WORKING PAPER 9

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Water Distribution Equity in Sind Province

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IWMI
INTERNATIONAL WATER
MANAGEMENT INSTITUTE

FUTURE HARVEST
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Working Paper 9

Water Distribution Equity in Sindh Province, Pakistan

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and
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International Water Management Institute

Extended Project on Farmer Managed Irrigated Agriculture Under The National Drainage Program (NDP)

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1 CONCEPTS OF EQUITY AND EQUALITY IN WATER DISTRIBUTION

a) The Concept of Fairness

The concept of equity of water distribution is widely used in assessment of irrigation water management performance but in reality there is considerable confusion between the concepts of equity and equality. In understanding what options are open to both groupings of water users and national or provincial irrigation agencies it is useful to distinguish carefully between different strategies for water allocation and distribution.

Equality divides up a common resource in a set of equal shares that can be related to a directly measurable parameter. The most common form of division in irrigation systems is by area, whereby each unit area of land receives the same water allocation. In some frequently smaller systems managed entirely by the local community, a water share may be assigned to each person irrespective of the area of land they own or cultivate, and can include land-less members of the community.

At a more complicated level equality of water distribution may be based on assessment of the potential productivity of land resources, giving more water to more productive land. It may also be based on assessment of soil type so that soils with high water holding capacities receive less water than soils with lower water holding capacity.

Equity is based on a principle of fairness that is accepted by all members of the community involved in sharing a common resource. The fairness reflects the values of the society and does not have to be based on equal share. Some people may get a larger share of water than others either due to prior rights, in compensation for more input in system construction or maintenance. It is much more difficult to define entitlement to water based on value systems than entitlement based on a principle of equal sharing.

In practice large-scale irrigation systems are almost always based on water entitlement on equality rather than equity because of the difficulty of accurately determining what a society considers fair. Further, many larger irrigation systems are constructed in areas that are previously not irrigated, that cover several different communities which may have different views of fairness and where there is weak communication between system designers and future water users.

The result is that it is much easier for irrigation system designers to design systems based on an assumed concept of equality which later is assumed to be equitable. As irrigation communities grow and mature and their experience of what may or may not be considered fair becomes clearer, a second phase of reassessing water entitlements may emerge at local level that requires adjustments in the way systems are operated by national or provincial agencies.

The move towards transferring management responsibilities from government agencies to water users may re-ignite the debate over what is considered fair. The process of transferring responsibility of operation and maintenance inevitably carries with it the right of water users to reassess how they decide to allocate water among themselves. The simple principles of equality inherited from government agencies are not automatically viewed as the most appropriate or desirable allocation principles for local communities, but government agencies who retain some form of oversight for the newly established communities may still desire to keep the old allocation principles active.

This is the situation facing both the newly established Farmer Organizations (FOs) in Sindh and the newly created Sindh Irrigation and Drainage Authority (SIDA). As FOs begin to take full responsibility for operation and maintenance they may wish to change the allocation rules to reflect other principles they see as important.

b) Water Allocation and Distribution Policies in Pakistan

The standard allocation practice in Pakistan has been to allocate water on the basis of an equal share of water per unit area of land. Although there are variations in the water allocations between different canal commands, the result of changing national policies or assessment of overall water availability at the time of construction, within a canal command the share is normally more or less equal[1].

As a result of this allocation principle it is normally possible to define a canal command water allowance in a simple term. Traditionally this is expressed in cusecs/1000 acres[2]. Typical water allocations are between 2.5 – 3.5 cusecs/1000 acres or something in the order of 2 mm/day.

As it is impossible to cultivate all of the irrigated area of a canal command with low water allowance, a planning goal is derived to accompany the water allowance. The planning goal indicates the expected cropping intensity of each of the two main seasons (Rabi or winter season and Kharif or summer season). Typical cropping intensity targets twice as much cultivation in winter when crop water requirements are lower than in hotter more water-demanding summer months. A typical annual target is 50% cropping intensity (33% in Rabi and 17% in Kharif).

In the pilot area of this project the water allowance is approximately 3.8 cusecs/1000 acres, or 2.28 mm/day, with an annual cropping intensity target of 81%. This means that in the Rabi (winter) season 54% of land should be irrigated, while in the Kharif (summer) only 27% should be irrigated. If these cropping intensity targets were met, then the functional water allowance would be about 4.2 mm/day in Rabi and 8.4 mm/day in Kharif.

c) Design and Operational Strategies to achieve Water Allocation Policies

The water allowance policy is perhaps the classic case of a supply-based system where there is no intention of delivering sufficient water to all cultivators for irrigation of all their land. Water, by design, is always scarce.

At the same time, the principle of equity of water allocation among cultivators is seen as essential for effective use of irrigation facilities. The expectation is that all cultivators should always receive their equal share of water irrespective of location within the system. This contrasts strongly with experiences in other countries where only a set portion of the irrigation system is irrigated whenever water is insufficient to meet all of the potential demand[3].

To accomplish this very demanding policy, two overriding principles were adopted within the majority of systems in British colonial India: proportional division of water in the water delivery system at secondary level, and a rigid turn system between water users at the tertiary level. Under abnormal condition a third strategy, that of rotation between secondary canals was also adopted.

Proportional division of water at secondary level is normally accomplished by using a submerged fixed orifice at the head of every tertiary canal. The size and elevation of the orifice is calculated to allow a set and proportional discharge to enter the tertiary canal as long as operational water levels are at or close to design levels. As long as the orifice dimensions are not altered and channels do not accumulate sediment or suffer scouring, it is possible to achieve quite accurate control over water levels along a secondary canal without using any cross-regulation structures of control gates. Also as long as water levels are at design level the flow through the orifice is close to the design. To ensure integrity of the system water users were not allowed by law to modify the dimensions of the outlet structure, while the Irrigation Department

[1] In some canal commands villages that had an existing irrigation system or had some other prior right may have a higher water allocation than the rest of the system

[2] 1 cusec/1000 acres is 28.3 l/sec for 405 ha, approximately 0.07 l/s/ha or 0.6 mm/day

[3] Different countries have different policies to share scarce water. In Indonesia there is typically a priority for different parts of a system that has a three-year cycle (golongan system), so that over the full cycle each farmer has one year of high priority and two years of lower priority. In Sri Lanka traditional bethma systems allow tail end farmers to cultivate land in the head end of the system when water is in scarce supply, with head end farmers giving up a portion of their land for that season only.

had to closely monitor water levels at head and tail of each secondary canal.

Turn System, or warabandi, is a necessary and logical complement to proportional water deliveries at the head of each tertiary canal. A standardized formula was developed over several years that determined the exact number of minutes each water user should receive each week to share water equally. The formula allows for the precise area owned by each water user and also includes allowances for filling or draining of sections of the watercourses as the turn passes from one farmer to another.

Rotation between secondary canals is required if there is insufficient water to keep all secondary canals within 30% of design discharge. If the water level drops too low in a canal then the hydraulic principles used in determining outlet dimensions and elevations no longer guarantee accurate or equal water distribution. Under such conditions certain secondary canals are closed completely so that the remaining canals flow at design discharge. Normally closure is for a 7 or 8-day period, after which the priorities change and dry canals get full supply discharge. In this way water shortages at system level are shared equally among all water users.

d) Constraints to Achieving Water Distribution Equity

In reality it is not always easy to achieve water distribution equality as called for in the operation principles. Typical causes of deviation from design are included in Table 1.1, from which it can be seen that the location of the causes may be far removed from the place where unequal access to water is being felt.

Table 1.1. Causes of Unequal water distribution in typical Pakistan irrigation systems.

Factor causing Unequal Distribution of Water	Location in Canal System	Responsibility
Incorrect canal discharge	Main canal headgate	Executive Engineer
Fluctuating discharge	Main canal headgate	Executive Engineer
Incorrect canal discharge	Secondary canal headgate	Assistant Engineer
Fluctuating discharge	Secondary canal headgate	Assistant Engineer
Improper rotation	Secondary canal headgate	Assistant Engineer
Sedimentation	Secondary canal	Assistant Engineer
Scouring	Secondary canal	Assistant Engineer
Outlet tampering	Tertiary outlet	Water users
Poor maintenance	Watercourse	Water users
Improper turn system	Watercourse	Water users

It is also clear from Table 1.1 that the nature of the cause of inequality of water distribution can either be operational, at the main or secondary canal headgate along a watercourse, or it can be related to ineffective maintenance at secondary or watercourse level[4].

The net conclusion from this discussion is that the real causes of inequality of water distribution in a typical Pakistan canal system are not easily identifiable. While the effects will always be seen at watercourse level, it is not immediately obvious where the inequality started and who was responsible. This makes it difficult to determine effective remedial action, and makes it easy to assign blame to the authority. To overcome this problem, IWMI has undertaken three sets of studies in the three districts included in the Left Bank Outfall Drain (LBOD) that were aimed at measuring water, assessing the effectiveness of water distribution practices, and attempting to identify at which locations in the system inequality was introduced. These studies are described in the next section.

[4] Ineffective maintenance at main canal level has fewer negative effects because discharges can be regulated at secondary canal cross regulators. This option is not available below secondary canal head gates because there are few, if any, cross-regulators along secondary canals.

2 IWMI STUDIES ON WATER DISTRIBUTION IN SINDH PROVINCE

a) Location of Sites for Data Collection

Since IWMI commenced work in Sindh, based in the IWMI Field Office in Hyderabad, data has been collected in three different projects with a different combination of canals. Each of the projects and the data collected is described in the following two sections.

I) *Farmer Managed Irrigated Agriculture – Phase I*

The first phase of the Pilot Project for Farmer Managed Irrigated Agriculture (FMIA-Phase 1) under the Left Bank Outfall Drain Stage 1 Project started in July 1995. This project was funded through the International Development Agency (IDA) of the World Bank and the Swiss Development Cooperation (SDC), with the Sindh Directorate of Agricultural Engineering and Water Management of the Provincial Department of Agriculture and Wildlife.

The overall objectives of the FMIA – Phase 1 project were:

- to develop and implement a program to organize farmers at secondary canal level to enable them to take over full operation and maintenance responsibilities from the Sindh Irrigation and Power Department; and
- to monitor various aspects of canal and watercourse operation and maintenance that would enable evaluation of transfer of operation and maintenance responsibility to organized farmer groups.

