to the Superintendent Engineer.

The warabandi plan proposed in 1994 was the first effort to have an official seasonal planning for the Chishtian Sub-division. However, the preference order of the Chishtian Sub-division, with reference to other upstream sub-divisions, was not considered when the rotation plan for three sections of the sub-division was prepared. A straight 8-day rotation was proposed for three sub-groups of the Chishtian Sub-division, from the start to the end, of the season. According to this plan, the third group of the Chishtian Sub-division, was on the last preference whenever the sub-division was on the last preference.

This flaw has been taken care of in the plan for 1995. Table 5 proposes internal rotations only when the sub-division is in the second preference (there is no third preference for the sub-divisions in this plan). The 1995 Plan assumes that all distributaries of the Chishtian Sub-division can get water when the sub-division is in the first preference. The shortage of the 2nd preference is shared among three groups. If this plan is successfully followed, each sub-group will be on the 3rd preference only for four weeks during the whole season.

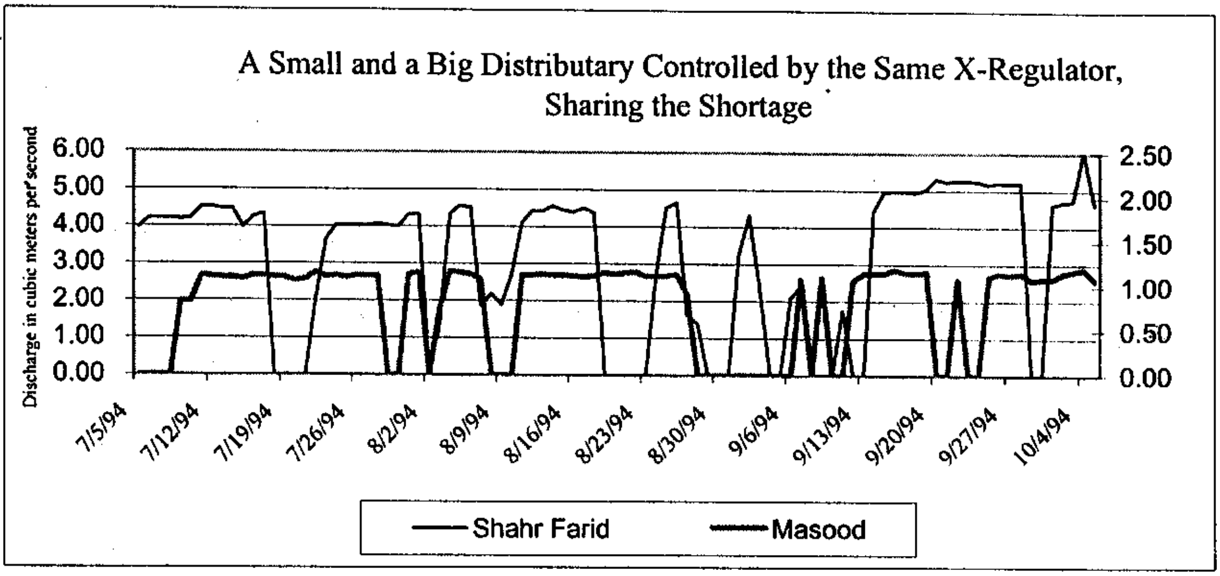
An important instruction given in the 1995 Plan is to close the distributaries from left to right in case of shortage. The technical reason for this procedure is not known, but it justifies the actual practice at the tail of Fordwah Branch, where Azim Distributary always takes a bigger share of the shortage when compared to the Fordwah Distributary.

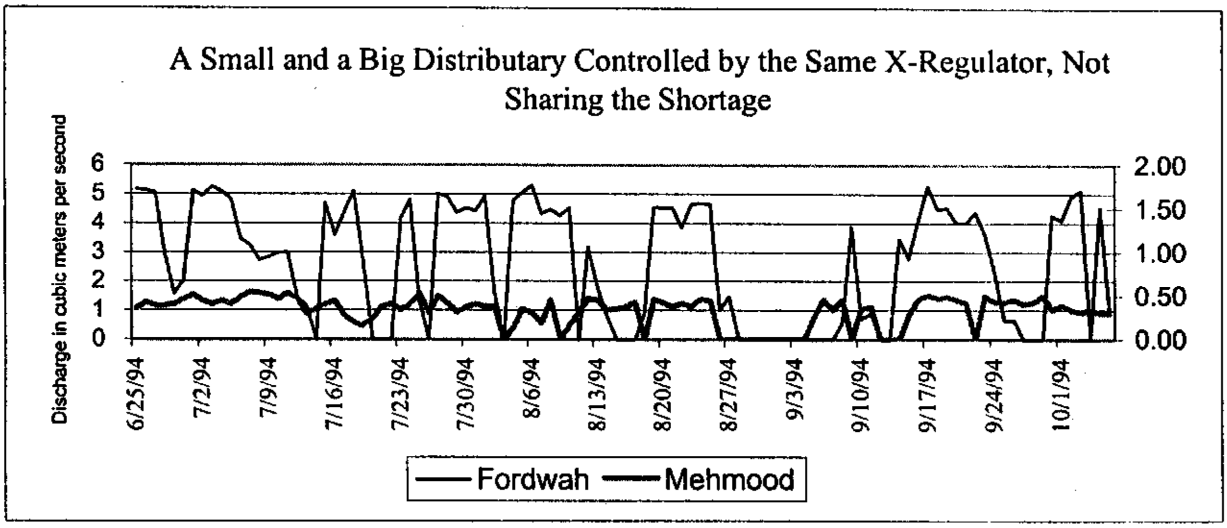
The analysis of the actual situation indicates that the 1994 situation was not very different from that of 1993 or 1995. During all of these years, an irregular type of rotation was carried out among four big distributaries. As a local management tool, some of the small distributaries shared shortages with the big distributaries (for example, Masood with Shahar Farid). A few others are left out of the rotation (for example, Jagir and Mahmud). Four small channels have weir heads and cannot participate in the planned rotation, but always follow the increase or decrease, in the water levels of the main canal. This behavior is shown in Figure 7.

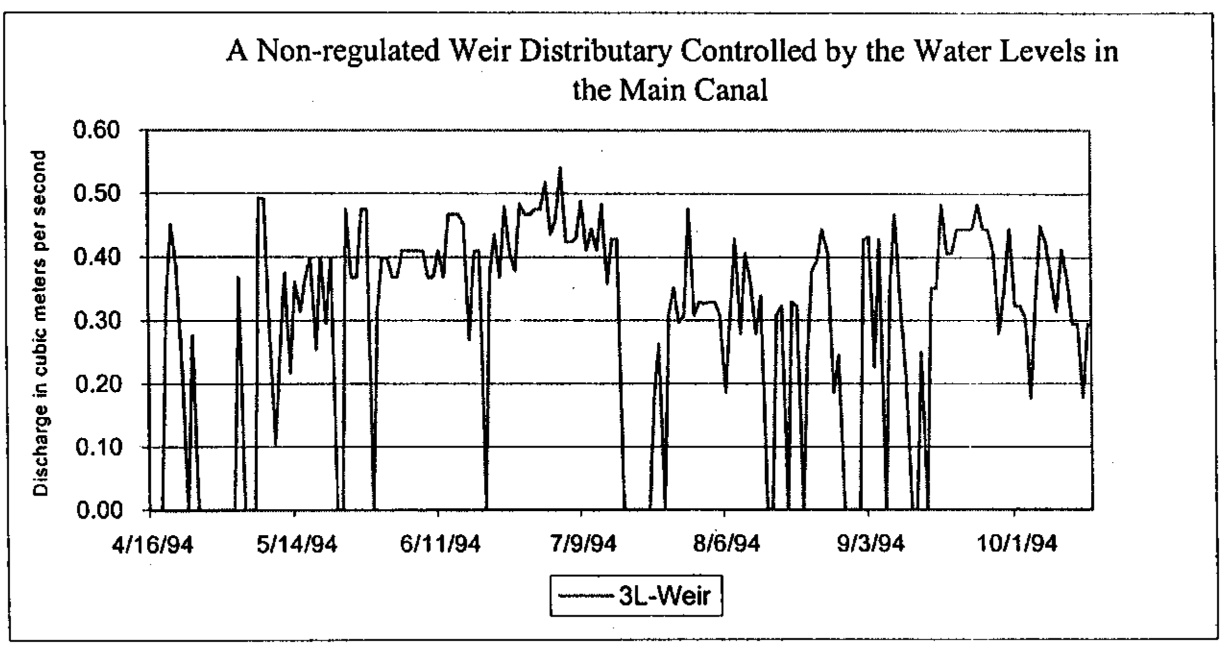
To understand the rotational pattern of four big distributaries, their weekly average supply and indent patterns are shown in Figure 8. Although not very clear patterns exist, the following can be summarized when analyzed with reference to total water availability at the head of the Chishtian Sub-division.

a) Four main distributaries can be operated at the full supply level when discharge at the head of the sub-division is more than 32 m^3/s (design discharge =36.5 cumecs). Practically, this can only be done for a smaller period with maximum precautions, as happened for three weeks in June and July 94, when discharge at the head was near to the design discharge. However, all small distributaries were not operating at full supply discharge during this period.

Figure 7. Local Operations of Regulated and Un-regulated Distributaries of Chishtian Sub-division.

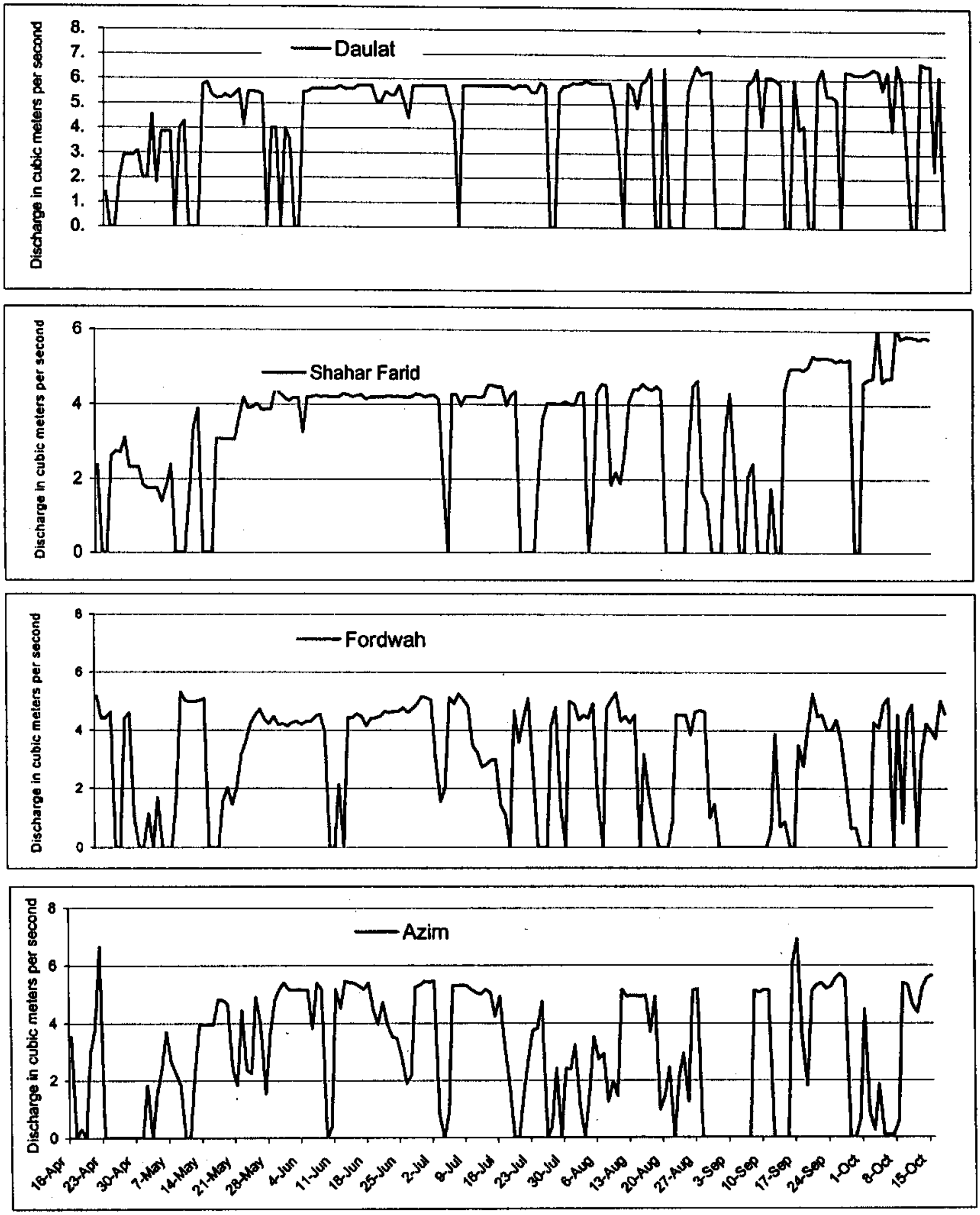






Next >>

Figure 8. Daily Flow Pattern of Four Big Distributaries .



When discharge at the head is in the range of 25-32 m^3/s, either one big distributary is closed, or the shortage is shared by two big distributaries.

b) Shortages are not equally distributed among the four big distributaries. A comparison of Fordwah and Azim Distributaries, from mid-May to the end of June, shows that the Fordwah Distributary was closed for three days, dropped to less than 50% of design for one day, and received a stable supply (120% of indent) for four weeks. While, during the same time period, Azim Distributary was closed twice, dropped to less than 50% four times, and was never stable for more than three days; whereas, Mahmud Distributary was always on full supply (Figure 9). *This is indicative of the fact that there is a definite local operational preference at the tail of the system for Fordwah Distributary over Azim Distributary. This factor is officially justified in the* warabandi *schedule for 1995, when instructions were given to always close the canals from left to right.*

4.2.2. Head Gauge and Discharge

As indicated in Table 2, gauge and discharge at a control structure are the primary parameters monitored and used by the Irrigation Department for water management and distribution. The actual conditions of these parameters have been compared with the improvements carried out during the implementation of Decision Support Systems (DSS) in the Chishtian Sub-division.

4.2.2.1. Head Regulator of the Chishtian Sub-division

The practice of gauge reading is carried out regularly at this location. The downstream gauge and its corresponding discharge is recorded hourly by the local gate operator. A simple rating curve is used for the depth-discharge relationship, which is officially updated once every couple of years.

IIMI's field staff first calibrated this cross regulator in 1993 using the standard structure formula and downstream rating curve. The updated rating curves indicated a difference of more than 150 ft^3 per second from the official table. The discharge recorded at the head by the ID was higher than the actual by this amount. This explains a very high indent requested by the SDO while the maximum delivered discharge is very close to the design discharge, so, the indent carries the difference caused by the rating curve (Table 5).

The design discharge at the head of the Chishtian Sub-division is 1287 cusecs (36.45 cubic meters per second) in *kharif* and 450 cusecs (12.74 cubic meters) in *rabi*. The maximum discharge requested by the Sub-divisional Officer at this point is 1440 cusecs (40.80 cubic meters per second). The maximum delivered discharges indicated in the official register is also 1440 cusecs.

Figure 9. Open and Closure Pattern of Three Tail-end Distributaries Reflected in Daily Discharge.

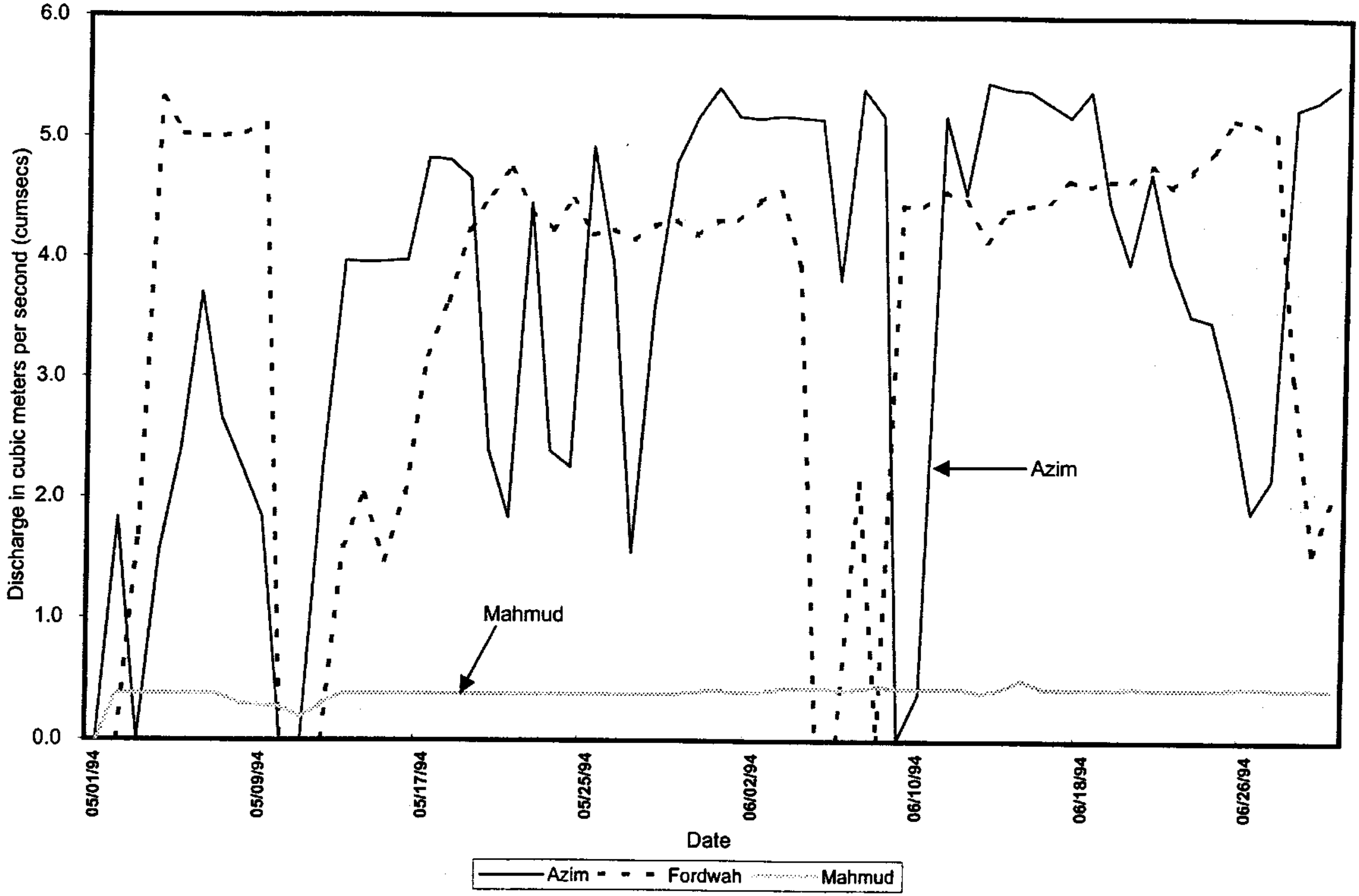


Table 5. Indent, Design and Actual Delivered Discharge (m^3/s) to the Chishtian Sub-division in *Rabi* 1993/1994 and *Kharif* 1994.

Season	*Rabi* 993/1994 Cubic meters per second			*Kharif* 1994 Cubic meters per second		
Discharge parameter	Indent	Delivered ID-Rec	Delivered Actual	Indent	Delivered ID-Rec	Actual
Maximum	19.9	23.2	15.5	40.8	40.8	37.6
Average	16.1	11.9	8.6	34.9	30.2	25.7

The structure formula used for the discharge calculation by IIMI was rechecked in 1994-1995. As the cross regulator is in a good condition, and modular, no variation in the discharge coefficient was found within three years. However, a correction factor in the discharge coefficient at very small and very high gate openings is required, which can be taken care of with a relatively complicated formula (Skogerboe, G.V. 1987).

IIMI also used the KD formula to develop a downstream rating curve for the head regulator, which was found 'less permanent' because of the measurement accuracy of the downstream gauge. Normally, these changes are caused due to changes in the canal cross-section, which was, in fact, not the case at this location. The second important cause could be reinstallation, or adjustment, of the gauge itself, which did occur a few times a year at this important location. The old and new discharge rating curves of the head regulator are shown in Figure 10.

Figure 11A shows the actual, design and indent pattern for the whole year. Obvious from the figure is that the indent was achieved for 50 % of the time, according to the ID register. As shown in Table 5, the actual water delivered was, on average, 24% less than indent in *kharif,* and 45% in *rabi*. In *rabi*, a relatively higher indent is placed at the head of the sub-division.

Another flow characteristic indicated by Figure-11A is the variability of daily discharges and indent in *kharif.* To check this behavior, a two-week campaign was launched to operate the canal under steady state as much as possible. Hourly monitoring of all gauges was carried out during this period. The behavior of Chishtian head regulator is shown in Figure 11B by plotting once a day versus hourly discharges for 10 days. The small adjustments carried out during the day do not affect the total volume significantly, however, the changes carried out on 29th of June and 1st of July indicate that a long-term adjustment could be made after the morning reading of the gauge. Under normal conditions, the variability will be much higher, but the analysis of this report is based on once-a-day reading of the gauges.

Figure 10. Old and New Discharge Rating Curves for Chishtian Sub-division Cross Regulator.

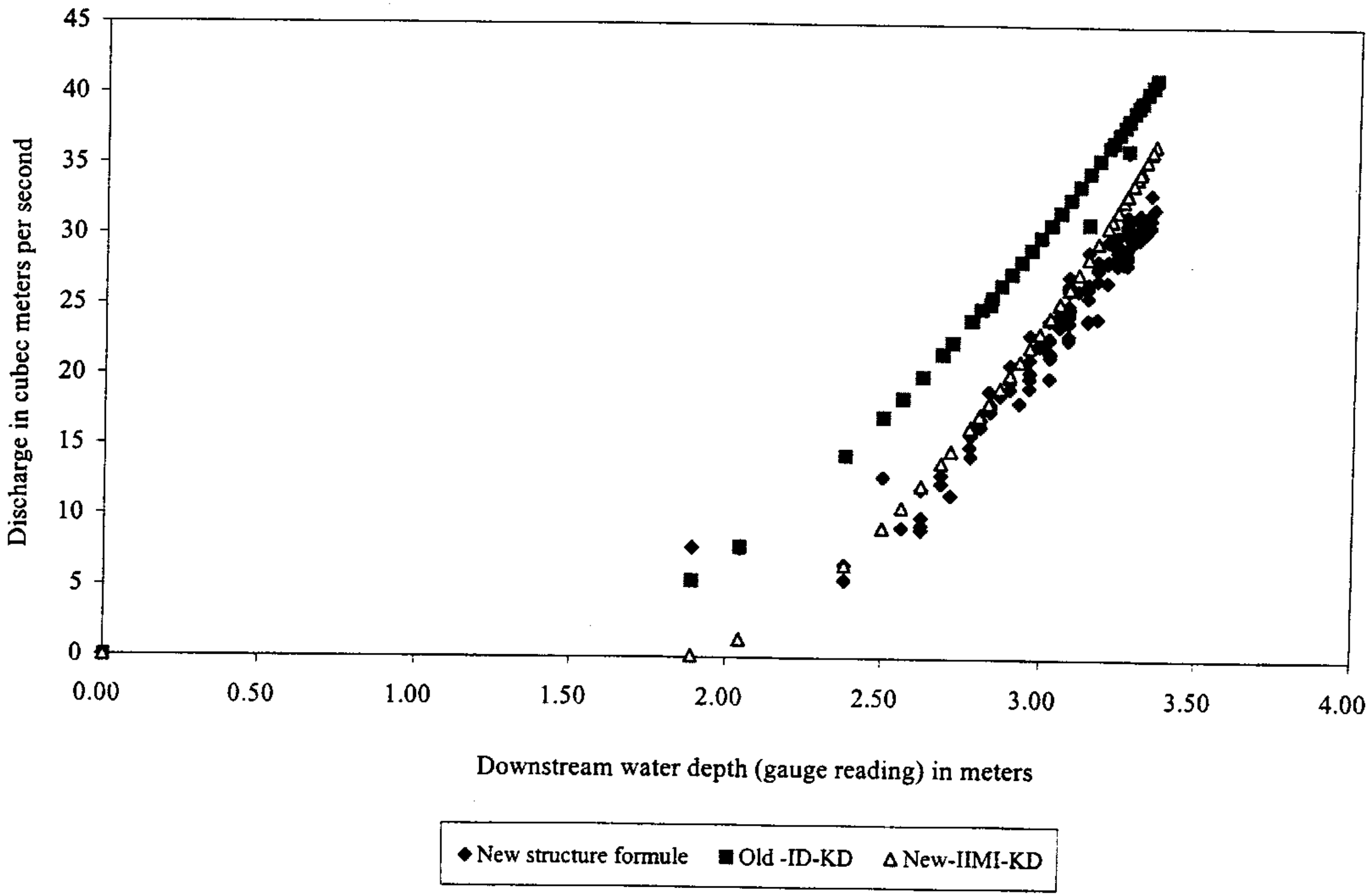


Figure 11A. Actual, Indent and Design Allocations for the Chishtian Sub-division During Rabi 1993-94 and Kharif 1994.

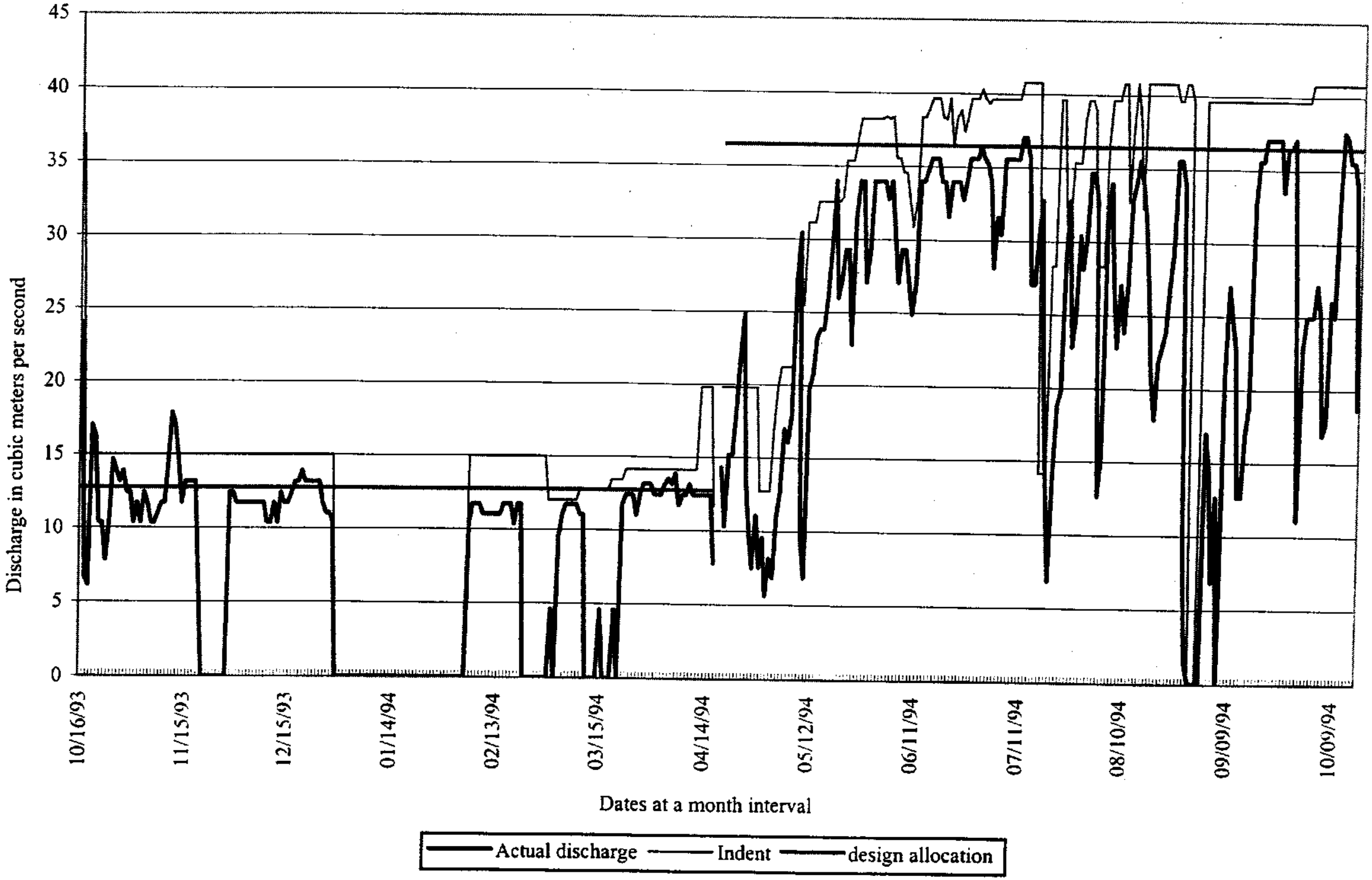
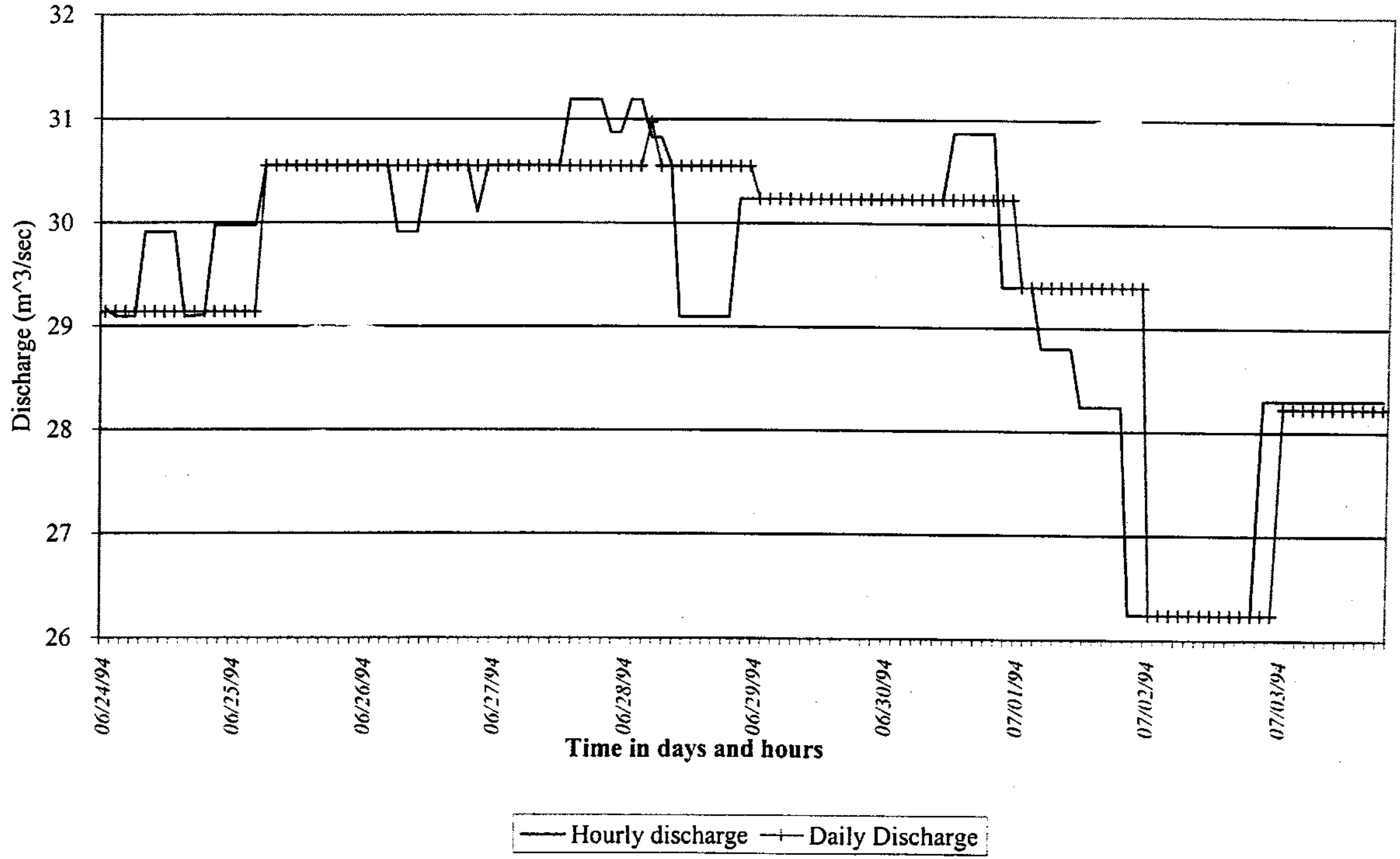


Figure 11B. Hourly and Daily Monitoring of the Head Regulator for Chishtian Sub-division.



