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WATER LEVEL FLUCTUATIONS AND DISCHARGE VARIABILITY IN THE MIRPURKHAS SUB-DIVISION, JAMRAO CANAL, NARA CIRCLE, SINDH PROVINCE, PAKISTAN

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This report presents the results of studies on water levels fluctuations and discharge variability for three consecutive seasons (*Rabi* 1996-97, *Kharif* 1997 and *Rabi* 1997-98) in the Mirpurkhas Irrigation Sub-division, Jamrao Canal.

We would like to thank the Mirpurkhas field team, namely Mr. Zahid Hussain Jalbani, Mr. Mohammad Ali Khowaja, Mr. Mohammad Hashim Memon and Mr. Waqar Hussain Khokhar for their dedicated efforts in collecting the information/data. This report could not have been compiled without their committed work.

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SUMMARY

Mirpurkhas is the third, and most important irrigation sub-division of the Jamrao Canal, and serves a command area of about 236,000 acres through 11 distributaries/minors and about 96 direct outlets. The flow control structures in the Jamrao Canal Section were remodeled in 1993-94, while those in the West Branch Canal Section are decades old. The purpose of this research activity was to evaluate the water level fluctuations in the main canal and water distribution and supply to the off-taking channels.

This study has focused on the analysis of daily water level fluctuations in the main canal and the supply and distribution reliability of irrigation water into the off-takes of the Mirpurkhas Sub-division, Jamrao Canal, during three cropping seasons (Rabi 1996-97, Kharif 1997 and Rabi 1997-98). Likewise, the round-the-clock water depth measurements for three different weeks, one each in March-April, June and August 1998, have been studied at the selected points along the Jamrao Canal and West Branch Canal Sections.

Water levels during the first and second rounds of the hourly measurement campaigns along the Jamrao Canal and West Branch Canal Sections were quite stable in both, magnitude and variation. However, in the third campaign, water levels gradually receded during the first half of the week, while it gradually increased in both the canals during the second half. Flow variability into the off-takes, especially during the June round, has been caused by the (frequent) gate manipulations at the respective heads.

The daily water level measurements for the period from November 1996 to April 1998 have shown little variation. However, water supply into the distribution system has been unreliable for most of the period. February and March were mostly unreliable months during the Rabi 96/97 season, while during Kharif, July and August were the most unreliable months for most of the off-takes. This variability is more prominent in the West Branch Canal Section than in the Jamrao Canal Section. However, Rabi 1997-98 has brought much improvement, whereby the water supply has been more reliable than during the preceding two seasons.

The water distribution pattern (among the off-takes of both canals) has almost remained very poor, particularly during two seasons (Rabi 96/97 and Kharif 97), except for November and December 96, while the distribution in Rabi 97/98 has significantly improved and was almost in fair condition (except February).

The implementation of rotational closure is quite erratic. A considerable variation has been observed in the rotational closures of the major off-takes of the Mirpurkhas Sub-division. The frequency and intensity is less during Rabi than in Kharif, when a few distributaries remained closed continually for more than a month along the West Branch Canal Section. A comparison between the two Rabi seasons shows a considerable disparity in rotational closures.

FOREWORD

The International Irrigation Management Institute (IIMI) opened an office at Hyderabad in Sindh Province on 1 September 1995. This was done to undertake a pilot study of Farmer-Managed Irrigated Agriculture under the Left Bank Outfall Drain Stage-I Project. About 16 months earlier, planning had been completed to support this research effort with a program on Decision Support Systems (DSS) under the project, Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan, funded by The Netherlands.

The Planning for this DSS program began in early 1996. A few months later, Mr. Abdul Hakeem Khan was transferred from Lahore to Hyderabad. Mirpurkhas Sub-division of Jamrao Canal was selected for the initial effort because:

1. One of our three pilot distributaries was located in this command area;
2. The remodeling of Jamrao Canal had been completed in June 1994; and
3. A telecommunications system was to be installed for Nara Canal, which includes Jamrao Canal.

Several meetings were held with staff of the Department of Irrigation and Power, Province of Sindh. Also, a one-day seminar on DSS was conducted in Hyderabad. The Inception Report was completed during the summer of 1996.

A field team of five people were recruited in August 1996 and trained in Malik Sub-division near Bahawalnagar in Southeastern Punjab during August-September 1996. The Mirpurkhas Field Station (DSS) was opened in September 1996. Then, the field research program was underway.

There have been two previous reports, one on field calibration of the distributary head regulators, and another report describing the physical system and providing an evaluation of the operational performance of Mirpurkhas Sub-division, representing some of the essential requirements for DSS. This report provides much insight into the present operational situation with particular reference to discharge variability at selected cross-regulators and distributary head regulators. Clearly, there is a strong need to improve the hydraulic performance in this sub-division in order to provide more reliable water supplies to farmers.

The annexures for this report, containing 59 pages of tables, has been published separately in a very limited quantity. This data can be reviewed at the IIMI-Pakistan Library, and those libraries in the Province of Sindh that are on the IIMI mailing list.

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1 INTRODUCTION

Fluctuation in water levels along the main canal and water distribution among the off-taking channels are the major variables to assess the performance of the system. Now-a-days the performance of the irrigation system has become a growing concern for researchers, irrigation engineers, and donor agencies. Professionals related to irrigation fields have explained problems of the irrigated agriculture system differently at different levels. Related issues include water delivery at source, timely supply of water, reliable water supply to the farmers and distribution among the system off-takes and its proper application.

The performance assessment of the system has been ascertained in two ways; the variability in water supply with time and distribution among the off-taking channels. Off-taking channels are the gated structures that could be manipulated/adjusted by the system operator. However, these adjustments are only being made on the basis of the available water supply. The performance evaluation for the water level, gate adjustment and water delivery at the head regulators has also been conducted.

In a country like Pakistan, agriculture is the main source of economic development, being irrigated through a network of irrigation systems comprising storage reservoirs, barrages, inter-river link canals, siphons, main canals, distributaries, minors and watercourses. Rivers are the primary source of surface water used for agriculture. The agricultural production is largely based on the productive use of irrigation water and the mobilization of available water resources. The network of irrigation systems spread over the country's entire command area that feeds the agricultural land. That agriculture is the most important sector of Pakistan's economy is crystal clear, and it employs 54 percent of the workforce, contributes 26 percent of the GDP, and accounts for 75 percent of the country's foreign exchange earnings. Ninety percent of Pakistan's agricultural output come from irrigated agriculture--an area of 16.2 million hectares out of a total cultivable area of 20.7 million hectares.

The hydraulics of open channel flow is so complicated that any change in water delivery/supply in the conveyance system at the main canal and distributaries will subsequently change the downstream flow condition of the system. The water level fluctuation (rise or fall of the water level) results in discharge variations along the off-takes of the system. The rise and fall of the water level has different effects on water discharge in the off-taking channels. The waves produced due to the canal water level fluctuation destabilizes the flow pattern. This unstable condition, or water level fluctuation, creates problems in the canal operation, regulation and distribution of water. The wave propagation, positive or negative, increases or decreases water discharge in the downstream off-takes. The flow of water in the off-takes is also dependent on the degree of sensitivity of the gated structure, and flexibility in the water level of the main canal. The control structures, which are more sensitive, will have bigger effect on water distribution among the off-taking structures.

The frequent adjustment of regulator gates by the gate keeper influences the water distribution along the system. This frequent adjustment of gates continuously destabilizes the hydraulic/flow condition in our open channel. Unfortunately, the gatekeepers of the system do not know the sensitivity and flexibility of the regulating structures and their effects. Opening or closing the gates without realizing the effect downstream which in turn deteriorates the system in different ways i.e. proper and timely supply of water, equal distribution of water, as well as the regime of the channel.

The operational system is very dependent on effective and timely communication among the control points of the system, and to the sub-divisional officer (SDO). However, the change in

the water level or flow rate, communicated in time to every point should be managed properly. Therefore, any hydraulic effect is to be minimized or avoided.

Similarly, the rotational closure system of the canal also affects the performance of the canal supply and distribution enormously. Two types of rotation are generally observed in this sub-division; the planned rotation and the actual rotation. The planned rotation for the sub-division is quite different from one channel to another. Likewise, planned rotation and actual rotation are also different from each other.

Edward (1990) has said that the discharge variability interpenetrating the pattern of water distribution equity has important implications for actual surface water supply conditions encountered by farmers in their watercourses, especially where farmers' irrigation turns are governed by the common 7 day warabandi. Typically, the warabandi cycle begins on a Monday morning, with the irrigation turns of farmers whose lands are closest to the watercourse head. In the normal roster of irrigation turns, farmers whose turns are due on Friday are commonly those whose fields are more than half-way down the length of the main watercourse.

Abernethy (1986) has explained that the unequal distribution of water has a direct influence upon production because part of system receives less water than their agronomic water requirements and will produce less than efficacious. The areas receiving more water than needed, do not indicate improvements in yield; thus, the excess water does not serve a productive purpose.

1.1 PROJECT INITIATION AND DATA COLLECTION

The project was initiated on the irrigation system of the Mirpurkhas Sub-division of Jamrao Canal from November 1996. The concentration was focused on evaluating the operational performance of the irrigation system. Data related to the water level at both, upstream and downstream of the off-takes, were collected on a daily basis. Furthermore, the hourly data for the water level over one week in three different periods during Kharif 1998 were also collected. These week-intensive data were collected to ascertain the variations in water level, if any, during the day and during the night. This information would prove very helpful towards diagnosing the system in detail, so that proper recommendations are made to operate the system appropriately. In addition, all the water levels measured upstream and downstream have been converted into discharges. The discharge of each channel has been calculated using developed rating equations and curves. The summary of developed rating equations for head regulator structures of this sub-division is presented in subsequent sections.

1.2 OBJECTIVES

The main objective of the study is:

1 To assess the operational performance of the Jamrao Canal and the West Branch Canal of the Mirpurkhas Sub-division

The sub-objectives are:

1 To evaluate/determine the variability in water supply (reliability) at source points; and variability in water distribution among the off takes; and

2 To assess the fluctuation in water levels during day and day-night time.

1.3 BRIEF DESCRIPTION OF THE MIRPURKHAS SUB-DIVISION

The Mirpurkhas Irrigation Sub-division is one of five sub-divisions of the Jamrao Canal along the middle portion at RD 291 (Figure 1.1). There are three cross regulators and eleven head regulators, of which six head regulators are located on the Jamrao Canal and five on the West Branch Canal. These head regulators feed distributary channels, namely Doso Dharoro Distributary, Mirpurkhas Distributary, Kahu Visro Minor, Kahu Minor, Bareji Distributary and Sanro Distributary of the Jamrao Canal and Lakhakhi Distributary, Bhittaro Minor, Sangro Distributary, Daulatpur Minor and Bellaro Minor of the West Branch Canal. Mirpurkhas Sub-division, along with RD-wise locations, is shown in Figure 1.2. The salient features of the Mirpurkhas Sub-division are shown in Table 1.1.

Table 1.1 Salient Features of Distributaries and Minors of the Mirpurkhas Sub- division.

Parent Channel	Distributary/Minor	Off-take (RD)	CCA (acre)	Discharge (cfs)
Jamrao Canal	Mirpurkhas Disty	343	16815	64.00
	Doso Dharoro Disty	343	22743	66.00
	Kahu Visro Minor	383	3622	11.90
	Kahu Minor	385	12018	43.51
	Bareji Disty	408	14032	41.50
	Sanro Disty	408	15475	53.77
West Branch Canal	Lakhakhi Disty	38	17606	64.00
	Bhittaro Minor	65	3690	11.36
	Sangro Disty	88	30954	103.7
	Daulatpur Minor	115	10766	49.00
	Bellaro Minor	143	17124	54.78

Source: Jamrao Canal Division, Sindh Irrigation Department, 1998.

The portion of the Jamrao Canal forming the Mirpurkhas Sub-division was remodeled as a part of the overall Jamrao Canal Remodeling Project, whereby all the cross regulators and head regulators in this sub-division were newly constructed in 1993-94. So, all the major structures in this part are in good physical condition. Those of the West Branch Canal off-takes are very old and have been poorly maintained. All the distributaries and minors have mechanical-gated head regulators, except the Bhittaro Minor, which has a rectangular iron orifice without any extra control. New gauges were mounted at the upstream and downstream wing walls of the head regulators of the Jamrao Canal after the remodeling in 1994. Now, most of these gauges are unreadable. The West Branch Canal Section either does not have the gauges, or are having their zero levels referred to the old design of the channel, which has changed considerably because of the sedimentation in the main canal, as well as that of the distribution system.

The number and size of gates is different for different channels of the Mirpurkhas Sub-division, depending upon the capacity of the channel and the age of the head regulator. The head regulators of the West Branch Canal Section off-takes have either one or two gates each, mostly with 6 feet widths, while those of the Jamrao Canal Section have 1 to 3 gates of 5-feet widths each. The operation of the gates is very asymmetrical. Usually, in the case of a three-gated head regulator, the middle gate is kept more open than those on the sides. The number of gates, widths and flow conditions of all the head regulators are given in Table 1.2.