In consultation with government officials' three pilot distributaries (secondary canals) were selected for the Pilot Project. The location of these canals is shown in Figure 2.1, while the main features of the canals are shown in Table 2.1.

Table 2.1. Distributaries Included in Farmer Managed Irrigated Agriculture Project – Phase I.

Secondary Canal	Main Canal	Area (ha)	Design discharge (m3/sec)	Number of Watercourses
Heran Distributary	Nara Canal	6235	1.64	31
Bareji Distributary	Jamrao Canal	5822	0.97	25
Dhoro Naro Minor	Gajrah Branch	5418	1.46	24

Data collection for these three canals commenced in December 1995 with a set of baseline studies that measured outlet dimensions and conditions and also obtained benchmark set of discharge measurements at watercourse level. Outlets were calibrated based on the actual dimensions determined in the field.

A routine monitoring program was established in March 1997 and continued through March 1998 to cover two full cropping seasons. This was achieved through use of other IWMI funds from 1 January 1998 together with the special funding arranged for IWMI for the FMIA–Phase 1 project because the official LBOD Project expired on 31 December 1997. Once the 1997-98 Rabi season was over IWMI was no longer able to continue intensive field monitoring and data collection halted.

ii) *Decision Support Systems Project, Sindh Component*

Even before the initiation of the FMIA–Phase 1 Project, IWMI was interested in undertaking fieldwork in Sindh for Dutch-funded project "Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan". This formed part of a wider concern of IWMI to help develop Decision Support Systems (DSS) for improved irrigated agriculture. Implementation of this activity was delayed for several external reasons but in September 1996 the project commenced in Mirpurkhas Sub-Division of Jamrao canal and continued until April 1998. Between January and March 1998 the project was used to fund the continued monitoring program of the FMIA-Phase 1 project.

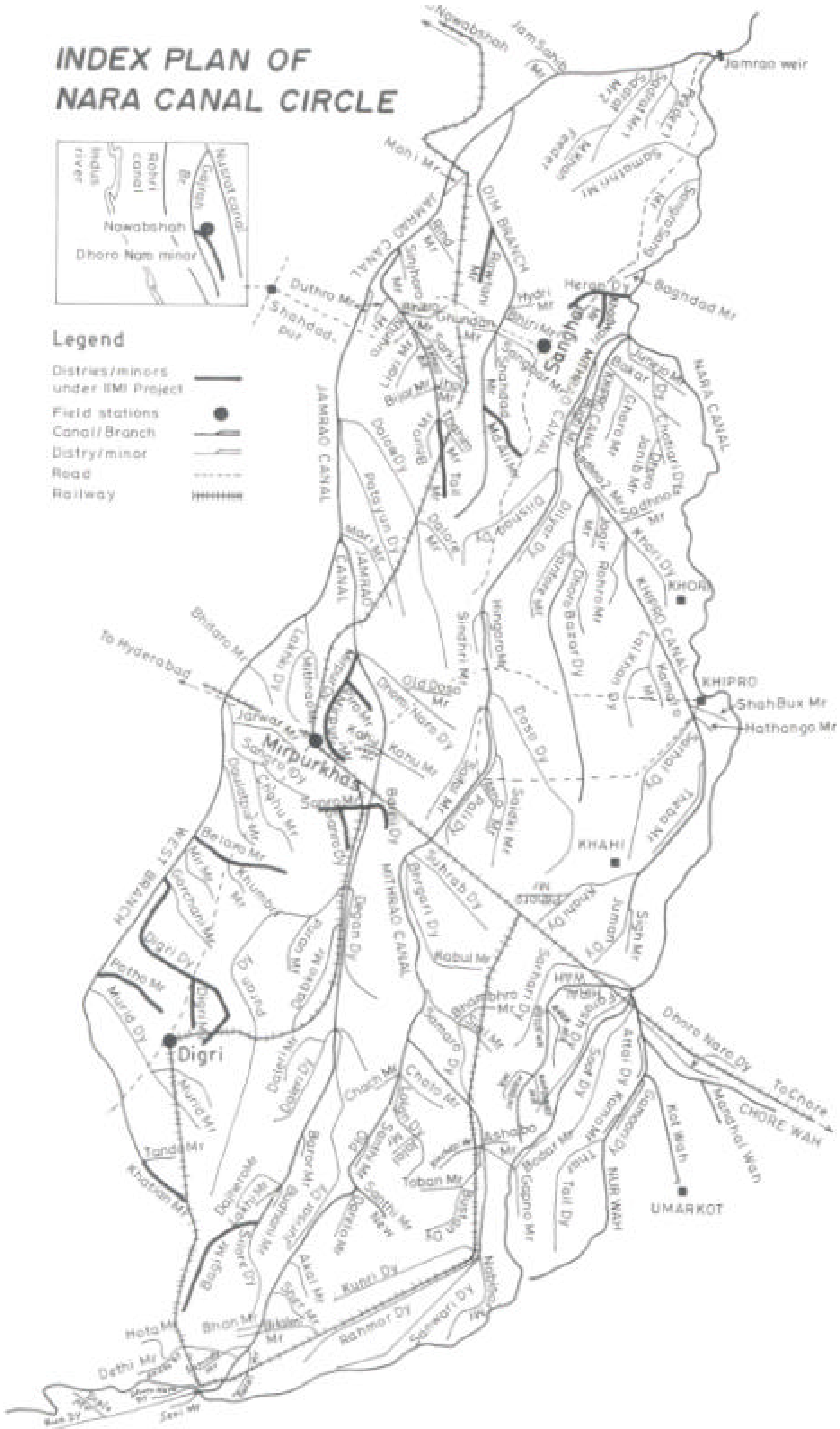

Figure 2.1. Location of IWMI sample secondary canals in Sindh.

The main objectives of the DSS project component in Sindh were:

- analysis of daily water fluctuations in the main canal system, and
- analysis of supply and distribution reliability of irrigation water into secondary canals.

The nature of data collection program complemented the on-going FMIA-Phase 1 project as it viewed secondary and main canal conditions. While the FMIA-Phase 1 activities viewed in more detail secondary and tertiary level conditions. For financial and logistic reasons, the DSS Project was restricted to only one of the three sub-divisions included in the FMIA-Phase 1 project.

The project selected all of the 11 distributaries and minor canals in Mirpurkhas District. This includes two reaches of main canal, Jamrao Canal between Mitho Machi cross-regulator and the cross-regulator at RD 448, and Jamrao West Branch Canal between Mitho Machi cross-regulator and the cross-regulator at RD 143. The details of these canals are presented in Table 2.2, while the locations are shown in Figure 2.1.

Table 2.2. Canals included in decision support project measurement program.

Main Canal	Secondary Canal	Design Discharge (m^3/sec)	Irrigable Area (ha)	Water Allowance Imperial	Metric
Jamrao Canal	Mirpur Distributary	1.83	6808	3.8	0.27
	Doso Dharaoro Distributary	1.87	9208	2.9	0.20
	Kahu Visro Minor	0.34	1466	3.3	0.23
	Kahu Minor	1.23	4866	3.6	0.25
	Bareji Distributary	1.17	5681	3.0	0.21
	Sanro Distributary	1.52	6265	3.5	0.24
West Branch	Lakhakhi Distributary	1.83	7123	3.6	0.26
	Bhittaro Distributary	0.32	1494	3.1	0.21
	Sangro Distributary	2.94	12532	3.4	0.23
	Daulatpur Minor	1.39	4359	4.6	0.32
	Bellaro Minor	1.55	6933	3.2	0.22

Note: Water Allowance Units: Imperial: cusecs/1000 acres; Metric: l/sec/ha

iii) Farmer Managed Irrigated Agriculture – Phase II

The third measurement program was conducted under the Farmer Managed Irrigated Agriculture Project (FMIA-Phase II). In most respects this project is similar to the FMIA-Phase I but there are two important differences:

- in FMIA-Phase II the executing agency was the Sindh Irrigation and Drainage Authority (SIDA) with funding provided through the National Drainage Program (NDP), creating a more direct linkage between the farmer organization program and the agency which had monitoring and other oversight responsibilities for farmer organizations; and
- the project extended its activities to cover another 10 secondary canals within Sanghar and Mirpurkhas Districts, while continuing to monitor activities in the original three canals covered in Phase I.

The Phase II-project started in April 1999 and was completed by October 2000. Field data collection commenced in May 1999 in the original three canals, while data collection on additional 10 canals started in November/December 1999 through gauges which were installed and calibrated during October/November 1999.

The main features of the 8 new canals that were included in the Phase II activities are shown in Table 2.3 while their locations are shown in Figure 2.1.

iv) Overall data availability

From these three data collection programs measurements of a total of 20 canals were taken during the period November 1996 to May 2000. There are a total of 281 canal-months of data falling into six seasons: Rabi 1996/97, Kharif 1997, Rabi 1997/98, Kharif 1999, Rabi 1999/2000, and part of Kharif 2000.

Table 2.3. Distributaries included in farmer managed irrigated agriculture project–phase II.

Secondary Canal	Main Canal	Area (ha)	Design discharge (m3/sec)	Number of Watercourses
Rawtiani Minor	Dim Branch	3658	0.83	19
Mohammed Ali Minor	Dim Branch	1552	0.31	10
Tail Minor	Shahu Branch	3355	0.63	14
Mirpurkhas Distributary	Jamrao Main	6566	2.75	59
Sanharo Distributary	Jamrao Main	6222	1.52	30
Belharo distributary	Jamrao West	6914	1.66	34
Digri Distributary	Jamrao West	12394	2.69	70
Potho Minor	Jamrao West	3264	0.82	19
Khatian Minor	Jamrao West	3996	0.78	21
Bagi Minor	Jamrao Main	3630	1.16	15

During the DSS study and the FMIA-Phase II study daily data were collected at canal heads so the data sets are complete (except for Sundays and public holidays). These data allow a full analysis to be undertaken because the days when water was not flowing in canals was recorded.

In the FMIA-Phase I study, however, data were only collected twice a week and only when canals were flowing. This data set, covering three canals and involving a total of 22 canal-months of data, do not provide information on canal closures and so it is not possible to determine the frequency of closed days or undertake an analysis of rotational closures.