4.2.2.2. Head Gauge and Discharge of Distributaries

Officially, the gauges installed downstream of distributaries are collected twice a day for the head section, once every three-hours in the tail sections, and once a day for the remaining distributaries. The gate operator himself has adopted a three-hour interval at the tail. According to him, the reason is continuously fluctuating water levels at the tail, which forces him to operate the gates at smaller intervals.

Accurate information for gauge readings and discharges at the intake of distributaries plays a pivotal role in the water distribution to the tertiary system. Besides trained staff (sub-engineers), this implies good monitoring of the physical conditions of the discharge measuring structures (flumes, weirs), upstream and downstream gauges, and modularity of the control structure. Sedimentation in the downstream reach of the structure can disturb the scale of the gauge, as well as the modularity of the structure. Hence, in most cases, downstream rating tables need to be checked and updated regularly.

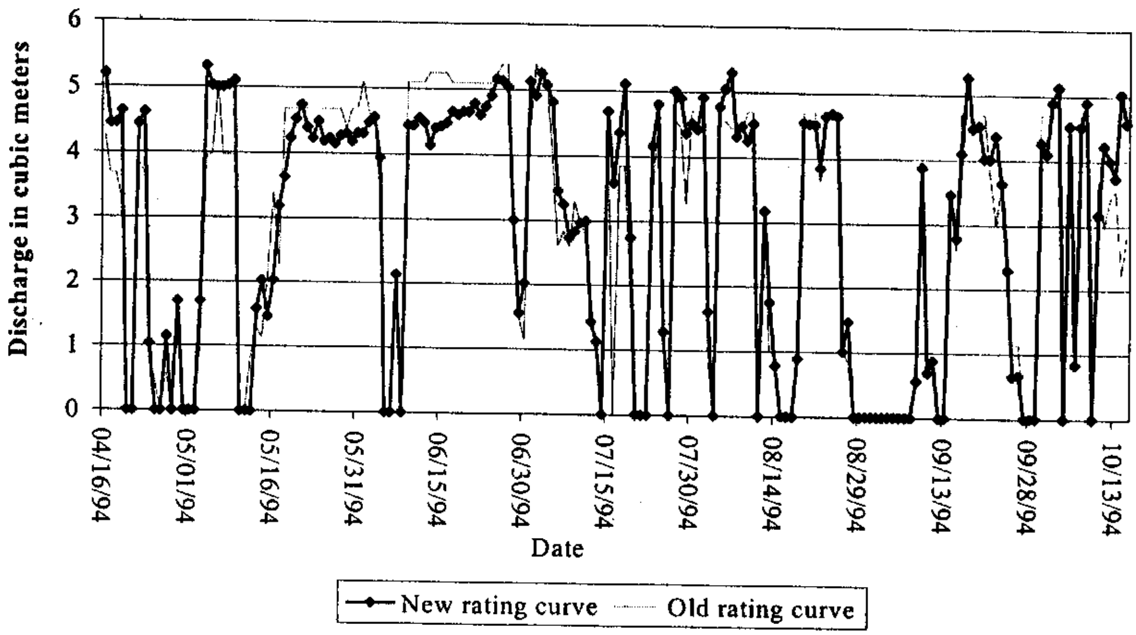
As in the case of Chishtian Sub-division head regulator, rating tables for the distributaries were found to be outdated. IIMI-Pakistan's field staff conducted current metering for all of the structures from 1993-1995, and finally, the issue was addressed in a joint IIMI-irrigation agency field calibration campaign (IIMI, 1995). The discharge coefficients were updated for the structure formula, as well as for the KD formula, used by the department.

The discharges computed by revised and in-practice rating curves for two tail end distributaries are shown in Figure 12 (Azim and Fordwah Distributaries). The revised rating curve for Azim Distributary measures about 15% less than the recorded discharge. Azim Distributary is the biggest, but non-perennial distributary, which has already been given the last operational preference. An out-dated rating curve conceals the real shortage by 20%, during high demand periods, which substantially underestimates the deteriorated water delivery conditions of this distributary. While in the case of Fordwah Distributary, the difference is not so big.

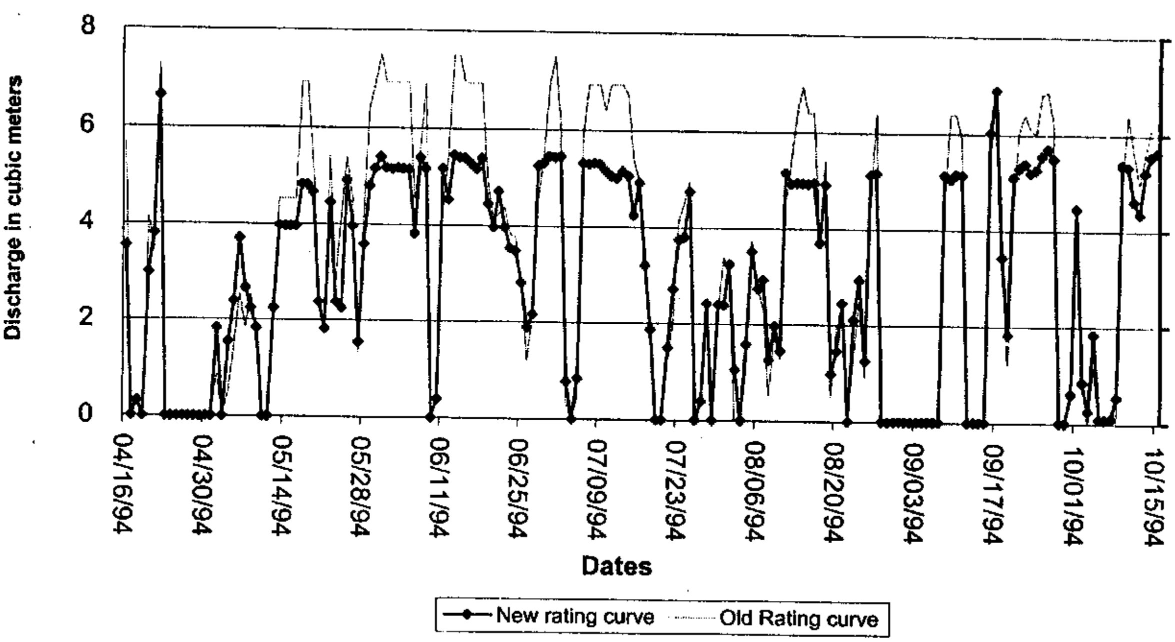
The experience of the Chishtian Sub-division shows that the rating tables, which depend solely on the downstream water levels, need to be updated at least twice a season because of siltation and deformation of the canal reaches (Figures 10-12).

Figure 12. Discharge of Fordwah and Azim Distributaries, Computed by the New and the Old Rating Curves.

(A) Fordwah Distributary



(B) Azim Distributary



4.2.2.3. Regime Operations of the Distributaries

The regime theory of Lacey is strongly recommended for operation of the alluvial channels of the Indus Basin, which dictates a supply of more than 70 % when a canal is operated, and an uninterrupted supply for an entire *warabandi* period (7+1 days). When regime theory and rotational operations are implemented together, a canal should be getting either more than 70% of full supply discharge, or be closed. In actual practice, the group in third preference gets the remaining supply of the two higher priority groups, which could be in any range. Hence, the regime conditions are the target during the first and second preferences, and principally, could be maintained without much efforts.

After re-calibration of the structures and daily discharge monitoring at the head of the branch canal and the distributaries, testing whether all, or most, of the canals of the Chishtian Sub-division could be operated under regime conditions or not, was made possible.

The split of distributary inflow discharges within three recommended ranges of operations, 0, 0-70%, and higher than 70% is summarized in Table 6.

Table 6. Head Regulators Supply Pattern, in Number of Days and The Average Discharge: *Rabi* 1993/1994 and *Kharif* 1994.

	***Rabi* 1993/1994**			***Kharif* 1994**		
	Discharge > 70%	Dry days	Average supply (m^3/sec)	Discharge > 70%	Dry days	Average supply (m^3/sec)
RD 199	31	63	7.76	108	8	37.6
Daulat	NP	168	.21	123	39	3.9
3 L	NP	175	.0128	23	39	0.3
Mohar	NP	178	.014	76	51	.57
4 L	NP	168	.022	106	39	.3
Khemghar	NP	176	.02	113	39	.57
Phogan	NP	115	.09	136	29	.63
Jagir	66	70	.41	131	20	.84
Shahar Farid	NP	167	.15	122	32	3.18
Masood	107	68	.82	144	38	.66
Soda	NP	164	.1	90	24	1.37
5 L	98	78	.09	149	32	.18
Fordwah	95	72	2.83	106	43	2.93
Mahmud	115	61	.23	168	10	.33
Azim	40	142*[13]	.19	60	43	2.98

[13] Azim Distributary has the worst supply conditions, but the number of days its head was getting water in *rabi* is better than in other distributaries. Interviews of the gate operators indicate that these days are more than the numbers shown in the official record. There is a tendency not to close its gates properly when it is closed officially.

Three operational ranges for discharges of 0, 0-70% & >70% are shown in Figure 13. The information given in Table 7 and Figure 13 can be summarized as described below.

Although the branch canal was only closed for 8 days during the *kharif* season (4% of time), it was operated at higher than 70% of design discharge for 57% of the time. If this supply is distributed to the secondary channels under ideal conditions, each area can get near to full supply at least for 38% (2/3 of 57%) of the time, while receiving higher than 70% of the design discharge for more than 57% of the time.

- The discharge pattern of Figure 13 shows that four big distributaries were not getting water from 17% to 23% of the time. Two of them were operated at higher than 70% of design discharge for 65% of the time, one for 60% of the time, and the biggest one, for only 33% of the time. Hence, the regime conditions in these canals were maintained, on average, for 55% of the time, and in the worst case, for 33% of the time.
- Other gated distributaries (Mohar, Khemgargh, Phogan, Masood, Jagir and Mahmud) remained closed for a varying number of days; from 4% to 28%. The regime conditions in these distributaries vary in a bigger range when compared with the four big distributaries; from 12% to 80%. Although these distributaries are small, their operational ranges indicate a need to think about the causes of this big diversity within the system.
- The behavior of four un-gated distributaries (3L, 4L, 5L and Soda) contribute towards understanding the system. The water surface level in the main canal, with respect to their crest levels, determines the water drawing capacity of these channels. 3L Distributary, which is in the head reach of the canal, works under worse conditions; almost always with less than 70% of design discharge. Two tail end channels perform much better. This difference is due to available working heads of these canals and the hydraulic conditions of the main canal.

4.2.2.4. Water Distribution During *Rabi* Season

In *rabi*, five perennial distributaries are supposed to receive a continuous water supply, except during the official canal closure for about a month. The non-perennial canals are entitled to get three weeks of canal supplies during *rabi* for the wheat cultivation. But these supplies and their timings are subject to the availability of water in the main system. Analysis for *rabi* shows that the water delivered to the perennial canals follows less variable patterns than distributaries that operate in the recommended range of higher than 70% discharge most of the time. However, there are more dry days due to closure works. Information about the non-perennial distributaries are not very reliable for this period; apparently, water was not supplied to them for the recommended three turns. The leakage has been recorded in Azim Distributary, where there was less than 10% of the full supply water in the channel for about 30 days (Figure 14).

Figure 13. Regime Operations of Fordwah Branch System in Kharif 94.

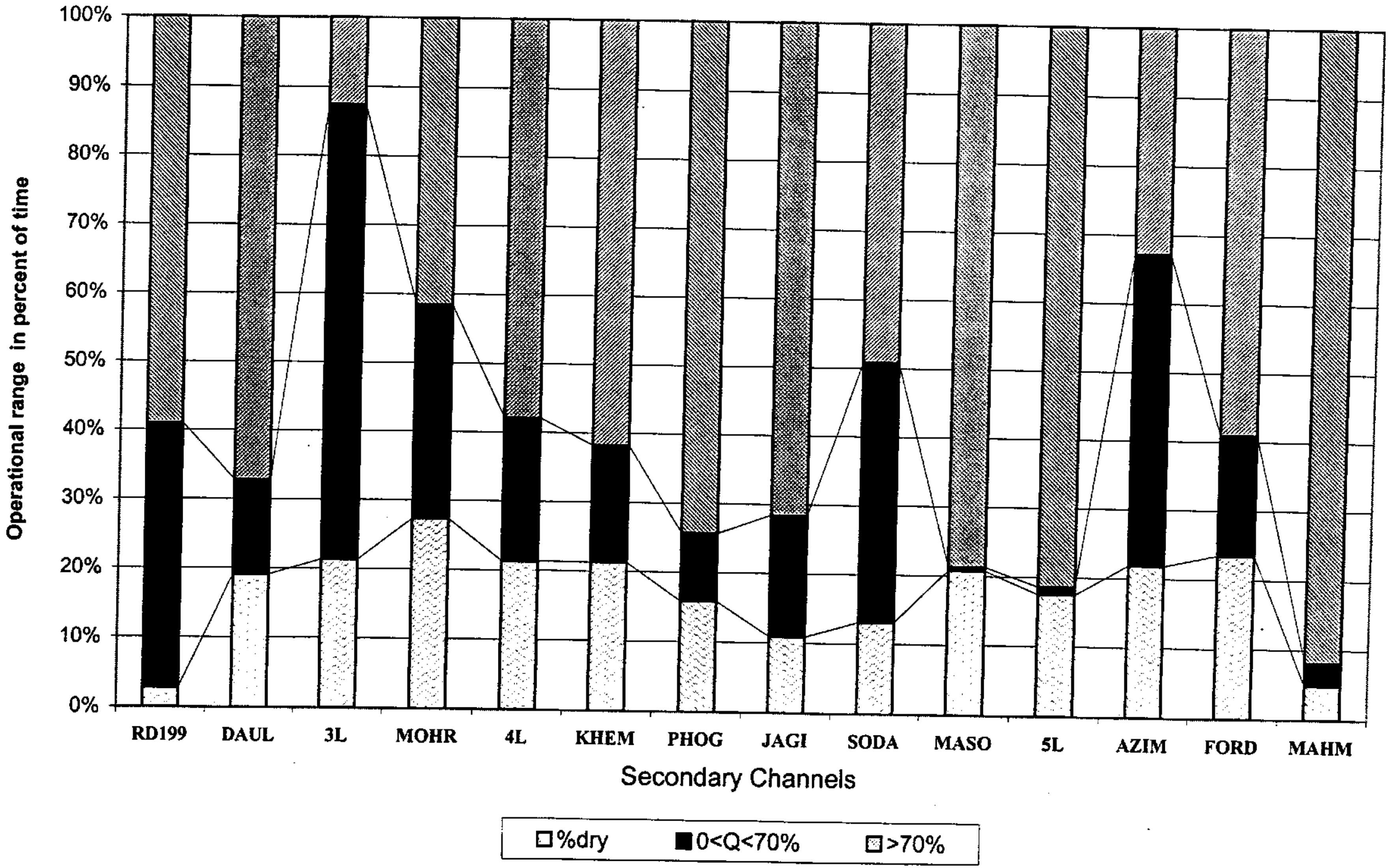
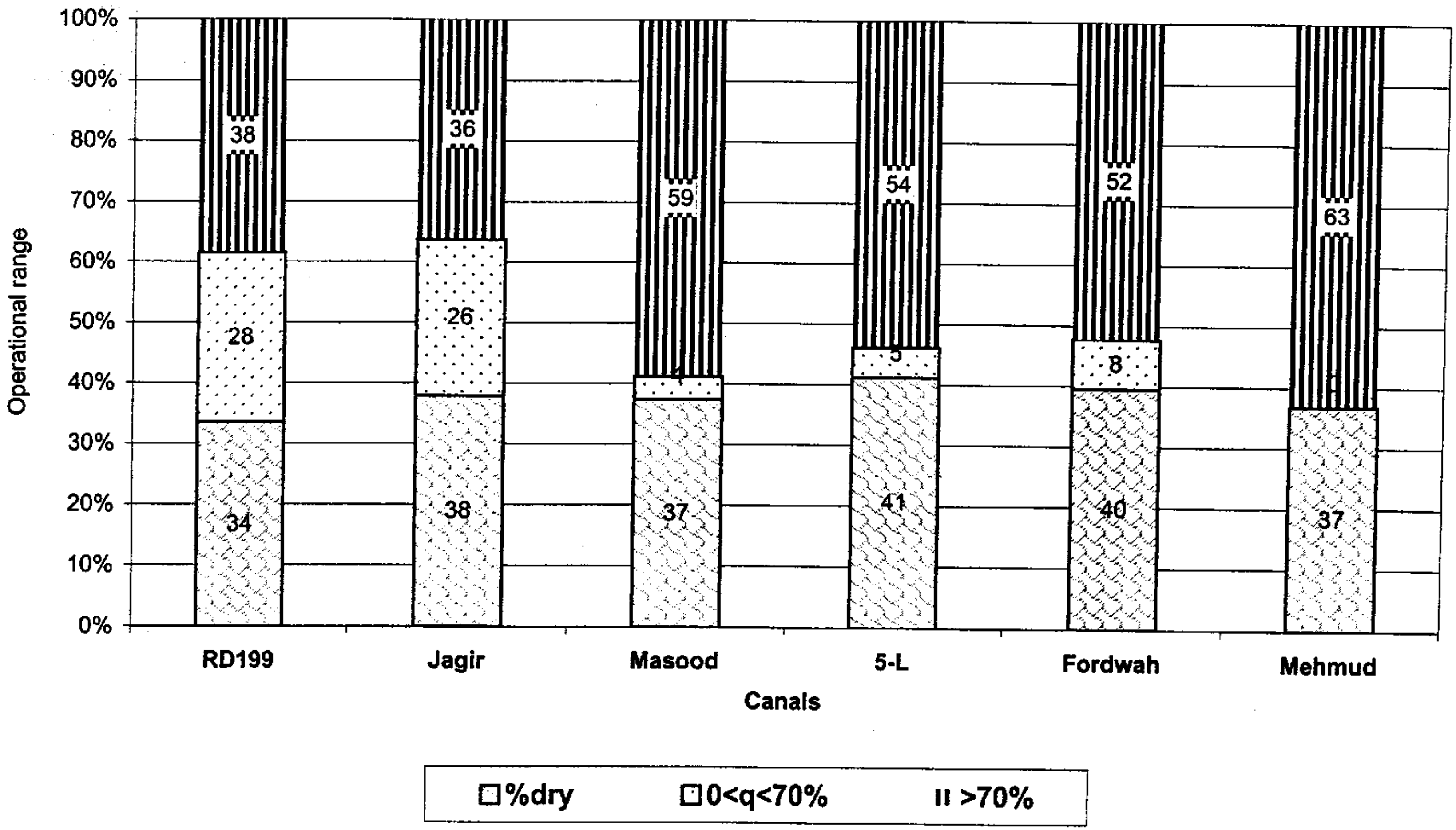


Figure 14. Regime Operation of the Perennial Canals in *Rabi* 93-94.



The head gauge and discharge analysis indicates that the monitoring activities are being carried out, but their effectiveness for the evaluation of the system has lessened due to:

- *Lack of initiative in seasonal planning;*
- *No coherence in target setting at different levels;*
- *Inappropriate gauges;*
- *Out-dated rating curves;*
- *Passive and local implementation of rotation among a few distributaries;*
- *Non-regime operations of the system; and*
- *Passive communication, or feedback network.*

4.2.3. Tail Conditions at the Head of Distributaries

The tail gauges were monitored for three years by IIMI staff, with the help of farmers. The authorized tail gauge is one foot. The tail section is designed to feed the tail outlets equitably at a low working head. Some features of the canal water supply at the tail of Chishtian distributaries are shown in Table 7.

Table 7. Tail conditions of the Distributaries in Chishtian Sub-division: *Rabi* 1993/1994 and *Kharif* 1994.

Distributary	Dry Tail (No of days)	Tail Gauge > 1ft (No. of days)	Canal Length (meters)	Head discharge for tail = 1 ft (% of design)	Q_{max} at the head (% of Q_{design})	Tail Gauge$_{max}$ (ft)
Daulat	130	36	35098	70	113	2.03
3-L	81	102	8230	45	83	2.33
Mohar	57	117	6169	85	117	1.73
4-L	48	53	6005	95	166	1.43
Khem	47	48	7010	100	127	1.53
Phog	38	47	2667	75	220	2.45
Jagir	47	111	4215	65	218	2.41
Sh-Farid	68	4	22823	-	133	1.36
Soda	68	16	13320	100	118	1.68
Masood	61	92	15941	100	146	1.66
5-L	46	46	3444	140	320	1.47
Azim	97	64	37996	70	100	1.71
Fordwah	88	83	42605	110	136	2.2
Mahmood	9	168	3615	100	198	2.2

Two big distributaries, Daulat and Shahar Farid, have good head supply conditions, but their official tail gauges are mostly nil, due to special operational conditions in their tail reaches. In the case of Daulat, the last two outlets of the distributary belong to one family, where water is mostly diverted to the command area from the upstream outlet in order to increase the water use efficiency at the farm level. In the case of Shahar Farid, the original tail has been practically curtailed after floods in 1976, and the functional tail continues to shift, even at the maximum supplies. Hence, for these two distributaries, tail gauges are not representative, but are still considered as the official tails of the distributaries.

Table 7 shows that, in general, tails of the big distributaries (Fordwah and Azim) were not getting water from 40 to 70% of the time, while the tails of small distributaries were dry for 25 to 40% of the time. Also, it shows that the maximum tail gauge in *kharif* is much higher than the recommended value of one foot. A few factors can contribute to this behavior:

- due to conveyance inefficiency and maintenance problems, tails of the longer distributaries are more likely to be dry;
- tails receive water when it is higher than the design discharge, or surplus in the upstream reaches; and
- physical conditions in the tail reaches have changed canal cross-sections, hence, the tail gauges and their calibration.

For the Irrigation Department staff, benchmarks to be monitored and maintained at the distributary level are head and tail gauges and discharges, if no other regulation structure exists. An assumption is that a channel in good condition will be able to convey the tail's share if it is operated under regime conditions. But, if a canal is silted up or other physical problems exist, the required head discharge could be higher. To evaluate the relation between the actual head discharge and tail supply conditions for the secondary canals, $Gauge_{tail}$ versus Q_{head} is plotted for all distributaries. The appropriate discharge at the head, for which the tail will receive one-foot water supply, is estimated from these graphs (Column 5 of Table 7). To represent different situations, the head-tail relations for three distributaries are shown in Figure 15A to 15C.

The Fordwah Distributary is a big distributary, functioning properly according to Chishtian standards. The tail supply is certain when the head receives a supply in the range of 90% to 120%, and no upstream intervention occurs (Figure 15A). The dry tail during good head supply (points on the x-axis) is due to upstream interventions and the time lag between head and tail. The scatter shown by the graph is caused by the fluctuations in head supply. A few points on the y-axis and low supply area are due to time lags. However, water depth at the tail is more than recommended, mostly, in the range of 1.2 to 2.2 feet.

Figure 15A. Water Depth at the Tail versus Discharge at the Head of Fordwah Distributary; Kharif 94.

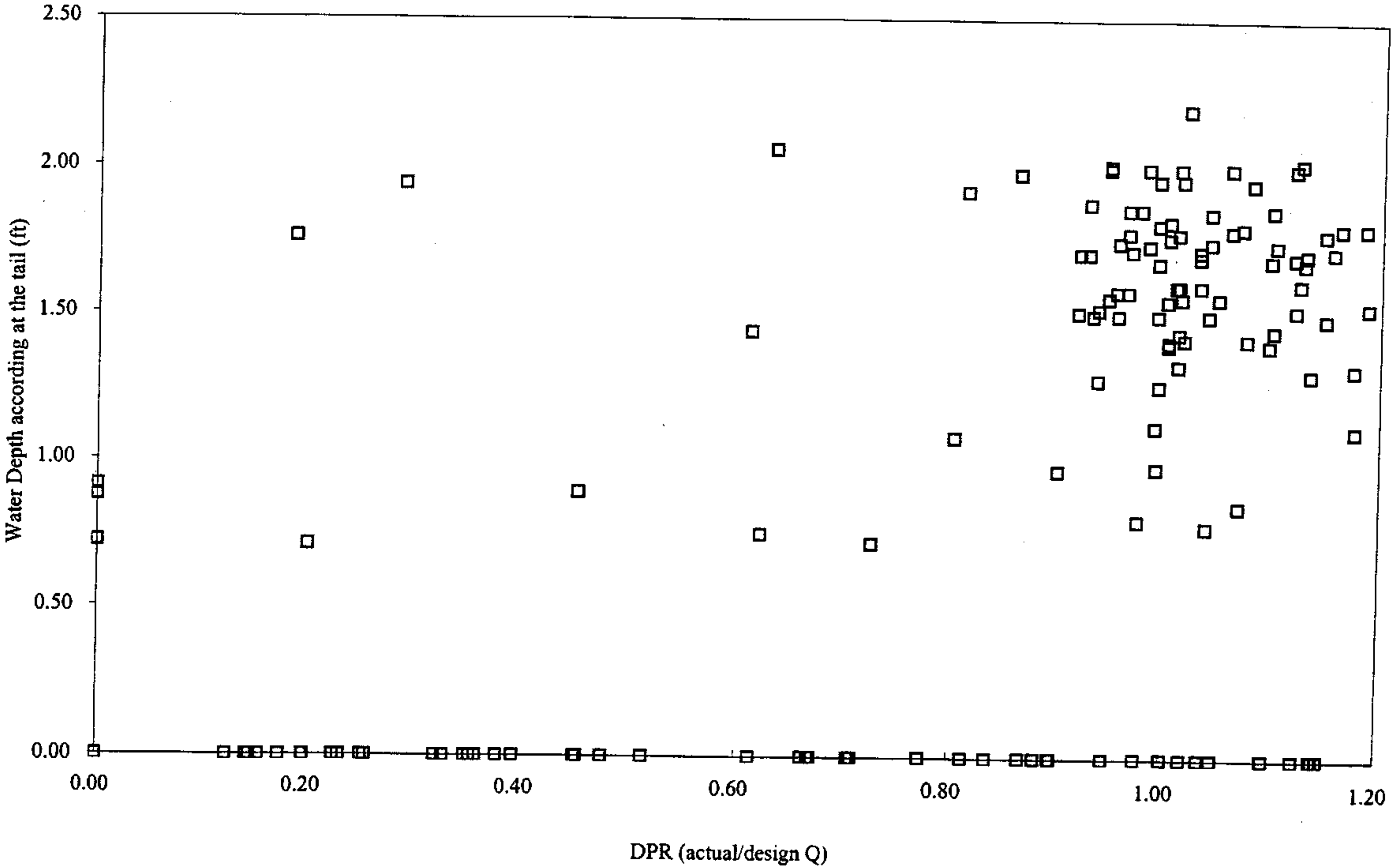


Figure 15 B. Water Depth at the Tail versus Discharge at the Head of Azim Distributary; Kharif 94.