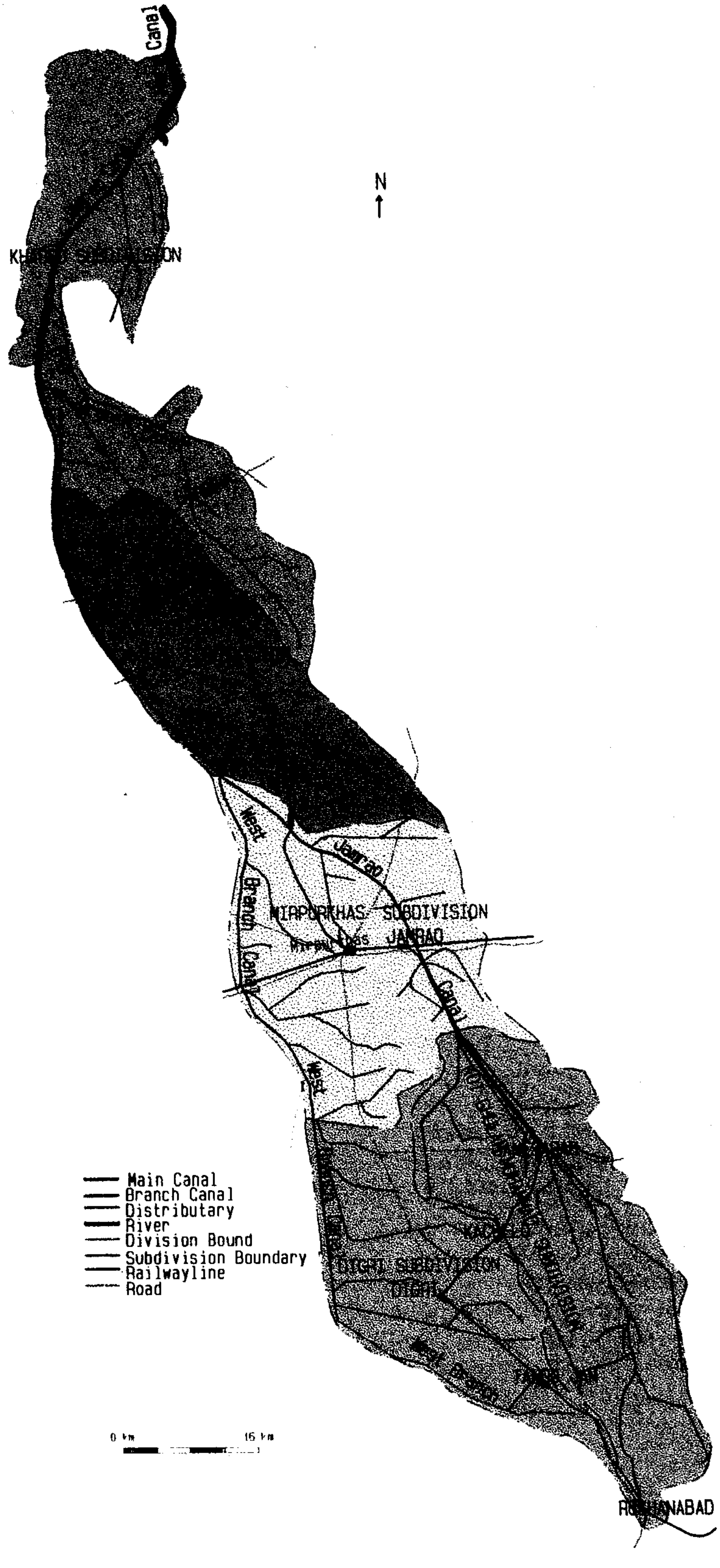

Figure 1.1. Jamrao Canal Command map with sub-divisional boundaries

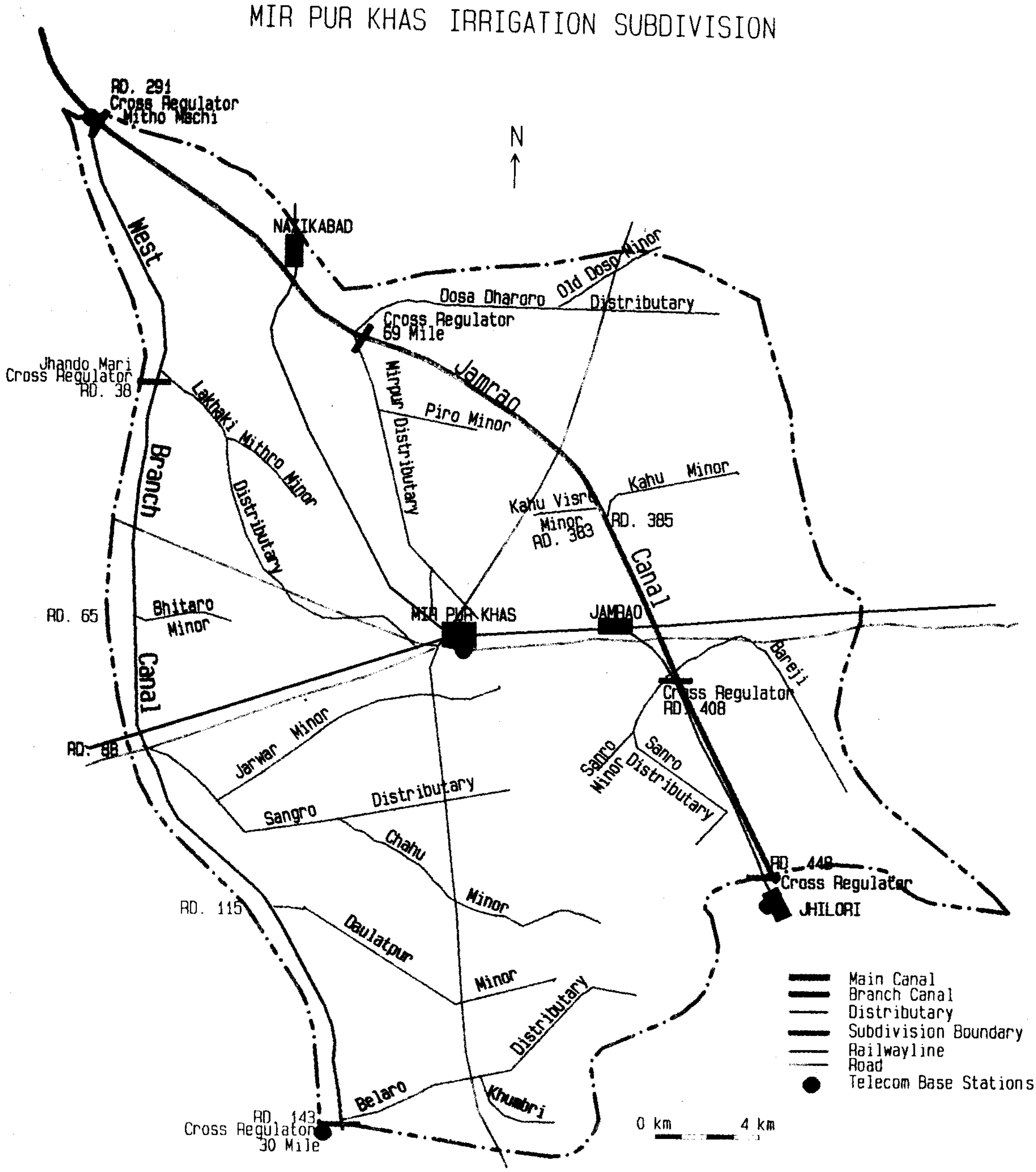

Figure 1.2. Mirpurkhas irrigation sub-division command map with offtaking channels.

Table 1.2. Number of Gates, Widths and Flow Conditions of the Mirpurkhas Sub-division Off-takes.

Name of channel	Number of gates	Width of gate (ft)	Flow condition
Mirpurkhas Disty	3	5	S.O.F.
Doso Dharoro Disty	3	5	S.O.F.
Kahu Visro Minor	1	5	F.O.F.
Kahu Minor	3*	5	F.O.F.
Bareji Disty	3	5	F.O.F.
Sanro Disty	2	5	F.O.F.
Lakhakhi Disty	1	10	S.O.F.
Bhittaro Minor	Fixed orifice of 1.25x1.25 feet		F.O.F.
Sangro Disty	2	6	S.O.F.
Daulatpur Minor	2	6	S.O.F.
Bellaro Minor	1	6	F.O.F.

Note: S.O.F. = Submerged orifice flow
F.O.F. = Free orifice flow
* = Only two gates are operated, the left gate is closed.

1.3.1. Organizational Setup of the Mirpurkhas Sub-Division

As mentioned earlier, the Mirpurkhas Sub-division draws irrigation water from the Jamrao Canal that off-takes from the Nara Canal of the Sukkur Barrage. The operation and maintenance staff of the irrigation system has been divided into different setups so that the system could be managed properly. The managerial and operational staff of the Mirpurkhas Sub-division, with its hierarchy from the top down, is briefly shown in the following organizational chart (Figure 1.3).

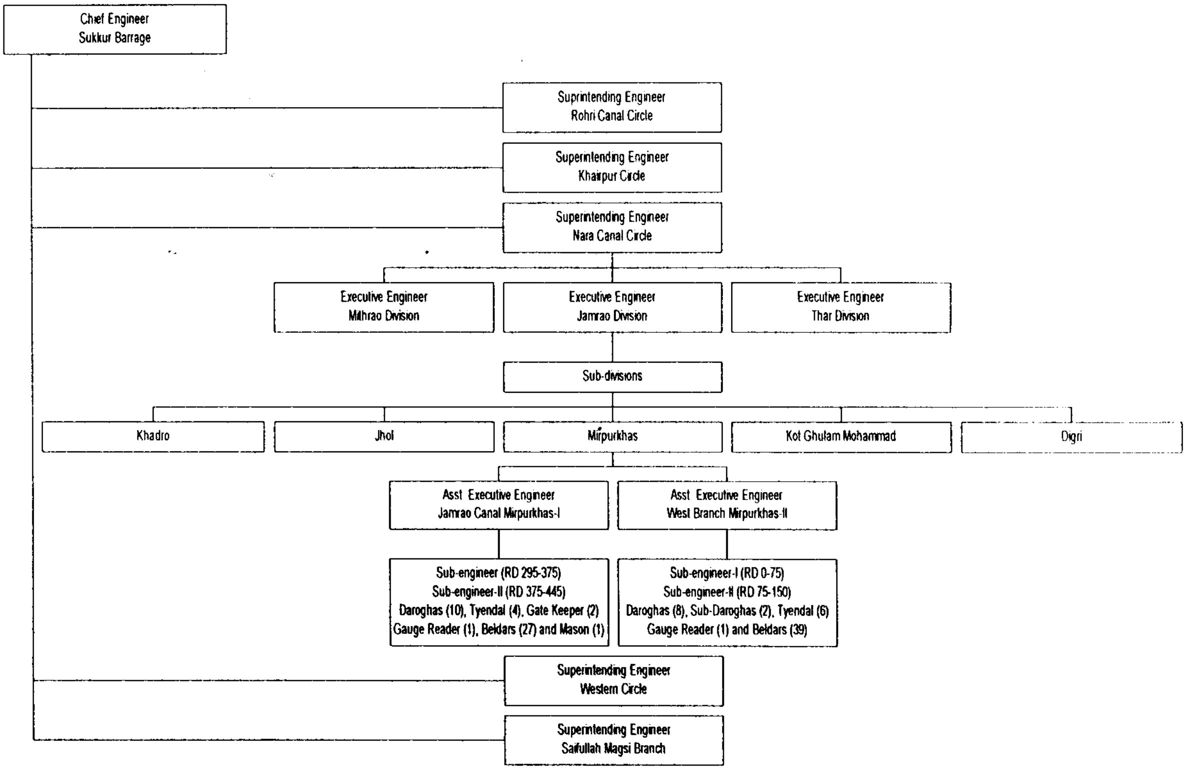

Figure 1.3. Field staff organization chart of the Mirpurkhas Sub-division.

Tab

2 METHODOLOGY[1]

2.1 DATA COLLECTION

In many developing countries, it is relatively easy to collect, from a project agency, a series of data on the physical environment (climatic and hydrological data, physical infrastructure), on agricultural production, on staff and on O&M costs of an irrigation project. These data can be obtained from agencies performing relatively well within a short time. However, the greatest difficulty is found in obtaining and interpreting data on water supply. When these data exist, they are often too unreliable for analytical uses. In most cases, what could be obtained are the volumes delivered to large sections of a project. In these cases, without field research and monitoring, there is no possibility of determining the water use efficiency at the conveyance, distribution and field levels (Plusquellec, 1990).

The above statement is also very true in this study's context. All of the actual flow levels and delivery data needed to be directly collected in the field, and then analyzed.

2.2 WATER DEPTH MEASUREMENTS

The staff gauges to measure upstream and downstream heads either did not exist or had become obliterated and were hardly readable. As an alternative, benchmarks were established on all of the flow control structures for measuring flow depths. These benchmarks were marked with white paint on the walls of the control structures at points where there was a minimum of turbulence in the flow. For free flow control structures, benchmarks were reestablished on the upstream side of the structure, while for submerged flow structures, both, the upstream and downstream benchmarks were established.

These benchmarks were marked in November 1996 and referenced to the crest levels of the respective flow control structures, which were rechecked in January 1997 during the annual canal closure to minimize the error that might have occurred in readings taken in flowing water. Daily flow depths were computed from the tape measurements to the smooth water surface taken from these benchmarks.

2.3 GATE OPENINGS

One of the most difficult tasks in calibrating a gate structure is obtaining an accurate measurement of gate opening (Skogerboe and Merkley 1996). Obtaining a reasonably accurate measurement of gate opening for a hydraulic control structure is a very difficult and sensitive job. A small error in gate opening has a tremendous effect on developing an accurate and reliable discharge rating.

Two benchmarks were marked on the frame of each gate, one on the right and another on the left side, to avoid any error due to faulty functioning of the gate. The elevations of these benchmarks were taken from the top of the gate when the gate was completely closed. Daily tape measurements from the benchmark downward to the top of the gate were subtracted from the benchmark elevation, which are averaged to obtain an average gate opening for each gate.

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[1] A major portion of this chapter has been taken from the "Physical Characteristics and Operational Performance of Mirpurkhas Sub-division, Jamrao Canal Division, Nara Circle, Sindh Province, Pakistan" by Abdul Hakeem Khan, Rubina Siddiqui, Zahid Hussain Jalbani, Mohammad ali Khowaja, Waqar Hussain Khokhar, Muhammad Hashim Memon, Bakhshal Lashari and Gaylord V. Skogerboe. Published under the Pakistan National Program, International Irrigation Management Institute, Pakistan (September 1998).

2.4 DISCHARGE MEASUREMENTS

The area-velocity method was used for discharge measurements. The two-points (0.2d and 0.8d) method was used for measuring velocity in a vertical. The average of the two measurements has been taken as the mean velocity in the vertical. Each cross-section was sub-divided into twenty or more verticals, depending upon the width of the cross-section. However, the verticals were not spaced closer than one foot (Corbett and others 1943).