The location and periods of measurement are provided in Table 2.4. It is clear that there is good coverage in four of the six seasons of study. The data is limited for Kharif 1999, and incomplete for Kharif 2000. However, the data collection program will continue until September 2000 which will enable a complete analysis of the Kharif 2000. Data for January has been ignored because canals are normally closed for most of the month and the remaining data is too less for any serious analysis.

b) Data Collection Program and Performance Assessment Criteria

The main strategy of the measurement program to better understand water distribution is to determine the values for a set of performance indicators that describe how well the designed objectives of the system are being met. The designed objectives discussed in Section 1.c above indicate the following conditions should be met:

- as long as there is adequate water available at the head of the main canal,
- distribute this water equitably among secondary canals,
- maintain secondary canals so that correct discharges pass into each reach of the secondary canal, and
- maintain secondary canals so that correct discharges pass into watercourse every day, and
- ensure that discharges are within an acceptable tolerance
- in case of shortages of water at the head of the main canal,
- implement a fair and equal rotation among secondary canals,
- ensure discharges in operating canals do not fall below 70% of design discharge, and
- ensure that discharges are within an acceptable tolerance.

The designed objectives of the system and the appropriate performance indicators are summarized in Table 2.5

Based on this analysis of objectives and performance indicators, it is a simple task to develop the monitoring program to meet the evaluation objectives. IWMI therefore developed a monitoring and evaluation package that included the following elements.

Table 2.4. Data availability for analysis of water distribution equity.

Command	Kotri	Nara	Jamrao																	
Main Canal	Gajrah	Nara	Dim		Shahu	Jamrao						West Branch								
Secondary	Dhoro N	Heran	Rawtiani	Md Ali	Tail	Mirpur	Doso	Visro	Kabu	Bareji	Sanro	Lakhi	Bhitaro	Sangro	Daulat	Bellaro	Digri	Potho	Khatian	Bagi
Nov-96						x	x	x	x	x	x			x	x	x				
Dec-96						x	x	x	x	x	x	x	x	x	x	x				
Jan-97																				
Feb-97						x	x	x	x	x	x	x	x	x	x	x				
Mar-97						x	x	x	x	x	x	x	x	x	x	x				
Apr-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
May-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Jun-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Jul-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Aug-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Sep-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Oct-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Nov-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Dec-97	o	o				x	x	x	x	x	x	x	x	x	x	x				
Jan-98																				
Feb-98	o	o				x	x	x	x	x	x	x	x	x	x	x				
Mar-98	o	o				x	x	x	x	x	x	x	x	x	x	x				
Apr-98						x	x	x	x	x	x	x	x	x	x	x				
May-99	x	x																		
Jun-99	x	x								x										
Jul-99	x	x								x										
Aug-99	x	x								x										
Sep-99	x	x								x										
Oct-99	x	x								x										
Nov-99	x	x	x		x	x				x	x					x				
Dec-99	x	x	x		x	x				x	x					x	x	x	x	x
Jan-00																				
Feb-00	x	x	x		x	x				x	x					x	x	x	x	x
Mar-00	x	x	x	x	x	x					x					x	x	x	x	x
Apr-00	x	x	x	x	x	x					x					x	x	x	x	x
May-00	x	x	x	x	x	x					x					x	x	x	x	x

x Complete daily data set available
o Sample daily data set available

Table 2.5. Designed objectives, performance indicators and data requirements.

Objective	Performance Indicator	Data Requirement
(a) Normal Conditions		
Equity of water distribution at secondary canal level	Delivery Performance Ratio at head of secondary canals	Design discharge and actual discharge at secondary canal head.
Equity of water distribution along secondary canals	Delivery Performance Ratio of head, middle, and tail reaches of secondary canals.	Design discharge and actual discharge at head of each canal reach.
Equity of water distribution between watercourses	Delivery Performance Ratio at head of watercourses	Design and actual discharge at head of watercourses
Discharges within acceptable range of tolerance	Coefficient of variation of discharges	Actual discharges at heads of secondary canals and watercourses
(b) Water Short Conditions		
Fair and equal rotation among secondary canals	Proportion of time each canal remains closed	Presence/absence of water at head of secondary canal
Discharge remains above 70% of design discharge	Delivery Performance Ratio is above 0.70	Design and actual discharge at head of secondary canal
Discharges within acceptable range of tolerance	Coefficient of variation of discharges	Actual discharges at heads of secondary canals and watercourses

i) *Discharge*

Secondary Canal Heads: discharges were measured at the head of each secondary canal on a daily basis in each of the three measurement programs.

At each secondary head in the FMIA projects a staff gauge was installed, and readings of water levels taken each day (except for one day a week and on public holidays). Each staff gauge was calibrated using a current meter and a rating curve was developed. If changes in canal cross-sections occurred, staff gauges were re-calibrated.

In the DSS project discharges were calculated by calibrating the headgates in the main canals cross-regulators and in secondary canal offtake structures. The calibration was based on gate openings and dimensions, and upstream and downstream water levels, with rating curves developed by current metering the canal downstream of the headgate. This was done using a boat in main canals and large secondary channels.

Heads of Secondary Canal Reaches: in FMIA-Phase II additional gauges were installed at locations that represented the start of the middle reach and the tail reach of the secondary canals.[5] The exact location of the gauge was selected to ensure suitable hydraulic conditions to eliminate backwater effects but as far as possible they were located approximately one-third and two-thirds of the distance from the head of the secondary canal. At each location water levels were taken each day (except for one day a week and on public holidays). Each staff gauge was calibrated using a current meter and a rating curve was developed. If changes in canal cross-sections occurred, staff gauges were re-calibrated.

Heads of Watercourses: each watercourse structure was calibrated through the use of painted reference marks on the upstream and downstream face of the outlet structure. Readings of the difference between the water level and the reference mark were converted to actual upstream and downstream head, and the data converted to discharge based on rating curves developed by current metering in the head of the watercourse. When outlets were tampered with current metering was repeated and a new calibration curve developed.

For logistic reasons it was not possible to take daily readings at all watercourses on all canals. In FMIA-Phase I a strategy was developed whereby all watercourses on each of the three pilot secondary canals were read twice a week. In FMIA-Phase II watercourse readings were only taken on the original three secondary canals, and only for a six-month period. Five or six sample watercourses were selected on each secondary and daily readings were taken at these locations, while readings on all watercourses were taken twice a month, and before and after desilting in January 2000.

ii) *Delivery Performance Ratios*

Each main, secondary and tertiary canal in Pakistan has a known design discharge and it is expected that as far as possible the actual discharge should equal the design discharge. This makes it a simple matter to calculate the Delivery Performance Ratio (DPR):

$$Delivery\,Performane\,Ratio\ \ (DPR) = \frac{Actual\,Discharge}{Desig\,Discharge}$$

To make the evaluation easier, Irrigation Department defines one tolerance standard. If the actual discharge drops below 70% of design discharge then rotation is applied, so that minimum acceptable DPR is 0.7. There is no comparable upper limit but it seems realistic to have a similar upper limit, so anything above 1.3 would be considered poor performance.

More rigorous performance criteria are used at watercourse level where discharges are supposed to be within ±10% of design. We therefore adopt the following performance assessment criteria:

[5] In two very short secondaries, Bagi Minor and Tail minor, only one gauge was installed as close as possible to the halfway distance along the canal.

Good performance:	DPR between 0.9 and 1.1
Fair performance:	DPR between 0.7 and 0.9 or between 1.1 and 1.3
Poor Performance:	DPR less than 0.7 or more than 1.3

Wherever possible, IWMI has converted actual discharge data into DPR values because this is a standardized ratio that permits simple comparison of performance in canals with different design discharges. This comparison can be made using daily data for a single day for several canals, or calculated for a single location over a set time period (typically a week or a month) so that a time series of DPR values can be developed.

A second way of using DPR values is merely to add up the number of occurrences when DPR falls outside the acceptable limit. The percentage of sub-standard days should be equal over space if all areas are to be treated equally.

iii) Variability of Discharges

The second performance parameter used by IWMI is aimed at assessing the variability in canals over a specified time period because there is evidence that if canal supplies are unreliable, water users risk fewer inputs and yields drop.

While an average figure for discharge or DPR over a period of time may fall within the tolerance limits defined above, the variability may not. The easiest standardized measure of variability that can be compared to DPR is the Coefficient of Variation (CV), which is independent of the actual average:

$$Coefficient\ of\ Variation\ (CV) = \frac{Standard\ Deviation\ of\ Discharge}{Average\ Discharge}$$

CV values can also be used in both a spatial manner, where CVs for the same time period in different locations are compared, and in a temporal dimension to see how variability changes over time at a single location.

The tolerance for CV is more difficult to define because there are no specified targets in the operational rules of the Irrigation Department. Two approaches can be adopted, one based on general guidelines developed by Molden and Gates (1990), or more site-specific tolerances based on operational rules of the Irrigation Department.

Molden and Gates propose that the temporal measure of variability, which they term reliability, should have three categories: if CVt is <0.10 variability is good, if CVt is between 0.10-0.20 it is fair, and if CVt is more than 0.20 it is considered poor. The spatial measure (CVs) is slightly less stringent: good is less than 0.10, fair is when CVs is between 0.10-0.25, while poor is when CVs is greater than 0.25.

However, these limits do not fit comfortably with those inherent in the Irrigation Department rules. It would be acceptable under current Department rules to deliver water on alternate days into a secondary canal with a DPR of 0.7 and a DPR of 1.3. This would translate over a month into a CV of 0.305. A rather more stringent rule is applied at watercourse level where discharges are not supposed to vary by more than ±10%, so that the maximum acceptable CV is 0.101. Combining these two criteria is impossible, and so a three-fold assessment of CV is used here:

Good performance:	CV <0.10
Fair performance:	CV <0.30
Poor Performance:	CV >0.30

No distinction is made between spatial and temporal CV because the rules of the Irrigation Department do not distinguish between tolerances for spatial and temporal variation: all canals should be treated equally at all times.