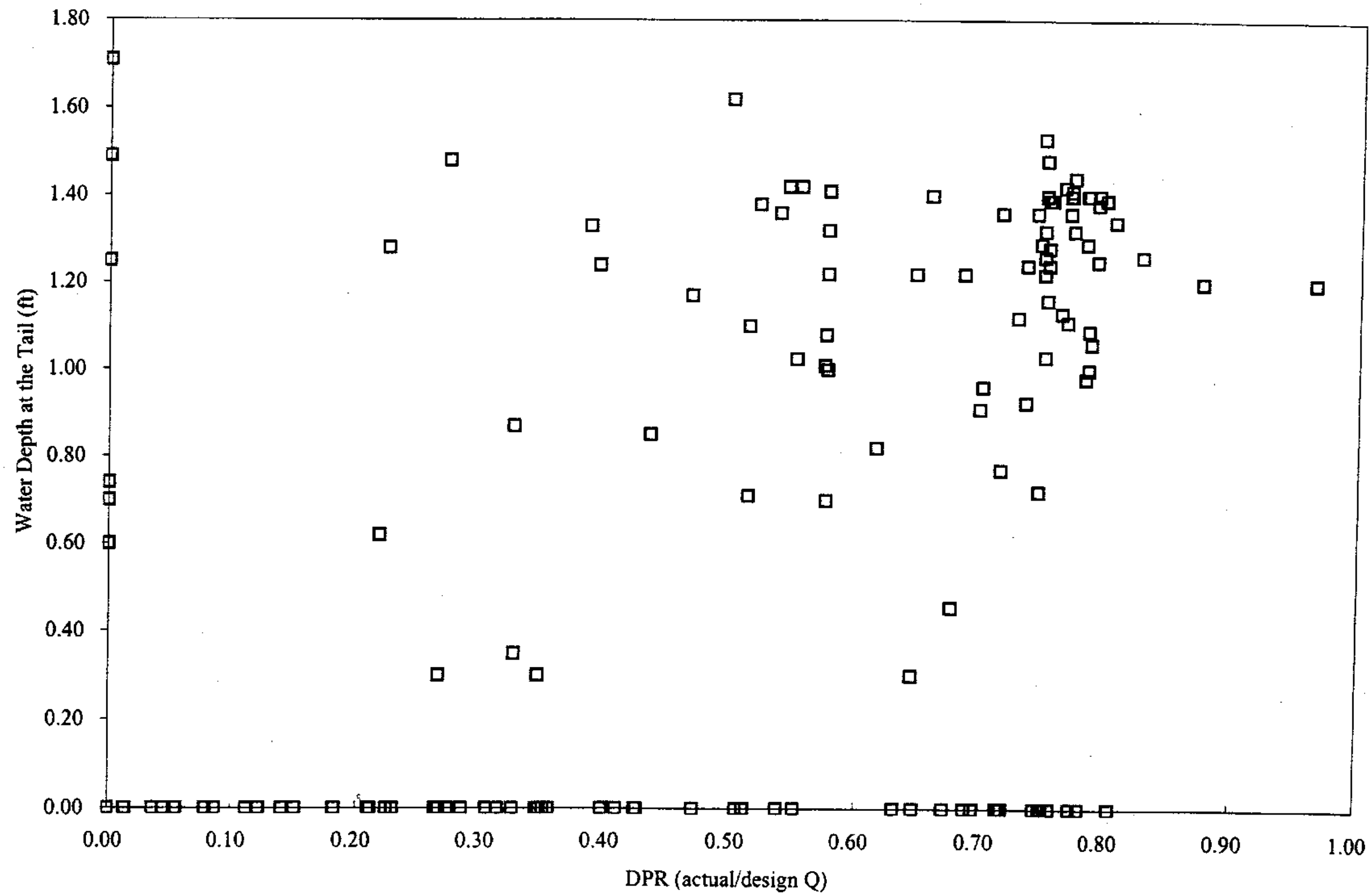
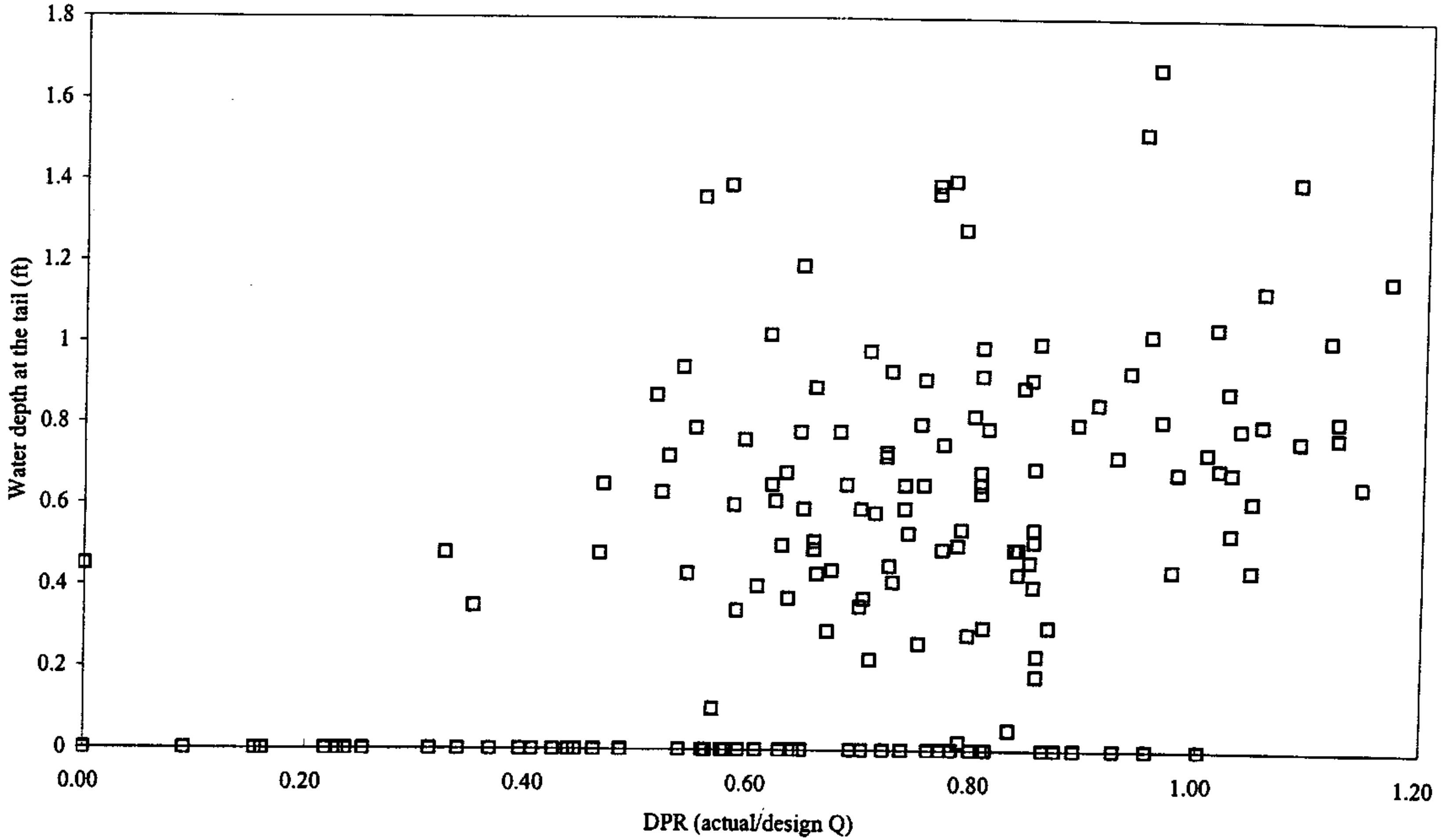


Figure 15C. Water Depth at the Tail versus Discharge at the Head of Soda Distributary; Kharif 94.



For the distributary with worse supply conditions, Azim, head-tail relations are shown in Figure 15B. A large scatter, due to fluctuating discharge at the head, is obvious. The tail of the distributary was dry for 97 days in *kharif* (55% of the time). The maximum head discharge was 80% of the design, and the maximum tail depth was 2.2 ft. Frequent, and large, discharge fluctuations at the head of Azim Distributary worsen the tail supply conditions. The time lag between the head and tail of Azim and Fordwah Distributaries is more than ½ of a day, and the canal filling time is always more than the emptying time, so the canal head closure duration is prolonged towards the tail. This is a strong indication that for Azim Distributary, the regime conditions are necessary for the operation of this canal for equitable distribution of water to the tertiary systems. A frequent opening and closing of the canal head is badly affecting the tail conditions.

An important case is shown in Figure 15C; Soda is a medium-sized non-regulated distributary with a weir head structure. The water depth at its tail continues fluctuating between zero and 1 ft while the head discharge varies between 60% and 120% of the design discharge. The tail is mostly less than one foot. To ensure the recommended tail gauge reading, Soda needs to have a full supply level in the main canal. As no control structure is available at this location in the main canal, the distributary has to follow all of the fluctuations occurring in the main canal.

The appropriate head supply range essentially required to feed the tails of each distributary is assessed from these figures and shown in Column 5 of Table 7. This range is quite variable, but mostly close to the design discharge.

To check the ID's benchmark of 70% design discharge, Figure 16 indicates a relation between dry tail conditions and less than 70% of design discharge at the head for twelve distributaries of the Fordwah system. Two distributaries discussed in the first paragraph are not included in this analysis. The trend line shows an almost linear correlation between two conditions. The correlation equation indicates that the chances of a dry tail increases with a multiple of two as the days with less than 70% of design discharge increases at the head. Hence, the benchmark of 70% is valid as the real minimum level; operations below this range are fatal for tail supply conditions. But, as shown by head-tail relations, most of the distributaries need to be operated at full supply to feed the tails, so, in fact, this benchmark has moved upwards.

As mentioned above, dry tail conditions are more common for long distributaries. Normally, no control structures are available on these canals, maintenance conditions are not up to the mark and water volume continues to decrease towards the tail. The influence of other factors, like extra supply to some of the outlets, illegal water extraction and operational losses, also accumulate towards the tail.

A correlation between canal length and dry tail conditions is shown in Figure 17. The chances of a dry tail are pronounceably higher in longer distributaries. This explains the worse tail conditions in four big distributaries of the Chishtian Sub-division.

Figure 16. A Correlation Between Head and Tail Flow Conditions of the Secondary Canals.

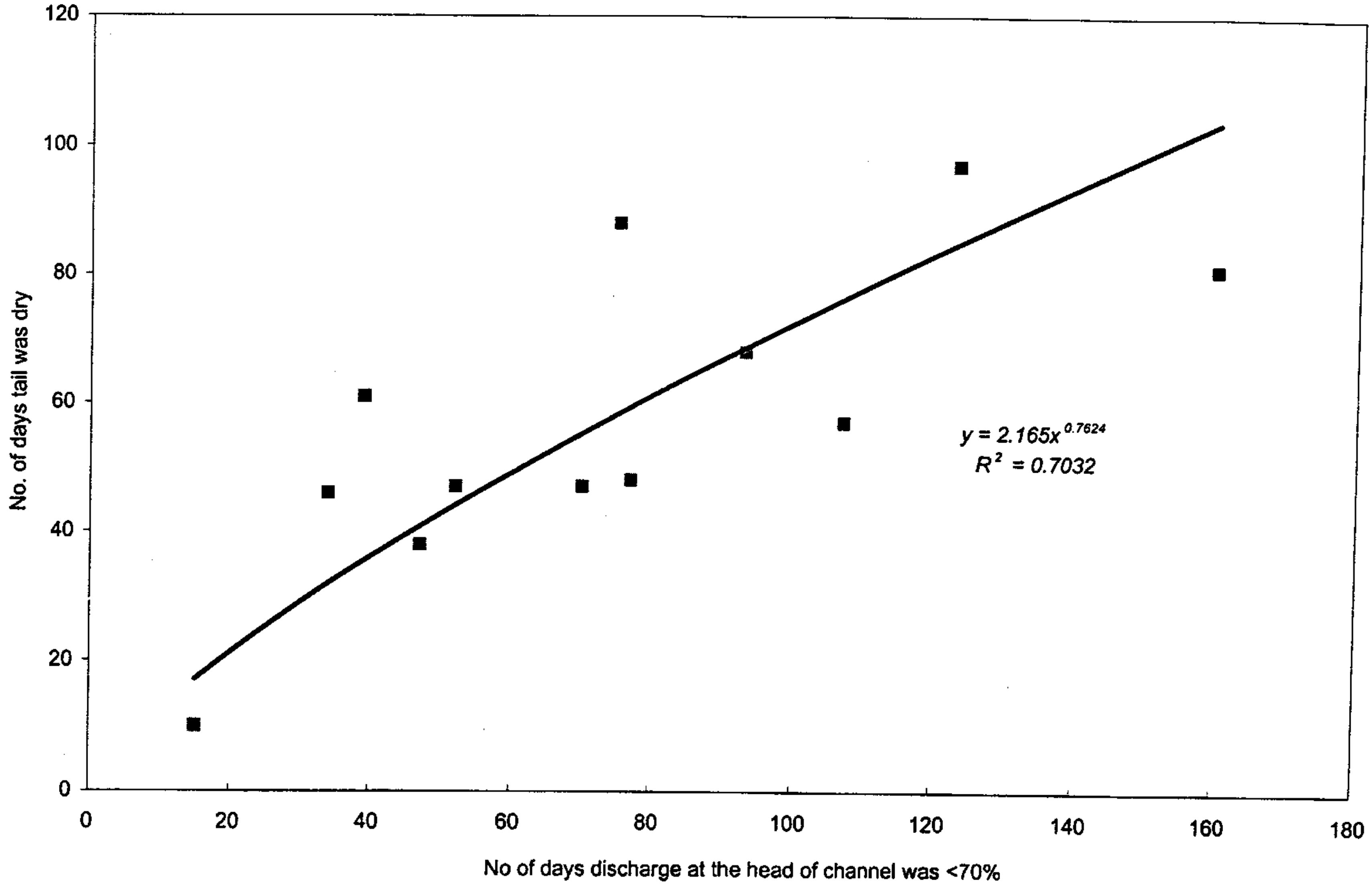
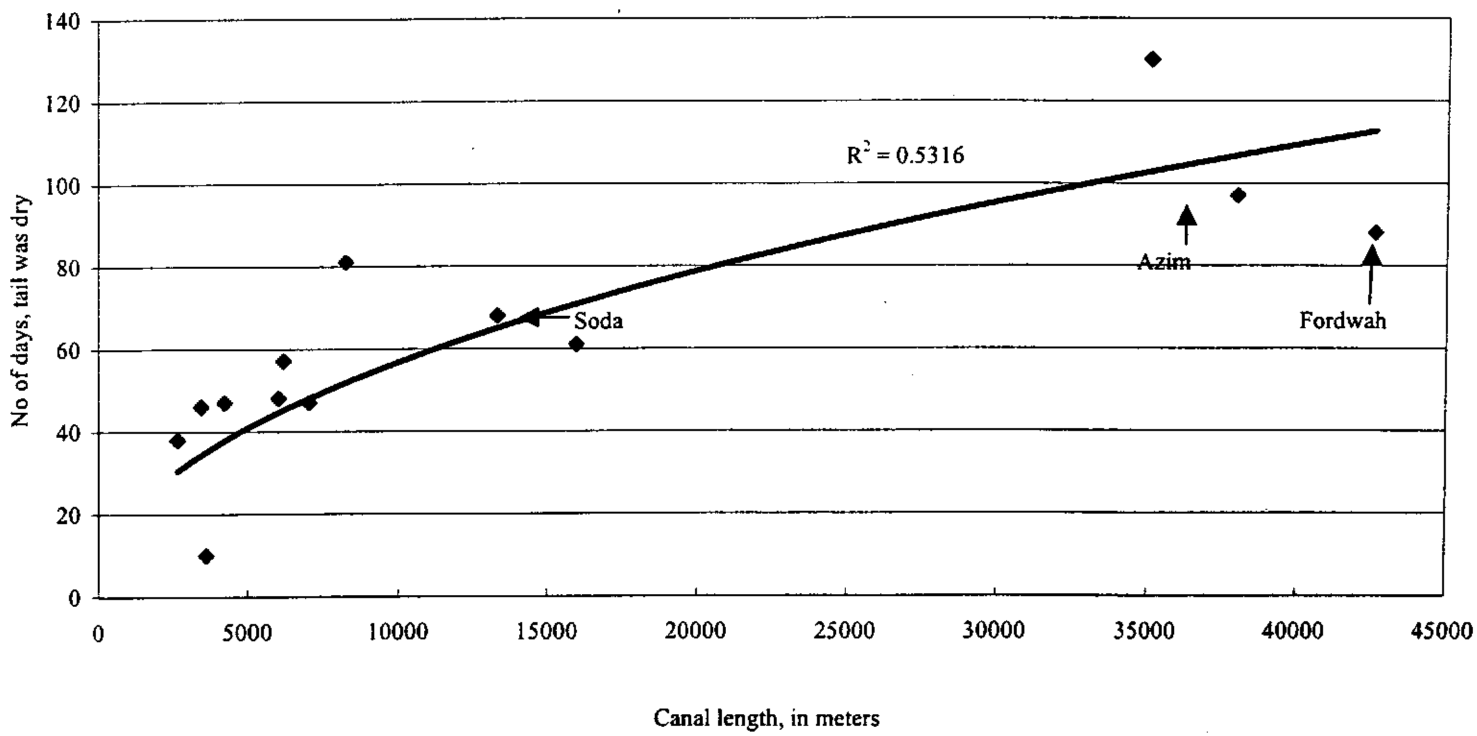


Figure 17. Dry Tail as a Function of Canal Length for Chishtian Distributaries; 1993-94.



4.2.4. Submergence of the Hydraulic Structures

The modularity of structures is especially important for frequently operated water distribution structures. A simple modular rating table is normally provided to gate operators, in addition to the downstream gauge rating. The instructions regarding O & M emphasize maintaining the modularity of all structures, and monitoring their behavior regularly. This practice ensures a good estimation of water quantities, which is essential for proper management of the water distribution process. The discharge measurements for a submerged structure is not a problem unless its level of submergence and hydraulic behavior (hydraulic jump and working head) vary in a wide range and become unstable. To have a good estimate of the water volume passing through this type of structure, a set of discharge equations and coefficients for all possible flow conditions and the exact knowledge of its flow regime, is required. The modular rating curves provided to the gate operator leads to the wrong calculations. The downstream rating is more appropriate for these types of structures, because it does not include submergence in discharge computations.

The average submergence ratio, taken during Kharif season, for all of the structures is shown in Figure 18. In reality the critical value for H_d / H_u for submergence vary from structure to structure. The range shown for this ratio in the figure is the commonly accepted range for the submergence. Out of five, three cross regulators of the system are submerged. Seven distributary head regulators are non-modular, five distributaries modular, while two are partially modular.

To demonstrate the temporal behavior of structure performance, the day-to-day variation in submergence (Hd/Hu) for three distributary head regulators is shown in Figure 19. One of the regulators is consistent in its free flow behavior. The second one is always submerged, and its submergence ratio is quite high, about 90%. While the third structure continues to shift from free flow to highly submerged flow during the continuous three-week period.

In case of a free flow structure (Figure 19), there is no problem in discharge measurement and regulation. As shown in the previous analysis, inflow into Shahar Farid is relatively stable and reliable. A proper estimation of discharge is difficult for a drowned structure (3L is an example). A weir structure with 90% submergence cannot deliver its design discharge. The behavior of the third structure (Fordwah) is completely unstable, which could lead to an over, or an under, estimation of the discharge, unless rating curves for both of the situations are implemented and each shift in flow conditions is recorded properly.

Figure 18 and 19 indicate that two-thirds of the structures in the Chishtian Sub-division can suffer due to submerged flow conditions.

Figure 18. Submergence of Cross-Regulators and Distributary Head Regulators, July 1994.

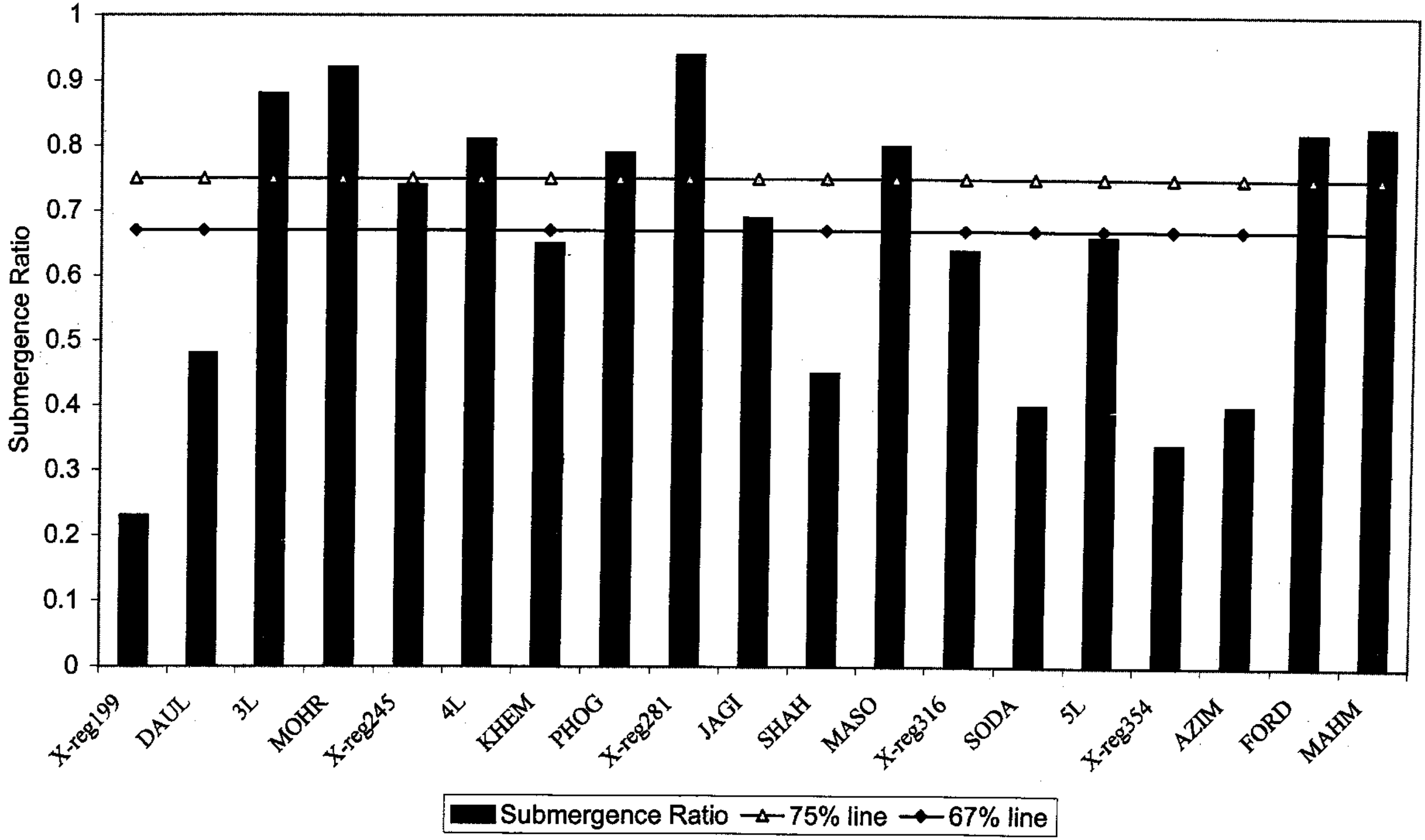
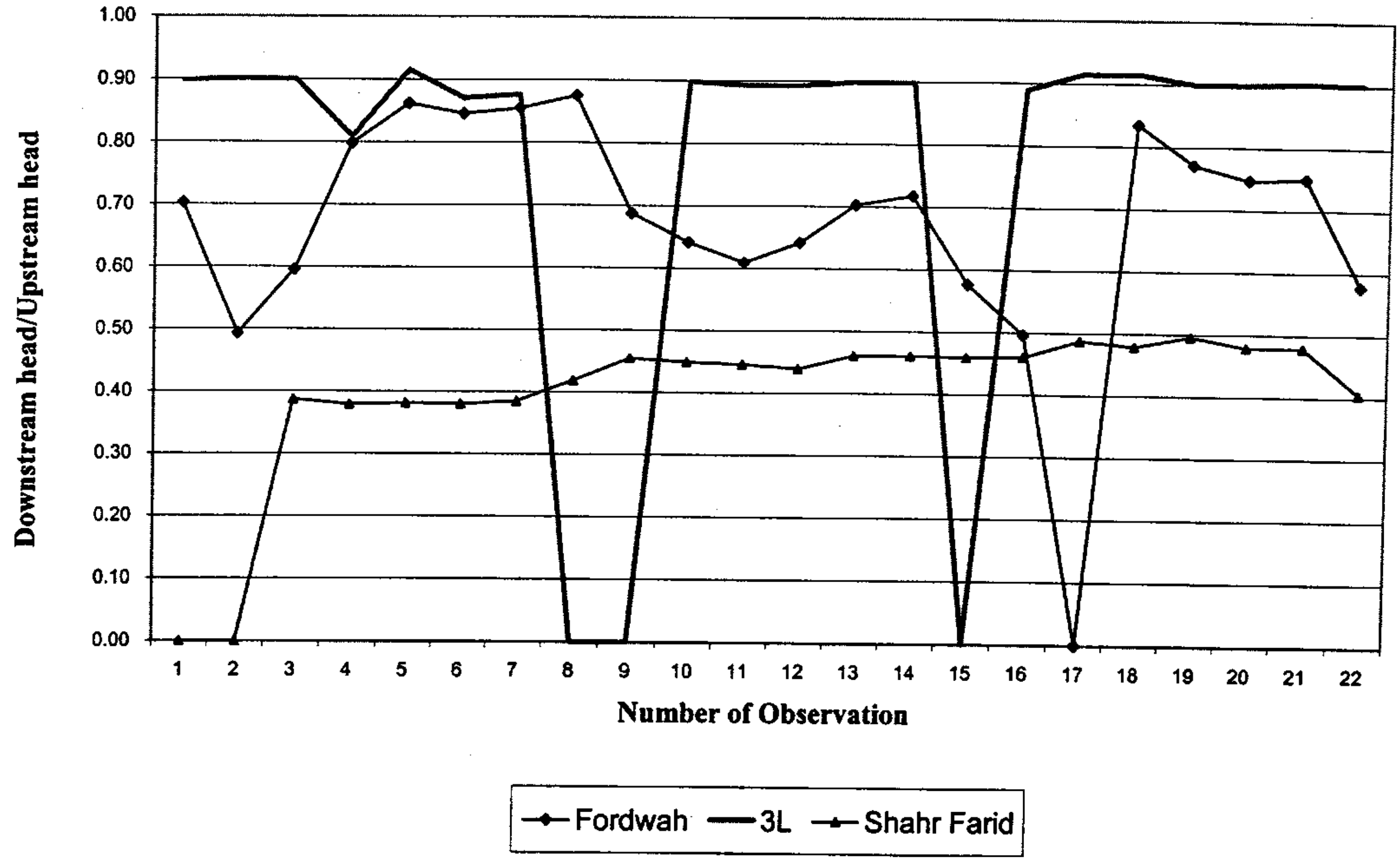


Figure 19. Submergence Ratio for Three Head Regulators.



4.2.5. Outlet Behavior

The performance of the outlets is not evaluated in this report, but as it is an important part of the water distribution process, a brief description of the four commonly used terms is included here. A very clearly mentioned responsibility of the Irrigation Department is to maintain the functioning of an outlet structure (*mogha*) so that it can receive its fair share under all accepted flow conditions in the parent channel.

The department's staff at the section level (three sections in Chishtian Sub-division) are responsible for checking and maintaining appropriate functioning of the outlet according to these criteria.

Flexibility is the capacity of an outlet to vary its discharge with a change in the discharge of the distributing channel; defined as the ratio of the rate of change of discharge of an outlet to the rate of change of discharge of the parent channel.

$$F = m/n.\ D/H$$

Where, ***m*** is the offtake index and ***n*** is the channel index. For 100% proportionality:

$$H/D = m/n$$

Sensitivity is the ratio of the rate of change of discharge of the outlet to the rate of change in the water level of the distributary, taking into account the changes in water levels caused due to canal bed, slope and maintenance conditions.

Efficiency is the term used most, which is defined as the ratio of the head recovered to the head put in and takes care of the working head of the outlets and the downstream water level. In the case of a weir, it is the same as ***submergence ratio,*** whereas, in orifice semi-modules, it is the ratio of height of jump to the depression head.

Adjustability is more related to the type of outlet and ease with which to change its machine (physical dimensions). Before any remodeling, the irrigation engineer must consider the type of outlet structure, which is appropriate for that location, while taking into account flow conditions of the canal and the properties of the command area. For example, open flumes are difficult to be adjusted without remodeling but with the provision of roof block flexibility is provided for easy adustment.

Canal Cross-Sections

The major activity regarding maintenance is to keep the design physical conditions of the main, branch and the secondary canals. A daily monitoring procedure and sufficient field staff is provided to check canal embankments, berms and the inspection paths. To ensure canal capacity and design physical conditions, annually, canal closure occurs for two weeks to one month, which is provided for silt clearance, bank strengthening etc. throughout the basin.

For the Fordwah Branch Canal and different distributaries, many topographies surveys have been carried out for the assessment of hydraulic performance. These data are used and analyzed in different model studies (Hart, W.W.H., 1996, Kuper, M. et al 1994). Most of the secondary canals of Fordwah Branch have good physical conditions and no capacity problem. However, the branch canal itself and the biggest distributary (Azim) of the sub-division have a tendency of sedimentation and face capacity problems in some of their reaches. The reason in both cases is non-regime operations of the channels; Fordwah Branch is operated at 30% of its full supply in *rabi,* while Azim is a non-perennial distributary with the lowest delivery performance in the system.

5. OUTPUT SPECIFIC INDICATORS OF EQUITY, RELIABILITY, TIMELINESS AND ADEQUACY

The indicators discussed in the previous section have been set by the operating agency to help its field staff to operate canals according to predefined rules for the scheduling and distribution. The targets addressed by these indicators were quite direct and basic. The indicators applied in the following sections are more complex and use mathematical or statistical, properties of the discharge parameters. The water delivery system has been analyzed for the distribution of its output (discharge) over space and time, with the help of these indicators. The input and management processes are not exclusively addressed in this analysis, however, their influence is built into the targets for delivery and distribution. Three reference values of discharge are used to understand the behavior of actual supplies:

i) the targeted value of discharge (design or authorized);
ii) services promised by the local manager (indent discharge); and
iii) water requirements of the command area.

5.1. EQUITY INDICATORS

5.1.1. Equity of Water Allocation and Distribution

Equity, or fairness of distribution, is the most discussed performance measure for large-scale supply-based irrigation systems. These systems have long and complex conveyance networks, which carry a limited amount of water to a vast command area. Two forfeitures of these systems are that extra supplies to one section of a canal can cause a water shortage in another section, and that deteriorated maintenance conditions can disturb the water-carrying capacity of the canal. To confront these limitations, the equitable distribution of water has been presented as a primary measure with its specific meanings in the context of Indus Basin systems. All design documents, O&M manuals and guidelines for canal regulation discuss about equity of water distribution by supplying the design discharge. The measures suggested to achieve equity are:

(i) Appropriate planning of water regulation and distribution (through scheduling) at the divisional, and sub-divisional, levels;
(ii) Appropriate maintenance and operation of the irrigation network; and
(iii) To help and guide water users to follow a strict predefined water-turn roster called *warabandi*.