2.5 DISCHARGE RATINGS

Several discharge measurements over a normal operating range of gate openings were taken for developing discharge ratings for the respective control structures. The following equations were used to compute the discharge coefficient, C_d, from the measured data in the field. For free orifice flow head regulators

$$Q_f = C_d G_o W \sqrt{2 g h_u} \tag{1}$$

For submerged orifice flow head regulators

$$Q_s = C_d G_o W \sqrt{2g(h_u - h_d)} \tag{2}$$

Where

Q_f = discharge in cusecs for a free orifice flow condition
Q_s = discharge in cusecs for a submerged orifice flow condition
G_o = average gate opening in feet
W = width of the head regulator gate opening in feet
h_u = upstream head in feet
h_d = downstream head in feet
C_d = discharge coefficient

Obtaining an accurate gate opening, G_o, measurement is a difficult job. Errors may be introduced if the gate is not completely horizontal or the gate lip does not seated at the same elevation as the gate sill, and/or the bottom and sides of the gate leak even when the gate is totally seated. This implies that the datum for measuring the gate opening is below the gate sill.

In order to determine a constant value of C_d, a gate opening correction, ΔG_o, was introduced into Equations (2.1) and (2.2) and rewritten as:

For free flow orifice, where $[(h_u)_{\Delta Go} = h_u - \Delta G_o]$

$$Q_f = C_d (G_o - \Delta G_o) W \sqrt{2 g (h_u)_{\Delta G_o}} \tag{3}$$

Also,for submerged flow orifice, where ΔG_o is a measure of the zero datum level below the gate sill.

$$Q_s = C_d (G_o - \Delta G_o) W \sqrt{2g(h_u - h_d)} \tag{4}$$

In order to determine an appropriate value of ΔG_o, the trial-and-error method was employed. The resulting values of C_d for different values of ΔG_o were computed from Equations (2.3) and (2.4). The values of ΔG_o, for which the C_d values had a minimum of difference, were taken as an appropriate value for the respective control structure. The summary of developed ratings for each head regulator of the Mirpurkhas Sub-division is given in Table 2.1.

Table 2.1. Summary of Equations Developed to Compute the Discharge at the Head Regulators of the Mirpurkhas Sub-Division, Jamrao Canal.

Name of Channel	Flow Condition	Developed Equation
JAMRAO CANAL		
Mirpur Distributary	Submerged Orifice Flow	$Q_s = 0.60(G_o+0.04)W \sqrt{2g(h_u - h_d)}$
Doso Dharoro Distributary	Submerged Orifice Flow	$Q_s = 0.684(G_o+0.04)W \sqrt{2g(h_u - h_d)}$
Kahu Visro Minor	Free Orifice Flow	$Q_f = 0.528(G_o+0.05)W \sqrt{2g(h_u + 0.05)}$
Kahu Minor	Free Orifice Flow	$Q_f = 0.432(G_o+0.12)W \sqrt{2g(h_u + 0.12)}$
Sanro Distributary	Free Orifice Flow	$Q_f = 0.518(G_o+0.09)W \sqrt{2g(h_u + 0.09)}$
Bareji Distributary	Free Orifice Flow Submerged Orifice Flow	$Q_f = 0.527(G_o+0.02)W \sqrt{2g(h_u + 0.02)}$ $Q_s = 0.630(G_o+0.02)W \sqrt{2g(h_u - h_d)}$
WEST BRANCH CANAL		
Lakhakhi Distributary	Submerged Orifice Flow	$Q_s = 0.674(G_o+0.10)W \sqrt{2g(h_u - h_d)}$
Bhittaro Minor	Free Orifice Flow	$Q_f = 0.60\ A \sqrt{2g(hu)}$
Sangro Distributary	Submerged Orifice Flow	$Q_s = 0.710(G_o+0.03)W \sqrt{2g(h_u - h_d)}$
Daulatpur Minor	Submerged Orifice Flow	$Q_s = 0.540(G_o+0.04)W \sqrt{2g(h_u - h_d)}$
Bellaro Minor	Free Orifice Flow	$Q_f = 0.490(G_o+0.06)W \sqrt{2g(h_u + 0.06)}$

2.6 VARIABILITY ASSESSMENT

The performance of irrigated agriculture is a complex subject. Irrigation systems often have a number of competing objectives and are assessed by interest groups with differing values and perspectives. A wide range of performance indicators is thus required. Any framework and any set of indicators will only capture a part of the complex reality (Rao 1993).

The basic objective of this study is to evaluate the water level fluctuations and discharge variability in the major off-takes of the Mirpurkhas Sub-division of the Jamrao Canal.

The system is supposed to be run with a minimum of interventions in order to supply equitable water deliveries at each off-take. While, in water short periods, rotational closures could be executed with prior intimation to the end users. Similarly, reliable water supplies for irrigation purposes should also be an objective of a good irrigation system.

The primary objective of a good water delivery system would be to deliver the amount of water required to adequately meet the crop needs. The irrigation systems in Pakistan were designed to serve a certain percentage of the culturable command area during a year, which ranged from 80 to 120 percent of the CCA during a year. However, with the growing needs for food larger areas are being brought under irrigation, resulting in higher demands for water. In some cases, the capacity of the conveyance systems has been increased to some extent to meet (partially) the growing water demands, however, the majority of the old irrigation channels do not fulfill the crop water requirements. Similarly, the design discharge values would not be

appropriate to use as a reference for two reasons; (1) a reliable record is not available; and (2) after rehabilitation and remodeling, the capacity of the Jamrao Canal has increased. The average of the actual daily flow rates drawn by each channel for the respective seasons (*rabi*, *kharif*) has been taken as a reference value in the analysis.

2.7 INDICATORS

Two parameters have been quantified to evaluate variability (temporal and spatial) in the Mirpurkhas Sub-division (1) Variability in water supply, which defines reliability, or dependability and (2) variability in water distribution, which defines equity.

1. Variability in water supplies: Reliable or dependable water supply is an important parameter from the farmers' standpoint, because it allows for proper planning. A water user can plan for a dependable delivery of an inadequate supply of water by growing less, or different, or adjusting other farming inputs.

Reliability is defined as the temporal variability of the ratio of the delivered amount of water to the required or scheduled amount that occurs over a region (Molden and Gate, 1990). (In this case, the seasonal average of the available discharge has been considered as the scheduled amount). The indicator used to measure this variability is:

$$\text{Reliability} = CV_t\,(Q_a/Q_s)$$

Where:

CV_t= temporal coefficient of variation (ratio of standard deviation to mean)
Q_a= discharge delivered at head of a system
Q_s= average seasonal discharge of the system.

As the value of reliability approaches zero, the relative water delivery becomes more uniform over time.

2. Variability in water distribution: This parameter explains the spatial uniformity/ variability of water distribution throughout a system. Equity has been evaluated by the spatial variability of the ratio of the available amount of water to the scheduled amount of water and is measured by:

$$\text{Equity} = CV_s\,(Q_a/Q_s)$$

Where;

CV_s = Spatial coefficient of variation of the ratio Qa/Qs over the area of interest.

The closer the value of equity is to zero, the greater the degree of equity.

Molden & Gate (1990) have recommended values to assess the performance of a system in terms of variability in water supply (reliability) and water distribution (equity) as given in Table 2.2.

Table 2.2. CV values to assess Discharge Variability.

Parameter	Good	Fair	Poor
Reliability	0.0 - 0.10	0.11 - 0.20	> 0.20
Equity	0.0 - 0.10	0.11 - 0.25	> 0.25

3 WATER LEVEL FLUCTUATIONS

The irrigation systems of Pakistan have been built to operate in the range of 70 to 110 percent of the design allocation. An irrigation channel receiving less than 70 percent of the design discharge is supposed to be shut off to avoid sediment deposition due to low flow velocities. However, due to the introduction of mechanical regulating devices (gated head regulators and cross regulators), that are easy to operate, the unauthorized external intervention in the operation and regulation, and the perturbations in irrigation water distribution have increased alarmingly in recent years. Unwanted gate adjustments by either, the personnel of the operating agency and/or by the farming community, add to the downstream system water level fluctuations. Another factor contributing to water level fluctuations is the increasing trend in some areas to avoid night irrigation due to the availability of water during the day; total or partial closure of outlets in the evening by the water users causes an increase in the water level, especially at the tail of the parent channel, which starts decreasing in the morning when outlets are opened.

These fluctuations have a tremendous effect on the expected efficiency of the irrigation systems. The water users are unable to plan properly in advance according to the amount of water available for a certain period of time. The fluctuating discharges, especially to the tail-enders, have resulted in the abandonment of agricultural lands in certain areas.

The lack of specific objectives and targets from the operational and management point of view regarding water distribution has also adversely affected the stability and consistency in water levels at all levels (i.e. primary to tertiary).

Daily water level data have been collected at major off-takes of the Mirpurkhas Sub-division to evaluate water level fluctuation in this system from November 1996 to April 1998. These data include upstream and downstream water levels, and gate openings of head regulators and cross regulators in the main canal. Most times, the cross regulators were kept completely open and had no effect on upstream or downstream water depths. Similarly, water depths and gate manipulations were monitored more intensively by taking hourly measurements for one week each in March-April, June and August 1998 to obtain an in-depth understanding of the perturbations occurring in the system.

Water allocation is normally carried on the basis of culturable command area (CCA) under a channel's command, that is, the design discharges of the irrigation channels normally differ to the CCA proportion. However, there are variations in these allocations from channel to channel. Similarly, the water deliveries issued to each off-take also vary considerably from time to time. To easily understand the graphical representation of discharge data, the duty (expressed in cusecs per thousand acres of CCA) has been used for the distributaries and minors, while comparing the water level fluctuations and the withdrawals of the off-taking channels.

3.1 VARIABILITY IN HOURLY WATER LEVELS

The data collected has been analyzed for different periods. The monitoring period covered three seasons e.g *Rabi* 1996-97, *Kharif* 1997 and *Rabi* 1997-98. These measurements include water depth readings at selected points along the main canal, and upstream and downstream of the head regulators of the off-taking distributaries and minors. The hourly water depth measurements taken in March-April, June and August 1998 for a period of one week each have also been analyzed.

Usually, the water level in the main canals (Jamrao Canal and West Branch Canal) remains stable. However, the flow delivered into the off-taking channels is varied through head regulator manipulations. These manipulations reflect the local water management of the local operating staff. The ease provided by the gated head regulators is being exploited to the maximum possible limits. The hourly water level fluctuations in the main canals have been shown in Figures 3.1 and 3.2 on an exaggerated scale to understand the magnitude of these fluctuations. In general, these variations are not very significant, because mostly the difference is not more than 0.15 foot for both, the March-April and June rounds of the hourly water depth measurement campaigns of the Jamrao Canal Section. But, during August, the water depth decreases in the first half and then gradually increases in the second half of the round (Figure 3.1).

Similarly, the water levels in the West Branch Canal head (downstream) has remained almost the same with negligible minor variations during the June and August rounds of the hourly measurements (Figure 3.2). The water depth during the one-week hourly measurement in March-April was less by about one foot than the June-August readings, however, the fluctuations were minor with an increasing trend in the water level. The water depth increased by about 0.20 foot only towards the last half of the March-April week. Figure 3.3 shows the hourly water depth measurements in and along the Jamrao Canal Section of Mirpurkhas Irrigation Sub-division from 26 March to 2 April 1998.

Water levels at Mitho Machi Cross Regulator (RD 291 of Jamrao Canal and the upstream turnover point of Mirpurkhas Sub-division) and Jhalori Cross Regulator (RD 448 of Jamrao Canal and downstream turnover point of Mirpurkhas Sub-division) have remained almost stable, except negligible variations at Jhalori Cross Regulator during the whole week of observations. But, withdrawals by the four off-taking distributaries vary from time to time, despite the fact that Mirpurkhas and Doso Distributaries are off-taking from the Jamrao Canal at the same location (RD 343), but from the opposite banks. Similarly, the Bareji and Sanro Distributaries are also off-taking at the same location (RD 408) of Jamrao Canal. Also, the observation period (ending of March and beginning of April) is a low demand period because the rabi crops are ready for harvesting, yet the water distribution is haprazard because of interventions by regulating staff.

The change of managerial staff has a tremendous impact on the operational performance of an irrigation system as is evident from Figure 3.4. The Jamrao Canal Section and West Branch Canal Section constitute the geographical boundaries of the Mirpurkhas Sub-division, both having different operating and managerial staff. Like the Jamrao Canal Section, the water levels in the West Branch Canal Section are also stable, however, withdrawals by the off-takes (located about 8 kilometers away from each other) are also comparatively stable. There are slight variations in flow deliveries to the off-takes, especially Lakhakhi Distributary; overall, they have performed quite well.

The second round of hourly observations was conducted from 1800 hours of 1 June to 1800 hours of 8 June, 1998. The peak water demand period of Kharif crops is from June to August and the non-occurrence of rains during this period proves to be a test for the management of canal irrigation systems. Figures 3.5 and 3.6 show the water levels in the parent canals and withdrawals by the distribution system of the Jamrao Canal and West Branch Canal Sections, respectively. With almost no change in the discharge in the main canal, the discharge in the distributaries is changing every day or so. Sometimes, frequent gate adjustments by the Irrigation Department staff on their own, or on the water users' request, cause these fluctuations in flow deliveries to flow into the off-taking channels.