One methodological problem that arises is that there are sometimes days when no water is delivered to the head of a secondary canal but rotational irrigation is not being practiced. Typical causes for such interruptions in supply include upstream or downstream breaches that require canals to be closed so that repairs can be made, or closure of canals due to rainfall that means crops do not require water. Most data sets do not indicate whether water users knew of such disruptions in advance or not. The CV values can be calculated to include or exclude occasional closures depending on whether we assume there is good communication or not.

We therefore calculate the data in two ways. We use all data, including days when there was no discharge recorded, to represent the situation where communications are extremely poor and water users do not know when water supplies will stop. We use a data set with all zero discharge days removed to represent the situation where water users are assumed to have advance warning of all closures and disruptions to supply. In reality, some intermediate situation is probably close to what water users actually experience.

iv) Rotation

The final performance evaluation relates to the implementation of rotations. Normally most water users know when they are in a period of rotation, and will therefore expect some periods when canals are closed. However, the precision of implementation of rotational irrigation is not always guaranteed. Performance assessment therefore looks at two different elements of the implementation of rotational irrigation: equality of dry days between canals, and the attainment of minimum discharge targets during periods when water is flowing.

A well-implemented rotation period would ensure that all canals get an equal number of days of closure, but when water is delivered it is with a DPR of 0.7 to 1.3 to maintain hydraulic integrity along the secondary canal. It is inevitable that there will be higher variability of discharges in periods of rotation because of the frequent draining and filling of canals but the differences in CV between different canals should be more or less the same if the implementation is done with care.

3 ANALYSIS OF WATER DISTRIBUTION EQUITY IN SINDH PROVINCE

This section describes the results of the analysis of the data set described in Section 2. It is based on monthly data only. While it would be possible to undertake a more detailed daily or weekly analysis this has not been included in this report.

Monthly analyses tend to be more indicative of overall conditions because they even out short-term deviations and fluctuations. It therefore includes any managerial adjustments that were made for unexpected changes in water availability at the head of the system.

To put the monthly data into perspective it is useful to calculate the average DPR for all canals included in each season of study. These data are summarized in Table 3.1.

Table 3.1. Seasonal Delivery Performance Ratios (DPR) and Coefficients of Variation (CV).

Season	Rabi 96/97	Kharif 97	Rabi 97/98	Kharif 99	Rabi 99/00	Kharif 00
Number of Canals	13	13	13	3	13	13
DPR						
All data	1.18	1.23	1.25	1.31	1.12	0.83
Excluding closed days	1.22	1.43	1.26	1.61	1.28	1.18
CV						
All data	0.21	0.40	0.17	0.47	0.38	0.68
Excluding closed days	0.14	0.12	0.11	0.11	0.12	0.11

From a seasonal perspective the overall performance is generally only satisfactory. Looking at the DPR values using the entire data set five of the six seasons show DPR values within the 0.7-1.3 range. The exception is Kharif 1999 where the data set is too small to be significant. Rabi 1999/2000 shows best performance, but this was a winter season when water availability was lower than normal due to restricted releases from Tarbela and Mangla reservoirs.

The restrictions on water in Rabi 1999/2000 are evident from the overall seasonal CV, which is much higher than a normal Rabi season, and reflect the need to impose rotations in January-

March 2000. The effect of rotations is seen in every Kharif season where CV values are always above 0.4, a value that is classified as poor performance.

By excluding zeros the effects of rotations can be better understood. By only considering days when water was issued to canals we observe two main trends:

- Variability of discharges drops dramatically so that in every season the average CV is in the range of 0.11-0.14, which is satisfactory for all seasons, and
- DPR values all rise, showing that when canals are operated, discharges are actually much higher than design and performance is poor in two seasons and only satisfactory in the remaining four seasons.

This seasonal analysis puts into context all of the remaining analysis described in this section.

a) Equity of Water Distribution Between Secondary Canals

This sub-section looks at the monthly equity of water distribution at the head of all the secondary canals in each season of the study.

i) Monthly Delivery Performance Ratios

The full set of results for the entire period of observation is shown in Appendix 1, Tables A.1 (all data) and Table A.2 (excluding days when water was not issued to that canal).

It is clear that there is a very wide range of DPR values in Table A.1. To easily understand the equity the best indicator is the Interquartile ratio (IQR) that compares the ratio of the highest 25% of values to the lowest 25% of values. In a situation of true equity, the value of this ratio will be 1.0 and will increase with greater inequity. The results of this analysis are shown in Table 3.2.

Table 3.2. Interquartile Ratios for Delivery Performance Ratios for Secondary Canal Heads.

Season	Rabi 96/97	Kharif 97	Rabi 97/98	Kharif 99	Rabi 99/00	Kharif 00
Number of Canals	13	13	13	3	13	13
All data						
Ave. DPR, high 25%	1.49	1.64	1.52	1.84	1.53	1.20
Ave. DPR, low 25%	0.88	0.89	1.00	0.80	0.72	0.60
Interquartile Ratio	1.69	1.84	1.52	2.03	2.13	2.00
Excluding zeros						
Ave. DPR, high 25%	1.52	1.90	1.59	1.98	1.86	1.51
Ave. DPR, low 25%	0.95	1.03	1.02	0.95	0.84	0.82
Interquartile Ratio	1.60	1.84	1.56	2.08	2.21	1.84

This table shows that even under the most charitable interpretation, there is very large inequity between secondary canals in the sample area.

When all data, including zero discharge days, are analyzed, the canals with the highest water deliveries have DPR values 1.20 to 1.84 and average 1.50 (150% of design discharge). The canals with the lowest DPR values range from 0.60 to 1.0 and average only 0.81 (or 81% of design discharge).

As a result Interquartile ratios are extremely high, ranging from 1.52 to over 2.0, meaning that the most favored canals get 50 to 100% more water than the least favored canals. There is no clear seasonal trend.

When zero days are excluded then the situation hardly changes, except that all DPR values naturally increase. When water is flowing, the most favored canals get between 151% and 198% of design discharge, while the least favored canals get only 82% to 103% of design discharge. Interquartile Range figures are almost exactly the same.

A second way of assessing the inequity of water distribution is to look at the distribution of months in the three performance categories of good, satisfactory and poor. These data are summarized in Table 3.3.

Table 3.3. Delivery Performance Ratios for Secondary Canal Heads.

Season	Rabi 96/97	Kharif 97	Rabi 97/98	Kharif 99	Rabi 99/00	Kharif 00
Number of Canals	13	13	13	3	13	13
Seasonal DPR	1.18	1.23	1.25	1.31	1.12	0.83
DPR > 1.3	13 (31%)	25 (37%)	22 (40%)	7 (50%)	9 (19%)	1 (4%)
1.1 < DPR <1.1	12 (28%)	18 (27%)	20 (36%)	2 (14%)	15 (31%)	4 (17%)
0.9 < DPR <1.1	11 (26%)	11 (17%)	7 (13%)	2 (14%)	13 (28%)	3 (13%)
0.7 < DPR <0.9	2 (5%)	7 (11%)	6 (11%)	1 (8%)	5 (11%)	5 (21%)
DPR < 0.7	4 (10%)	5 (8%)	0 (0%)	2 (14%)	5 (11%)	11 (45%)
Good	11 (26%)	11 (17%)	7 (13%)	2 (14%)	13 (28%)	3 (13%)
Satisfactory	14 (33%)	25 (38%)	26(47%)	3 (22%)	20 (42%)	9 (38%)
Poor	17 (41%)	30 (45%)	22 (40%)	9 (64%)	14 (30%)	16 (49%)

This table is very important in understanding some of the main causes of inequity between secondary canals. If overall water availability at sub-divisional level, or at each branch of the main canal system is high, then performance will be poor because many secondary canals can get higher than designed discharge. Similarly, if discharges at sub-divisional level or into each branch of the main canal system are low, then performance is also poor because many canals cannot get enough water. The least inequitable periods are when seasonal supplies to the overall area are in the range of 1.1 to 1.2 above design.

In other words, as far as the SDO is concerned, it is upstream actions that determine overall performance at secondary canal level, although there is clearly scope for reducing inequity by more effective operation of secondary canal headgates.

i) Variability of Discharges

The complete data sets for variability of discharges calculated on a monthly basis are provided in Appendix 1, Tables A.3 (all data) and A.4 (excluding zero data)

Analysis of the variability of discharge (Table 3.4) shows if all data are included in the analysis, variability is generally extremely high and performance is classified as poor in the Kharif season. Normal Rabi seasons are somewhat better, with performance being either good or satisfactory about 80% of the time (Rabi 1999/2000 showed poorer performance).

Table 3.4. Variability of canal discharges at secondary canal heads.

Season	Rabi 96/97	Kharif 97	Rabi 97/98	Kharif 99	Rabi 99/00	Kharif 00
Number of Canals	13	13	13	3	13	13
All data						
CV > 0.3	11 (26%)	43 (65%)	8 (15%)	9 (64%)	25 (53%)	23 (96%)
< CV < 0.3	12 (29%)	11 (17%)	23 (42%)	4 (29%)	14 (30%)	1 (4%)
CV < 0.1	19 (45%)	12 (18%)	24 (43%)	1 (7%)	8 (17%)	0 (0%)
Excluding zeros						
CV > 0.3	2 (5%)	1 (1%)	1 (2%)	0 (0%)	1 (2%)	1 (4%)
< CV < 0.3	19 (45%)	43 (55%)	30 (46%)	7 (50%)	21 (45%)	11 (46%)
CV < 0.1	21 (50%)	34 (44%)	34 (52%)	7 (50%)	25 (53%)	12 (50%)

However, when zero discharges are removed from the data set we see a dramatic transformation in performance. There are virtually no occurrences of poor performance and almost all months are split more or less equally between good and satisfactory performance. We can thus conclude that although discharges are not equitable the system operates predictably: in over half the months as the data set discharges do not vary by more than ±10% of average discharges, while in the other half of the time the variation is less than ±30%.

A somewhat more pessimistic interpretation is that reliability is maintained irrespective of discharge: favored canals rely on being favored, while unfavored canals continue to receive less than fair water delivery.

b) Implementation of Rotations at Secondary Canal Level

The second set of actions required by those in charge of the main, branch and secondary headgates is the fair and appropriate implementation of rotations between secondary canals, and ensuring that discharges do not fall below 70% of design.