To test the proportional distribution of water shortages, and excesses, within the Chishtian Sub-division, five equity indicators have been used to evaluate the spatial distribution of water to fourteen secondary canals:

i. Modified Inter-quartile Ratio;
ii. Relative Equity Ratio;
iii. The Relative Mean Deviation (UCC);
iv. Spatial Coefficient of Variation; and
v. Theil's Coefficient.

5.1.2. Modified Inter Quartile Ratio (MIQR)

MIQR was proposed by Abernathy (1986) and has been recommended by many researchers due to its simple and quantitative nature. Originally, it was defined as the ratio of average depth of water received by all land in the best quarter, to the average depth of water received by the poorest quarter of land. This definition targets on equal water depth for all distributary commands. However, for the manager of the Chishtian Sub-division, the target is to deliver an authorized discharge to each distributary, or to achieve a delivery performance ratio (actual/design discharge) equal to one.

In this section, quartile analysis is carried out to test both of these objectives. To evaluate equity against delivery performance ratio, the command area of all distributaries is placed into four groups, while for the analysis against water depth, the actual irrigated area is divided into four quartiles. As the information is available at the secondary level only, distribution of water and water-depth within each distributary is considered uniform, which is a big assumption. The time step for this analysis is one week. Efforts are made to form equal and discrete groups but a big range of distributary command area, and all varying DPRs and WDs, make formation of equal area groups difficult.

The relevant characteristics of each distributary and the average values of quartiles are given in two tables below.

Table 8. The Division of Fourteen Distributaries into Quartiles with Reference to DPR and WD, *Kharif* 94.

Distributary	CCA (ha)	Average Delivery Performance Ratio (DPR)	MIQR Quartile Based on DPR	Irrigated Area (ha)	Average water Depth (WD) (mm)	MIQR Quartile Based on WD
Daulat	32718	.73	2	24335	681	2
3-L	4451	.45	4	1247	918	1
Mohar	2973	.53	4	2216	1000	1
Phogan	2213	1.31	1	1742	1410	1
Khemgarh	5057	.69	2	2975	763	2
4-L	2055	.66	2	1932	602	3
Jagir	4451	1.03	1	2761	1203	1
Shahar Farid	24913	.75	1	15095	843	1
Masood	8106	.83	1	5627	580	3
Soda	10122	.62	3	4865	1099	1
5-L	885	1.57	1	619	1094	1
Azim	30485	.43	4	22780	505	3
Fordwah	36709	.65	3	31266	364	4
Mahmud	2008	1.44	1	1350	932	1

Table 9. Average Values for MIQR Quartiles.

MIQR-Quartile	Average DPR	Command area of the quartile (ha)	% of total command area	Average WD at canal head (mm)	Irrigated area of quartiles (ha)	% of total irrigated area
1	1.16	42578	25%	1054	30044	25%
2	.69	39830	23%	690	27310	23%
3	.63	46831	28%	551	30339	26%
4	.44	37909	23%	399	31266	26%

The following observations can be made from these two tables:

- The members of the best, and the worst, quarters are different in both cases. This means that equitable water delivery is not the same as providing equal water depth to different sections of the command area. The major cause of this disparity is unequal seasonal water allocations to the distributaries and a big variation in the actual cropping intensities.

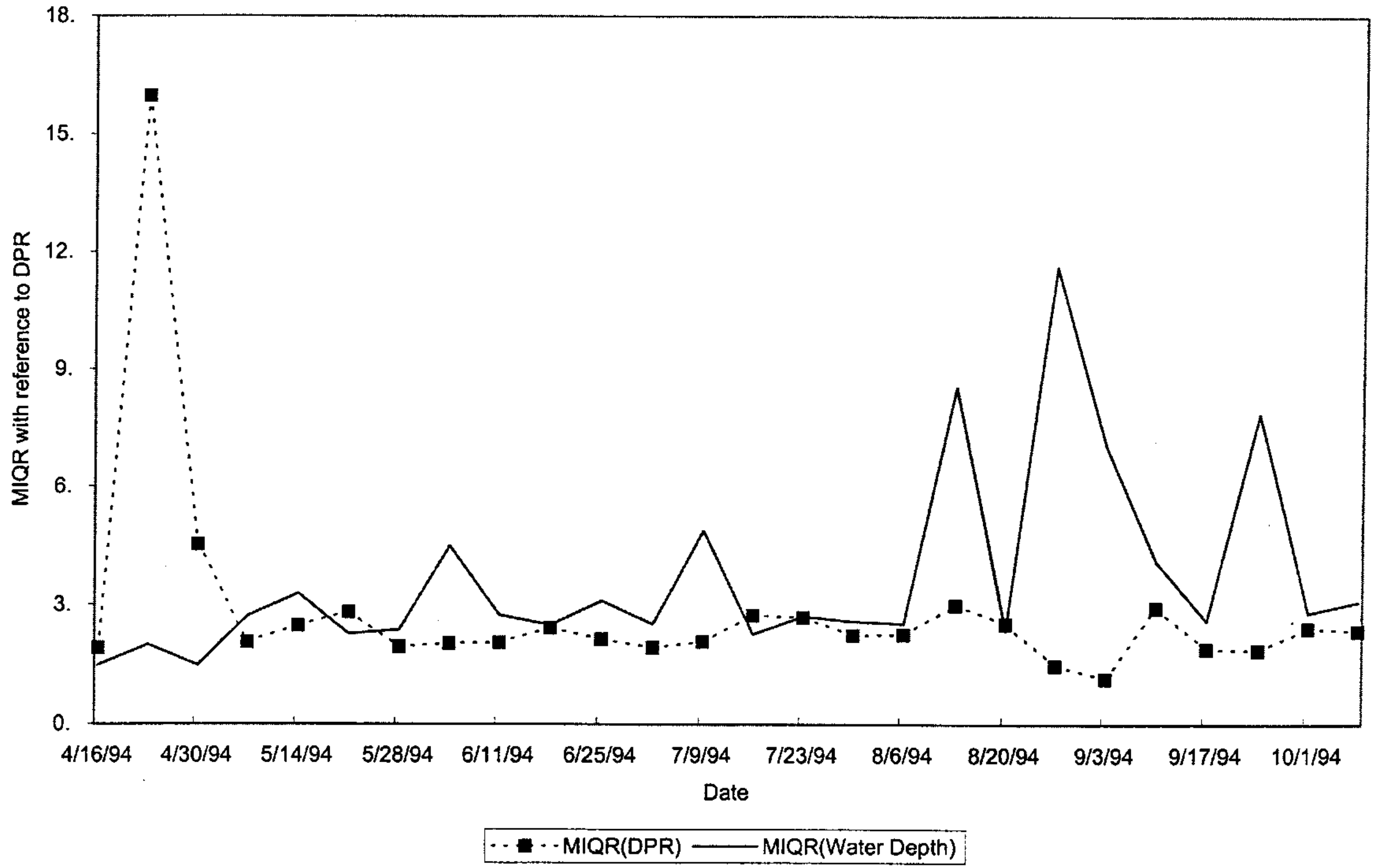
- The units of analysis of different sizes impose a limitation on the information revealed by quartile analysis. The average size of four big distributaries is about fifteen times more than the average size of ten small distributaries. To conceive the level of diversity, the biggest distributary is 35 times bigger than the smallest distributary. For the present analysis, targets are considered valid at heads of the distributaries, and uniformly distributed after that. However, the analysis carried out in chapter four indicates a large variance between the head and tail of big distributaries. Hence, inequity computed at this level may be enhanced at the watercourse and the field levels.

- Average values show that Quartiles 2 and 3 are very near to each other.

Figure 20 shows the Modified Inter Quartile Ratios computed for a six-months period, May to September 1994, according to both of the criteria mentioned above. During this period, MIQR(DPR) varies in the range of 2.05 to 2.8, which is the level of inequitable distribution of water between two extreme quarters at the secondary level. However, the maximum variation is in the range of 1.5 to 3.35 during August and September, and a big peak occurs in April. These are the periods of disturbed supplies when some of the distributaries were closed due to rains.

Figure 20 indicates that MIQR(WD) behavior with reference to water depth is very unstable. This erroneous behavior is caused due to the unsteady supply pattern of group four, which consists of only one, but the biggest, distributary of the sub-division. The average MIQR value is 3.69, which is much higher than the indicator value with respect

Figure 20. Modified Inter-Quartile Ratio with reference to Delivery Performance Ratio and Water Depth; Kharif 94.



to DPR. The information provided by the temporal pattern of MIQR(WD) clearly indicates "sufferings" of one-fourth of the irrigated area which is getting much less, and continuously varying supplies when compared to that of the best quarter.

There is a need to mention here, that in its computations, MIQR considers the best situation as its target without taking care of the validity of this situation (for example, the average DPR of the first quarter is 30% more than its share). The best quartile of MIQR can be a privileged section receiving water in excess of its share. The ratio of the best, to the worst, though representing the level of inequality, does not indicate the actual departure from the required fairness.

A slightly different comparative technique is used in the next section to incorporate the fairness of distribution more explicitly.

5.1.3. Relative Equity Ratio (RER)

Abernathy mentioned this type of technique with reference to a paper (which was not published) in 1987, but no analysis is available using this indicator. The analysis carried out in this section is an effort to have an apportionment of the areas based on the equity principle.

RER is a ratio between the best-off and worst-off groups, but the number of groups is three, and the middle, or reference group, receives water within 10% of the proportionately fair amount. The groups are not of equal sizes, all of the area getting a fair amount of the targeted value is put in the reference group, which is called 'the standard group'. The areas receiving water higher, or lower, than this range, are put, respectively, in the privileged and deprived groups.

The Relative Equity Ratio is tested for the secondary system of the Chishtian Sub-division, again for DPR and water depth (WD). The fourteen distributaries of Fordwah have been divided into three unequal sections in both cases. In the case of DPR-based analysis, the standard section receives water within the Irrigation Department's recommended range of 70 to 110%. The privileged section gets more than 127% of the design (target), while the deprived section receives less than 56%. The breakdown of command area, based on this criterion, is already quite informative; only 11% of the area is privileged while about 33% of the area is deprived. The average water received by the privileged section is 74% higher, while by the deprived section is 21% lower. The temporal variation of RER(DPR) is shown in Figure 21.

Figure 21. Relative Equity Ratio (w.r.t DPR), Kharif 94, for Privileged/standard & Deprived/standard Sections.

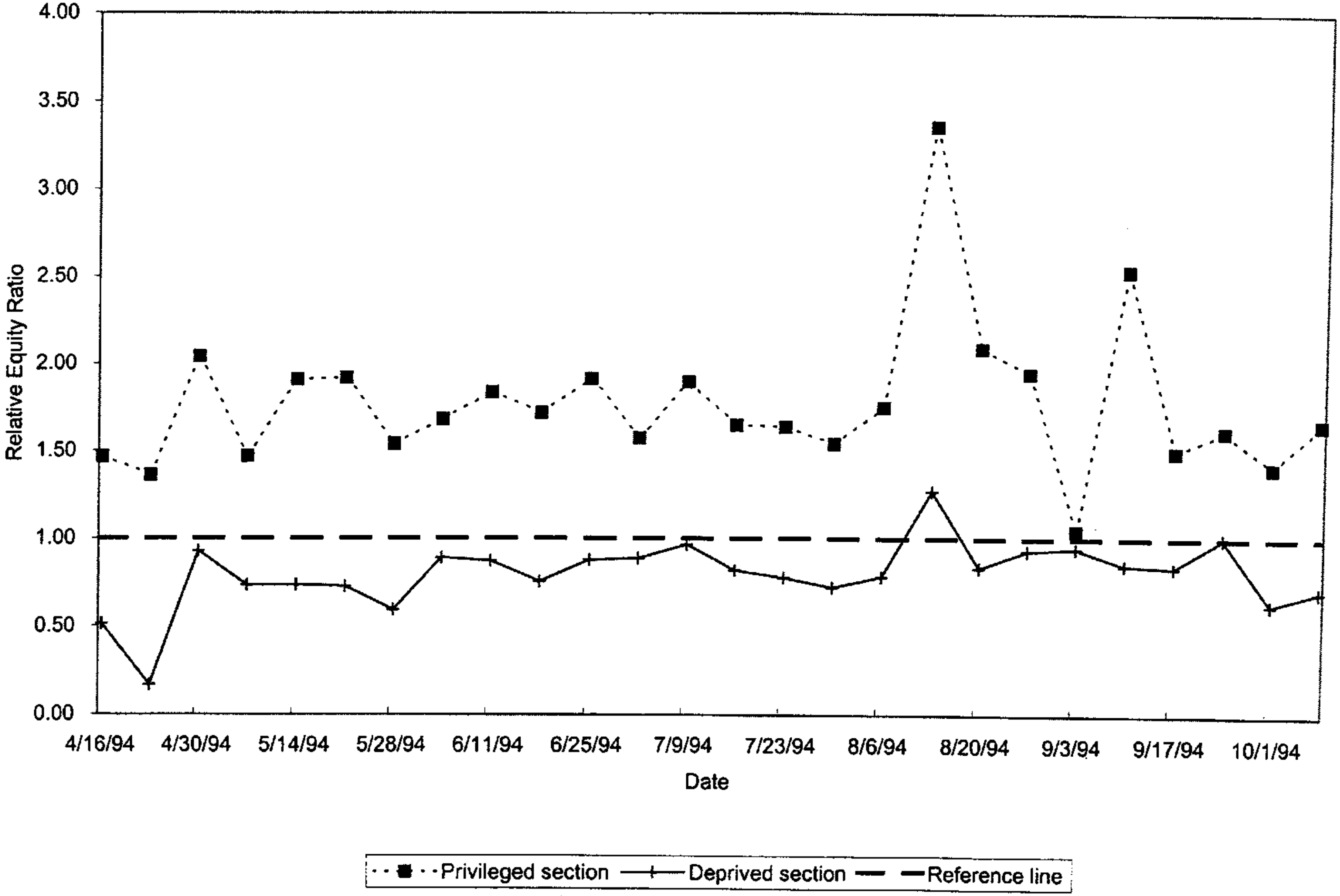


Table 10. The Average DPR and Command Area of Each Group of RER.

RER Section	Average DPR	Total Command Area (ha)	Percent Command Area	Average Water Depth (mm)	Total Cropped Area (ha)	Percent Cropped Area
1	1.27	17665	10.6	935	13702	12
2	.71	94340	56.4	788	43652	37
3	.56	55143	33.0	509	61605	52

In the case of water depth-based analysis, a historical reference, or standard value, is not available because actual available canal water depth is much less than the design value, while net water depth has a component of ground water utilization. Based upon the definition of equity, the standard section consists of distributary command area, which lies within the 10% range of the average water depth (WD). The composition of groups on this criterion is again non-uniform. The privileged group consists of 12% of the irrigated land, much smaller than the other two groups, but still double that of the DPR-based privileged group. The deprived group is the biggest; 52%. The level of inequity is much smaller when compared to DPR analysis; on average, the privileged section gets 20% higher WD, and the deprived section gets 34% less WD as portrayed in Figure 22 which shows quite variable behavior within the season.

An important trend is indicated by the actual available water depths in the distributary commands; it seems that the boundaries between perennial and non-perennial areas are not discrete. Inequity in achieving the allocated water supplies has moved the available water depths towards a closer range in different sections of the main canal command.

5.1.4. The Relative Mean Deviation (UCC)

The Christiansen coefficient of variation is a range variable proposed by many researchers as a measure of spatial uniformity. Originally defined as:

$$UCC = 1 - \sum_{i}^{n} (|X_i - \overline{X}| a_i) / (\sum_{i}^{n} a_i)\overline{X}$$

where

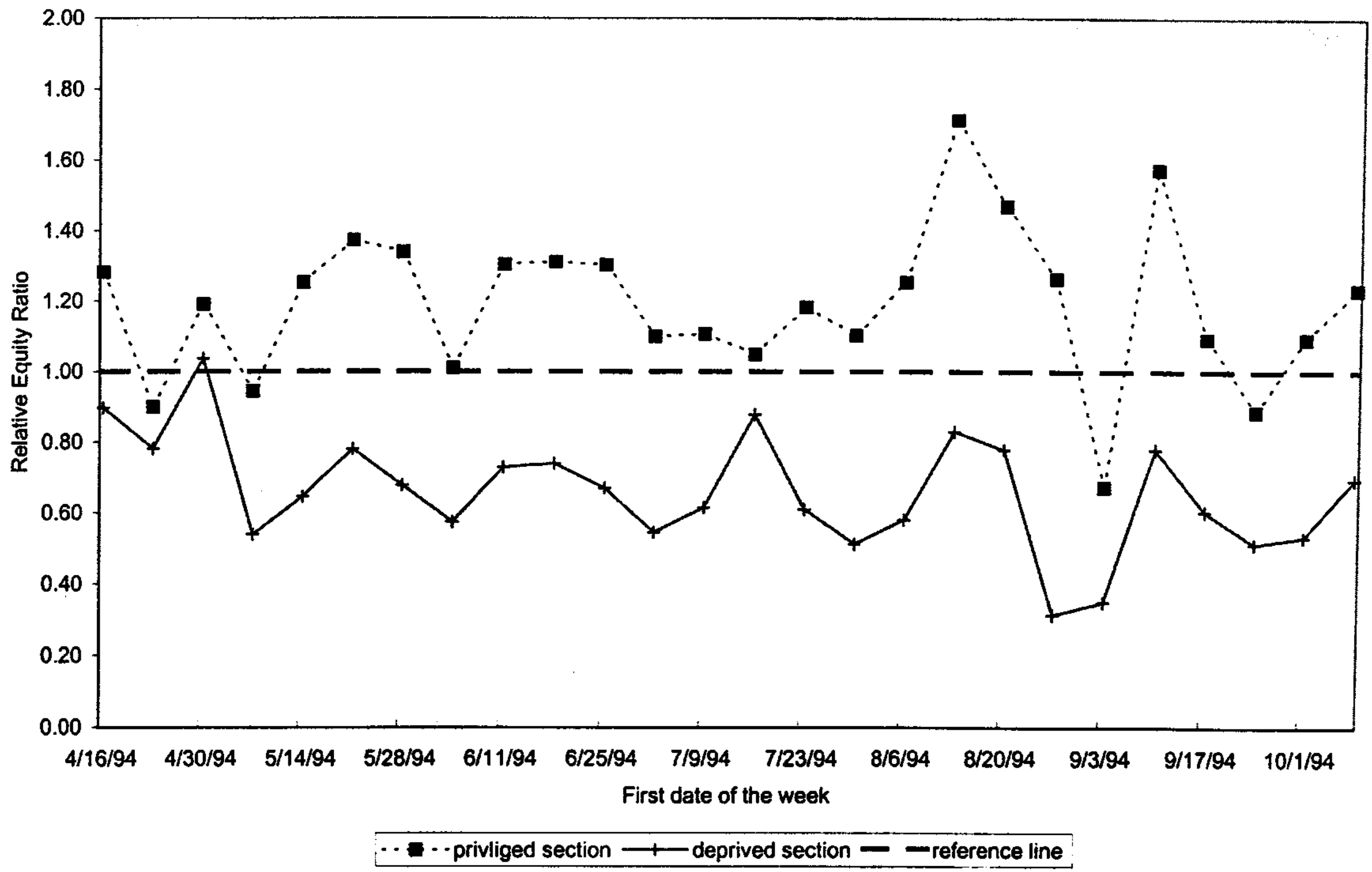
X_i is the value of a single unit (DPR of a distributary)

$\overline{X}$ is the average value (average DPR)

a_i is a unit (distributary)

n is the number of units (number of distributaries)

Figure 22. Relative Equity Ratio (w.r.t WD), Kharif 94, for Privileged/Standard & Deprived/Standard Sections.



This coefficient is a relative mean deviation, which compares the value of a quantity for each unit (DPR in this case) with the gross mean value, by taking the average of all absolute differences of the mean, and the actual, values. The average absolute difference is then subtracted from 1. The maximum value of UCC is one for complete equality, where all individual values are the same as the mean value. For this study, only the mean deviation term of the equation is used to make it comparable with other range variables (coefficient of variation, Theils' coefficient), which should have a value of zero for the complete equality.

Figure 23 shows Relative Mean Deviation of DPRs for fourteen distributaries. The low values of 0.14 to 0.26 occur during a disturbed supply period, while for the normal supply period, it varies between 0.26 to 0.48, with an average value of 0.35. These values indicate a 35% average deviation from the uniformity.

As mentioned by Sampath (1988), UCC is not sensitive to a shift within the units lying on the same side of the mean share, but it is sensitive to the mean value itself, which means that in conditions when there is a change in the DPR of a few distributaries, all having less than the average DPR, and there is no change in the average DPR, the value of UCC remains the same.

The important characteristic of the UCC is that if all units are getting low supplies, variation within the units will be less important because UCC will have a smaller value for the same level of inequity. Hence, for this indicator, inequity is more important at higher supplies when compared to the lower supplies.

5.1.5. The Spatial Coefficient of Variation

The Coefficient of Variation, Cv, is the most used statistical measure of a distribution function, and is defined as:

$$cv = \sqrt{\frac{\sum_{I=1}^{N} X_I^2 - (\sum X_I)^2}{n(n-1)}} \Bigg/ \frac{\sum X_i}{n}$$

Where, x_I and x are as defined in the previous section, and n is the number of units.

Cv takes care of inequality of a distribution irrespective of its average level, by dividing the standard deviation of a sample by its mean. The important characteristic of the coefficient of variation is its sensitivity for extreme values.

For water scarce irrigation systems, where zero, or low, supplies could not be avoided, Cv varies in a big range. This variation indicates the level of *non-uniformity* over time and its pattern characterizes the pattern of supply, or scheduling. In itself, Cv is not a real measure of fairness, especially for those systems where supplies can fluctuate between extreme values.

Figure 23. Weekly Variation of the Spatial Equity measured by UCC.

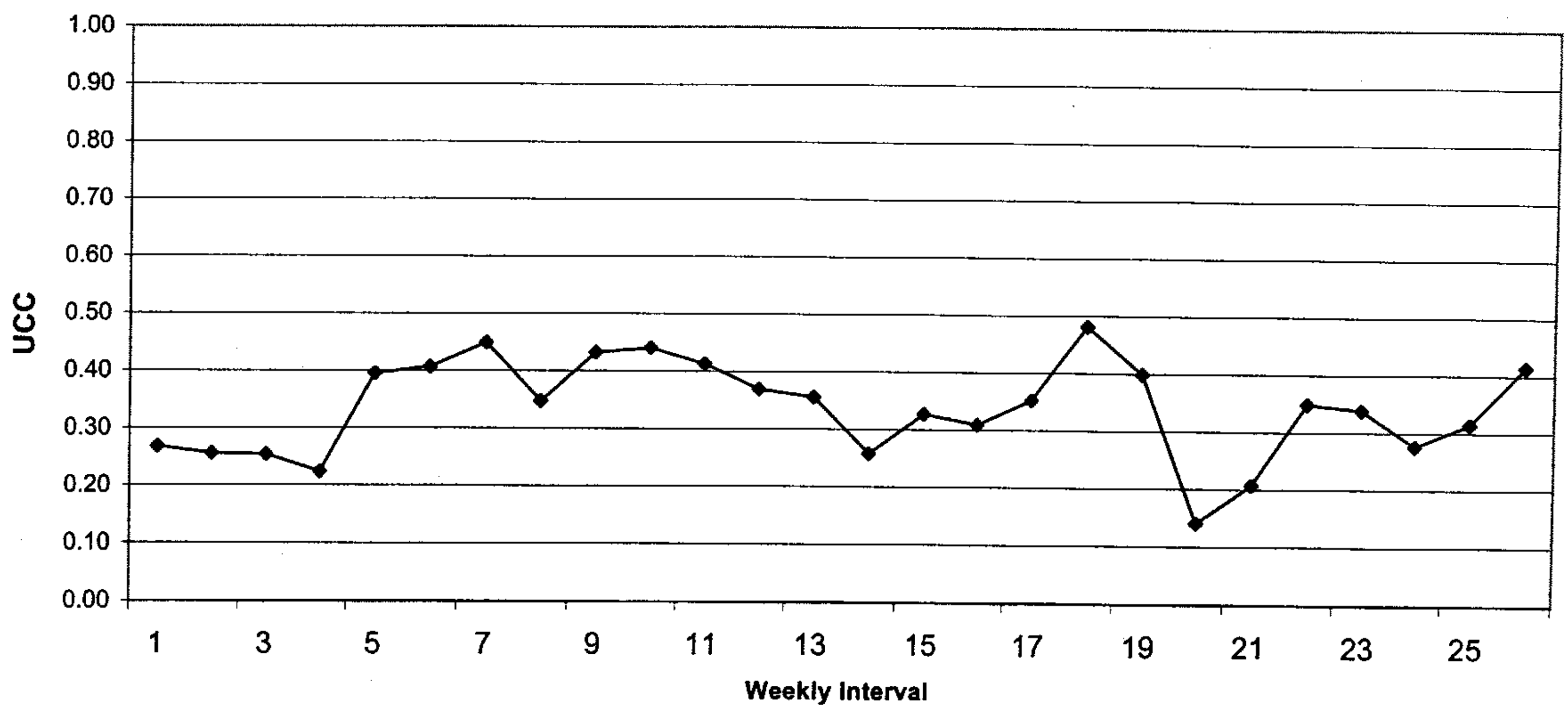


Figure 24 shows that the spatial coefficient of variation (Cv) for *Kharif* 94 varies in a range of 0.4 to 1.05, with its value being higher than 0.6 during the rains, and low demand periods (the unstable periods). Even during the most stable period, it varies between 0.4 and 0.5, indicating daily fluctuations in the system.

The volatile nature of Cv can provide a good preliminary insight into those systems where a good knowledge and comprehensive information are not already available. The sharp peaks and valleys indicate that the extreme variations, or abnormal behavior, is evident , which can be further explored.

5.1.6. Theil's Information Measure

Theil's measure for inequality is a logarithmic expression basically used to represent the entropy. Entropy is defined as a measure of disorder, or disorganization, in thermodynamics, and as a rate of transfer of information in mathematics. Sampath (1998) proposed it for irrigation systems because of its ability to capture the contribution of different components of the system properly. Theil's coefficient for inequality is defined as:

$$\text{Theil's Coefficient} = \log n \; H(y) = \sum_{i=1}^{n} y_i \log n \;\; y_i$$

Where n is the number of units to be analyzed and y_i is the fractional share of ith unit. The H(y) is a measure of the entropy, and is subtracted from its maximum value (log n) to have Theils' coefficient, which varies between zero to log n. The value of Theil's coefficient is higher when the number of units (n) is higher.

Theil's coefficient (TC) is calculated for the fourteen distributaries by taking weekly DPR as the unit value. As the number of units is only fourteen distributaries, the coefficient varies in a small range of .04 to 0.25 (Figure 25). Although there are peaks during the unstable period, when the variations are big, the period from mid-June to mid-August seems stable and equitable.

Theil's coefficient shows the same trend as Cv, including the over-sensitivity, to extreme values.

A Comparison of Equity Indicators

The behavior of four equity indicators (Theil's coefficient Cv, UCC and MIQR (DPR)) is compared in Figure 26. The trends shown by Cv and Theils are similar for the whole range, while UCC also shows the same trend during normal conditions. The opposite trends of Cv and UCC during the low supply periods indicate UCC's insensitivity at the low supplies and Cv's over-sensitivity for the extreme cases. From the above discussion of each indicator, it can be concluded that Cv is good in indicating the stability, while UCC is good to estimate the average quantitative value of inequity within the system.

Figure 24. Weekly Variation of the Spatial Equity Measured by Coefficient of Variation.

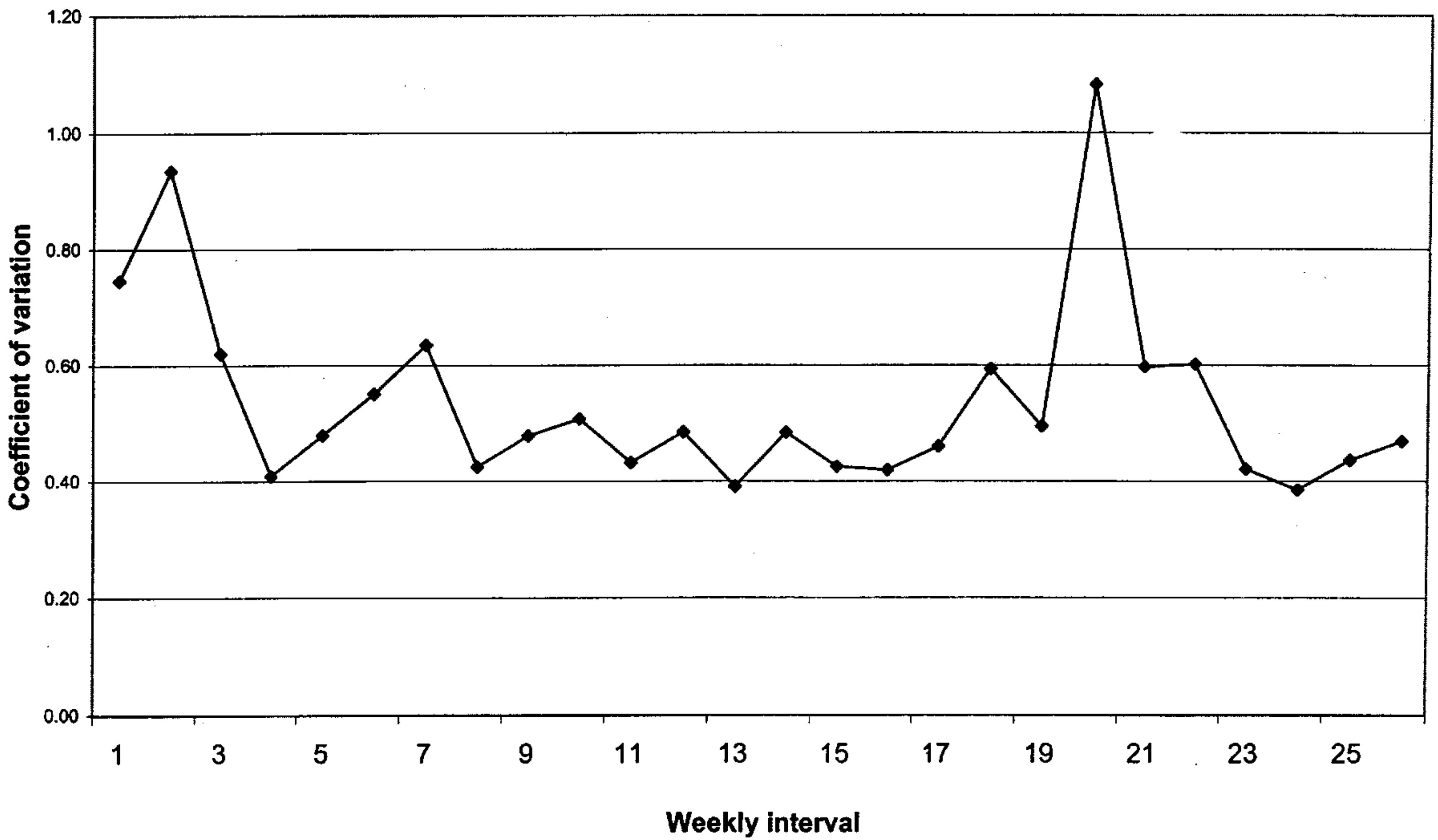


Figure 25. Weekly Variation of the Spatial Equity Measured by Theils Coefficient.