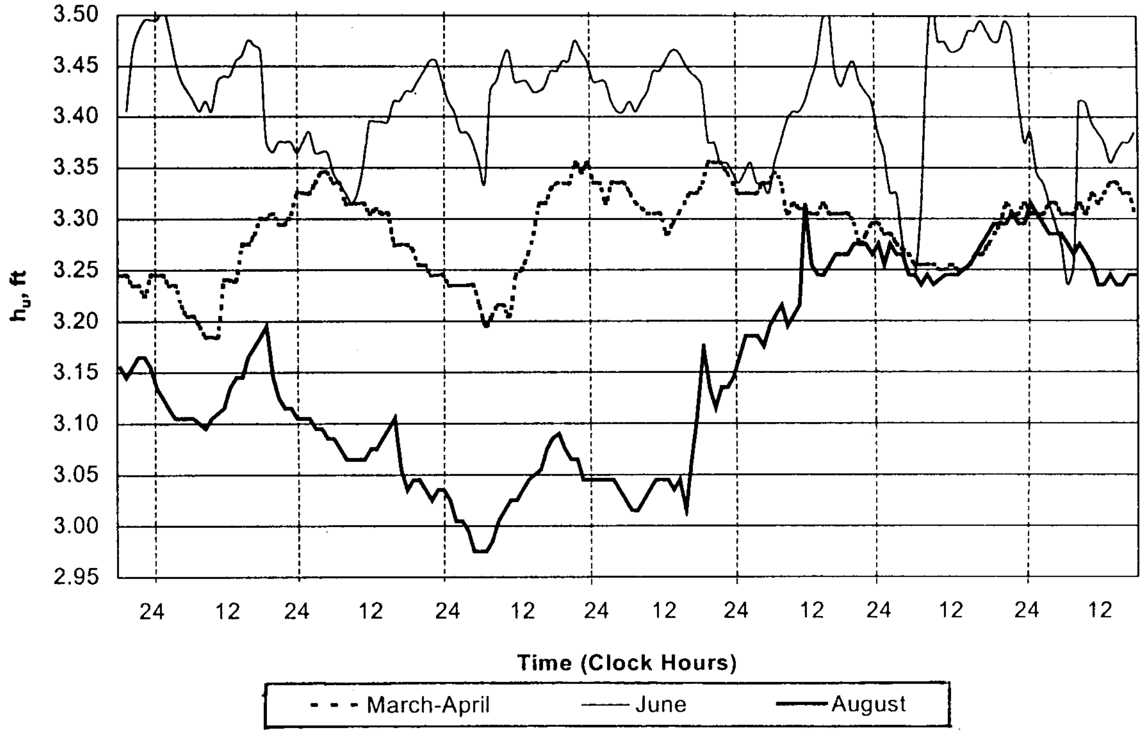

Figure 3.1. **Water Level Fluctuations at Upstream Turning Point (RD 292) of Mirpurkhas Sub-division, Jamrao Canal, during the Hourly Measurements.**

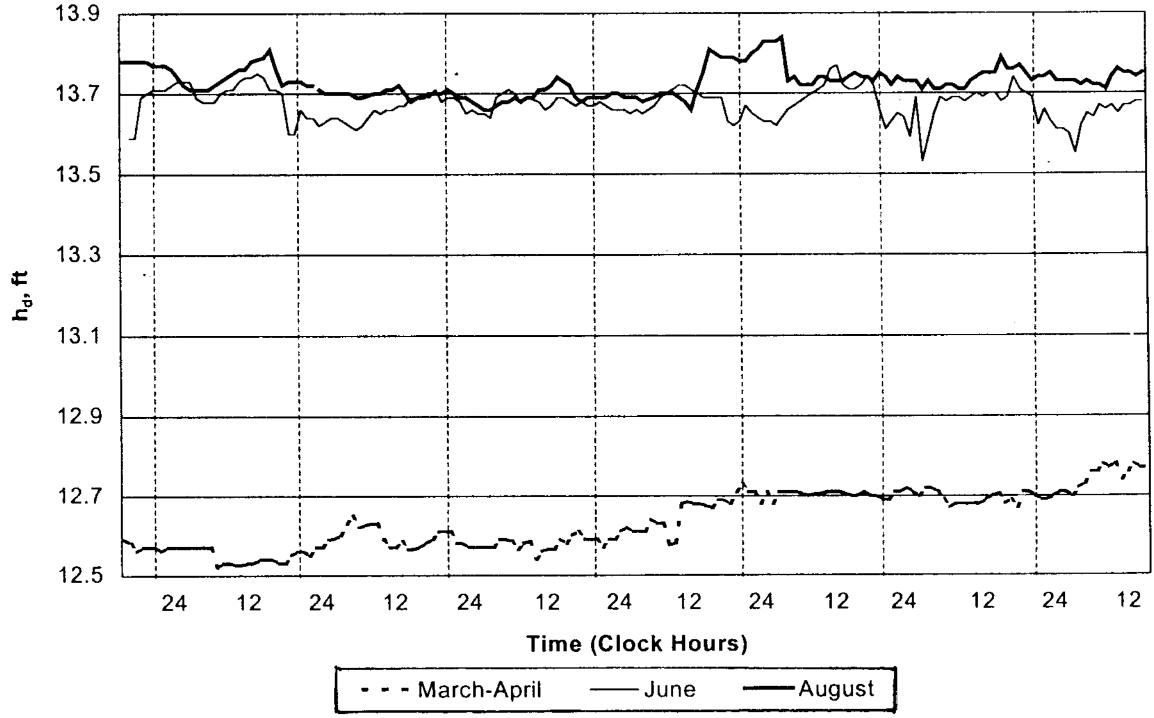

Figure 3.2. **Water Level Fluctuations at the West Branch Canal Head (Downstream, RD 0) during the Hourly Measurements.**

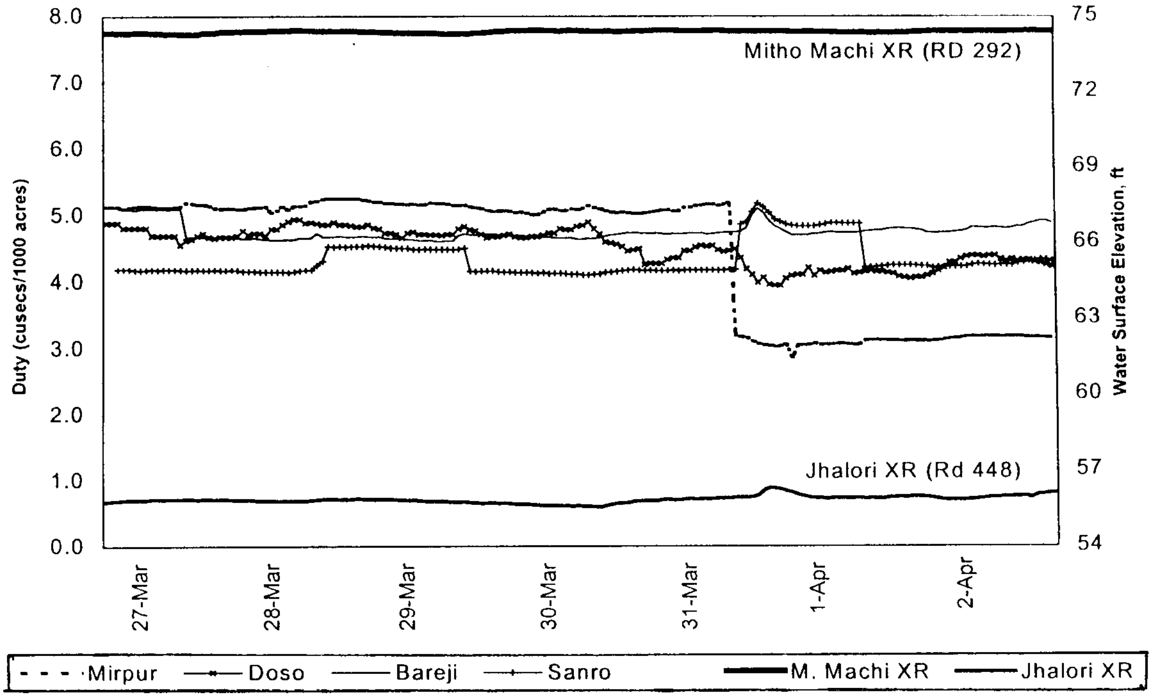

Figure 3.3 **Variations in Water Surface Elevation at Upstream Turning point (RD 292) and Downstream Turning point (RD 448) Mitho Machi Cross Regulator and Jhalori Cross Regulator and Water Distribution along the Jamrao Canal Section, (26 March to 2 April 1998).**

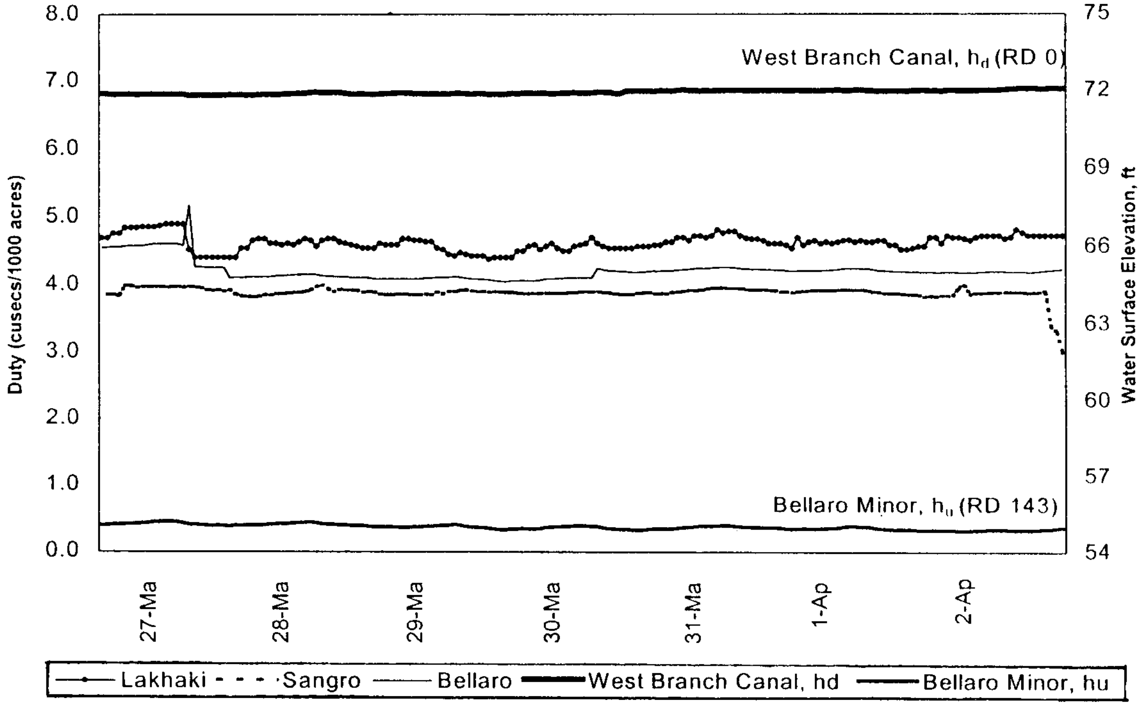

Figure 3.4. **Variations in Water Surface Elevation at Downstream of the West Branch Canal (RD 0) and Upstream of the Bellaro Minor (RD 143) and water distribution along the West Branch Canal Section, (26 March to 2 April 1998).**

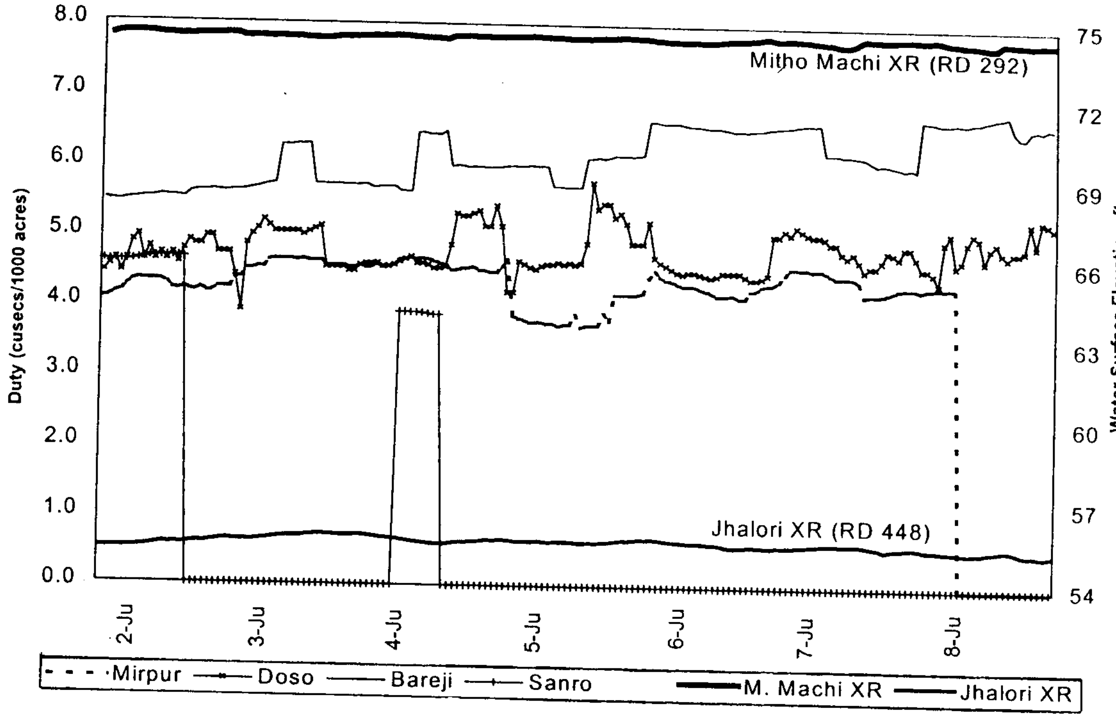

Figure 3.5. **Variations in Water Surface Elevation at Upstream Turning Point (RD292) and Downstream Turning Point (RD 448) Mitho Machi Cross Regulator and Jhalori Cross Regulator and Water Distribution along the Jamrao Canal Section, (1 June To 8 June 1998).**

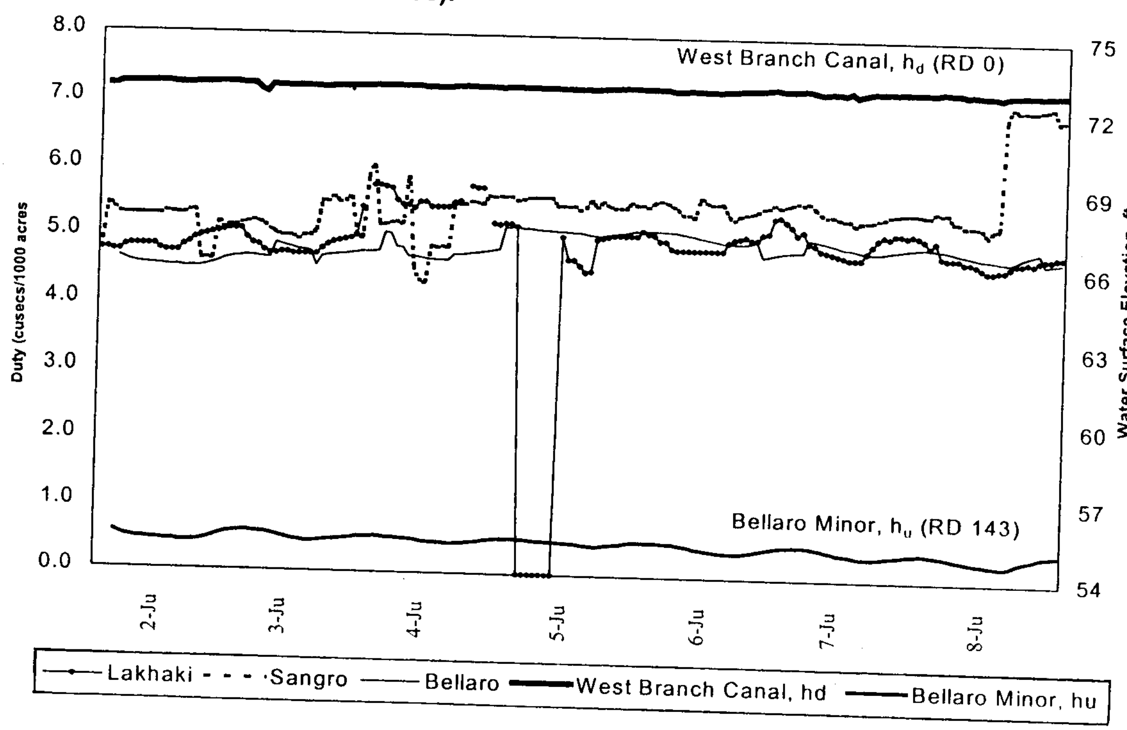

Figure 3.6. **Variations in Water Surface Elevation Downstream (RD 0) of the West Branch Canal Head and Upstream of the Bellaro Minor, and Water Distribution along the West Branch Canal Section (1 June to 8 June, 1998).**

For example, the gate opening of the Doso Dharoro Distributary Head Regulator have been changed thrice within a span of ten hours (0700 to 1700 hours) on June 2, 1998, and those of the Mirpurkhas Distributary were adjusted twice during the same period. Although the Sanro Distributary was closed from June 2 through 8, special adjustments can be made during the night to please somebody special (Figure 3.5). The gates were opened for about 9 hours (from 2130 to 0530 hours) to allow water into the distributary at the request of the farmer.