The full set of data used to assess implementation of rotational irrigation is presented in Appendix A, Table A.5 (number of days without water) and Table A.6 (Number of days per season when DPR values are less than 0.7). A summary of the percent of time that each canal is closed is shown in Table 3.5.

Other than the stipulation that rotation should affect all canals equally there is no clear guideline for what is an acceptable deviation from equal conditions. On rather generous assessment good performance is when all canals are within ±30% of the average time of closure for that season (equivalent to the variability criteria discussed earlier). We find that in most seasons there are no major deviations.

Contradictorily, there is more variability in the Rabi season than the Kharif season even though the Kharif season is when most rotations occur. The main reason appears to be that during Rabi there are few closures (typically 3-4% of the time) so that any canal that gets closed for longer appears to be highly unfavored. But this is not likely to be true in most Rabi seasons because closure comes from causes such as breaches, repairs and other disruptions rather than from shortage of water.

Table 3.5. Percentage of Each Season that Secondary Canals are Closed.

Season Secondary Canal	Rabi 1996/97	Kharif 1997	Rabi 1997/98	Kharif 1999	Rabi 1999/2000	Kharif 2000	Total Days Closed	Total Days Measured	% of time Closed
Dhoro Naro				14%	14%	34%	61	345	18%
Heran				7%	8%	10%	29	360	8%
Rawtiani					4%	30%	23	186	12%
Md. Ali					32%	30%	28	92	30%
Tail					15%	33%	37	176	21%
Mirpur	8%	17%	1%		15%	26%	72	594	12%
Doso	19%	13%	0%				38	413	9%
Visro	6%	14%	1%				31	414	7%
Kahu	6%	13%	0%				27	414	7%
Bareji	6%	11%	6%	32%	11%	23%	96	710	14%
Sanro	6%	6%	9%		27%	36%	85	591	14%
Lakhi	0%	24%	0%				44	396	11%
Bhitt	0%	10%	4%				25	396	6%
Sangro	4%	9%	2%				23	442	5%
Daulat	8%	19%	6%				51	439	12%
Bellaro	4%	18%	0%		17%	34%	75	600	13%
Digri					10%	38%	32	149	21%
Potho					19%	21%	29	147	20%
Khatian					11%	36%	32	150	21%
Bagi					19%	25%	30	140	21%
Total closed	52	280	46	69	203	215	868	7154	12%
Total Days	822	2013	1753	403	1401	762	7154		
% Closed	6%	14%	3%	17%	14%	28%	12.13%		

Only in Rabi 1999/2000 was there a need to practice rotation. Two of the 11 canals in the Jamrao command (Mohammed Ali minor and Sanhro Distributary) were closed more than 160% of the average, and a further 2 (Potho minor and Bagi Minor) were closed for over 130% of the average. One canal, Rawtiani, was only closed for 4% of the time compared to the average closure of 12% of the time.

In the two Kharif seasons with sufficient data to make some definitive conclusions there is a contrasting and quite remarkable, situation. In Kharif 1997 two canals (Lakhaki Distributary and Daulatpur Minor) were closed much more frequently than average, while two canals (Sanhro and Sangro Distributaries) were closed much less than the average. In Kharif 1999 all canals in the Jamrao command were closed with more or less the same frequency and none deviated more than 30% from the average.

The reason for the change in performance of rotations appears to be that the water shortage in 2000 is much more severe than in 1997. In 1997 average DPR for all canals was 1.23 whereas in the first two months of 2000 the DPR only averaged 0.83. But although the water supply was 50% lower in 2000 than 1997, the rotation schedule was twice as intense for canals being closed almost 30% of the time.

We can conclude that when water gets short then there is much tighter management applied and the result is a much more equitable pattern of canal closures.

The same conclusion can be drawn from the analysis of number of days when discharges drop below 70% of design. The results of Table A.6 are summarized in Table 3.6. It is obvious that in the period November 1996 to April 1997 there were a large number of occurrences of lower than permitted discharges in both Kharif and Rabi seasons. The total number of days on which discharge fell below the permitted level ranged from 10-15% in these three seasons. We can be sure that on those days when discharges were at this level tail end farmers were highly unlikely to get any water at all.

Since June 1999 there were only three cases of discharges below 70% of design, all of which occurred on consecutive days in the same canal. It appears that by intensifying the intensity of rotation periods from 14% to 28% of the time it has been possible to virtually eliminate periods of time when discharges are less than 70% of design.

Table 3.6. Number of Days per Season when Discharges are Less Than 70% of Design.

Season	Rabi 96/97	Kharif 97	Rabi 97/98	Kharif 99	Rabi 99/00	Kharif 00
Number of Canals	13	13	13	3	13	13
Number of Days when DPR<0.70	114	308	71	0	3	0
Number of days of observation	822	2013	1753	403	1401	762
% of time when DPR < 0.7	13.8%	15.3%	9.7%	0%	0.2%	0.0%

c) Equity of Water Distribution Along Secondary Canals

The equity of water distribution along secondary canals has been made possible by installation of gauges at one or two locations along 11 canals on which Farmer Organizations have been formed.[6] Because these locations were calibrated using current meters it was possible to calculate the DPR at each of the gauges and assess the variability of discharges. In this report a comparison is made between the readings taken at the head gauge and the gauge at the start of

[6] Gauges could not be installed in Mohammed Ali Minor before the January 2000 desilting and were removed on several occasions in Dhoro Naro Minor before and after desilting.

the tail section.[7] Data have not been analyzed for the gauges at the start of the middle section of the canal.

Further, data are presented for a specific period. In January 2000 there was a major desilting campaign throughout Pakistan at the behest of the Chief Executive. He mobilized the army to supervise compulsory desilting in almost every secondary canal in the country. The head and tail gauge data that was already being collected by IWMI under the Farmer Organization program provides an outstanding opportunity to determine the impact of desilting on water distribution equity.

Data sets were taken to cover three months before desilting (gauges on most of the new canals were installed in November 1999 giving six to eight weeks of daily readings before desilting) and the subsequent three months of data (February-April 2000) were used to represent the post-desilting period.

i) Delivery Performance Ratios

Data for DPR values before and after desilting are presented in Table 3.7. Before desilting the average ratio of head: tail DPR values were 1.66 and there were only two canals (Potho and Bagi Minors) where the tail had a higher DPR than the head. After desilting the average ratio of head: tail DPR values had dropped to 1.2, and six of the 11 canals actually saw better tail DPR values than the head. Eight of the eleven canals showed increases in tail end DPR values.

To understand the importance of these figures, it is worth recalling that in Section 3.a.i Interquartile Ratios for most and least favored canals were reported, and that the values of these ratios was always greater than 1.56. While the situation before desilting is comparable (five of the eleven canals show ratios of more than 1.56), after desilting only two canals (Heran and Belharo Distributaries) with head: tail show ratios in excess of 1.56. There is no apparent relationship between head DPR and the head: tail ratio.

We can therefore safely conclude that in general there is less inequity generated along secondary canals than between secondary canals as long as secondary canals are desilted properly. The implications of this conclusion are discussed in the next section.

Variability of Discharges

A similar analysis was undertaken to determine changes in variability of discharges along secondary canals. Because variability must increase along an open channel without control structures, the ratio of variability is expressed as head: tail ratio.

The results of this analysis are shown in Table 3.8. There are no dramatic changes in the situation before and after desilting. On average, the head: tail ratio declined slightly, from 2.21 to 1.81. But two data points that are very high distort these high figures because incoming discharges at the canal head are almost constant. A more realistic assessment shows that CV increased on average by 0.08 points before desilting and 0.11 points after desilting.

These data, which exclude days without discharge, are comparable with those for variability of discharges between secondary canals. We can therefore conclude that there is as much variability introduced along secondary canals as between secondary canals.

[7] The term “tail gauge” refers to staff gauges installed at the start of the tail section of a secondary canal. It should not be confused with the tail gauge at the end of the secondary canal installed by the Irrigation Department, as data have not been collected from them for many years. Most are missing.

Table 3.7. Delivery Performance Ratios before and After Desilting, Head and Tail Gauges.

Distributary	Before Desilting, January 2000			After Desilting, January 2000		
	DPR at Start Head Section	DPR at Start Tail Section	DPR Ratio Head:Tail	DPR at Start Head Section	DPR at Start Tail Section	DPR Ratio Head:Tail
Heran	1.36	0.38	3.53	1.31	0.51	2.55
Rawtiani	1.71	1.71	1.00	1.54	1.71	0.90
Tail	1.49	1.20	1.23	1.15	0.96	1.20
Mirpur	1.02	0.39	2.64	0.94	0.66	1.44
Bareji	2.13	1.63	1.30	2.13	2.36	0.90
Sanrho	1.29	1.11	1.16	1.34	1.58	0.85
Belharo	1.11	0.36	3.07	1.07	0.79	2.27
Digri	1.17	1.12	1.04	1.04	0.90	1.16
Potho	1.02	1.28	0.79	0.74	0.98	0.76
Khatian	1.31	0.65	2.00	1.25	1.35	0.92
Bagi	0.58	0.80	0.72	0.71	1.36	0.52
Average	1.29	0.97	1.68	1.20	1.20	1.22

Table 3.8. Coefficient of Variation of discharges at Head and Tail Gauges of Secondary channels.

Distributary	Before Desilting, January 2000			After Desilting, January 2000		
	CV at Start Head Section	CV at Start Tail Section	CV Ratio Tail:Head	CV at Start Head Section	CV at Start Tail Section	CV Ratio Tail:Head
Heran	0.15	0.22	1.48	0.17	0.38	2.20
Rawtiani	0.10	0.12	1.23	0.14	0.17	1.18
Tail	0.21	0.28	1.32	0.16	0.21	1.28
Mirpur	0.21	0.23	1.08	0.20	0.23	1.19
Bareji	0.13	0.14	1.05	0.08	0.08	1.05
Sanrho	0.14	0.13	0.95	0.02	0.16	3.20
Belharo	0.03	0.22	8.50	0.15	0.27	1.78
Digri	0.08	0.15	1.88	0.16	0.32	2.00
Potho	0.07	0.17	2.35	0.19	0.44	2.32
Khatian	0.10	0.29	2.93	0.12	0.25	2.17
Bagi	0.25	0.39	1.53	0.23	0.39	1.66
Average	0.13	0.21	2.21	0.15	0.26	1.82

d) Equity of Water Distribution Between Watercourses

The data set used for this analysis only covers the three secondary canals of Heran Distributary, Dhoro Naro Minor and Bareji Distributary as no watercourse level data were collected in any other secondary canal. Further, data are only sufficient to examine three seasons in details.

i) Delivery Performance Ratios between watercourses

The performance of the three canals in terms of DPR is shown in Table 3.9. It is clear that in all canals performance is poor because the majority of watercourses have a DPR higher than 1.3. However, it is also true that in almost all of the seasons of study the DPR at the head of the secondary canal was also poor, and this impacts directly on the performance at watercourse head. In a secondary canal with no cross-regulators or other control structures, water distribution is controlled strictly by the hydraulic conditions at each watercourse outlet and no management actions are possible to reduce the effects of poor performance at the head. Under these conditions it is unrealistic to blame water users alone for the poor performance at watercourse level.