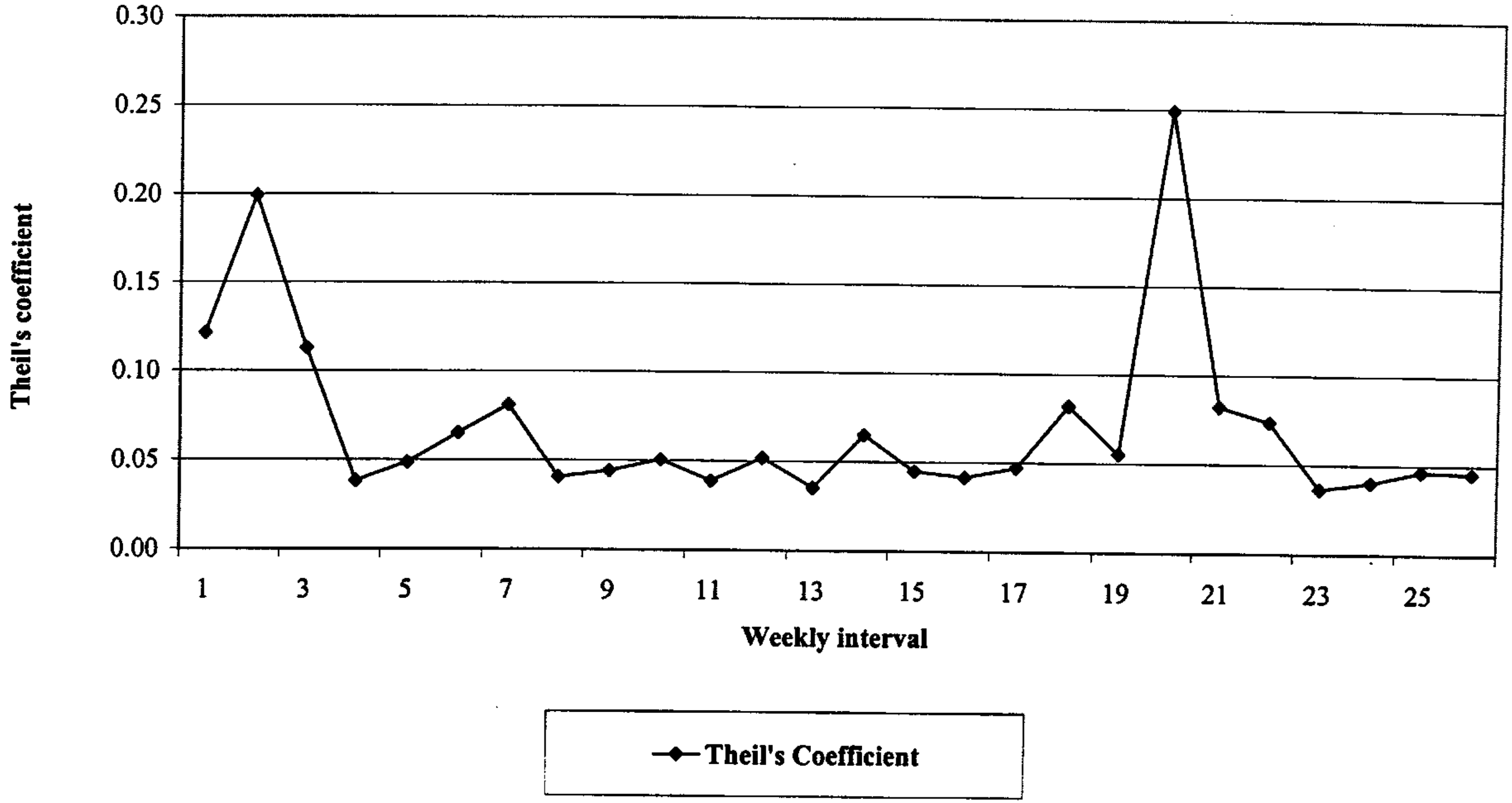
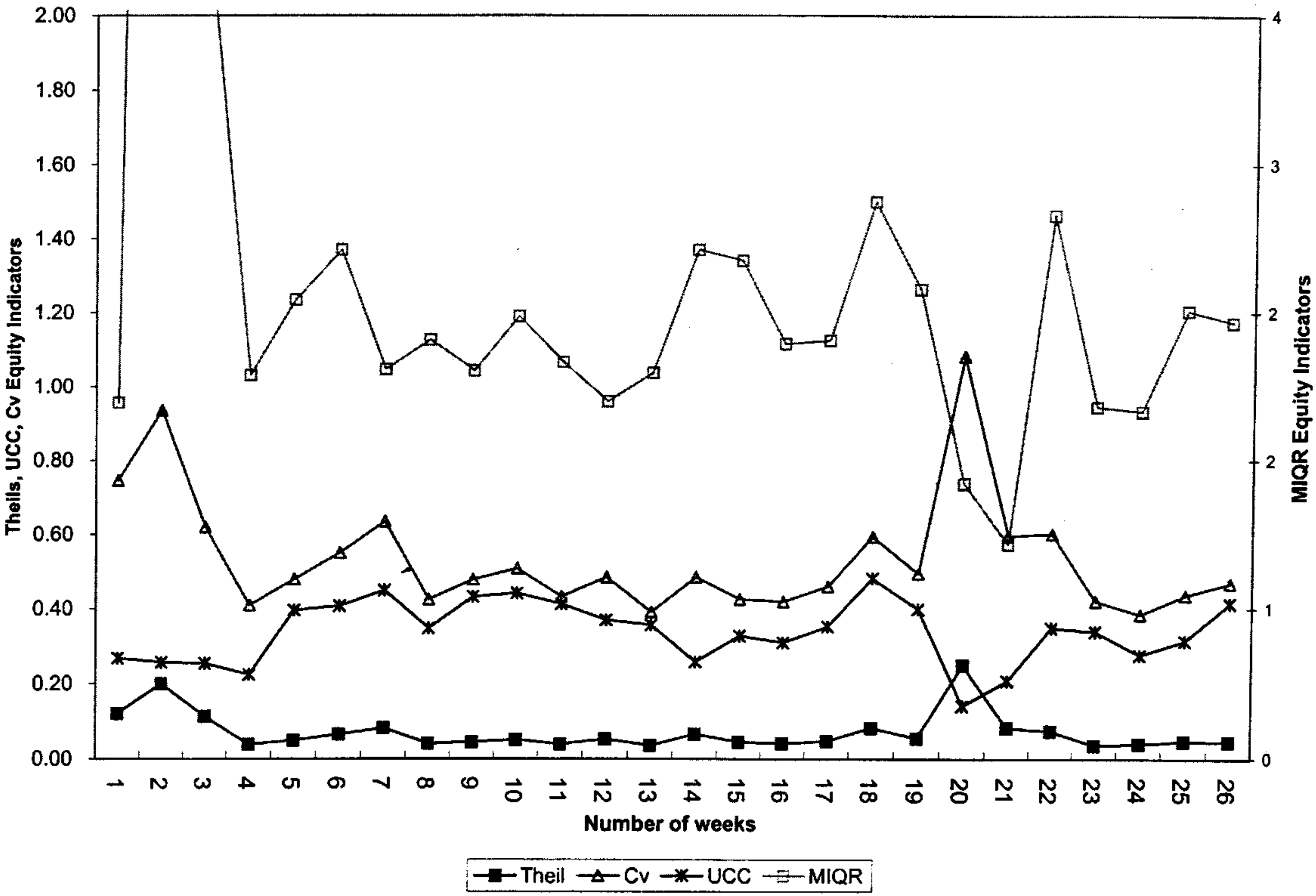


Figure 26. Comparison of Spatial Indicators of Equity.



In the figure, MIQR is shown on the secondary y-axis, because it is basically a different type of indicator, which gives a quantitative comparison of the best quartile with that of the worst quartile. The ideal value for MIQR is 1. Other than one peak, the graph shows that the best quartile receives its relative share 2 to 3 times more with respect to the worst quarter. The seasonal average is 2.25. The temporal trend shown by MIQR is the same as other indicators of equity.

5.2. RELIABILITY OF WATER SUPPLY

Reliability is defined here as a degree to which water deliveries accommodate the expectation of the system manager (and consequently of water users) and match the planned schedules of the Irrigation Department. If the operational plans have been properly prepared and advertised (by the irrigation agency), farmers can know about the timing of the supplies, even if they are not 'timely' for crop requirements. Reliability is very important from the farmer's point of view, affecting the efficiency of various field activities. This includes the concept of predictability of flows as indicated by water delivery schedules, or an operational plan without which the concept of reliability does not make sense (Rao 1993). A major assumption in this concept is the value placed in the water delivery plans by considering them equivalent to the expectations of the users.

To measure the reliability of the supplies, the weekly coefficient of variation for the ratio of actual and targeted discharge has been computed. The daily target (indent) values reported by local gate operators for seven distributaries are taken as a target. The weekly values of reliability, with reference to indent discharge, for these distributaries, and for the head of the sub-division (RD 199), are plotted in Figures 27 and 28, respectively. These plots indicate that the supplies at RD199 are reliable from the first week of May to the third week of August, while for the rest of the period, reliability is quite poor. The two distributaries at the head (Daulat, Shahar Farid) perform better than the two distributaries at the tail (Azim, Fordwah). The range of weekly variation of reliability indicates that the supply patterns are quite undependable at the secondary level, and that the flow to the tertiary systems will be even more unpredictable.

The seasonal values of the temporal coefficient of flow variation for all of the distributaries are shown in *Table 12.* These coefficients are computed with reference to design and indent discharges to illustrate the quantitative improvement in the reliability of supplies with the introduction of indent. During the *kharif,* for some of the distributaries, indent indicates much better reliability over the design discharge. The reliability indicator with respect to the design discharge, $Cv(actual\ discharge/design\ discharge)_t$, represents an overall variability of flow hydrograph, while $C_v(actual\ discharge/indent\ discharge)_t$ represents the variability with respect to planning.

The values of Cv are quite high in both seasons. If the design discharge is considered a target, the secondary inflow is quite undependable. A small improvement shown by indent is much less than the expected improvement in case of a good planning.

Next >>

Figure 27. Reliability of Supplies at the Head of Fordwah Branch and two Secondary Canals; Kharif 1994.

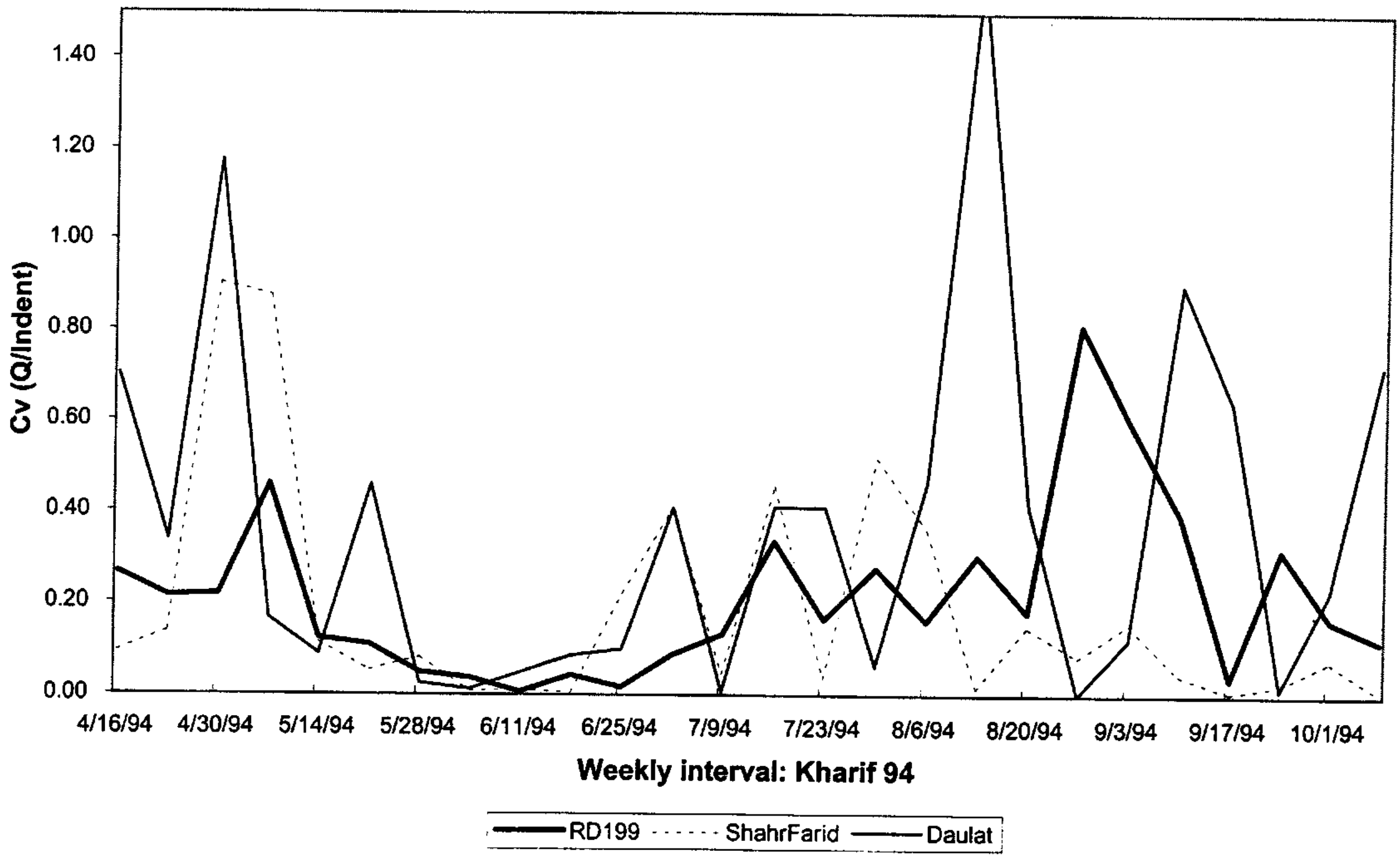


Figure 28. Reliability of Supplies at the Head of Fordwah Branch and two Secondary Canals, Kharif 1994.

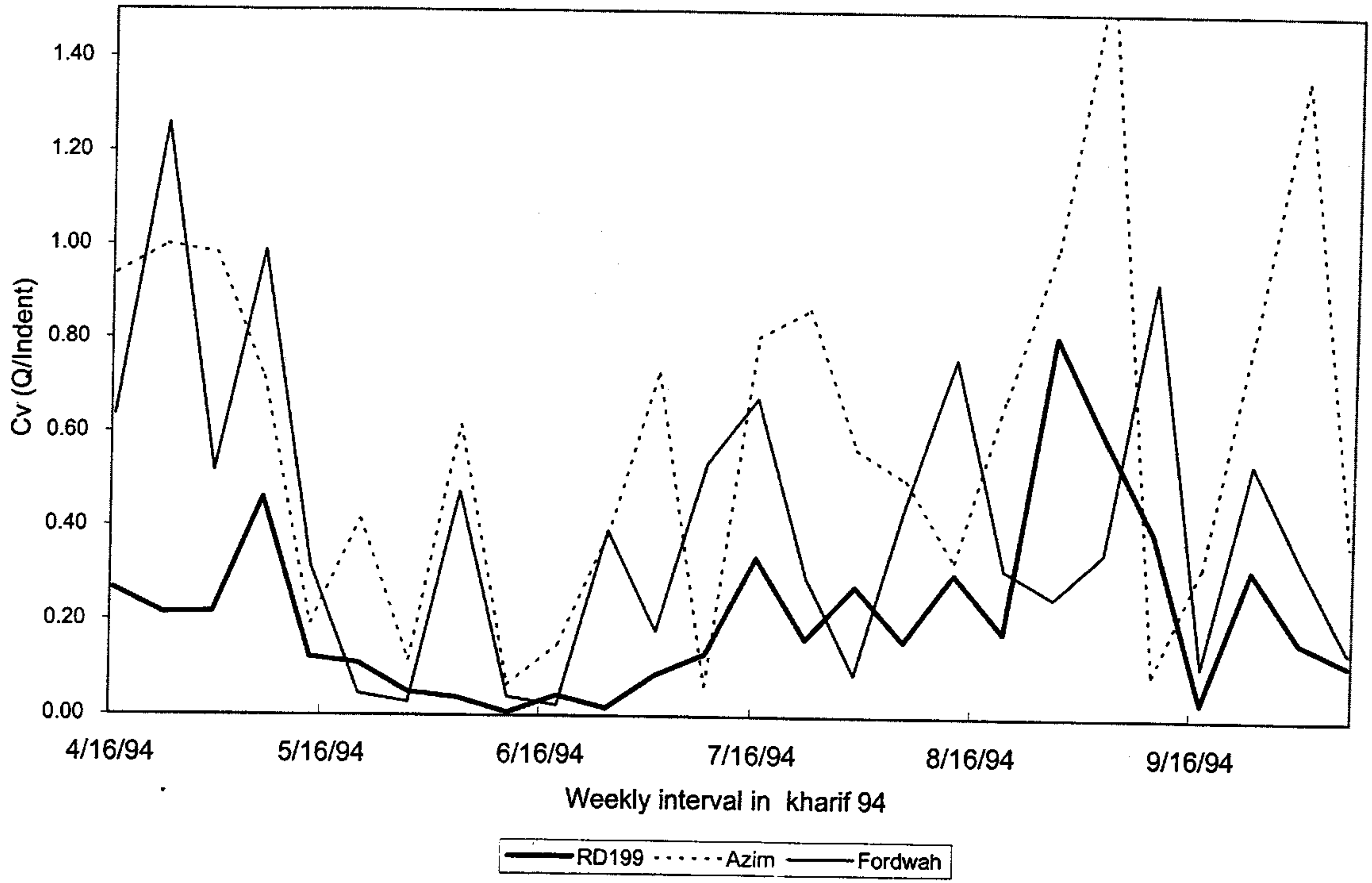


Table 11. Coefficient of Variation ($C_{v(t)}$) of Actual versus Design and Indent Discharges).

Canal	**Reliability Coefficient** *Kharif* **94**		**Reliability Coefficient** ***Rabi*** **93-94**	
	Design discharge	Indent discharge	Design discharge	Indent discharge
Head Regulator	.39	.30	.78	.48
Daulat	.54	.50	NS	NS
3-L	.57	NA	NS	NS
Mohar	.68	NA	NS	NS
Phogan	.53	NA	NS	NS
Khemgarh	.59	NA	NS	NS
4-L	.59	NA	NS	NS
Jagir	.57	.37	.77	NA
Shahar Farid	.54	.28	NS	NS
Masood	.51	.13	.83	.48
Soda	.50	NA	NS	NS
5-L	.53	NA	.96	.63
Azim	.73	.55	NS	NS
Fordwah	.68	.46	.90	.56
Mahmud	.30	.23	.78	.44

NA : Indent not available.

NS : No supply to these canals in *Rabi.*

5.3. TIMELINESS OF CANAL SUPPLIES

In its generic meanings, the term timeliness is a measure of correlation between crop water requirements and actual deliveries to the command area. This is different to adequacy, which determines a quantitative ratio for supply and demand, and from reliability, which indicates a match between the actual and expected supply. As described by P.S.Rao, "timeliness" can be considered on the basis of the accuracy of fit between two time history curves, one of which represents the evapotranspiration needs of the crop throughout its season, and the other, the actual deliveries of water.

Timeliness is an important parameter from the farmer's perspective because it ensures availability of water when it is most required. This is a relevant indicator in reservoir supported supply-based systems. For these systems, the major purpose of the regulation is to improve the timeliness and the storage from the reservoirs is released to enhance the run-of-the-river system during the maximum demand periods.

However, in a multi-resource supply system, it is not easy to measure the real demand curve for a large command area with heterogeneous characteristics. Constraints, like uncertain inflow and less than required supply make farmers practices complex in terms of sowing, watering and supplementing their needs with other resources, i.e., ground water, purchase of canal water. Unavoidable variability in supplies can cause a substantial gap between peak demand and actual water application to a crop, and can adversely affect the crop yield. At the same time, farmers practices and availability of groundwater can introduce a scatter in the water demand curve.

The water demand curve of the Chishtian Sub-division for 1993-1994 is superimposed with the canal and the total water supply curves for the same periods, in Figure 29. The trend of the canal water supply curves matches the demand curve in shape, especially in the second half of the year (*kharif* season), though there is a big quantitative difference. The total supply curve (canal, ground water pumpage and rain) shows an improved quantitative match. Rain contribution is mostly during the three months of *kharif*. The graph makes it obvious that the canal supplies generally follow the demand curve, and that the ground water contribution plays an important role in filling the quantitative gap.

The demand and supply curves for two of the distributaries are shown in Figures 30 and 31, respectively. During the *kharif*, the canal supplies and demand curves follow the same shape, while the quantitative difference depends upon the canal water supply conditions of the distributary. For the non-perennial distributaries (Soda), supplies in *rabi* (winter) are managed by the farmers through ground water pumpage. A good quantitative match between demand and supply curves in *rabi* indicates farmer's consciousness to use expensive ground water carefully. These figures indicate a positive factor of the supply hydrograph, which is timely with relation to the demand hydrograph.

The perennial Jagir Distributary gets canal water during all of the year. The canal supply of this distributary is better than the most of the distributaries of Chishtian Sub-division, still it is less than the crop-demand (note that field efficiencies are not taken into account, so the actual demand will be higher by the factor of efficiency). Relatively, a low amount of groundwater is used by this distributary command.

5.4. ADEQUACY OF IRRIGATION SUPPLIES

To meet the water requirements of crops is a basic obligation of the farming system. In the conjunctive water use environment, this need is satisfied from different water resources -- canal, rain and ground water pumpage. Without a good knowledge of the net water availability and demand in the system, no improvement for the optimal utilization of the water resources can be suggested. In our framework, canal supplies are the primary resource and the ground water is pumped to supplement the shortage; at the farm level, use of ground water varies from zero to one hundred percent, which indicates its role in providing adequate supplies to the farmers.

Figure 29. Demand and the Total Water Supply to Chishtian Sub-division at the Farmgate; 1993-1994.

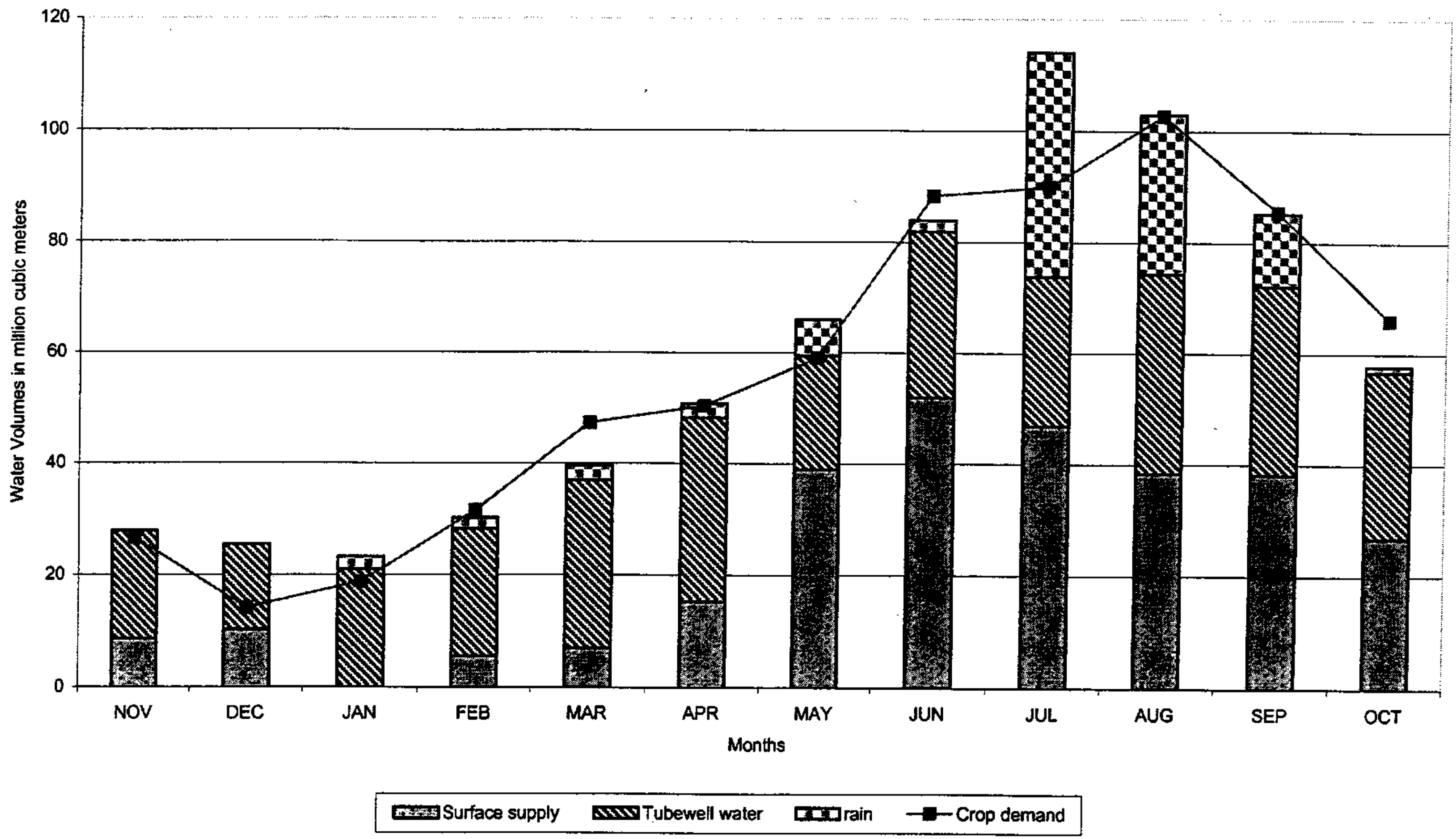


Figure 30. Demand and Irrigation Supply for Soda Distributary (non-perennial) at the Farmgate; 1993-94.