Similarly, in the third round (August 3 to 10, 1998) of hourly water depth measurements, the main canal water levels have remained almost stable, while those of the off-takes have been varying (Figures 3.7 and 3.8). Along the Jamrao Canal there were considerable fluctuations in the Bareji Distributary discharge, while others have drawn less variable flows except a one time or so abrupt change in the gate openings during the whole week. Again, there were few adjustments in the West Branch Canal off-takes head regulators to allow stable deliveries into the off-takes. Lakhakhi Distributary was closed after Sangro Distributary was opened; almost at the same time.

3.2 Variability in Daily Water Level Fluctuations

The daily water depth data were collected at five points each along the Jamrao Canal and the West Branch Canal Sections from November 1996 to April 1998. These data points were spaced about eight kilometers from each other along both sections. Since the variations in water levels were not high, only one point each on the Jamrao and the West Branch Canals was selected for analysis. Water levels at RD 343, where the first two major distributaries (Mirpurkhas and Doso Dharoro) of the Mirpurkhas Sub-division off-take from the Jamrao Canal have been analyzed. For the West Branch Canal, water levels at RD 38 (off-take point of the Lakhakhi Distributary) have been studied. The data have been analyzed season-wise and the results are very interesting. Figure 3.9 shows the water level fluctuations at RD 343 of the Jamrao Canal for three seasons (Rabi 1996-97, Kharif 1997 and Rabi 1997-98).

There is no particular variation in water depth during the beginning of both Rabi seasons (1996-97 and 1997-98). The water level is almost the same with smaller ups and downs. Though the magnitude of fluctuations has comparatively increased a bit after the annual closure period in January 1997, there is no significant trend of rise or fall during either seasons. The case for Kharif 1997 is similar, where water levels do not fluctuate much in the beginning of the season and vary mostly within a certain range after July. Also, there is a drop during July because of a breach in the upper reach of the Jamrao Canal.

Figure 3.10 shows the water depth variations at RD 38 of the West Branch Canal for the three seasons under consideration. This figure gives a different picture, though it is also a part of the Mirpurkhas Sub-division. All the variations coming from the upstream are probably diverted to the West Branch Canal. The water depth is higher in the beginning of Rabi as well as Kharif and decreases with smaller variations towards the middle. The magnitude of fluctuations is quite significant during the middle of the seasons (February and March in Rabi, and June, July and August in Kharif). There is a drop of about one foot or so during 1997 because of a breach in the West Branch Canal upstream of the monitoring point (RD 38). The water depth has gradually been increasing during March and April 1998. July and August have seen the highest peaks and deepest valleys during Kharif 1997.

Based on field observations, the Jamrao Canal Section is usually run at full supply level and the variations coming from the upstream are diverted to the West Branch Canal, which can accommodate an increase and sustain pressure. However, this is poor water management; the fluctuations need to be equally distributed. The following sections would also show the higher variabilities in the discharges of the West Branch Canal Section off-takes than that of the Jamrao Canal Section off-takes.

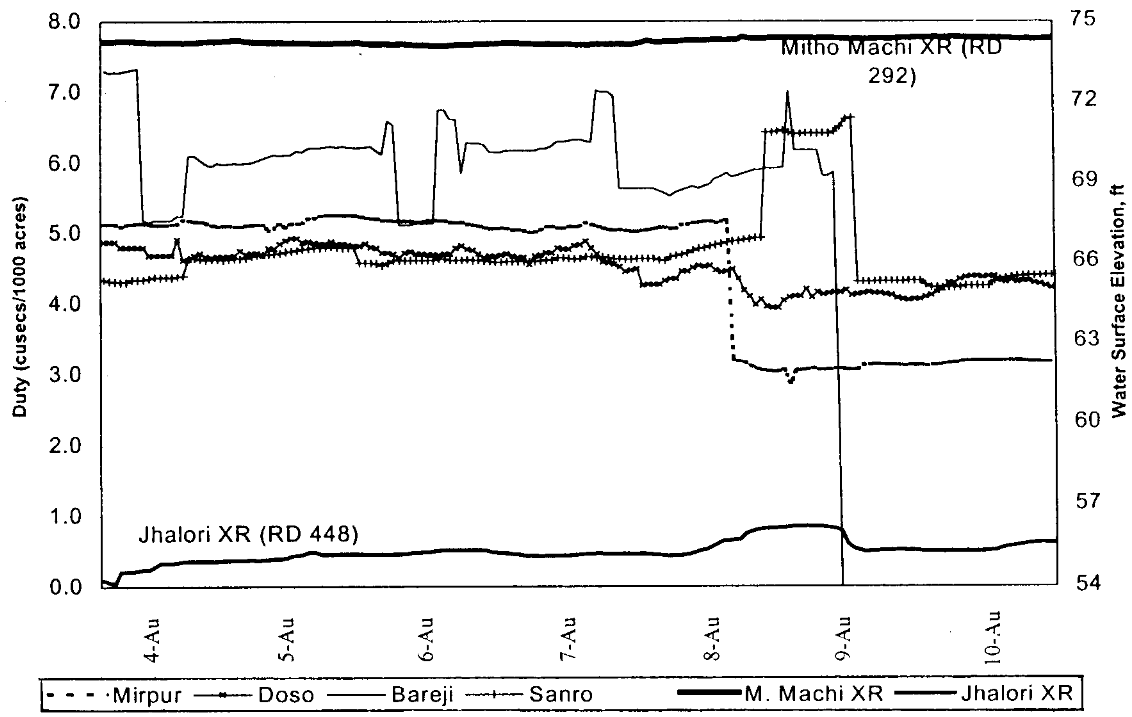

Figure 3.7. **Variations in Water Surface Elevation at the Upstream Turning Point (RD 292) and Downstream Turning Point (RD 448) of the Mitho Machi Cross Regulator and Jhalori Cross Regulator, and Water Distribution along the Jamrao Canal Section, (3 August to 10 August, 1998).**

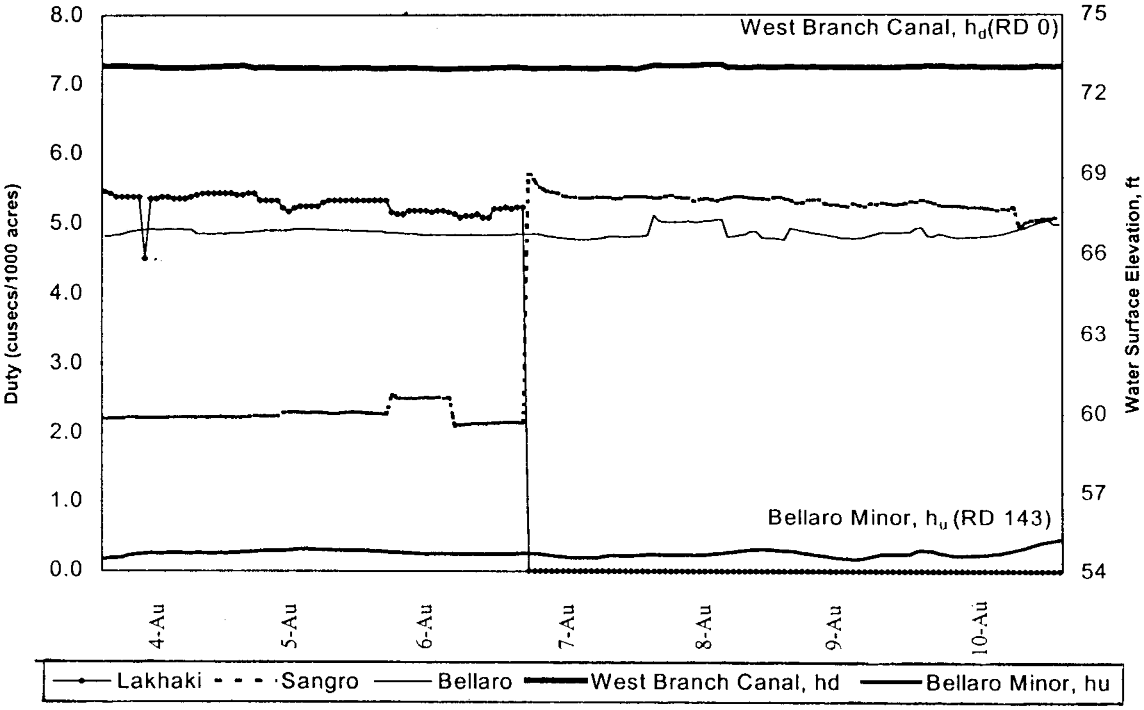

Figure 3.8 **Variations in Water Surface Elevation Downstream of the West Branch Canal Head and Upstream (RD 143) of the Bellaro Minor, and Water Distribution along the West Branch Canal Section, (3 August to 10 August,1998).**

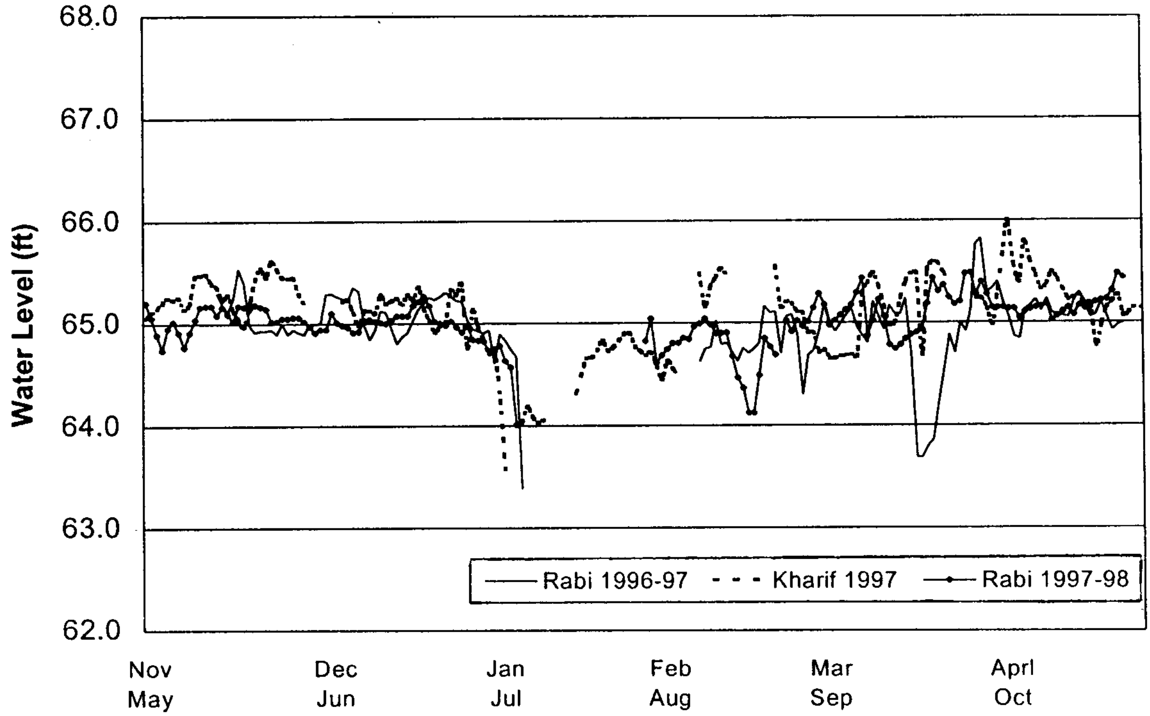

Figure 3.9. **Comparison of the Daily Water Level Fluctuations at RD 343 of the Jamrao Canal during the Three Seasons.**