The DPR ratios for the most favored 25% and least favored 25% of watercourses along each of the three canals are presented in Table 3.10. To help interpret the data, the DPR as the head of the secondary canal is also included in the table because the amount of water entering the secondary canal will greatly affect the DPR into individual watercourses. Also included is the Interquartile Ratio to help compare with similar data presented for secondary canal heads in Table 3.2.

The Interquartile ratios for the most favored and least favored watercourses along three secondary canals are much higher than those between the most favored and least favored secondary canals. As a result we can conclude there is a larger measure of inequity between watercourses along a single canal than between canals.

There are, no doubt, several contributing causes for this situation. One is that it is possible to capture a high DPR by tampering with a watercourse outlet and building up watercourse banks to convey higher discharge, an option simply not feasible at secondary canal level. Another is that tail end watercourses get consistently less than their fair share because of large upstream abstractions. In both Dhoro Naro, for reasons of water shortage, and in Bareji, due to high land elevation, tail end water users pump water either by low lift pump or by tubewell to compensate for lack of surface water deliveries into their watercourses. While this means that the overall head-tail difference is less than the figures in Table 3.10 would at first indicate, this does not detract from the serious differences between different watercourses that emerge from this analysis.

This second assertion is verified in case of Heran Distributary and Dhoro Naro Minor, where the IQR is inversely related to the DPR at the head of the secondary canal (Figure 3.1). It appears that once DPR at the canal head drops below 1.2 the IQR rises very rapidly because tail end areas get deprived of almost all their water. This pattern is similar to that found in similar analyses of data from the Punjab in Pakistan. Bareji Distributary does not show this trend, and unlike Heran and Dhoro Naro, there is no head-tail effect of watercourse DPR.

Table 3.9. Delivery performance ratios for watercourse heads.

Season	Kharif 97	Rabi 97/98	Kharif 99
Heran Distributary			
DPR at Head of Secondary	1.79	1.12	1.78
DPR > 1.3	21	13	18
1.1 <DPR < 1.3	5	1	0
0.9 < DPR < 1.1	4	6	1
0.7 < DPR < 0.9	0	7	2
DPR < 0.7	0	2	4
Bareji Distributary			
DPR at Head of Secondary	1.70	1.53	1.98
DPR > 1.3	18	17	18
1.1 <DPR < 1.3	1	3	2
0.9 < DPR < 1.1	2	1	1
0.7 < DPR < 0.9	0	0	0
DPR < 0.7	3	3	3
Dhoro Naro Minor			
DPR at Head of Secondary	1.08	1.29	0.95
DPR > 1.3	18	20	18
1.1 <DPR < 1.3	1	3	0
0.9 < DPR < 1.1	2	1	1
0.7 < DPR < 0.9	3	1	2
DPR < 0.7	1	0	4

Table 3.10. Delivery performance ratios and interquartile ratios between watercourses.

	Kharif 1997	Rabi 1997/98	Kharif 1999
Heran Distributary			
DPR at head of secondary	1.79	1.12	1.98
Ave. DPR most favored 25%	2.67	2.34	3.55
Ave. DPR least favored 25%	1.11	0.77	1.55
Interquartile Ratio	2.41	3.04	2.29
Bareji Distributary			
DPR at head of secondary	1.70	1.53	1.98
Ave. DPR most favored 25%	3.38	3.28	3.61
Ave. DPR least favored 25%	0.76	0.77	0.78
Interquartile Ratio	4.45	4.26	4.63
Dhoro Naro Minor			
DPR at head of secondary	1.08	1.29	0.95
Ave. DPR most favored 25%	3.59	3.98	3.37
Ave. DPR least favored 25%	0.85	1.01	0.55
Interquartile Ratio	4.22	3.94	6.13

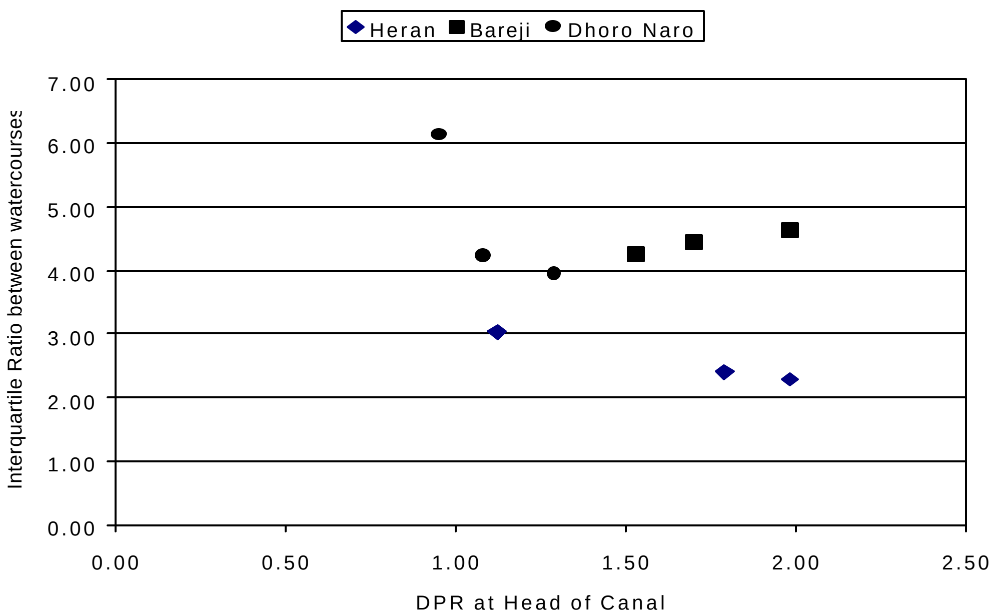

Figure 3.1. Relationship between delivery performance ratio at canal head and interquartile ratio between most favored and least favored watercourses.

ii) Variability of Discharges

Analysis of the variability of discharges in the three distributaries also shows relatively poor performance at watercourse heads, as shown in Table 3.11. Again these data must be interpreted in the light of the conditions experienced at the head of the canal. Because there is no continuous record of daily data for the 1996-1997 data the CVs cannot be directly compared, but in Kharif 1999 data are available. The seasonal CV of discharges to the head of Heran, Bareji and Dhoro Naro was 0.31, 0.73 and 0.43 respectively. Because it is impossible for the complete set of watercourses to show a lower level of variability than that experienced at the distributary head, it is inevitable that watercourse variability performance will be worse than at the head of the canal.

iii) Days without water

The final assessment of performance at watercourse level is to determine the number of occurrences when watercourses did not get any water. There are, of course, two reasons why watercourses may be dry: closing of the watercourse due to lack of demand by water users because of rain or harvesting, or lack of water at the distributary head. The two conditions can be distinguished in the data: deliberate closing of watercourses is random, while tail end water shortages affect all watercourses below a certain point on any given day.

Data for Heran and Bareji show very few watercourse closures: typically a watercourse may be closed for one to two days in a season. Further, the distribution of closure is more or less at random from head to tail so it is impossible to attribute the closing to lack of water. Dhoro Naro, however, shows a classic pattern of increasing lack of water towards the tail during periods when water is in scare supply. This is shown in Table 3.12.

Table 3.11. Coefficient of variation of watercourse discharges including days when watercourses were closed.

	Kharif 1997				Rabi 1997/98				Kharif 1999			
	All Data		No Zeros		All Data		No Zeros		All Data		No Zeros	
Heran Distributary												
DPR at head of secondary	1.79				1.12				1.98			
CV > 0.30	1	3%	1	3%	8	28%	15	52%	20	80%	4	14%
0.10 < CV < 0.30	28	93%	24	80%	14	48%	11	38%	4	16%	15	52%
CV < 0.10	1	3%	5	17%	7	24%	3	10%	1	4%	10	34%
Bareji Distributary												
DPR at head of secondary	1.70				1.53				1.98			
CV > 0.30	1	4%	0	0%	2	8%	1	4%	2	8%	2	8%
0.10 < CV < 0.30	16	67%	15	63%	19	79%	17	71%	19	79%	17	71%
CV < 0.10	7	29%	9	38%	3	13%	6	25%	3	13%	5	21%
Dhoro Naro Minor												
DPR at head of secondary	1.08				1.29				0.95			
CV > 0.30	20	69%	18	62%	19	66%	15	52%	20	80%	19	76%
0.10 < CV < 0.30	4	14%	7	24%	5	17%	9	31%	5	20%	6	24%
CV < 0.10	1	3%	0	0%	1	3%	1	3%	0	0%	0	0%

It is clear from Table 3.12 that with low DPR at the canal head water users are no longer able to properly manage their water and tail end areas suffer. In Dhoro Naro water users compensate by pumping groundwater, particularly towards the tail, as they no longer have confidence that water conditions at the head of the canal will be adequate to meet their needs.

Table 3.12. Effect of water shortage at secondary head on tail end water conditions Dhoro Naro Minor.

	Kharif 1997	Rabi 1997/98	Kharif 1999
DPR at Canal Head	1.08	1.29	0.95
Average number of head watercourses without water	0.6	0.0	0.2
Average number of tail watercourses without water	5.4	2.2	11.8
Interquartile Ratio	9	--	59

4 MANAGEMENT IMPLICATIONS

Two broad conclusions arise from the analysis of the data collected by IWMI over the past four years, which have considerable implications for the work of both the Area Water Boards established under SIDA, and Farmer Organizations being established in the Province.