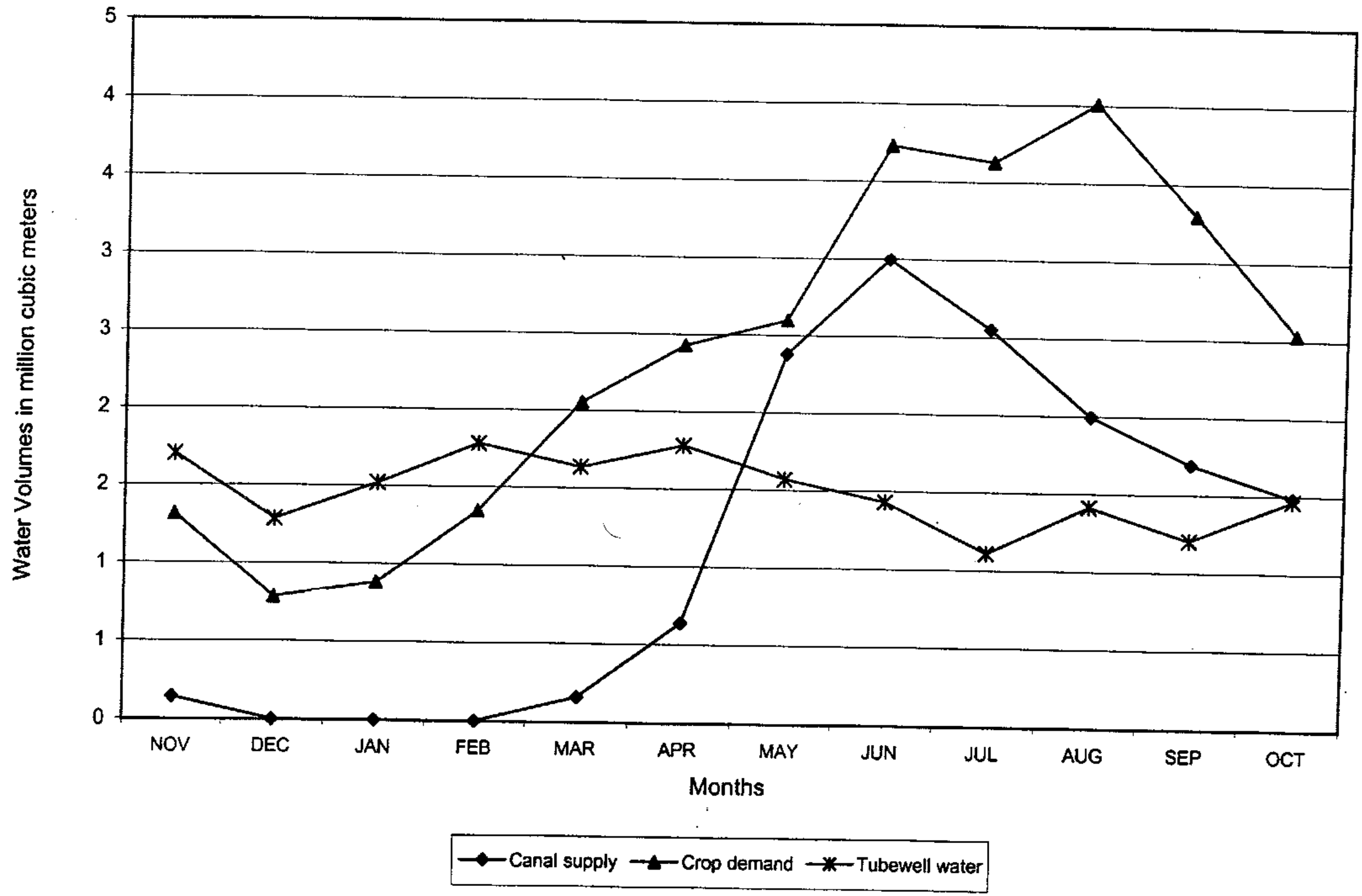
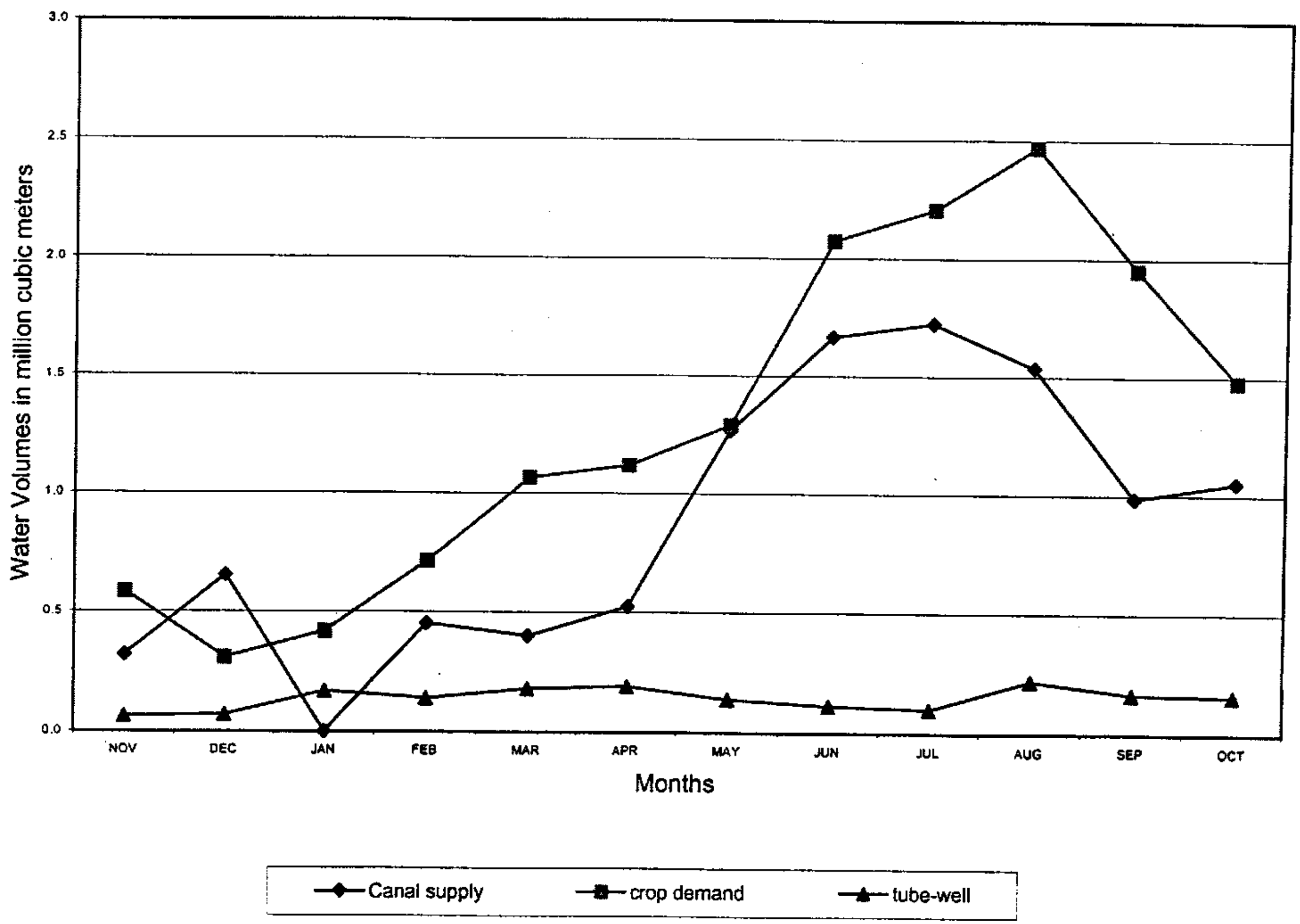


Figure 31. Demand and Irrigation Supplies for Jagir Distributary (Perennial) at the Farmgate; 1993-94.



For the supply-based systems of the Indus Basin, surface water allocations were done for low cropping intensities (of about 70% to 80% per year) and the ground water resource was not considered explicitly. In the last fifty years, the surface supply network of the Indus Basin has not changed substantially, but the cropping system has changed distinctly, with a one hundred percent increase in cropping intensities, and more than 40% of the irrigation water mined from the ground water storage. *The relations between current water availability and net production are discussed in another report.* In this section, an effort is made to compute the adequacy of the present supplies with estimated ground water pumpage.

By definition, adequacy of the supplies indicates the extent to which total water deliveries are sufficient to fulfill needs of the crops in a specific command area. Adequacy is an important indicator, which quantifies the compliance of water input for the process of crop growth. The commonly used measure of adequacy is Relative Water Supply (RWS), which is defined by Levine (1982) as:

RWS:	(Actual irrigation supply + rainfall)/ (Crop E_t + S&P)
Actual supply:	Actual irrigation water supply from canal system and ground water pumpage at the level of interest.
Rainfall:	Estimated rain for all units of the command area. Rainfall can vary spatially and is more important for the system where its effectiveness is quite high.
Crop E_t:	An estimation of crop evapotranspiration.
S&P:	An estimation of seepage and percolation losses.

According to this definition, seepage and percolation losses are a part of the demand parameter, which implies that S&P should include the contribution from different components of the physical section from the location of flow measurement to the field. For the current study, seepage losses from the main and distributary canals have been measured, but a good estimation of the *field efficiencies* is quite difficult due to a big variation in irrigation practices, physical field conditions, leaching requirements, etc. An estimated value for S&P can add a bias to the other three quantities which have been measured, or computed, for the actual conditions of 1993-94; hence, the recommendation of Abernathy (1989) is followed and only E_t is taken as a demand parameter in the denominator. The rainfall volumes are computed for the total rain occurring on the command area.

Network losses occurring in the secondary and tertiary system have been subtracted from the discharges taken at the head of the distributaries, but the losses occurring in field channels and crop fields are not considered. Ground water pumpage has been estimated from the tube-well operational pattern of the sample watercourses representing perennial and non-perennial areas and the actual tube well density of each distributary. Again, the losses occurring in the field channels are not accounted. Crop water requirements have been computed using the CROPWAT model of FAO.

Hence, RSW is computed at the farm-gate, without considering the efficiency and loss factors within the farm.

$$\text{RWS (farm gate)} = (\text{Total irrigation supply} + \text{total rain}) / \text{Crop } E_t$$

Figure 32 shows the relative water supply for the entire Chishtian Sub-division and individual distributaries for two seasons, *Rabi* 93-94 and *Kharif* 94. These calculations show that under-irrigation occurs on more than 85% of the command area. All big and medium size distributaries have a relative water supply near to "1" which is, in fact, water scarcity even for 100% field efficiencies.

For the non-perennial distributaries, the supply/demand ratio is worse during *rabi*, when all of the supply is provided by the ground water pumpage. There might be some underestimation of the ground water volumes because information about pumpage are difficult to be precise. But, as the maximum change in the ground water aquifer is not pronounced, a big difference in total water volumes is not expected. The perennial distributaries may fulfill the crop demands sufficiently if the field losses are controlled and higher (say 80%-90%) field efficiencies are achieved.

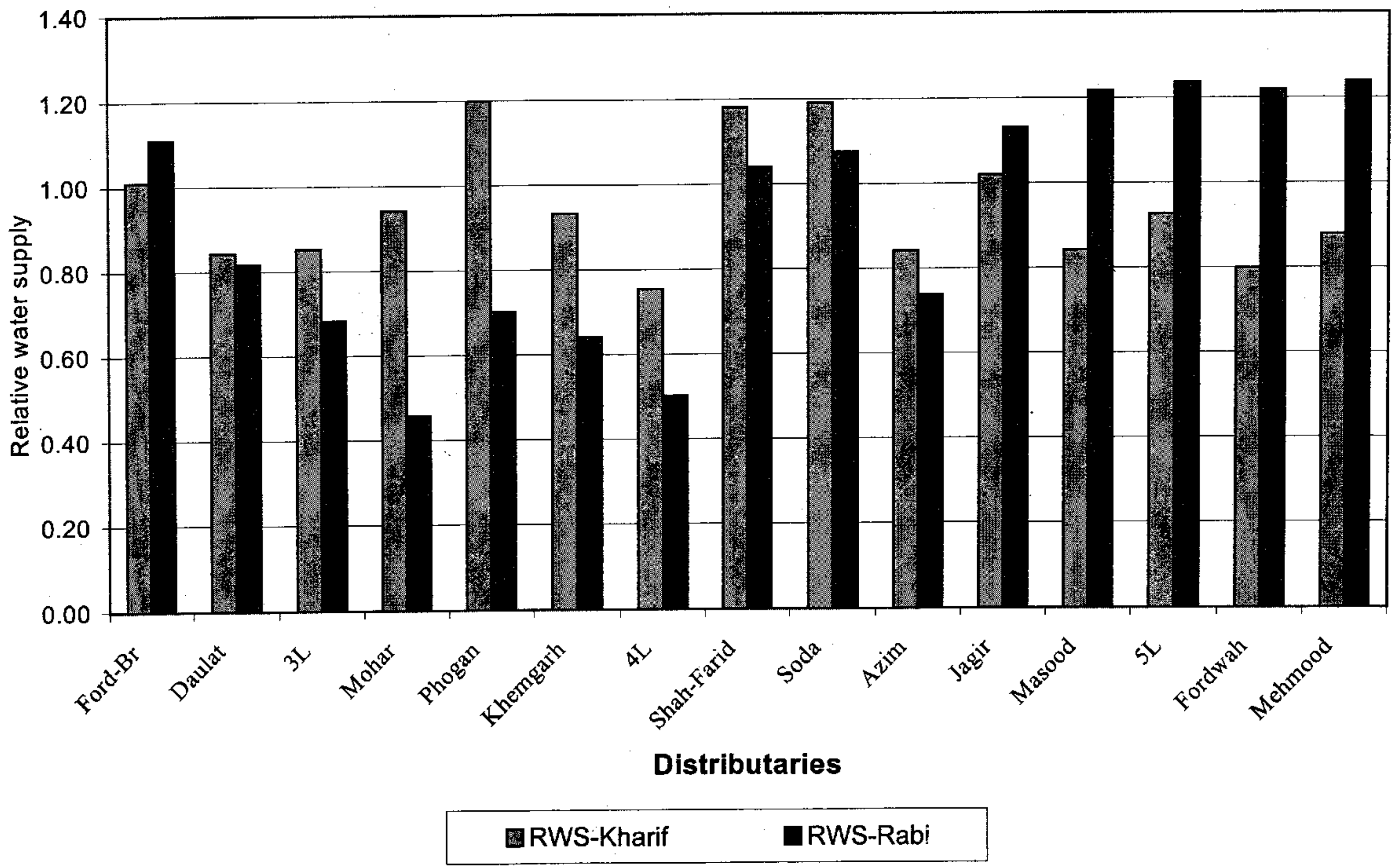
These relations in demand and supply shows that the major portions of CCA are intensive but under-irrigated and the heavy utilization of ground water may disturb the balance of water resources in the long run.

5.5. DELIVERY PERFORMANCE RATIO

For the systems where a seasonal planning and fixed *warabandi* roster is an authorized practice, supplies from the main canal to the secondary system should follow the pattern of the scheduling during all circumstances of flow shortage, or excessiveness. In actual operations, there are long and short-term perturbations, caused by the operations at upstream nodes, inappropriate water delivery schedules, local management's inability to operate according to the delivery schedules, limitations of the physical system, etc.. These factors create a noise in the system, which should minimally influence the planned operations of the system, if the historical flow hydrograph and the constant factors are properly considered in the planning.

The ratio of supply with respect to targeted discharge (design or indent) would be equal to unity if the target is 100% achieved, whatever the actual supply to the canal is. Otherwise, its value represents the degree to which the target has been achieved. Nevertheless, a major generic problem of these systems is the inconsistency of the targets, which are either not fixed for all units of the system, or not specified during all periods of a season. If more than one target exists at a single point, the management inconsistency can be estimated by their comparison.

Figure 32. Relative Water Supply at the Farmgate; Chishtian Sub-division, 1993-94.



For the Chishtian Sub-division, targets are handled like this:

1. The design discharge of each distributary is a general target, which is valid unless an explicit water demand is placed.
2. The indent is considered as a superior target, whenever it is provided by the department at the point of operation.

For seven distributaries, indent was recorded in the register of the gate operators, while for the other seven, the operational target was the design discharge. Considering these two conditions, two types of Delivery Performance Ratio (DPR) are defined as:

DPR with respect to the design discharge;

$$DPR(d) = Actual\ Q/Design\ Q$$

DPR with respect to the indent discharge;

$$DPR(i) = Actual\ Q/\ Indent$$

The weekly average DPR(d) for all of the head regulators of the Chishtian Sub-division is plotted in Figures 33 to 36, respectively; trends can be summarized as:

- No rotational pattern is obvious by the weekly average DPR(d). Most of the distributaries follow the weekly flow pattern of the sub-division head regulator, sharing the shortage each week. A six-week period in June and July is relatively stable, otherwise canals are closed and opened frequently as a local response to the inflow, not as planned in the *warabandi* roster.
- In each section, distributaries receive different shares of water and fluctuations; clearly there are privileged and deprived secondary channels.
- Some of the small distributaries have very high DPR(d) and are not sharing water shortages. The *de-facto* water rights of these canals are higher than the design water rights.
- Two big distributaries in the head, Daulat and Shahar-Farid, have better DPR than the two tail end distributaries, Azim and Fordwah (see Figures 33, 35 & 36, respectively).
- Some of the main canal reaches are more stable, which are reflected in the flow pattern of offtaking distributaries from different sections. All canals offtaking from section 2 have stable flow hydrograph, in comparison with the canals offtaking from the head and tail reaches (Figure 34, 33 & 36, respectively).

Figure 33. Delivery Performance Ratio (Design) for Three Distributaries in the Head Section of Fordwah Branch.

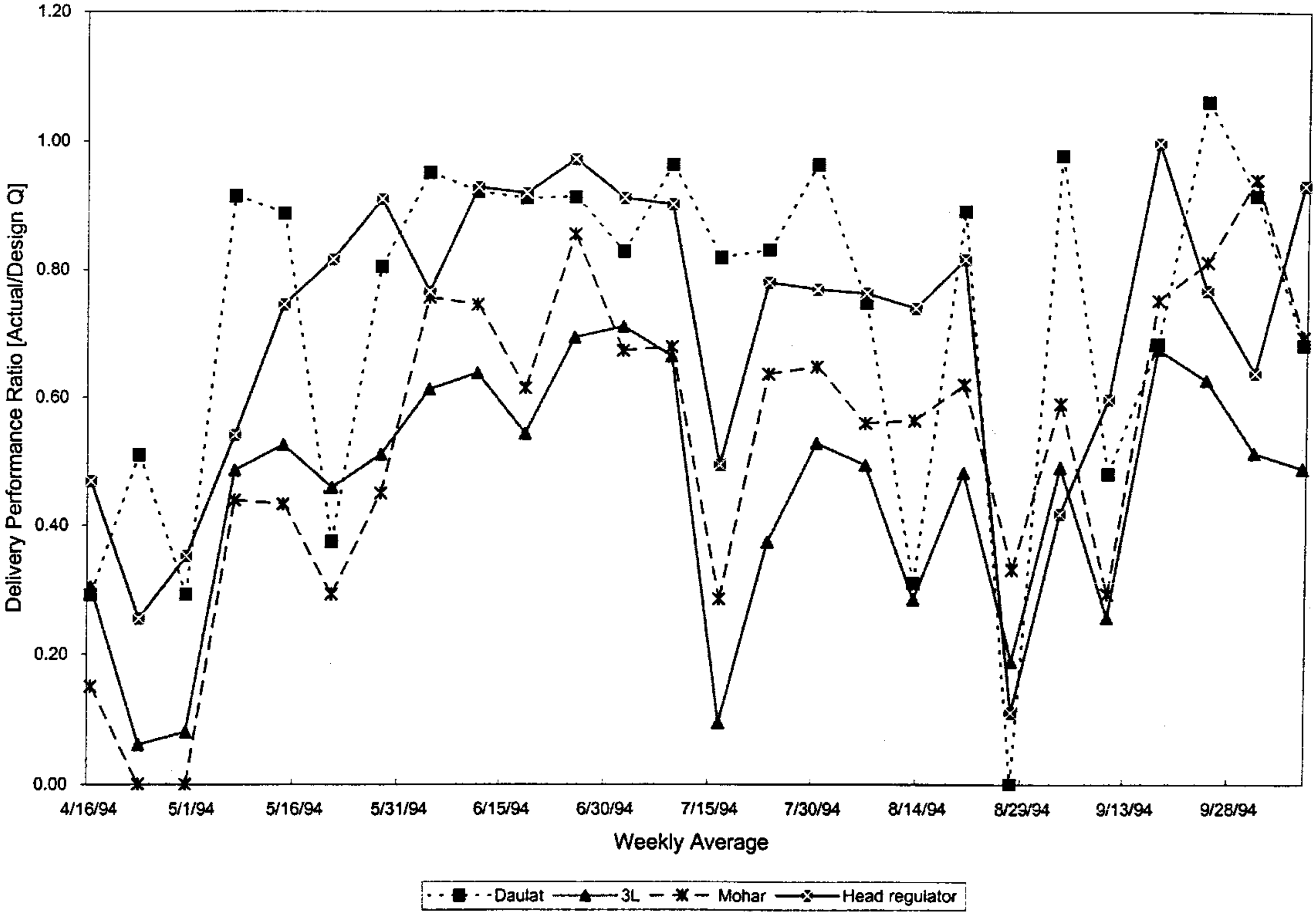


Figure 34. Delivery Performance Ratio (Design) for Three Distributariers in 2nd Section of Fordwah Branch.

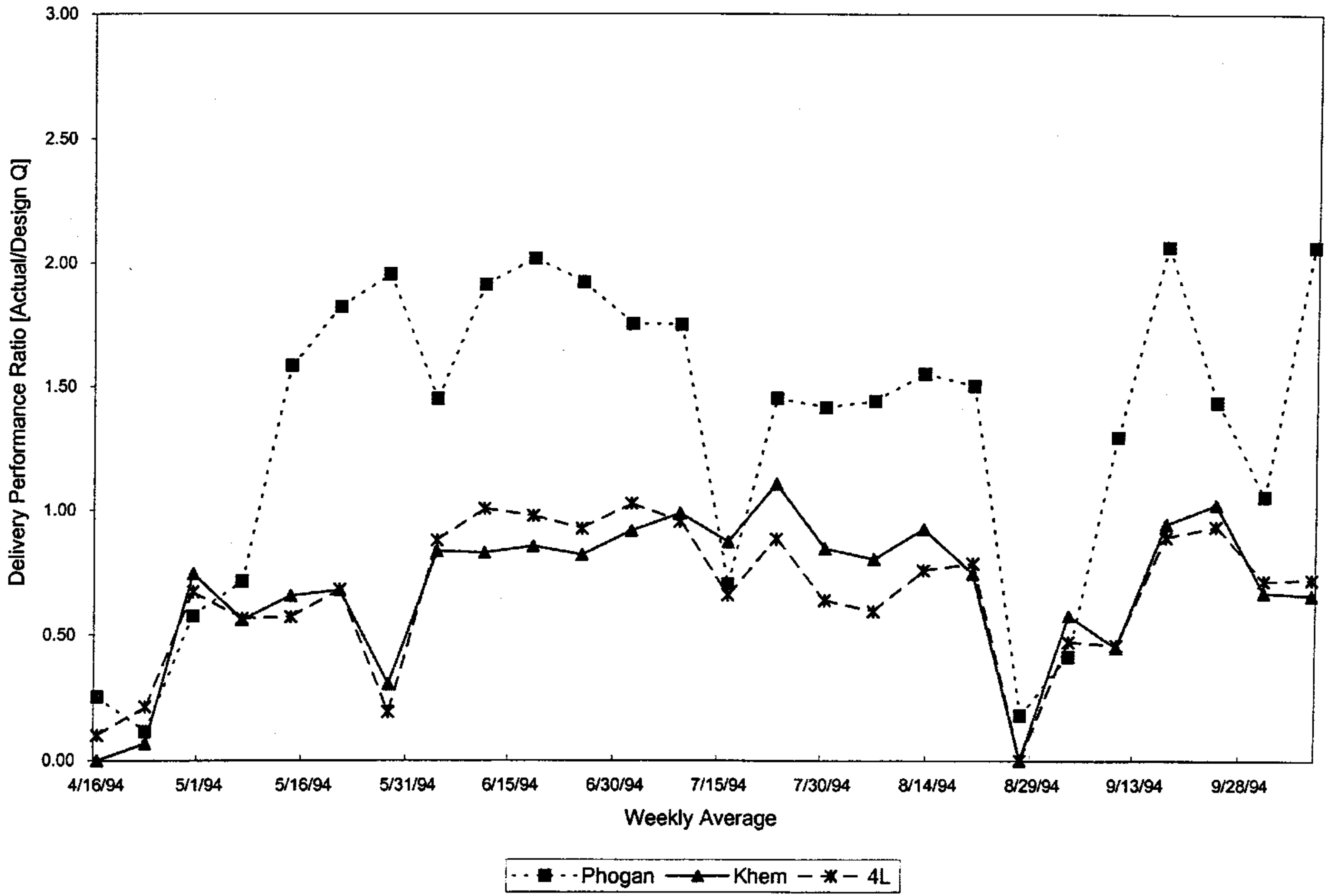


Figure 35. Delivery Performance Ratio (Design) for Another Three Distributaries in 2nd Section of Fordwah Branch.

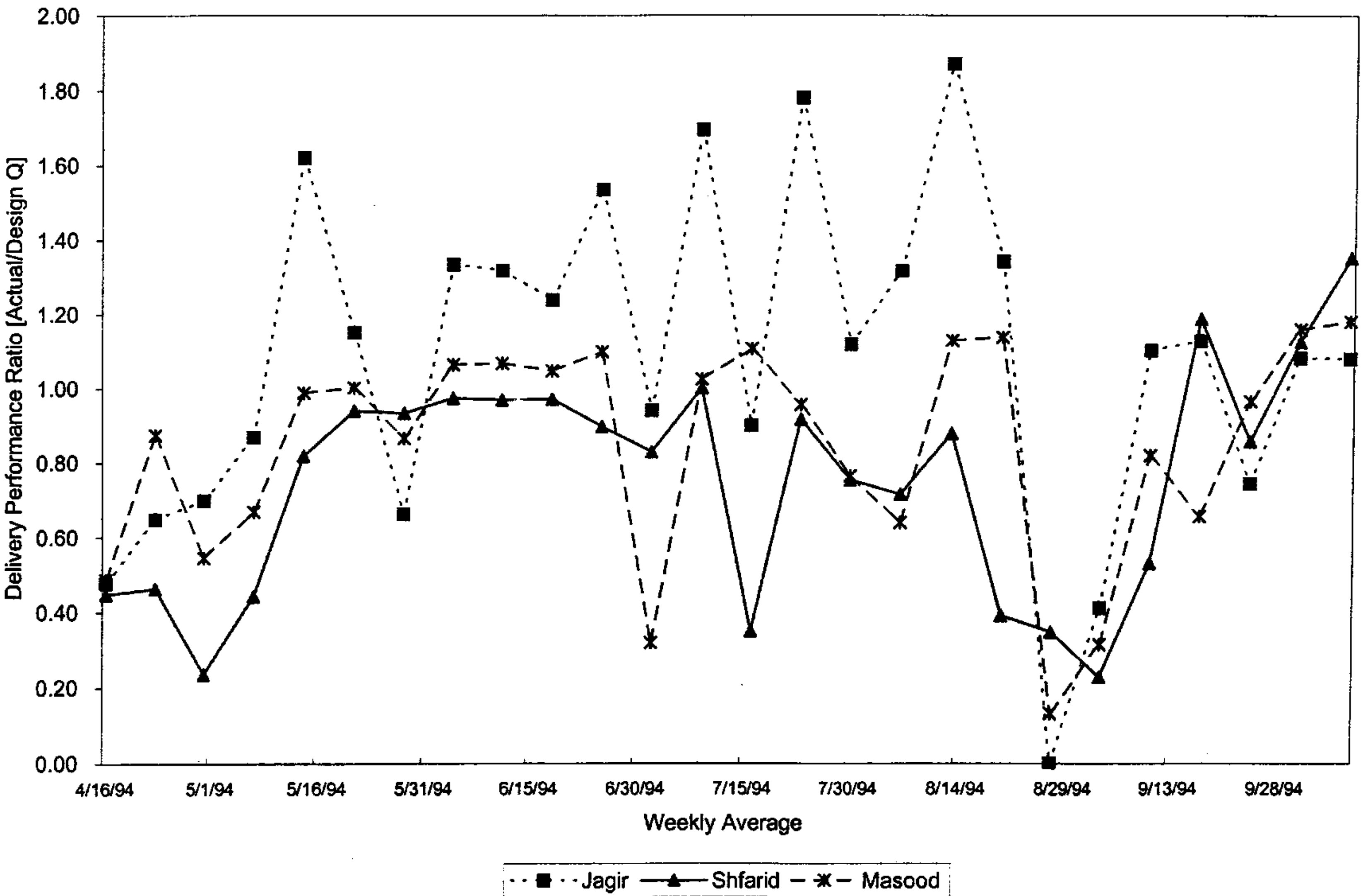
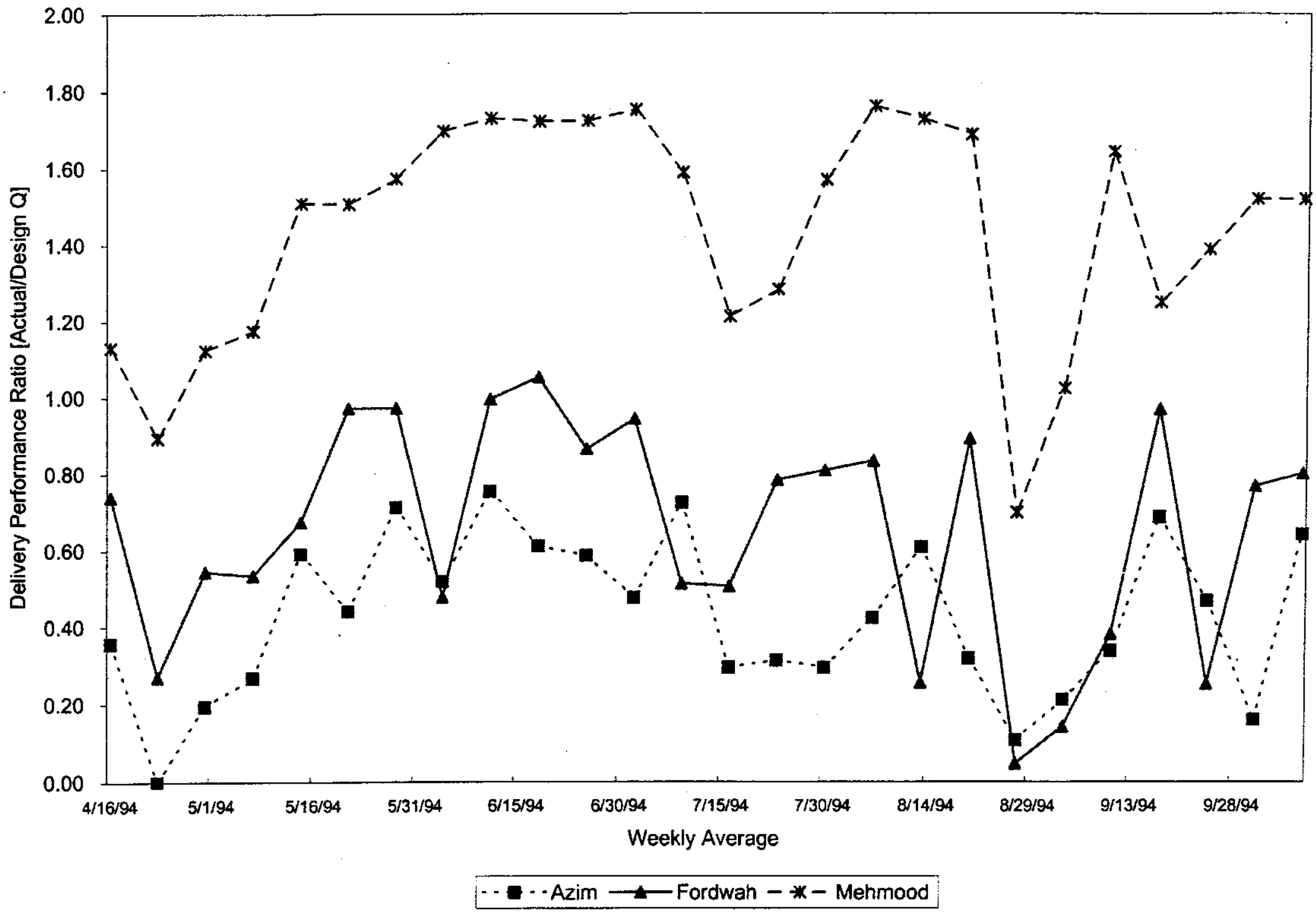


Figure 36. **Delivery Performance Ratio (Design) for Three Distributaries of the Tail Section of Fordwah Branch.**



- The local rotation and preferences are obvious from Figure 36, where three distributaries in the same section represent from the best, to the worst, situations of the water delivery. Mahmud is the best performing distributary with a DPR(d) in the range of 1.5, Fordwah gets normal supplies with DPR(d) very near to the sub-divisional average, while Azim has a minimum DPR(d) in the sub-division. The figure also shows the rotational preference between Azim and Fordwah Distributaries.