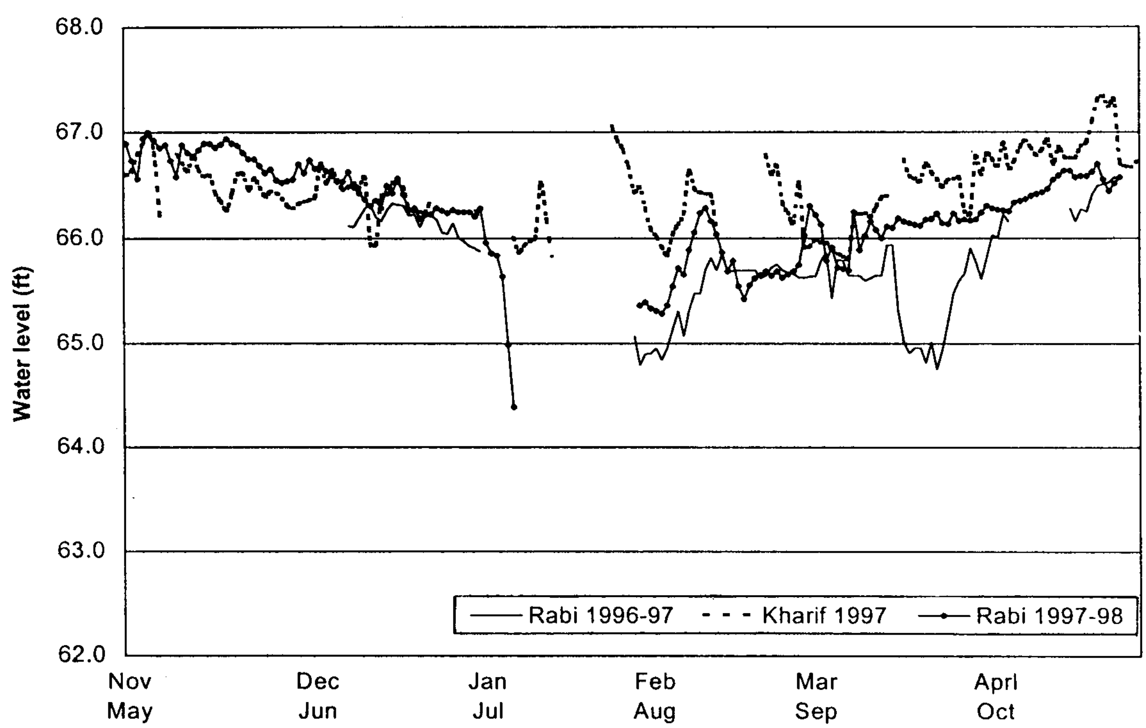

Figure 3.10. **Comparison of the Daily Water Level Fluctuations at RD 38 of the West Branch Canal during the Three Seasons.**

3.3 GATE MANIPULATIONS

The discussion in the previous section indicates that variations in water levels in both, the Jamrao Canal as well as the West Branch Canal are not very significant. However, there is much variation in the water deliveries into the off-takes, which is caused by the gate adjustments of the head regulators. These adjustments could happen any time and could be affected by the field staff of the operating agency according to either, their own judgement or instructions from superior authorities. The role of water users in manipulating the gates to suit their interests cannot be ignored either.

A comparison of the variations in water levels and gate adjustments has been made by taking the coefficient of variation of both parameters. Water depth fluctuation at RD 343 of the Jamrao Canal and RD 38 of the West Branch Canal have been considered. There is no major off-take upstream of these two points in the Mirpurkhas Sub-division jurisdiction. Fluctuations in the main canals at these points have been considered representative of all of the off-takes of the respective canals.

Figure 3.11 explains the variations in water levels at RD 343 and in gate manipulations of the concerned head regulators along the Jamrao Canal Section for the study period. The water levels have fluctuated by about 12 percent, while the gate adjustments have been varied from about 19 to 40 percent during Rabi 1996-97. The difference is evident. The ratio of variations of gate adjustments is 2 to 3 or so times higher than variations in water depth. Also, there is a difference from channel to channel, with the Sanro Distributary receiving the highest number of manipulations.

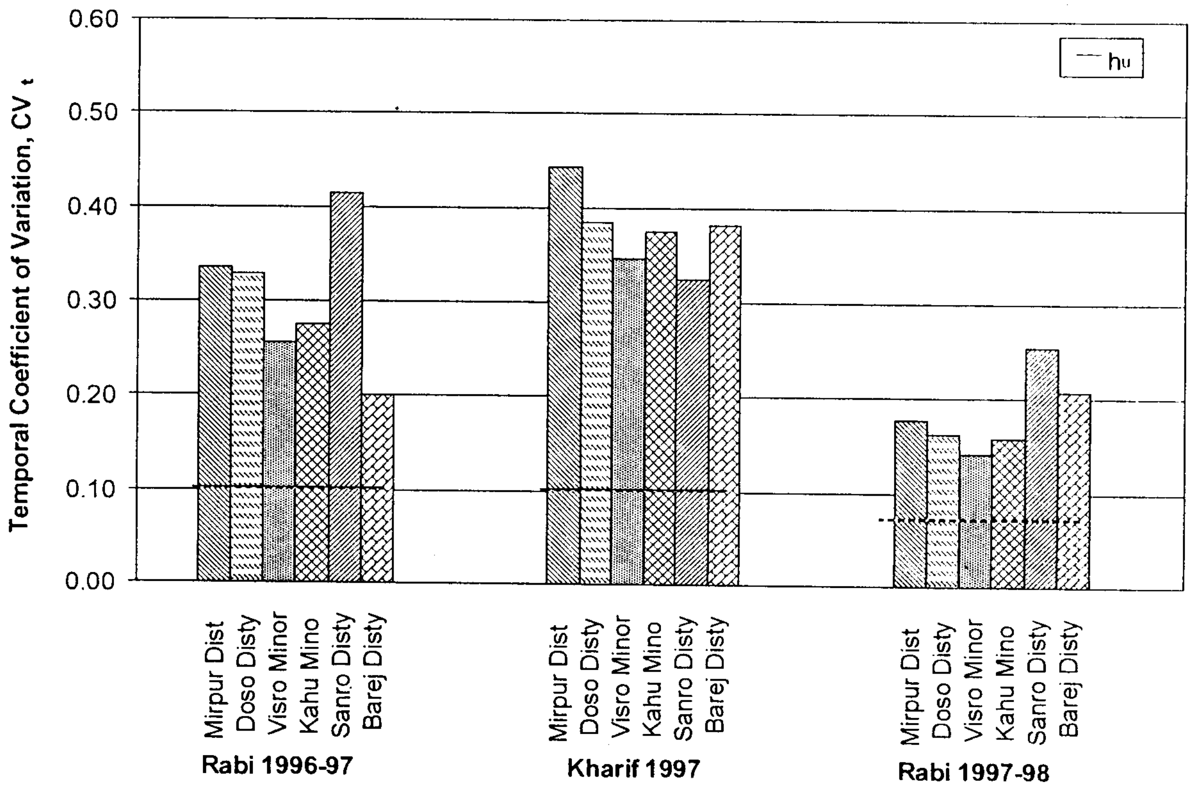

Figure 3.11. Water Level Variations and Gate Manipulations along the Jamrao Canal Section.

The variability has increased in both, water depths as well as gate operations during Kharif 1997. The water level variations are 13 percent, while those of the gate adjustments are from 30 to 40 percent, the highest being 43 percent in the Mirpurkhas Distributary Head Regulator. The Rabi 1997-98 has brought a lot of improvement in both, water level fluctuations as well as the gate adjustments. The operations have improved by about 50 percent over the Kharif season.

Figure 3.12 gives the variability in water levels and gate adjustments in the West Branch Canal Section. This figure shows that the frequency of water level fluctuations is lower than for the Jamrao Canal Section. For a CV value of 0.10 for water depth, the gate manipulations vary from about 0.12 to 0.32 during Rabi 1996-97. Though, the magnitude of water depth has increased in Kharif 1997, its frequency has decreased considerably, as is evident from the figure. However, the frequency of gate operations have increased considerably. Minimum adjustments were received by the Sangro Distributary and maximum were given to Lakhakhi Distributary.

Like the Jamrao Canal Section, there is considerable improvement in the operations of the West Branch Canal Section during Rabi 1997-98. A considerable decline has occurred in gate manipulations.

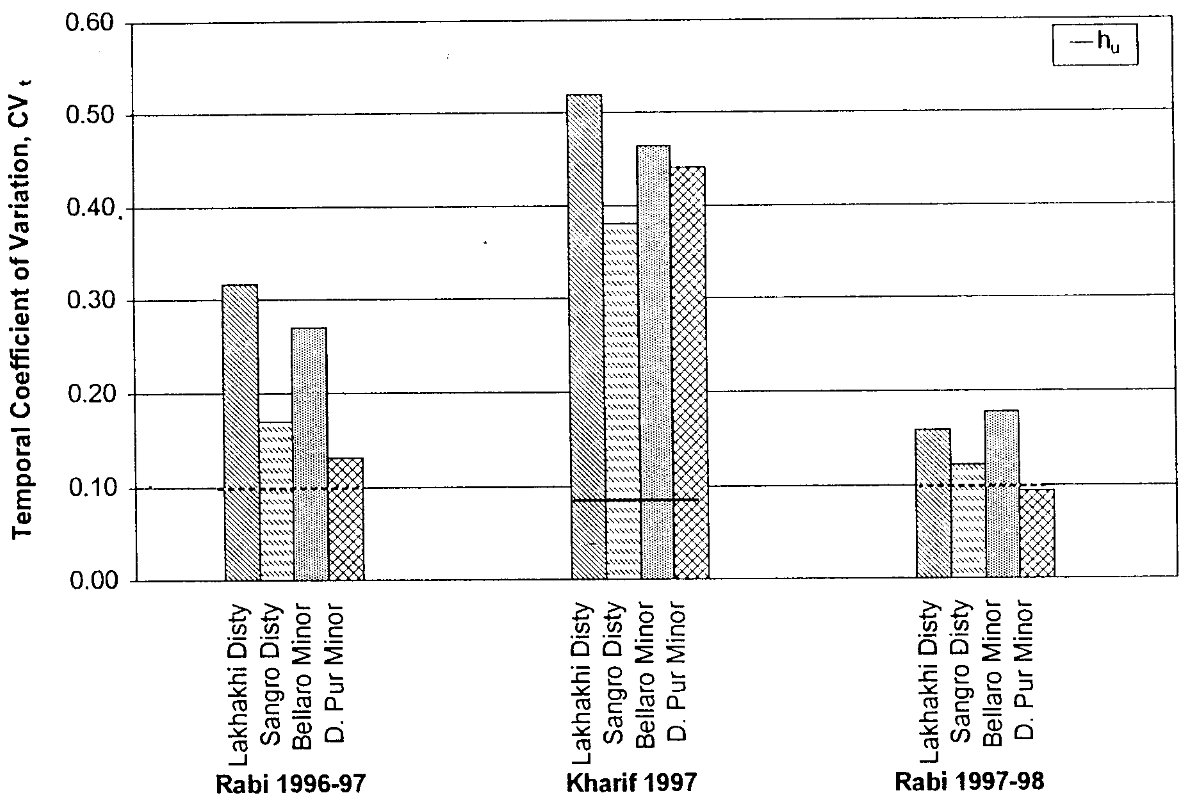

Figure 3.12. Water Level Variations and Gate Manipulations along the West Branch Canal Section.

4 VARIABILITY

4.1 Reliability in Water Supply

The previous sections analyzed and studied the variations in water levels in the parent channel on hourly and daily data basis, which showed that there were small fluctuations during the period under observation. This section will look into the variability in water distribution caused by external interventions. The ease provided by the gated head regulators in the operation of the off-takes can easily be manipulated to disturb flow deliveries according to the desired levels. Most cross regulators in the Jamrao Canal and West Branch Canal are seldom operated, and the regulation is usually carried out through operating the off-takes head regulators.

The temporal coefficient of variation (CV_t) has been used to evaluate variability in water supply for three seasons (*Rabi* 1996-97, *Kharif* 1997 and *Rabi* 1997-98). The Jamrao Canal Section and West Branch Canal Section have been studied separately. Figure 4.1 shows variability in the Jamrao Canal Section off-takes during *Rabi* 1996-97. Except for December, where the variations in withdrawals are less than 20 percent for all the off-takes, the remaining period has experienced wide variations, especially February, March and April. There is no significant trend of rise or fall during the entire season. Withdrawals to the level of above 70 to 90 percent variations by Mirpurkhas, Sanro and Doso Distributaries speak volumes for poor water management during February and March, 1997. Though, the Mirpurkhas and Doso Dharoro Distributaries off-take at the same location but in opposite directions from the Jamrao Canal, there is no match in the water flows delivered to them. However, Kahu Visro and Kahu Minors go all along from the beginning to the end of the season.

The West Branch Canal Section looks somewhat better than the Jamrao Canal Section during *Rabi* 1996-97 (Figure 4.2). There are two peaks of more than 60 and 70 percent in February and April for Daulatpur Minor and Lakhakhi Distributary, respectively. The months of December, January and April have done quite well when compared with others for almost all of the off-takes, except the Lakhakhi Distributary, whose performance has continuously deteriorated from January to April. The Bhittaro Minor receives its share of water through a gateless fixed orifice and has been least affected by external influences, resulting in almost stable deliveries throughout the season.

Figure 4.3 shows the water distribution variability during *Kharif* 1997 in the Jamrao Canal Section. Bar the start and end months of *Kharif* (May and October) the remaining four months have received highly variable flows for all of the off-takes. The majority of the channels have around, or above, 40 percent variable deliveries during June and September, while about half of the off-takes were supplied with 60 percent or so variable flows during July. Withdrawals by the Mirpurkhas Distributary have been continuously disturbed from May to August. Like *Rabi* 1996-97, the channels off-taking just close to each other have much variation in flow deliveries, i.e. Mirpurkhas and Doso Dharoro Distributaries and Bareji and Sanro Distributaries.

The West Branch Canal Section has been managed even poorer than the Jamrao Canal Section. The interesting thing about the Mirpurkhas Sub-division is that the location of the off-takes does not mean much regarding their operational performance. Usually, the tail end off-takes are affected more than the head end, however, this is untrue in this case. Every channel is operated independently of each other.