First, water distribution equity is unsatisfactory at main, secondary and tertiary level. There are few instances where performance is within the criteria established by the Sindh Irrigation and Power Department. Insofar as the IWMI data collection program was undertaken before any transfer of management responsibility to farmer organizations, much of the responsibility for sub-standard performance rests with the Irrigation Department.

Second, water distribution in the canal system of Pakistan is a continuum from barrage, through main and branch canals to secondary headgates, along secondary canals and into watercourses. The inadequate control infrastructure means an unforgiving type of design: the effects of changes in upstream discharge and variable upstream discharges will automatically be transmitted downstream, and there is little or nothing that downstream users can do to mitigate these negative effects.

a) Management Implications for Area Water Boards

Under the current structure of the Sindh Irrigation and Drainage authority, the Canal Area Water Boards (AWB) are responsible for operation and maintenance of main and branch canals, and for the operation of secondary headgates. The only responsibility they lose from operation and maintenance perspective is their obligation to maintain secondary canals and operate the very few cross-regulators that exist along secondary canals.

In all other respects the AWB obligations remain the same: they must deliver discharge into the head of each secondary canal, at which point responsibility for operation passes to a Farmer Organization (FO), and they must operate and maintain all main and branch canals.

A major difference, however, is that FOs will have greater legal entitlements to demand a clear water management contract that specifies the water delivery conditions at the point of transfer of responsibilities. Not only will AWBs have to agree to deliver a specified discharge, they will have to meet their commitment to share any excess water equally among all FOs. This has several implications for AWB management.

i) Discharge measurement

To meet both the contractual commitment to individual FOs and also share any surplus water equally between different FOs, AWB must have a capacity to measure discharges. In all of the IWMI studies the canals monitored had no head gauge or other device to measure discharges into secondary canals. While the reasons for this sorry state of affairs are not discussed in this paper, it is clear that at present AWBs will not be able to meet their legal commitments to FOs until such time as they establish a measurement capacity.

At present AWB staff deliver water to secondary canals on the basis of whether the water level looks about right: this is hardly professional, and certainly insufficient to meet legal challenges from FOs who claim they are getting less water than their entitlement. There needs to be a complete overhaul of the procedures involved in collecting, storing and disseminating information on discharges before FOs have a realistic chance of receiving what they are entitled to, and to protect AWBs from actions taken by FOs.

As a corollary to discharge measurement AWBs must continue maintaining those canals for which they retain responsibility. Maintenance is not an end in itself, but is the process required to ensure that conveyance of water is properly accomplished so that target discharges at each location in the system are properly met.

ii) Water Distribution between FOs

A second major change that will be required from AWBs is the capacity to deal simultaneously with different FO groups. The present system, which relies heavily on paternalism, has never had to face a situation where several secondary canal groups will be in legitimate communication concerning their water deliveries and other related matters. The opportunity to play one canal group off against another will diminish as FOs develop better communication among themselves, and begin to demand more openness about discharges being issued to canals other than their own.

Whereas in the past the discharge data was not released to outside parties, the situation will change because FOs can, and will, measure their discharges alongside AWB staff, and will communicate to others their information. As a result the AWBs will face an unprecedented situation where their capacity to deliver water simultaneously to several different FOs along the same main or branch canal will become a mater of public rather than private debate.

At present there is no evidence that AWBs have this capacity, either technically in terms of data collection, storage and dissemination, or managerially in terms of negotiation and compromise.

It is also unclear how well rotations are actually managed at present when water is in short supply. While the Kharif 2000 rotation seems to run fairly well, the exact days of cut-off and restoration of supplies are not always known or adhered to, so that a water user may lose two warabandi turns instead of one through no fault of his own. Failure to communicate such deviations makes water deliveries increasingly unreliable and leads to greater conflict among water users within FO groups.

iii) Monitoring Water Distribution Performance by FOs

The third challenge for AWBs is much more complex and probably the one that can lead to the most intense disputes between AWBs and FOs.

In the past Irrigation Department staff had the right to check dimensions of outlets, monitor discharges in watercourses, and rectify dimensions of structures to ensure that as far as possible equity was maintained between watercourses along a secondary canal.

With the establishment of FOs and transfer of operation and maintenance responsibility, it is no longer clear that AWB staff have this responsibility. Many AWB staff would like to see the FOs obliged to monitor watercourse discharges, check outlet dimensions and keep everything the same as it is. There are two aspects of this situation that merit more discussion.

First, AWB staff have clearly failed in their responsibility of ensuring equitable water distribution along secondary canals and it is therefore unrealistic to expect FOs to be able to readily accomplish something the AWB has been unable to do. If AWBs handed over secondary canals that were perfect, then they might have higher moral ground to stand on.

Second, transfer of management responsibility does not mean that if the work is transferred the rules are changed. If FOs wish to reallocate water among their members, they should do so, with the single provision that they still have to pay the same amount of money to the government as service fee for water delivered to the head of the secondary canal.

The implication of this last statement is critical. If AWBs feel that they will take over a policing role to ensure the old and largely unworkable water distribution rules at secondary canal levels, and blame FOs for the failure of perfect water distribution, then there will be long and bitter conflict between AWB and FO members.

AWBs must, therefore focus their operation and maintenance activities at main and branch canal level, ensure equal and fair water delivery into secondary canals in an open and transparent manner, and provide advice and assistance to FOs rather than police them.

b) Management Implications for Farmer Organizations

The newly established FOs are at the start of a long and probably very difficult period. They have endured an inordinately long delay in the passing of the necessary legislation by the government of Sindh. They have been ready for months and, in three cases, years to take over legal responsibility for infrastructure and operation and maintenance tasks, they have been trained in water measurement, management, accounting, budgeting and planning.

Despite these delays it is clear that the initial enthusiasm is still there, and that they clearly understand they have two distinct and different roles to play in accomplishing their objectives.

i) Ensuring Fair Access to Water

Perhaps the more important, and certainly the most innovative, aspect of FO obligations is to ensure that they draw up a water contract with the AWB and can monitor their water deliveries into their secondary canal.

It would be a major change but what perhaps is even more intriguing is that FOs recognize the need to work in a concerted manner to ensure that they are all treated fairly and as equally as possible. FO leaders meeting together recognize that unless they work together they run the risk of being picked apart by AWB staff in much the same manner as they were by Irrigation Department staff. As a divided group they have little prospect of getting more equitable water allocation and distribution policy.

To say this is a challenge for FOs is a gross understatement. It will be difficult to get agreement and consensus among all of the different FOs represented on a newly established Farmer Organization council so that they can make a united and strong case when their two representatives attend meetings of the Area Water Board. But it is essential.

The current inequity at secondary canal level is quite unacceptable at both professional and political levels. To fail to meet a set of simple discharge targets at secondary head gates is a sad reflection on the technical and managerial capacity of a government agency.

By acting as a strong pressure group the FOs can individually and jointly obtain more reliable and predictable water supplies at the heads of their canals and, as has been demonstrated earlier, this will automatically result in improved performance at secondary and tertiary level.

Fair and reliable water deliveries at the head of secondary canals are a necessary condition for secondary and tertiary level improvements in performance. It is technically impossible to overcome inequity and unreliability imposed on a secondary canal by poor management upstream.

Therefore it is clear that the first and overriding task of FOs is to be concerned about how much water they receive, when they receive and how reliable the timing and discharges actually are. Only then do they need to turn their attention to internal management issues.

ii) Internal Management by FOs to Achieve Water Distribution Equity

Issues of internal water allocation and distribution along secondary canals appear to have received undue attention compared to the upstream issues of the main and branch canals operation and management of secondary head gates. The data presented in Section 3 indicate that more inequity is introduced in the main and branch systems and operation of secondary headgates than along secondary canals. A significant percentage of problems between watercourses can be attributed to improper water delivery conditions at the secondary canal head.

It does not imply that there is no conflict over water distribution among water users within a secondary canal command: there is, and in many cases it results in a significant magnification of the problem.

But the solution does not start at the watercourse head. The FOs claim that if they get proper water delivery at the head of secondary canal, they can solve their internal problems. Time will tell if this is correct, but they must be given a fair chance. They certainly have undertaken maintenance tasks at secondary level with enthusiasm and as a result have reduced previous inequities in water distribution.

Further, and alluded to in Section 4.a.iii above, there is no reason why farmers of FO cannot choose to reallocate water among them if they believe it is fair and equitable. In some watercourses there is land that is no longer cultivable due to waterlogging and salinity and so does not require water. Some farmers prefer not to take their full share of water in some seasons due to high water tables.

The original determination of watercourse discharges dates back 70 years and it is completely unrealistic to assume that the areas used in those calculations are the same as those currently farmed. Why not let FOs determine new and acceptable water allocation policies and practices? They are, after all, legal entities, they have a democratically elected leadership structure, and all water users can become equal members of good standing. This is what management transfer is all about.

5 CONCLUSIONS

The current pattern of water distribution in Sindh is unfair and inequitable. From the head of the system at each level of operation, increasing unreliability in volume and timing of deliveries is experienced. While water users always feel the effects, the causes may be well above their level of responsibility, even with the establishment of Farmer Organizations who will take over full control of operation and maintenance at secondary canal level.

To accomplish the restoration of effective and fair water distribution within the Sindh irrigation systems several enabling conditions are required. However, four seem to be particularly important and are likely to underlie the success or failure of current activities.

a) Water Rights and Due Share

The development of contracts between FOs and AWBs must include specific reference to the discharge and timing of water deliveries. This is a de facto water right, if not a de jure one, because it obligates the AWB to either deliver the correct amount of water or to explain why they are unable to do so.

To date the AWBs have agreed to issue design discharge and then share excess water equally among all FOs. The first part is comparatively easy because, except under unusual conditions such as those being experienced in 2000, discharges in almost all canals are already above official design capacity.

The second part is much more complex because it involves knowing the degree of excess water available at the head of a canal command, already a challenge for most AWBs, and then operating the system to give a proportional share of the excess to all FOs. With typically over 100 FOs per AWB, this is no trivial task and yet no plans exist to make this agreement a reality. FOs need to ensure this promise becomes a reality and does not remains a merely lip service on the part of AWB staff.

b) Measurement Capacity

The above conditions cannot be accomplished without re-establishing measurement capacity. At present all secondary canal level measurement capacity has been lost, and it appears to be largely true at branch and main canal level as well.