The plots of DPR(d) clearly exhibit the differences in the behavior of different channels. The temporal and the spatial extent of inequity and unreliability for the secondary canals could be estimated quantitatively as well qualitatively from these simple graphs.

The seasonal plots of DPR(d) provide an insight into the comparative water supply to the different components of the system. The manager can see that the qualitative and quantitative deviation from equity and can identify badly performing systems for further analysis.

To compare the system's general global targets [represented by DPR(d)] with the manager's specific local targets [represented by DPR(i)], both of these indicators are compared in Figures 37 to 39, briefly.

- During high demand periods of May, June and September, the indent is normally placed higher than the design discharge, which is a valid effort by the local manager to utilize more water when the demand, and water in the network, are both high.

- For better performing distributaries, indent and the design discharge are equal most of the time (Shahar Farid, Mahmud), while the actual delivery is equal to, or higher than, the design discharge. In this case, the manager is satisfied with the functioning of the canal and does not feel a need to worry about the discharge targets.

- For some of the canals, indent is always less than the design discharge (Azim), i.e., a lower target has been officially justified. As the water demand of these canals is higher than the design discharge, a lower indent by the manager is unexpected. In reality, he tries to justify the physical and managerial limitations existing in the operation of Azim Distributary by regulating a low discharge; so, here indent does not reflect the demand, but the managerial choice, and the potential of the system at that particular location.

- When a small distributary is getting much higher supplies than the indent, or the design discharge (5L, Mahmud), there could be many reasons: the manager is giving a preference to that canal, he does not care because it is not an important canal, or he is not aware of the situation, as the correct discharge is not recorded. In the field situation, there could be a combination of these three situations.

Figure 37. Delivery Performance Ratio with Respect to Indent and Design Discharge for Mahmud Distributary.

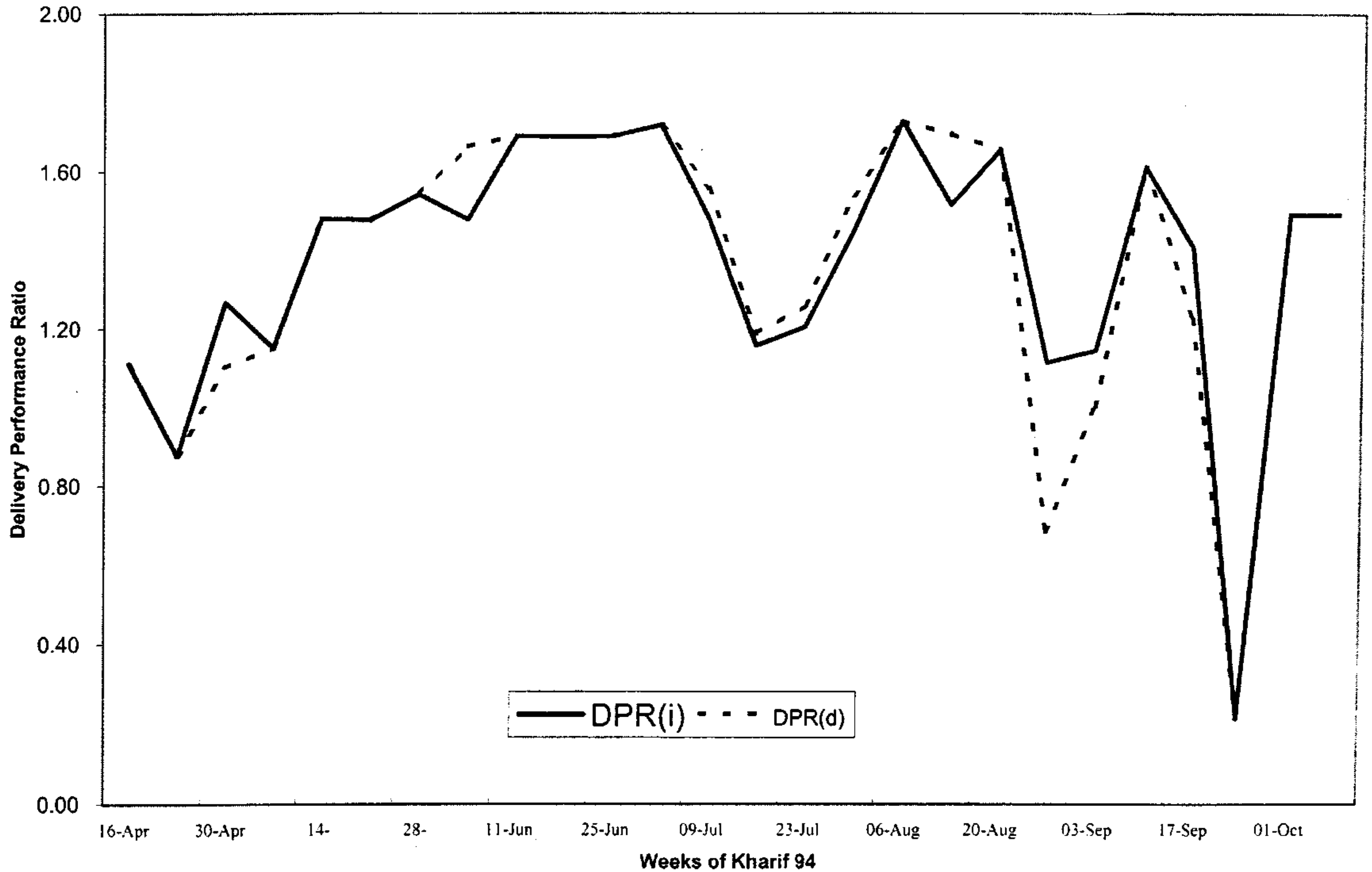


Figure 38. Delivery Performance Ratio for Indent and Design Discharge of Azim Distributary.

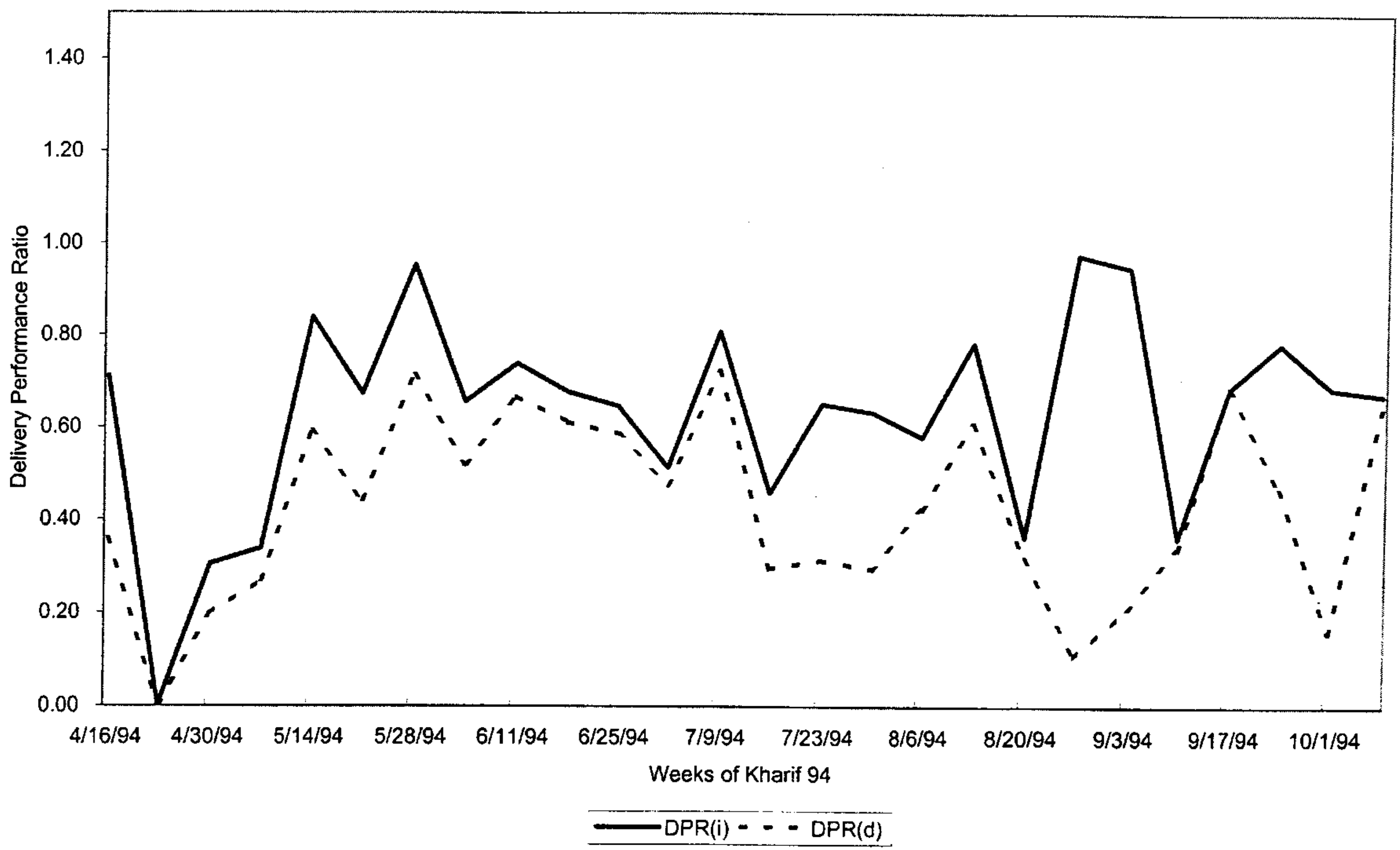
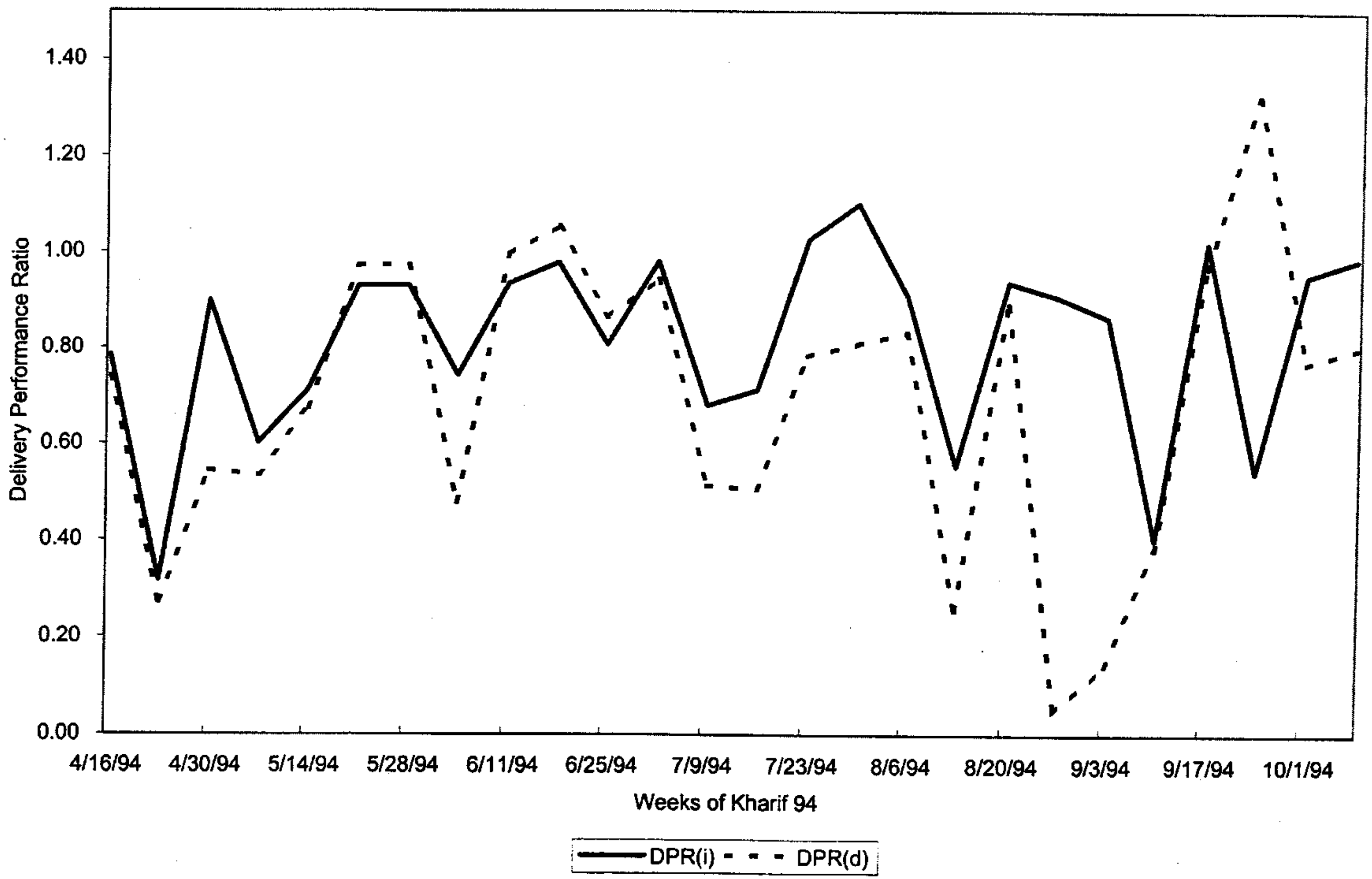


Figure 39. Delivery Performance Ratio with Respect to Indent and Design Discharge for Fordwah Distributary.



These two sets of graphs exhibit the potential of the Delivery Performance Ratio indicator for evaluating the manager's targets and equitable distribution of water among different offtakes over a time interval of the manager's choice.

5.6. ASSESSMENT OF THE MANAGERIAL PERFORMANCE BY THE TOTAL ERROR (TE) INDEX

Seckler, Sampath and Rehaja (1988), used the TE index to assess the effectiveness of the management performance of a *warabandi* system of 39 farmers. The index was defined by Theils (1966) as:

$$TE = \frac{\sqrt{\sum(\text{Targeted Value} - \text{Achieved Value})^2}}{\sqrt{\sum(\text{Targeted Value})^2}}$$

The major assumption in these computations is the equal weightage to the positive and the negative deviation from the target (absolute values), while a higher weightage is given to the bigger values (squaring of the values).

For the management of the delivery system, the best quantitatively expressible internal targets are DPR(d) and DPR(i). As discussed in the previous sections, the targeted value of these ratios is one. In the case of Chishtian Sub-division, the secondary canals DPR (d) could not be equal to unity due to water shortages, but its targeted value is still one, while the DPR (i) could be equal to one in the case of ideal planning and operations.

Using TE as an index to compute the effectiveness of the management for achieving the design delivery performance ratio on the seasonal bases, gives a 40% error which means a management effectiveness of 60%. The effectiveness improves about 10% for the planned deliveries, i.e., performance is 70% in achieving the planned objectives. If used only for the eight bigger distributaries, the management effectiveness is 80% and 85%, respectively, with reference to the design and planned targets.

Important to note is that the computed error value (or performance index) depends upon the realization of the objectives and their quantitative representation. For example, 70% performance effectiveness in the present case does not represent the command area performance, but carries with it the representation limitations of DPR, which treats the command area of a distributary as a unit of the same importance.

The Total Error (TE) index gives a good overall picture of the gross deviation from the targets and is easy to use.

5.7. INDICES OF IRRIGATION AREA AND WATER UTILIZATION

Mao Zhi, in 1989, presented a set of twelve techno-economic indices to assess the gross performance of an irrigation scheme in China. Five of these indices address the relative conditions of land and water utilization; these six indicators are computed here for *Kharif* 1994.

(1). *Efficiency of utilizing irrigation water resources*

$$S\ (\%) = W_p/W_d*100$$

Where, Wd and Wp are the design and actual annual water quantities supplied to a system during a season (m^3/season).

(2) *Gross Seasonal Irrigation Water Quota*

$$M\ (m3/ha/season) = W/A$$

Where, W is the total canal water used for irrigation, and A is the total area irrigated during the season.

(3) Irrigation application efficiency

$$E(\%) = W_f/W_h$$

Where, W_f is the total water delivered to the points of use in the field by the irrigation canal system, while W_h is the total water diverted from the headwork for irrigation.

(4) *Efficiency of actual irrigated area*

$$F(\%) = A/A_d$$

Where, A is the actual, and A_d is the design irrigated area.

(5) *Efficiency of facilities in good conditions*

$$G = N_g/N*100$$

Where, N is the total number of canal structures, and N_g is the number of structures in good condition.

Table 12 below gives the computed values of these indicators for gross seasonal quantities at the sub-divisional level.

Table 12. Indices of Irrigation Area and Water Utilization.

Distributary	S	M m^3/ha/s	F	E	G
Daulat	72	6878	2.13	62	69
3-L	45	9228	1.20	63.38	83
Mohar	52	10055	1.42	63.46	77
Phogan	128	14173	2.25	65.00	71
Khemgarh	67	7461	1.68	60.47	78
4 L	66	6054	2.69	63.46	78
Jagir	63	11882	1.22	64.51	78
Shahar Farid	73	8227	1.73	58.21	66
Masood	89	5760	1.45	60.58	88
Soda	63	11055	1.37	65.00	88
5 L	154	11057	1.40	55.25	50
Azim	43	5077	2.14	61.75	88
Fordwah	71	3658	1.77	62.28	83
Mahmud	153	9318	1.56	64.35	71

The indices shown above are quite powerful for providing a gross seasonal picture of the water availability and the irrigated area. The efficiency of utilizing irrigation resources is the same as the seasonal delivery performance ratio; 61% for the sub-division. At the secondary level, it varies over a large range. The most interesting features are shown for the biggest distributary, Azim, at the tail (20% of the whole area):

- efficiency of utilization of canal water resources is the lowest, 43%;
- irrigation efficiency is in the average range shown by distributary commands, 62%;
- the efficiency of facilities in good condition are better than average, 88%; and
- the efficiency of the actual irrigated area is towards the maximum, 214%.

Very high irrigation area efficiency of the distributaries is a check on the accuracy of low water utilization efficiency. Here, only canal water has been included, which is equally supplemented by the ground water; hence, the total water resources needs to be taken into account. The trend shown by the index 'S' is different from the trend by index 'F' due to the same reason.

The values of the index "M" help to understand the role of canal water which is always higher for the distributaries getting too much water, but not always lower for the distributaries having bad delivery performance ratio. This strange behavior of index 'M' can be explained by the original water allocations, which provide double the water depth to non-perennial areas. The index ‘F’ shows the existence of other factors, like ground water and land potential.

The physical conditions of canal structures are generally not too bad; more than 70% are operating properly, which is, however, not an acceptable value according to the official target of 100%. Some of the secondary canals have low efficiency of the irrigation facilities regarding good conditions, in the range of 50%, and need quick action to reform this situation.

As the information used in Mao-Zi’ indices should be officially available at the sub-division level; these simple gross calculations, and their comparative behavior, could provide a good insight of the system’s performance for the local management.

6. SUMMARY OF RESULTS AND CONCLUSIONS

The analysis carried out in this report addresses the performance of the physical and control processes (water delivery and distribution network) with reference to their relations with the decision-making (planning) and bio-mass production (water requirement) processes. The performance of the canal water delivery and distribution system has two input components (acquisition and management of resources) and two output components (bio-mass production and sustainable recycling of the resources). As the resource availability varies temporally and the physical system consists of heterogeneous groups with different rights of canal water, the management side is obliged to provide services under variable circumstances to achieve the targets set on the output side.

The evaluation of the canal water delivery process has been carried out within the existing framework of the upstream control and target-oriented operations of the system. Availability of resources on the users end has been analyzed through a comparison of demand and supply. The conjunctive water use environment indicates involvement of different actors in the resource management process, whereas about 40% of the total water used is mined and managed by the farmers.

The results of the analysis presented in this report are summarized and discussed here to highlight two aspects:

i. factors contributing to the system's performance; and
ii. the performance evaluation procedures and tools.

6.1. FACTORS CONTRIBUTING TO SYSTEM PERFORMANCE

6.1.1. Water Management

The canal water shortage and the variability of flows is a characteristic of the surface supply, built into the design network, management procedures and operational setup of the system. This is caused by the supply source and demand hydrograph, which has been incorporated into the design and operational setup.

The run-of-the-river and reservoir-based systems differ in their water supply and use pattern. The first one does not have a control on excesses and shortages and attempts to optimize water utilization when it is available, while the second one attempts to minimize the gap between demand and supply timing. The supplies to the Chishtian Sub-division are a combination of both setups. During *kharif*, the maximum demand is placed for all of the distributaries by local managers within constraints of the canal capacity and safety considerations (the temporary closure of canals due to rains or heavily silted water). While in *rabi*, water is conveyed from a reservoir 800 km away through link canals and river reaches to serve the perennial area, and to provide a minimum support to the wheat crop in non-perennial areas by providing them three turns of the canal supplies.

Hence, the actual supply to the system is influenced by multiple factors; run-of-the-river nature of the system, reservoir functioning, management and operations along a 800 km long conveyance passage, and socio-political and institutional influences. The real target for the management is to feed the secondary canals for maximum possible stable and equitable sharing of the given water hydrograph. ***To address this target, the system needs to be planned, observed and operated properly.***

Analyses of the seasonal rotational plans for the Chishtian Sub-division indicate that they are not comprehensive and transparent. A detailed planning for the whole system, and for the actual water shortages at different levels, would have been possible because the seasonal water supply hydrograph does not change much from year-to-year. The efforts made to improve water distribution within the Chishtian Sub-division confirm that no improvement is possible without considering the supply hydrograph and upstream operational plans properly.

An important factor involved in the simplification of planning is the easiness of the operations, which is a reason for having the sub-groups of different sizes in the rotational plan, and to exclude small distributaries from rotation. Very clearly, in planning, a preference is given to the head sub-divisions, and to the perennial distributaries in *kharif.* This type of practice is unusual at the planning stage. These areas usually suffer due to physical and operational limitations, not due to planning itself. In the case of the Fordwah and Azim Distributaries, planning seems influenced by the localized nature of the actual operations and the physical limitations of the system. In fact, this type of planning provides protection to the field practices and system limitation, and can influence remedial efforts in a negative way.

6.1.2. Knowledge of the System and Feedback

A basic requirement for the good management of a target-oriented system is a reliable feedback network, without which neither a proper evaluation of the "achieved targets " is possible, nor can improvements in operation and maintenance be recommended. A simple example is a common phenomenon of incorrect assessment of the daily discharges, although the gauges are monitored correctly. The absence of feedback affects planning and operations badly, and introduce a very basic error in the knowledge of the system. For example, in the Chishtian Sub-division, water demanded by the local SDO and the actual discharge, both, are 150cfs higher than the design discharge, while about 150-200 cfs seems to be disappearing between the main and secondary system. In reality, the main system cannot draw higher than the design discharge. With most of the rating curves out-dated at the primary and secondary levels, a manager cannot have a good knowledge base, and can hardly make decisions for improvements in a situation of ambiguity. Hence, he defers the process of decision-making at his level, which eventually shifts to the lower level.

The nature of decision making is bound to be different at the lower-level control point of two or three secondary canals. The local operator operates in a more specific, but detached, situation. He receives a discharge and water level, a part of which he has to divert to the secondary system. To take an action, he has a general reference of water levels (against design discharges) for the secondary and downstream system, pressures/influences from the users, historically established operational pattern, and sometimes, instructions from his superiors. The last one is a priority situation, which is normally adhered to. Otherwise, his actions are a combination of the above-mentioned factors, with minimum upstream and downstream links.

As a consequence, there is a weak relation between seasonal planning and the actual water distribution patterns. Indents (water demand by the manager) are more close to the actual discharge, and do not follow the priority roster set by the seasonal plans. The regime theory is not strictly followed for the secondary canal operations; head-end big distributaries have been given a preference over the tail-end big distributaries. As a consequence, net deliveries are finally a result of system constraints and flexibility, local efforts and decisions. *The continuity of the processes carries over the qualities and quantities of flow without generating any knowledge base to improve the management for the next time.*

The loop between planning, observing and operating does not work properly because of the weak links between three processes; (1) Planning; (2) Operation & Maintenance (O&M); and (3) Monitoring & Evaluation (M&E). The non-availability of feed-back defers the refinement of planning or operations. In the absence of responsive planning and feedback, the variability of the flow hydrograph at the sub-division head is multiplied by the response of the local operations towards the tail.

6.1.3. The Performance of Water Delivery Network

The main features of the behavior of water delivery network are summarized below.

Canal Capacities

The branch canal maximum capacity is about the same as the design discharge, not 120% of the design discharge, which is the criterion for the maximum capacity. This means a 20% reduction in the capacity. Field observations confirm that no freeboard is available along most of the canal length, whereas towards the tail the capacity reduction is more and the tail reach cannot feed all three distributaries at the full supply at the same time. Three out of fourteen distributaries have capacity problems and they are always operated at less than design discharge; this problem is serious for the tail-end biggest distributary, which has a history of breaches.

Head Regulators

All of the head regulators can draw the design discharge at full supply; most of the gated head structures have a flexible range of operations when operated in combination with cross regulators. Three head regulators have high crest levels; two of them are weirs and cannot draw an appropriate share for most of the operational range of the branch canal.

Variability of Supplies and Regime Operations

Much more than physical aspects, the managerial and operational aspects play a role in the variability of supplies. Sections on seasonal planning and regime operations, particularly, presented the contributions of the non-physical aspects. Figure 40 summarizes the operational range of the branch and distributary canals into five clusters. Three of the clusters are below the regime target of the manager, 70%. The level of non-optimal operations, as well as a significant difference among the distributaries is clear from this figure.

6.1.4. Water Distribution: Objectives and Realities

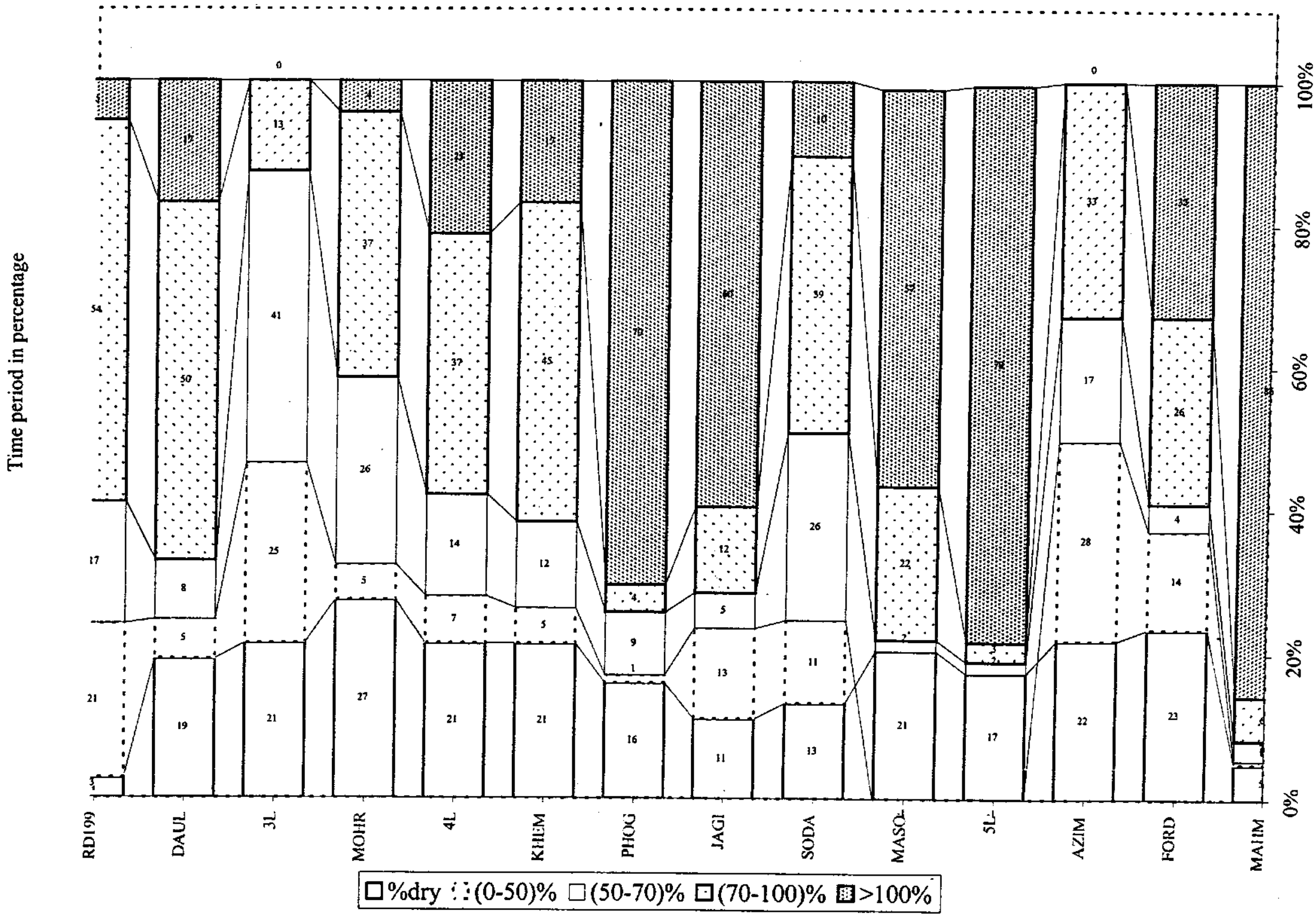
Equity and reliability are the system's direct objectives and guide the activities related to water management, regulation and operation to achieve them. Important to note and understand is that for a system with unequal seasonal water rights, equity promises the equitable distribution of already defined water rights, not the equal distribution of water to each command area. The seasonal variation of water rights to the perennial and non-perennial areas is bound into a big difference of water availability in the river between *rabi* and *kharif* seasons, and should not be compared blindly to analyze water delivery performance. An analysis of the criterion for water rights and allocation constraints is a separate subject. To incorporate the factor of seasonally unequal water rights, the Delivery Performance Ratio (DPR) is used as a water distribution target, not the net discharge or water volume.

6.1.4.1. Equitable Distribution

Different qualitative and quantitative aspects of the inequalities in the system have been addressed using different traditional parameters and the equity indicators in Chapters 4 and 5, respectively.