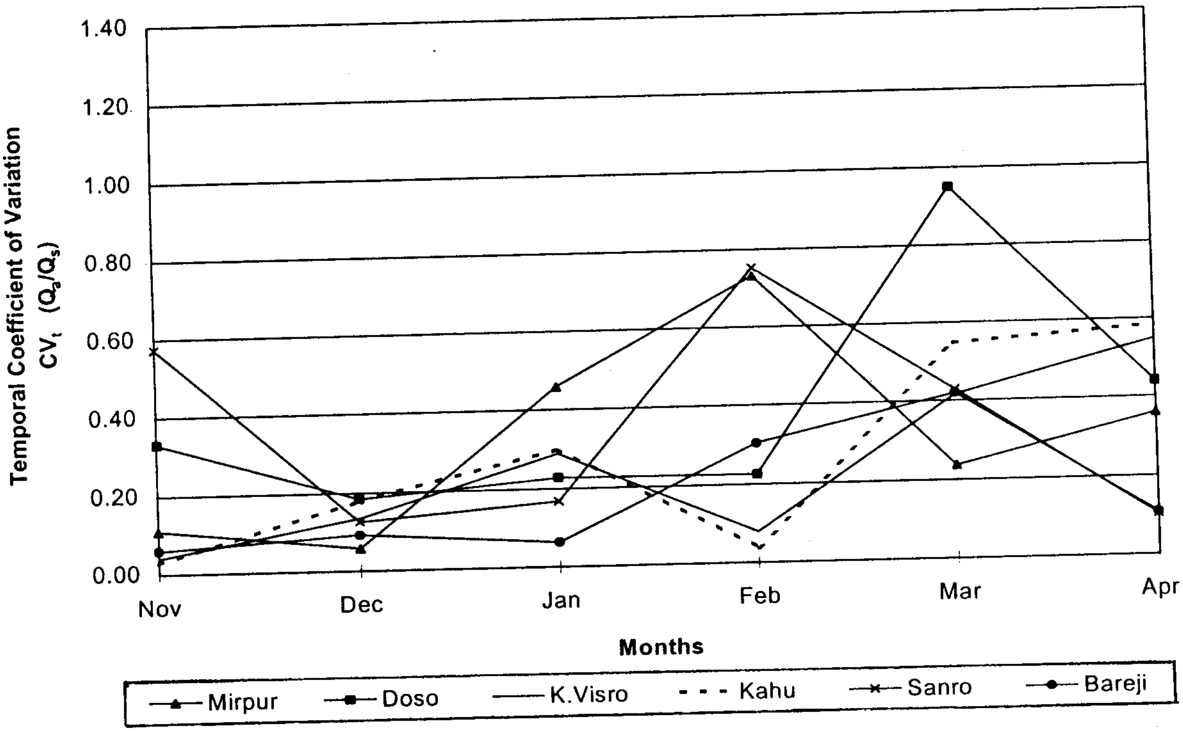

Figure 4.1. **Variation in Water Delivery of Jamrao Canal Section off-takes , Rabi 1996-97.**

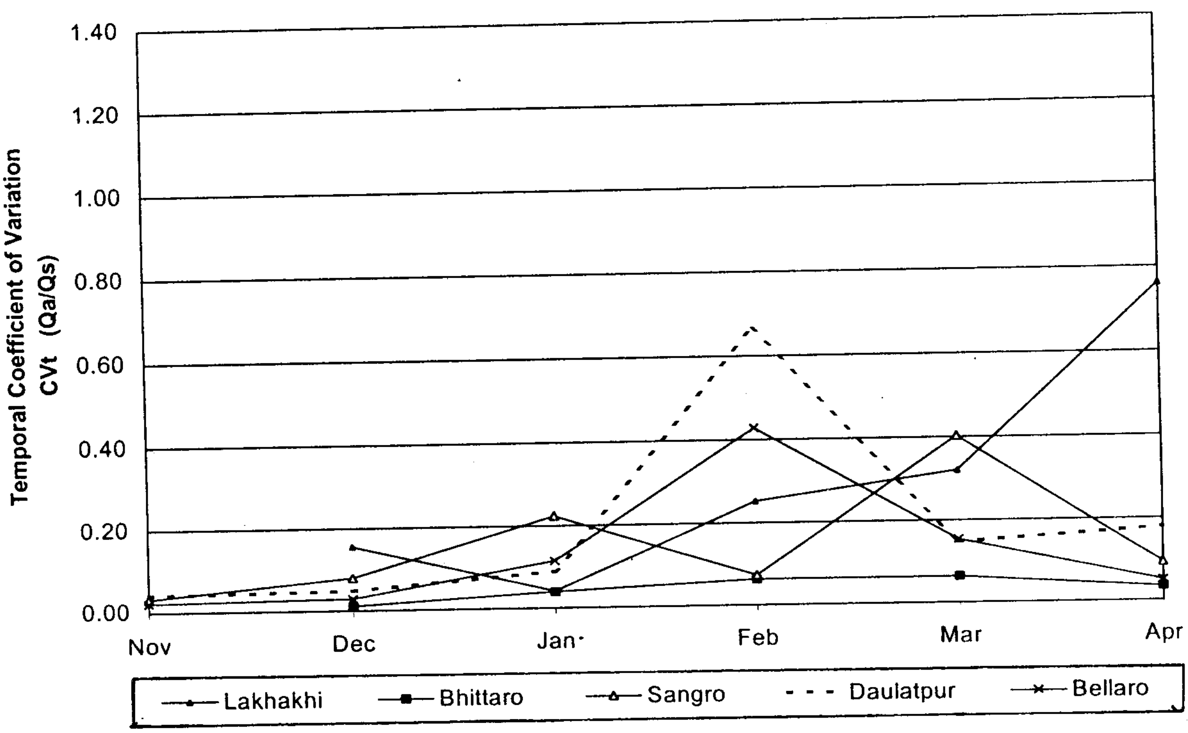

Figure 4.2. **Variation in Water Delivery of West Branch Canal Section off-takes, Rabi 1996-97.**

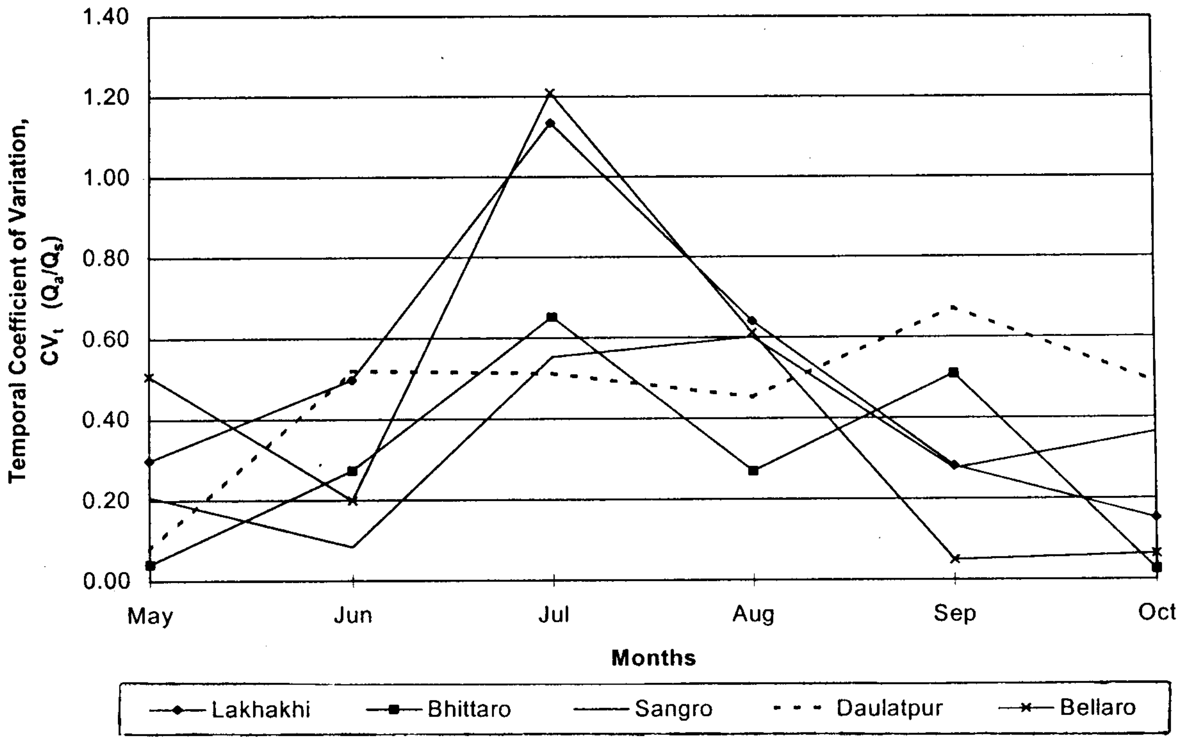

Figure 4.4. **Variations in the Water Delivery of the West Branch Canal Section Off-takes, Kharif 1997.**

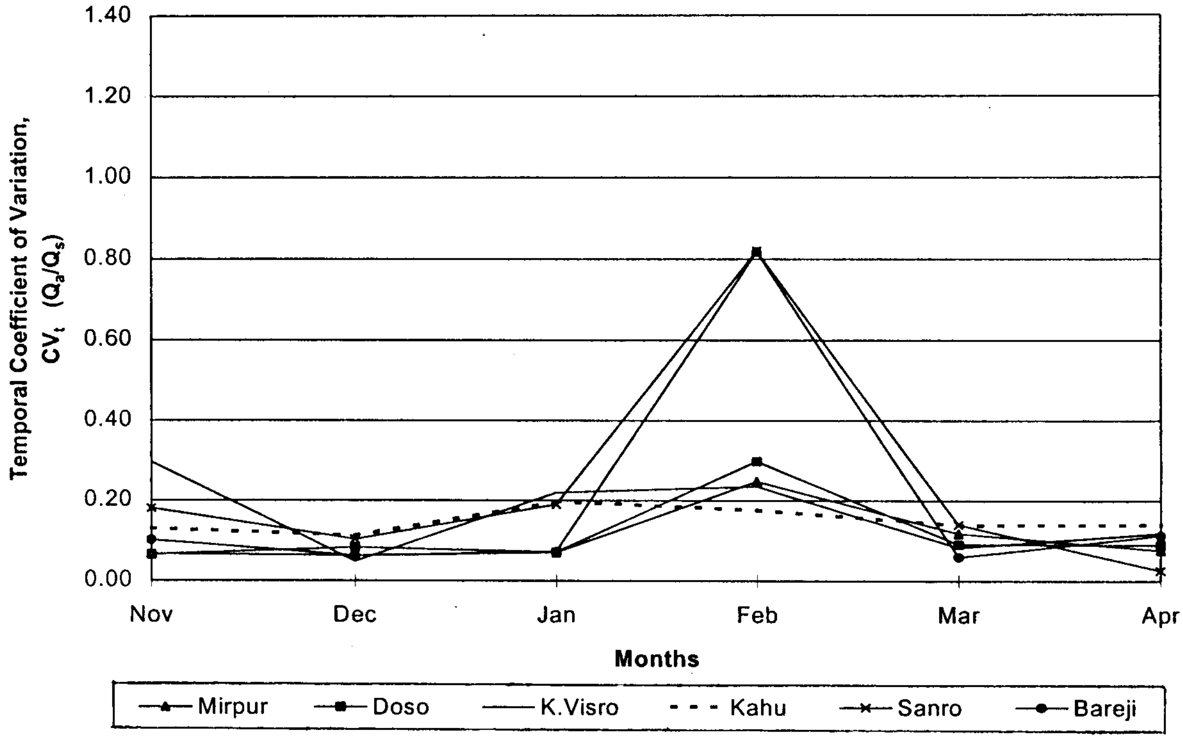

Figure 4.5. **Variations in Water Delivery of the Jamrao Canal Section Off-takes, Rabi 1997-98.**

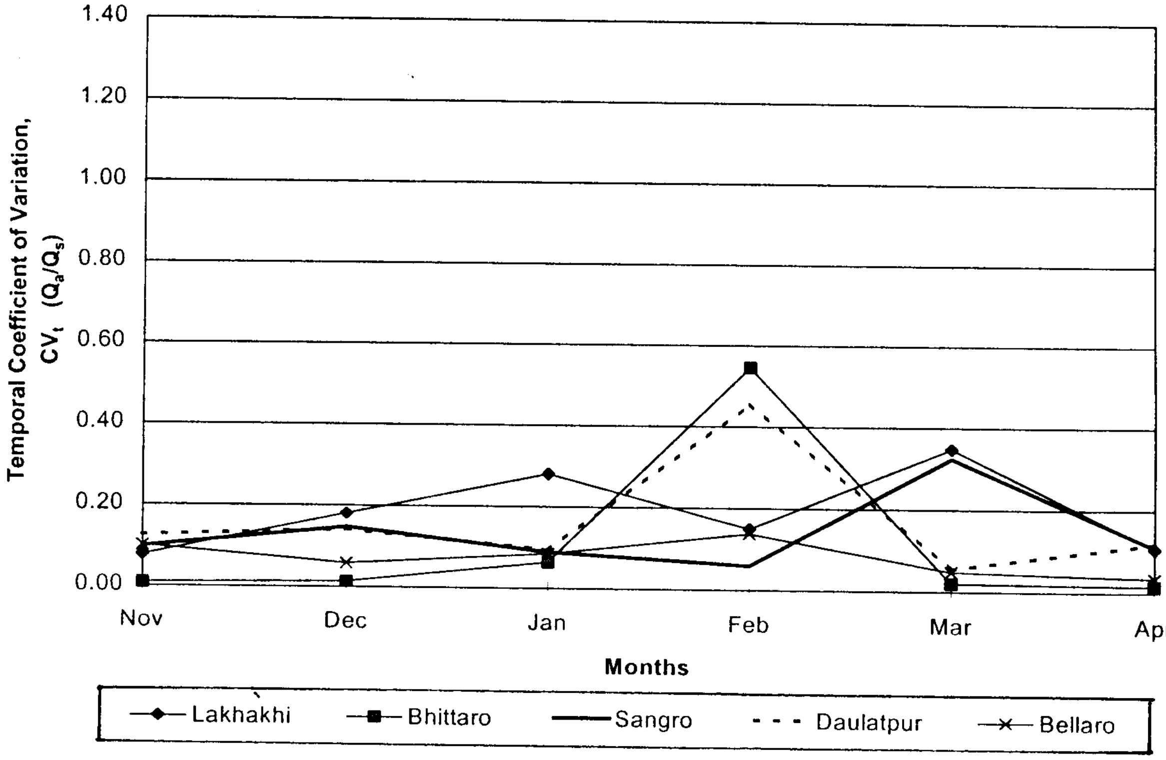

Figure 4.6. Variations in Water Delivery of West Branch Canal Section Off-takes, Rabi 1997-98.

4.2 EQUITY IN WATER DISTRIBUTION

The term equity is concerned with the uniformity of spatial distribution of water. This parameter for the assessment of operational performance of the system is being used in many studies of water distribution among the outlets of the distributary and the off-taking channels of the main canals. This parameter has been evaluated by calculating the spatial coefficient of variation of DPR [$CV_s(Q_a/Q_s)$]. The degree of performance of the channel in terms of coefficient of variation is ranked as depicted. Water distribution in terms of equity is analyzed. The results are explained as under.

Water distribution among the off-takes of the Jamrao Canal Mirpurkhas Sub-division has been analyzed.

The analysis of data for three seasons show that in Rabi 1996/97, the minimum variation has taken place in the months of November and December, that is 15 and 14 percent, respectively. The maximum variation took place in March, that is 52 percent; however the overall seasonal variation is 34 percent. The monthly variation is shown in Figure 4.7

Like-wise, the data for Kharif 1997 were analyzed. Results show that the minimum variation has taken place in the month of May and October, that is 26 and 27 percent, respectively. May is just the start of the season and October is almost the end of the season, while the maximum variation of the season has occurred in the month of July, that is 65 percent. This month and the following month are the hottest during the season and crops require more water because of more evaporation and lowered water table that results in an increase in the frequency of the application of water. The overall seasonal variation is 41 percent, which is significantly high. The results are shown in Figure 4.7.

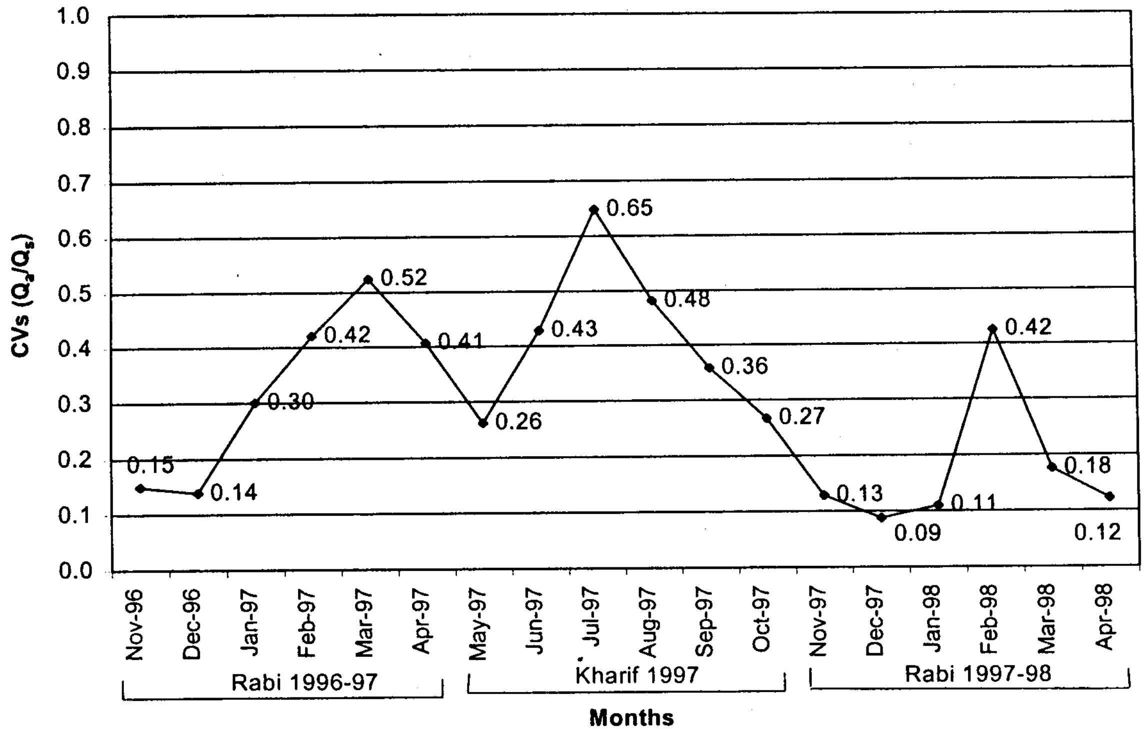

Figure 4.7. **Spatial Coefficient of Variation of the Jamrao Canal Section from November 1996 to April 98.**

Similarly, data for Rabi 1997/98 has been analyzed. Results of the monthly variation show a range from a minimum value of 9 percent to a maximum value of 43 percent. The overall seasonal variation is 18 percent. The maximum variation in flow distribution has taken place in the month of February. In view of the other figures, except for the month of February, all the values are in the range of satisfactory, as recommended by Molden and Gate (1990). The results are shown in Figure 4.7.

Comparing the results of three seasons, Kharif 1997 shows more and frequent variation, while the Rabi 1997/98 season shows a very satisfactory distribution. On the other hand, Rabi 1996/97 is shows an unsatisfactory variation.

The water distribution among the off-takes of the West Branch Canal has also been analyzed for the same period as for the Jamrao Canal.

The analysis of Rabi 1996/97 data show that the minimum variation in water distribution has taken place in the month of November 1996, that is, 7 percent, while the maximum variation in water distribution has taken place in February and April 1997, that is, 36 and 39 percent, respectively. Results are shown in Figure 4.8.

The analysis of Kharif 1997 data displays that the minimum variation in water distribution occurred in the months of May and October 1997, that is, 24 and 23 percent, respectively. This shows that during the start and end of the season, the variation in distribution among the systems is not very much. The maximum variation in water distribution among the systems has taken place in the month of July 1997, that is, 89 percent. But, it is very interesting that the variation trend has declined with time, as shown in Figure 4.8 and that variation has continuously decreased up to the end of the Kharif season and the following Rabi season.

This improvement in performance most probably took place because of proper monitoring and the interest of the concerned Executive Engineer.

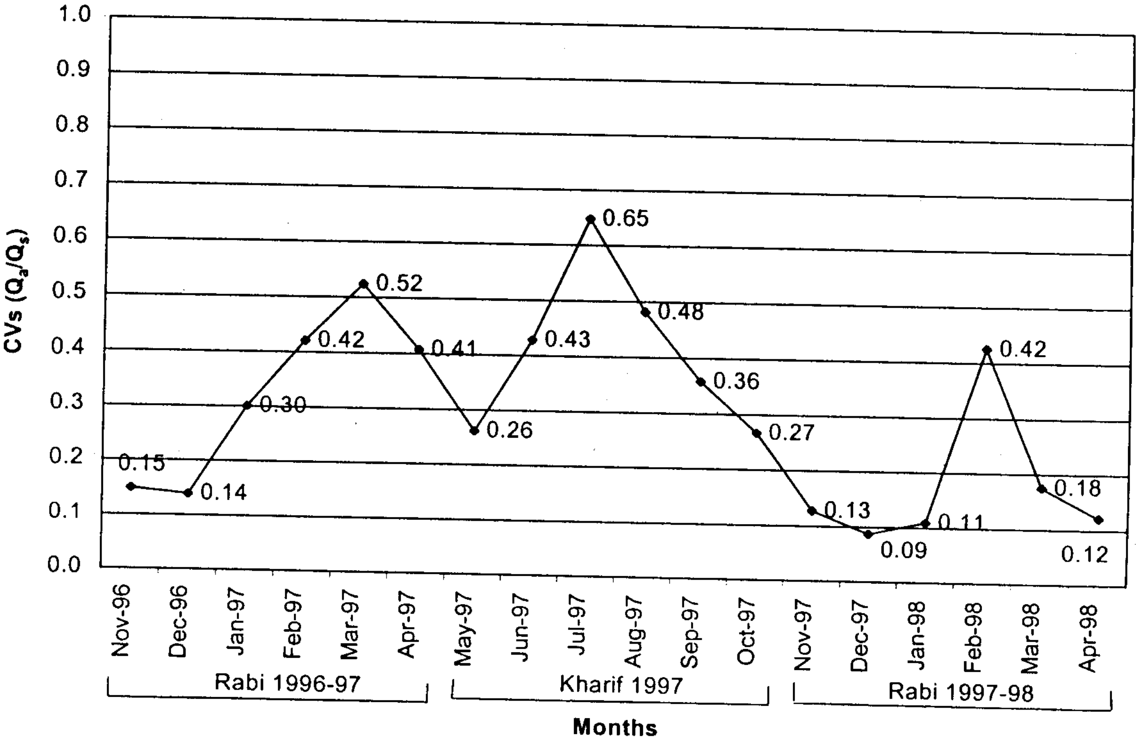

Figure 4.8. Spatial Coefficient of Variation of the West Branch Canal from November 96 to April 98.

Like-wise, the results of the *Rabi* 1997/98 data show that the minimum variation is 8 percent in the month of April 1998, and the maximum variation is 29 percent in the month of February 1998, as shown again in Figure 4.8.

Comparing the results of three seasons, it has been observed that Kharif 1997 shows a big variation in the distribution of water. The variation in distribution during Rabi 1996/97 is less when compared to Kharif 1998, but more when compared to Rabi 1997/98.

4.3 Rotational Closure

Rotational closures are supposed to be resorted to in case of shortages, where it would not be possible to run all the channels at full supply, or at 70 percent of the full supply level. Probably, this criterion has lost its value for some reason and is not followed in the Mirpurkhas Sub-division. The frequency and intensity of the rotational closure is higher during Kharif than in Rabi.

The planning and execution of the rotational schedules is also very much selective and arbitrary. Field monitoring and observations have proved the wide variations in the planning and implementation of the rotational schedules, which is one of the main reasons of discharge variability into different off-takes. Figure 4.9 shows the number of rotational closed days for each off-take of the Mirpurkhas Sub-division during Rabi 1996-97, Kharif 1997 and Rabi 1997-98. The most affected one during Rabi 1996-97 was the Doso Dharoro Distributary, which was

which was closed for 19 days, followed by Daulatpur Minor, for 14 days. The remaining channels were closed from 3 to 10 days during the season.

During Kharif 1997, the Lakhakhi Distributary was the worst hit, where channel water supply was terminated for 34 days, while the Daulatpur Minor was refused water for 31 days, which is more than twice of the Sangro Distributary's closed period. Along the Jamrao Canal Section, Mirpurkhas Distributary remained closed for the highest number of 27 days, followed by a 20 days rotational closure of the Doso Dharoro Distributary, Kahu Visro Minor and Bareji Distributary, each. The Kahu Minor and Sanro Distributary were closed for 15 days each during Kharif 1997, which is only 44 percent of the Lakhakhi Distributary closure period. Only 6 of the 11 off-takes of the Mirpurkhas Sub-division were closed for a few days during Rabi 1997-98. The Bareji and Sanro Distributaries were closed for 10 days each, while the remaining four channels were closed from 1 to 4 days only during the entire season, which is a tremendous improvement over the previous two seasons.

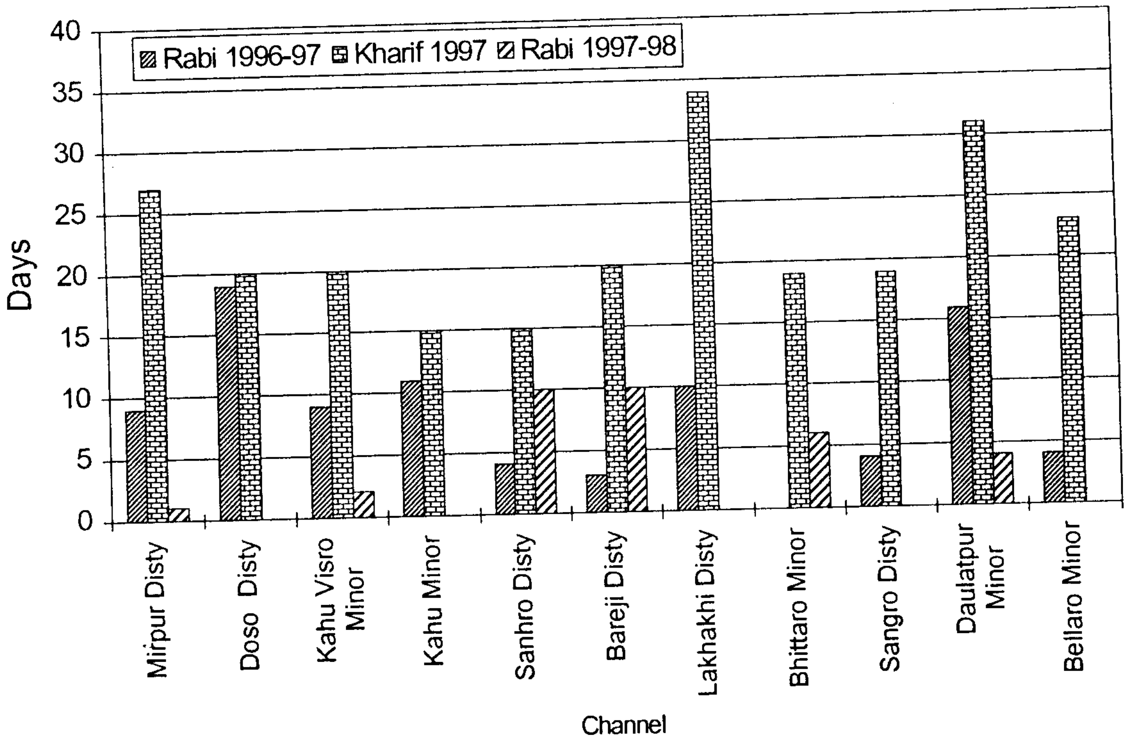

Figure 4.9. Variation in rotational closure during the three seasons.

5 CONCLUSIONS

This research study has drawn the following conclusions:

1. The water level fluctuations in hourly observations for three different periods do not show a significant change in day-night time. This indicates a more stable flow of water in the main canals.
2. Observations on daily bases for water levels during the study period from November 1996 to April 1998 at the selected points are almost stable.
3. The water supply/delivery to the off-takes of the sub-division for two crop seasons (*Rabi* 96/97 and *Kharif* 97) was very poor. However this has significantly improved in *Rabi* 97/98. This improvement was caused by constant monitoring of the system by IIMI and extended stay of the operating staff like the S.E., XEN and AXENs.
4. Water distribution among the off-take channels of the sub-divisions for the study period was almost very poor, but has slightly improved in *Rabi* 97-98 season.
5. The frequent adjustment of gates, ill monitoring process and poor record maintenance are the main reasons for unreliable supply and unequal water distribution.
6. The rotational closure is not being properly implemented in each season, thus, it has largely affected the reliable supply and equal distribution of water.

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