- The equitable distribution of water rights at the secondary level is better achieved when water in the system is maximum; hence, the spatial equity in the system varies on a temporal scale within the season.
- Water delivery performance is almost equitable for the distributaries serving 50% of the area, and is within a range of plus, or minus, 10% for 66% of the area (MIQR, RER). However, the best quarter of the area gets a delivery performance ratio 2.5 times better than the worst.
- The non-comprehensive planning for rotations and local decision-making is one of the causes for inequitable distribution; for both of these, equity principals are not followed properly (see sections on *warabandi*).
- Operational preferences exist at different levels. The causes of these preferences may be easiness of operation, operational rules, or the decision of a gate operator. The equity is adversely affected when more than one big distributary exists at a node.
- The physical factors of the secondary and the main canal play a role.

Figure 40. Inflow Pattern of Fordwah Branch and Secondary Canals in Kharif 1994.



- The dry-tail conditions and the relations between head and tail supplies provide good information about the spatial behavior of flows along the secondary canals. This shows that in most of the canals, water does not reach to the tail when the head is operated at less than 80% of the design discharge. A linear relation between less than 70% supply at the head and dry tail, suggests that the tertiary systems on some of the canals is severely suffering. The longer canals suffer more due to conveyance and maintenance problems (section on tail supply conditions).

6.1.4.2. Reliability of Supplies

To achieve an optimal reliability of the water supplies at the secondary and tertiary levels is the core of water management activities. An important water distribution target at the secondary level is to specify and maximize the period of ensured water supplies. Historical knowledge of the flow hydrograph, and proper seasonal planning, play key roles for achieving this objective. The sections on *warabandi*, reliability and delivery performance ratio addresses the reliability status of Fordwah Branch Canal supplies:

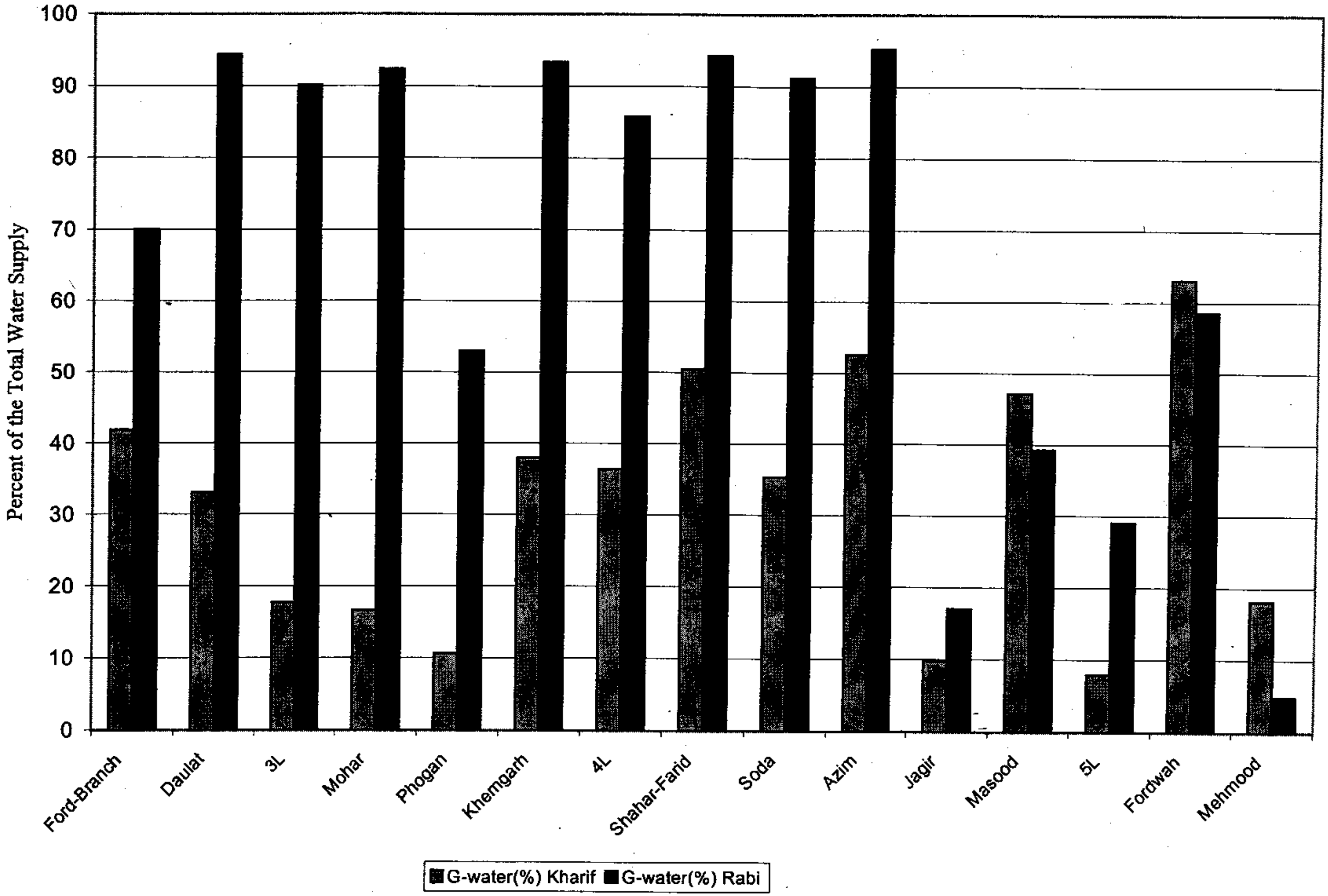
- The coefficient of variation of weekly average supplies is too high for most of the canals, even during relatively stable periods; improper planning and breakdown of the communication system contributes to these difficulties;
- An improvement in reliability with the indent (more specific target than design) discharge is not global over space and time, reasons lie in the procedure of target setting, which are not well adopted and uniform within the system; and
- Overall reliability is worse than the equity.

6.1.4.3. Conjunctive Water Use Environments

The role of ground water is indicated in the sections on adequacy and timeliness. The estimated ground water pumped in the sub-division is about 40% of the total irrigation supply in *kharif*, while the canal water entering into the system amounts to 45%, with the remainder (15%) being rainfall. During *rabi*, ground water is 70% of the total irrigation water supply, which is 140% more than the canal supply at the head of the sub-division. The ground water quantities are estimated from surveys and censuses carried out in the sub-division to predict the density and operation of tube-wells. All tube-wells in the area are installed and used by the farmers.

The tube-well water pumped for each distributary (as a percent of total irrigation supplies) is shown in Figure 41, where an average value for the sub-division is also indicated for both seasons. The difference between perennial and non-perennial distributaries is obvious, more than 90% of the supplies come from ground water pumpage for the second type of canals. For the biggest perennial distributary, 60% of the supplies are taken from the ground. It is clear that ground water is the major source of water in *rabi* and a crucial resource during *kharif*.

Figure 41. Conjunctive Water Use Environment Showing Heavy Exploitation of Ground Water in Rabi.



6.1.5. The Quality and Quantity of Water Shortage

The quantity and quality of water scarcity must be understood before planning any change. The different processes and indicators discussed in Chapters Three, Four and Five, respectively, indicate the nature of water shortages in the system. The important aspect of the water shortages is that the target level for the adequate supplies is different from different actors' perspectives.

6.1.5.1. From Irrigation System's Perspectives

The delivery performance ratio (DPR) at the head of the Chishtian Sub-division in *Kharif* 94 is 73%, which is quite a good value for a declared water short system on rotation. The temporal coefficient of variation of DPR (i) [delivery performance ratio against the planned target] is 0.39, which is quite a poor value for a rotational system. The second important result is that the delivery performance ratios with planned targets does not show much improvement on the delivery performance ratios with respect to a single seasonal target, DPR(d). Figure 42 shows seasonal average DPR(d) and $C_v(Q)_t$ for all distributaries, varying respectively in a wide range of 0.43 to 1.45, and 0.3 to 0.72.

For most of the channels, DPR does not reflect a critical situation; 50% have a DPR higher than 70%, while 25% have a DPR less than 60%. But, $C_v(Q)_t$ indicates severe variability conditions, with only one distributary having a Cv less than fifty percent. The weekly C_v behavior shown in Chapter 5 indicates a large range of variation for every distributary. Therefore, it can be concluded that water shortages in the sub-division are about 30%, which is distributed unevenly; the variability of flows is quite high, which is caused by inefficient operations of the system.

The positive side of the supply is its timeliness. The supply hydrograph for the branch canal and for most of the distributaries follows the trend of the demand hydrograph for the command area, though the shortages are quite pronounced.

6.1.5.2. From Command Area Perspectives

The demand and supply relations are discussed in the sections on adequacy and timeliness. The existing canal supplies are not sufficient for the existing cropping patterns. The shift from the optimal design situation for each distributary is summarized in Figure 43. The changes in water supply and cropping intensities are exactly in the opposite direction. Obviously, these higher intensities are supported by other sources of water. The present deficiency of canal water supplies in the supply-driven systems of the Indus Basin is described as *the shortage by design*. As indicated by the graph, *un-intensive irrigation* was the design characteristic, which was justified by a thinly spread population with agriculture as the main profession. The "under-irrigation" was definitely not a proposition, which is clear from the design and actual value of 'irrigation quota' and 'surface water utilization efficiency', Mao-Zi's indices. A comparison of the surface water availability per unit proposed and actual cropped area shows that canal supplies are not insufficient for the actual cropping intensities.

Figure 42. Seasonal Equity and Reliability of Water Distribution at the Secondary Canal Level; Kharif 1994.

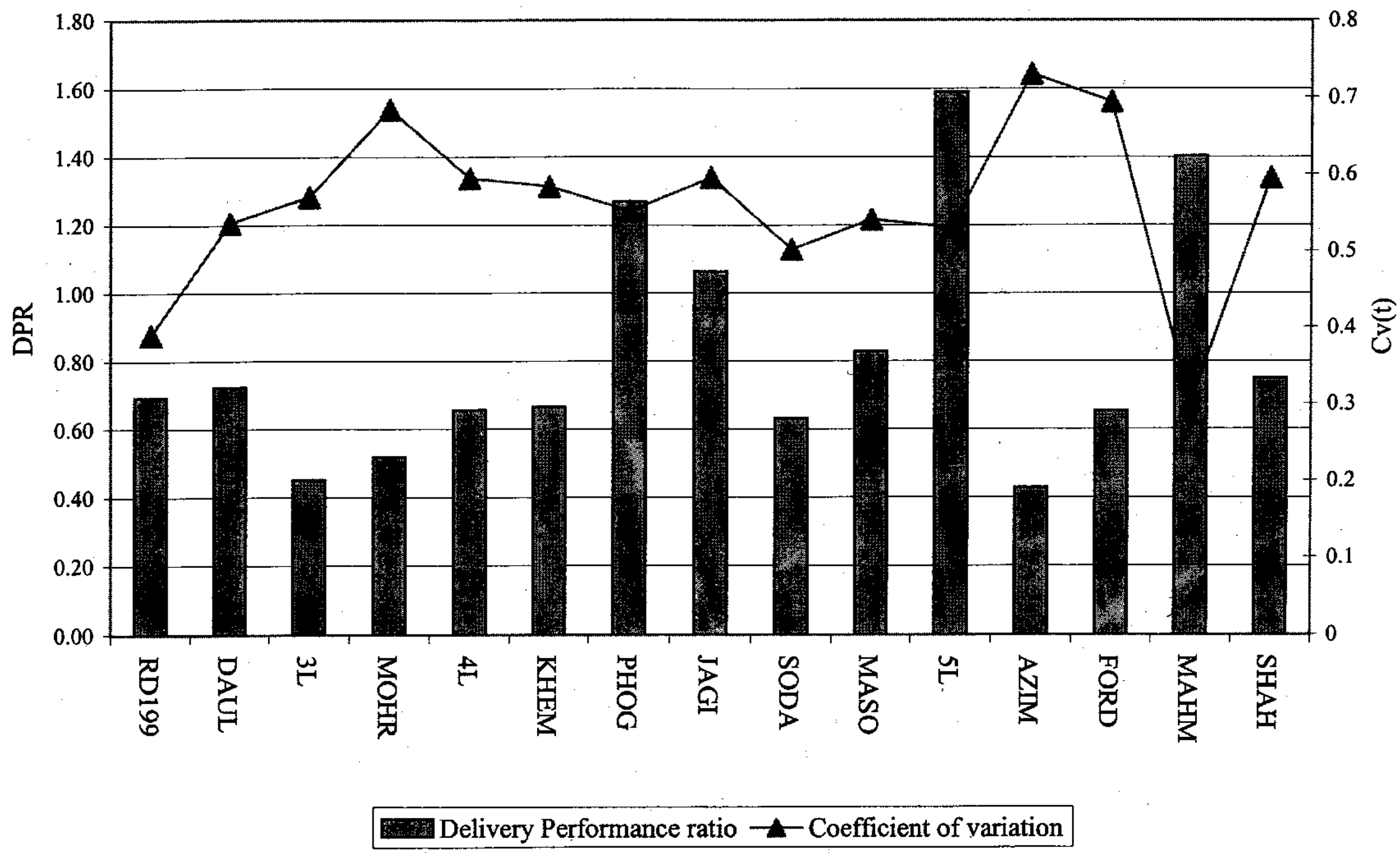
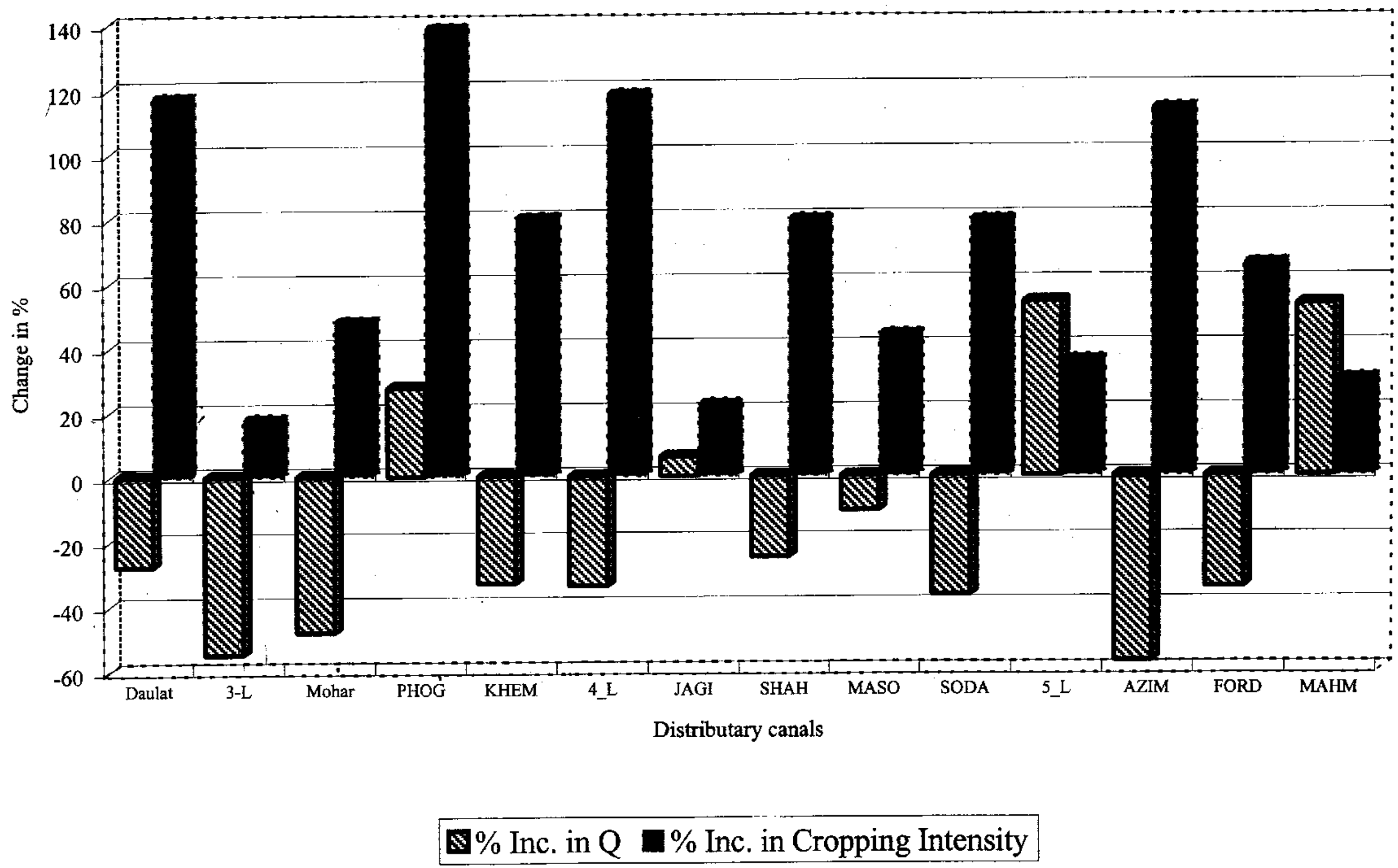


Figure 43. Percent Change in Discharge and Cropping Intensities from the Maximum Design Values, Kharif 94.



6.2. PERFORMANCE ASSESSMENT PROCEDURES AND TOOLS

The relevance and appropriateness of a performance assessment tool depends upon the properties of the process to be studied, evaluation or diagnostic objectives, scale of the process in time and space, and finally, the characteristics of the performance assessment tool. As mentioned earlier, this report uses a number of indicators to evaluate different aspects of the water delivery system, from simple operation guiding gauges to the complicated output evaluation-oriented statistical relations. As summarized in the previous section, this analysis gives an overall performance, as well as the performance of different components of the water delivery system. The framework, definition and boundaries of the analysis given in Chapter 2, and the hardware and software of the system given in Chapter 3, provide a justification for the analysis carried out in Chapters 4 and 5.

The first part (Chapter 4) covers monitoring and evaluation of the physical facilities, planning and management decision-making, and the simple traditional indicators used to test the achievement of the final target of the management (allocated water).

The second part (Chapter 5) analyzes the characteristics of the system's output (delivered water) for the promised qualities of equity, reliability, timeliness and delivery performance, as well as for the required qualities of the adequacy and the management effectiveness.

6.2.1. Traditional Performance Assessment Tools

Chapter 4 shows that the final target set for the system is not a "quantity fixed for always", rather, it is a "target achievable under some specific conditions". These conditions are determined by the inflow hydrograph, a fixed output reference (design discharge), a historical output reference (planned deliveries), rules of operations, and the functioning of the physical components.

In this context, the traditional performance indicators provide a series of targets and tools to evaluate and improve each component and process in the system for its particular function. All of these sub-targets provide conditions for achieving the final target. The individual performance of each component is finally reflected in the overall performance of the system, and each missing link, or badly performing component, imparts a specific deficiency. But, the modular nature of the system gives it a robustness, and the system, as a whole, does not fail, or collapse, with a few badly performing components.

A seasonal plan is the first tool that sets the targets, with criteria given to prepare, modify and evaluated these targets for use during the next season. This should be based on the historical trends of the inflow, and must be refined through day-to-day indents. For each structure, the plan and actual discharge and gauge must be recorded daily. In reality, targets are prepared, but not checked and improved. One reason is that to compare the daily gauge and discharge with the target values for each structure is a cumbersome process. There is a need to have a simple and explicit indicator to evaluate the seasonal planning and the indents at the same time at the end of the season. With reference to the discussion in Chapter 5, DPR seems a simple and useful ratio for this purpose.

After planning, operation is the first action taken to achieve the set targets. As discussed in Chapter 4, operations are mostly guided by a fixed reference of the design discharge, then by some rules, and in case of emergencies, by planned targets. So, here the link is already weak, and the actions taking place are quite isolated from the planning. However, it is shown that if the rules and the local targets are followed properly, a secondary canal at a particular node will operate with minimum fluctuations, and will be in a proper hydraulic state to deliver equitable supplies to the tertiary systems. *The monitoring of the daily gauge parameters shown in Table 3, along with the availability of the communication system, are two essential tools for proper operation of the system.*

There are two very clear operational rules: operate the distributaries in the regime range of higher than 70% of the design discharge; and maintain the tail gauge equal to one foot. Both of these are valid local targets as shown in the sections on the regime operations and the tail conditions. A refinement in the operational lower limit of 70% of the maximum discharge is suggested for most of the distributaries by the head-tail relationship. This limit needs to be moved upwards at 80% to 100%. A tail water shortage is shown for most of the distributaries as their tail ends do not receive water for most of their operational range. Even a good DPR at the head does not ensure reliable tail supply, which means either the regime of the canal is changed due to bad maintenance, or the water drawing capacity of some of the outlets has changed, or some other illegal practice is happening. *A remedial action is required, according to the official standards, based on the analysis of the head and tail gauges.*

The maintenance process goes with the operation process at all levels. The required performance of the canal structures should be recorded, evaluated and maintained regularly against authorized values. Targets are again very clear:

- maintain proportionality functioning and free flow conditions by measuring the gauges;
- maintain design, or authorized parameters, for dimensions of the structures; and
- maintain canal cross-sections.

Hence the gauges, their calibration, measurements and the design references for the maintenance are useful tools to accomplish, evaluate and readjust the basic conditions required to achieve the appropriate delivery performance. The lack of a communication network is mentioned at many places; in fact, it is the most important tool to make information available at different levels.

The traditional performance monitoring and evaluation setup has its strengths and weaknesses, which needs to be understood to place everything in a proper perspective. Strengths of the traditional system are:

- Provision of a discrete, simple, well-defined and achievable set of parameters and rules for monitoring and evaluation;

- The action-oriented nature of the M&E process leads to O&M activities, for which the nature of action and the role of each staff is established;

- The step-by-step process of management progress, from the implementation to the decision-making level, along with the information which accumulates towards the higher level; provides substantial knowledge according to the importance of the decision-making level;

- The hierarchical nature of the management provides an easy and centralized control on the system, which makes it possible that one XEN can control one main canal consisting of a few dozen distributaries (36 in Fordwah Canal) and thousands of tertiary offtakes, with the help of three to four engineers; and

- A loop between planning, operating, evaluating and re-planning exists with its complex links at different levels, but the system is robust and can sustain a few missing links.

This simplicity and straightforwardness impose some limitations and weaknesses:

- The discrete and detached nature of the operations cause weak links between different actions and hence non-optimal functioning; in a hierarchical system, one missing link can disturb the relevant functioning upstream and downstream;

- The link between the evaluation and decision-making process is empirical, which requires a good and reliable monitoring as a first step, then transfer of information to the decision-making level, and finally, the willingness and capacity to learn from the new realities before making decisions; this loop must continue over time for effective management;

- Though the proposed monitoring and communication is quite strong, the built-in knowledge base at the sub-divisional level is weak; information leads to action but is not converted into a consolidated knowledge, which could be easily available for the overall assessment of the water delivery system; and

- An analytical framework for the integrated evaluation process is not provided to quantify the performance at the sub-divisional level.

6.2.2. Indicators to Evaluate the Output Against its Proposed Qualities

A theoretical analysis, or in-depth comparison, of the performance indicators is not presented here; rather, Chapter 5 provides application examples to see the potential of different indicators in highlighting the flow properties.

Three equity indicators, Cv, UCC and Theils' coefficient provide almost similar information on the temporal variation of the spatial equity, although each has specific qualities. The coefficient of variation places uniformity in a narrow range and each large deviation (even by a single unit) takes inequity to the maximum, UCC ignores small shifts in the system, while the average and the sum of the absolute deviations does not change. Theils Coefficient represents scatter, or deviation, from the justified share, statistically the indicator is good, but not very simple to calculate, nor transparent in quality reflection, and needs a proper understanding of its meaning. All of these indicators give a good overall picture of the inequity. However, the quantitative values are relative and depend upon their computational technique. As shown in the section on equity, though the trends are similar, the numbers can vary differently.

A direct comparative indicator for equity is MIQR, which, quantitatively, gives a comparison of the best and the worst quartile. A justification for the best or the privileged group and the difficulties in splitting up an area into four equal groups are discussed. An alternative indicator, RER, divides the area into three groups based on fairness criteria. A water depth based analysis using MIQR and RER have the targets different from the accepted targets of the system, but give useful information from command area perspectives. A comparison of the quartile analysis with reference to DPR and water depth (WD), indicates the direction in which the system is moving.

The delivery performance ratios (DPR(d) and DPR(i)) are used as a basic parameter for all equity and reliability calculations. The section on DPR shows that the seasonal plot of its weekly average gives an indication of spatial and temporal variation of inequity. Hence, this simple ratio is a useful indicator to estimate the qualitative and quantitative behavior of each unit.

The reliability of supplies is shown by the temporal coefficient of variation of the delivery performance ratio for a single structure. The behavior of $C_v(DPR(i))_t$ provides information on the interference with the actual, versus planned, discharge; peaks are meaningful in this case because C_v must be near to zero for all conditions (rain, low demand, etc.) in the case of good planning.

The timeliness and adequacy show the relations between demand and supply. Both of these indicators are important for the best management of the canal water, and for an integrated management of the water resources. The concept is considered in the regulation, and rotation, but a clear reference is non-existent for the management.

The Total Error(TE) index used to assess the management effectiveness gives a simple gross tool, which seems quite representative for the seasonal overall evaluation. However, it needs to be further tested and compared with other indicators at a temporal and spatial scale.

Mao-Zi's indices give a good summary of water and land utilization. The information used for the calculation of the indices are mostly available at a sub-division level. In the environment of canal water shortage and conjunctive water use, the gross knowledge of the water and land utilization can guide the mangers in their decision-making at a division or a sub-division level.

An important conclusion is that most of these indicators provide useful knowledge about the system. Some of these are quite easy to compute, like DPR and C_V. The simple gross indicators about land and water utilization provide basic and pragmatic information about the system.

REFERENCES

1. Murray-Rust H., and W.Bart Snellen. 1993. Irrigation System Performance Assessment and Diagnosis. IIMI, ILRI, IHE. Colombo, Sri Lanka.

2. Abernathy.C.L. 1989. Indicators of the Performance of Irrigation Water Distribution Systems. Symposium on the Performance Evaluation of Irrigation Systems, November, Colombo, IIMI.

3. P.S Rao, 1993. Review of Selected Literature on Indicators of Irrigation Performance. Research Paper, IIMI, Colombo, Sri Lanka.

4. Abernathy, C.L. 1991. Indicators and Criteria of the Performance Of Irrigation Systems. In FAO, Improved Irrigation System Performance for Sustainable Agriculture. Proceedings of the Regional Workshop organized by FAO in Bangkok, Thailand. 22-26 October 1990. Rome: FAO.

5. The Manual of Irrigation Practices, Irrigation Branch of Public Works Department, Government of West Pakistan. 1963.

6. Sutlej Valley Project. 1920. Public Works Department, Government of the Punjab, Lahore.

7. Skogerboe, G.V., Shafique, M.S. and Gandarllias C. 1987. Field Calibration of Irrigation Structures for Discharge Measurement, International Irrigation Centre, Department of Agricultural and Irrigation Engineering, Utah State University, Logan, Utah, USA.

8. Hart, W.W.H., 1996. Research into the Relationship Between Maintenance and Water Distribution at the Distributary level in the Punjab, Msc Thesis. University of Technology, Delft, The Netherlands and IIMI-Pakistan.

9. Kuper M., Habib Z. and P.O Malaterre. 1994. System Objectives and Localized Control: Adequacy versus Equity. Internal Program Review, IIMI, Colombo, Sri Lanka.

10. Skogerboe G.V., Ren L.Y. and Yang D. 1993. Cutthroat Flume Discharge Ratings, Size Selection and Installation, International Irrigation Center, Utah State University, Logan, USA.

11. IIMI-Pakistan, August 1995. Training Course on Field Calibration of Irrigation Structures, Fordwah Canal. Technical Report No. R-3.

12. Bos, M.G. and J. Nugteren. 1990. On Irrigation Efficiencies. 4th Edition [Ist Edition 1974]. International Institute for Land Reclamation and Improvement/ILRI Publication 19, Waginengen, The Netherlands.

13. Chambers, R. 1988. Managing Canal Irrigation: Practical analysis from South Asia. Oxford and IBH Publishing Co., New Delhi.

14. Clemmens A.J. and M.G. Bos. 1990. Statistical Methods for Irrigation System Water Delivery Performance Evaluation. Journal of Irrigation and Drainage Systems 4: 345-365.

15. Lenton, R.L. 1984. A Note on Monitoring Productivity and Equity in Irrigation Systems. In Productivity and Equity in Irrigation Systems; Niranjan Pant (ed.). Ashish Publishing House.

16. Molden, David J. and Timothy K. Gates. 1990. Performance Measures for Evaluation of Irrigation Water Delivery Systems. Journal of Irrigation and Drainage Engineering. ASCE 116(6):804-823.

17. Palmer, J.D.; A.J. Clemmens; A.R. Dedrick; J. A. Replogle and W. Clyma. 1991. Delivery System Performance Case Study; Welton-Mohawak Irrigation and Drainage District, U.S.A. Journal of Irrigation and Drainage Systems 5:89-109.

18. Sampath, Rajan K. 1988. Equity Measures for Irrigation System Performance Evaluation. Water International 13:25-32.

19. Secler, David; R.K. Sampath and S.K. Raheja. 1988. An Index for Measuring the Performance of Irrigation Management Systems with an Application. Water Resources Bulletin 24(4):855-860.

20. Small. L.E. and Mark Svendsen. 1992. A Framework for Assessing Irrigation Performance. Working Paper on Irrigation Performance I. International Food Policy Research Institute, Washington, D.C.

21. Theil, H. 1996. Applied economic forecasting. In: Studies in Mathematical and Managerial Economics, Volume 4, North-Holland Publishing Company, Amsterdam, The Neterlands.

22. Vander Velde, Edward J. 1991. Performance Assessment in Pakistan: Opportunities for Improvement at the Distributary Level. Improved Irrigation System Performance for Sustainable Agriculture. Proceedings of the Regional Workshop organized by FAO, 22-26 October 1990. Bangkok. Rome: FAO.

23. Maz Zhi. 1989. Identification of cases of poor performance of a typical large-sized irrigation scheme in south China. Asian Regional Symposium on the Modernization and Rehabilitation of Irrigation and Drainage Schemes. Published by Hydraulics Research. Wallingford, England; Asian Development Bank, and National Irrigation Administration of the Philippines.

24. Wijayaratna, C.M. 1986. Assessing irrigation system performance: A methodological study with application to Gal Oya Scheme, Sri Lanka. Ph.D. thesis, Cornell University, Ithaca, New York, U.S.A.