AWBs run a real risk of being embarrassed professionally and legally if they cannot measure water in support of a contract with an individual FO or to meet the more complicated commitment to share excess water equally.

c) Transparency

Attitudes to information must change from the arcane process to a more transparent and open situation. With FOs legally entitled to know their water delivery, and to independently check secondary canal discharges, the old situation where only engineers knew (or professed to know) discharges will disappear.

The development of a more transparent attitude means not only AWBs lose their monopoly over data, but also are more accountable than they have been in the past. It would be surprising if they welcome this situation. But the obligation is also imposed on FOs. Those FOs who currently receive excess water must, in the interest of fairness and equity, accept they give their surplus to those canal commands that are less well served. For all involved, transparency is a two-edged sword that can cut both ways.

d) Communication

Finally, the improvement of water distribution to obtain a more equal share for everyone means that there must be improved communication.

This is not restricted to access to data about discharges. It must include improved communication concerning shortfalls in water availability, disruptions in supply due to breaches, clear and properly implemented rotational irrigation plans, and any other pertinent information that will help reduce uncertainty over the timing and volume of water deliveries.

ANNEXURES

Table A1: Monthly Delivery Performance Ratio of Secondary Canals, including rotations and other closures

	Kotri	Nara	Jamrao																		
	Gajrah	Nara	Dim	Dim	Shahu	Jamrao						West Branch									
	Dhoro Naro	Heran	Rawtiani	Md.Ali	Tail	Mirpur	Doso	Visro	Kahu	Bareji	Sanro	Lakhi	Bhitt	Sangro	Daulat	Bellaro	Digri	Potho	Khatian	Bagi	Ave.
Nov-96						1.19	1.02	1.68	1.89	1.57	0.97			1.46	0.98	1.20					1.33
Dec-96						1.16	1.17	1.42	1.66	1.60	1.02	1.30	1.60	1.56	1.03	1.20					1.34
Jan-97																					
Feb-97						0.73	0.93	1.21	1.16	1.33	0.55	1.09	1.45	1.15	0.54	0.93					1.01
Mar-97						1.11	0.51	1.33	1.24	1.37	1.07	0.64	1.44	1.02	0.82	1.07					1.06
Apr-97						1.00	1.17	1.37	1.73	1.60	1.08	0.74	1.51	1.26	0.55	1.13					1.20
May-97						1.30	1.18	1.82	2.39	1.52	1.03	1.16	1.59	1.25	0.91	0.85					1.36
Jun-97						1.11	1.25	1.59	2.24	1.69	0.86	1.07	1.46	1.41	0.64	1.13					1.31
Jul-97						0.92	1.43	1.18	1.75	1.46	0.81	0.65	1.06	1.03	0.76	0.54					1.05
Aug-97						0.85	1.31	1.54	1.60	1.45	1.18	1.14	1.46	1.08	0.74	0.95					1.21
Sep-97						1.13	1.39	1.93	1.28	1.36	1.06	1.25	1.25	1.32	0.63	1.20					1.25
Oct-97						1.20	1.51	1.77	1.22	1.58	1.13	1.25	1.64	1.23	0.73	1.13					1.31
Nov-97						1.17	1.32	1.57	1.10	1.40	1.17	1.23	1.66	1.35	0.76	1.02					1.25
Dec-97						1.11	1.27	1.60	1.08	1.49	1.08	1.32	1.62	1.36	0.81	1.17					1.26
Jan-98																					
Feb-98						1.11	1.18	1.75	1.27	0.96	0.70	1.14	1.18	1.31	0.81	1.09					1.14
Mar-98						1.35	1.32	1.44	1.11	1.63	1.52	1.17	1.53	1.18	0.81	1.09					1.29
Apr-98						1.25	1.26	1.60	1.38	1.67	1.17	1.33	1.60	1.25	0.89	1.09					1.32
May-99	0.58	1.70																			1.14
Jun-99	0.69	2.14								1.39											1.41
Jul-99	0.72	1.75								1.14											1.21
Aug-99	1.02	1.82								1.30											1.38
Sep-99	0.97	1.78								1.41											1.38
Oct-99	0.91	1.16								1.85											1.30
Nov-99	1.10	1.47	1.72		1.50	0.96				1.73	1.11					1.07					1.33
Dec-99	1.13	1.30	1.69		1.27	0.96				2.08	1.27					1.00	1.06	0.72	1.18	0.48	1.18
Jan-00																					
Feb-00	1.06	1.23	1.68		1.35	1.11				1.24	0.79					1.02	1.09	0.57	1.09	0.40	1.05
Mar-00	0.64	1.22	1.24	1.23	0.95	0.95					1.14					0.77	0.84	0.68	1.14	0.71	0.96
Apr-00	0.75	1.29	0.86	1.13	0.65	0.68					1.01					0.55	0.77	0.66	0.68	0.45	0.79
May-00	0.46	1.14	1.24	1.56	0.81	0.69					0.76					0.91	0.56	0.68	0.94	0.63	0.86
Jun-00																					
Ave	0.84	1.5	1.404	1.31	1.09	1.05	1.2	1.55	1.51	1.49	1.02	1.1	1.47	1.264	0.77	1.01	0.86	0.66	1	0.53	1.13

Table A-2: Monthly Delivery Performance Ratios excluding all days without water.

	Kotri	Nara	Jamrao																		
	Gajrah	Nara	Dim	Dim	Shahu	Jamrao						West Branch									
	Dhoro Naro	Heran	Rawtiani	Md.Ali	Tail	Mirpur	Doso	Visro	Kahu	Bareji	Sanro	Lakhi	Bhitt	Sangro	Daulat	Bellaro	Digri	Potho	Khatian	Bagi	Ave.
Nov-96						1.19	1.08	1.68	1.89	1.57	0.97			1.46	0.98	1.20					1.34
Dec-96						1.16	1.17	1.42	1.66	1.60	1.02	1.30	1.60	1.56	1.03	1.20					1.34
Jan-97																					
Feb-97						1.09	0.93	1.21	1.16	1.33	0.55	1.09	1.45	1.15	0.75	1.09					1.07
Mar-97						1.11	0.87	1.52	1.42	1.57	1.22	0.64	1.44	1.17	0.82	1.07					1.17
Apr-97	0.95	1.52				1.11	1.35	1.64	2.26	1.60	1.08	1.12	1.51	1.26	0.75	1.13					1.33
May-97	1.06	1.77				1.34	1.31	1.82	2.39	1.68	1.03	1.24	1.59	1.25	0.91	1.06					1.42
Jun-97	0.98	1.85				1.34	1.50	1.90	2.59	1.69	0.96	1.29	1.57	1.41	0.79	1.17					1.46
Jul-97	1.27	1.96				1.19	1.58	1.66	2.36	1.81	1.10	1.44	1.50	1.27	0.95	1.28					1.49
Aug-97	1.10	1.78				1.31	1.62	1.91	1.60	1.73	1.18	1.53	1.56	1.46	0.88	1.28					1.46
Sep-97	1.14	1.87				1.31	1.54	1.93	1.47	1.70	1.06	1.34	1.56	1.41	0.90	1.20					1.42
Oct-97	1.32	1.18				1.20	1.51	1.77	1.22	1.58	1.35	1.25	1.64	1.36	0.87	1.13					1.34
Nov-97	1.18	1.03				1.17	1.32	1.68	1.10	1.40	1.17	1.23	1.66	1.35	0.76	1.02					1.24
Dec-97	1.25	1.07				1.11	1.27	1.60	1.08	1.49	1.08	1.32	1.62	1.36	0.81	1.17					1.25
Jan-98																					
Feb-98	1.43	1.17				1.15	1.18	1.75	1.27	1.57	1.11	1.14	1.51	1.31	0.96	1.09					1.28
Mar-98	1.27	1.17				1.35	1.32	1.44	1.11	1.63	1.52	1.17	1.53	1.18	0.81	1.09					1.27
Apr-98						1.25	1.26	1.60	1.38	1.67	1.17	1.33	1.60	1.25	0.89	1.09					1.32
May-99	0.95	1.70																			1.32
Jun-99	0.90	2.14								1.88											1.64
Jul-99	0.90	2.13								2.00											1.68
Aug-99	1.02	2.05								2.01											1.70
Sep-99	1.01	1.84								2.01											1.62
Oct-99	1.07	1.37								2.27											1.57
Nov-99	1.10	1.47	1.72		1.57	1.09				2.04	1.20					1.07					1.41
Dec-99	1.18	1.30	1.69		1.40	1.09				2.08	1.38					1.14	1.17	1.02	1.30	0.58	1.28
Jan-00																					
Feb-00	1.06	1.35	1.68		1.35	1.11				2.10	1.36					1.11	1.09	0.71	1.31	0.51	1.23
Mar-00	1.14	1.34	1.48	1.82	1.22	0.95					1.35					1.08	1.04	0.70	1.22	0.88	1.18
Apr-00	1.04	1.29	1.43	1.88	0.89	0.89					1.33					1.00	1.01	0.82	1.20	0.75	1.13
May-00	0.91	1.46	1.54	1.93	1.32	0.89					1.38					1.18	1.16	0.88	1.32	0.70	1.22
Jun-00																					
Ave.	1.1	1.56	1.59	1.88	1.29	1.15	1.3	1.66	1.62	1.75	1.16	1.23	1.56	1.33	0.87	1.13	1.09	0.83	1.27	0.68	1.30

Table A-3: Monthly Coeffcients of Variation of Discharge, including all rotations and other closures.

	Kotri	Nara	Jamrao																		
	Gajrah	Nara	Dim	Dim	Shahu	Jamrao						West Branch									
	Dhoro Naro	Heran	Rawtiani	Md.Ali	Tail	Mirpur	Doso	Visro	Kahu	Bareji	Sanro	Lakhi	Bhitt	Sangro	Daulat	Bellaro	Digri	Potho	Khatian	Bagi	Ave.
Nov-96						0.11	0.33	0.04	0.03	0.06	0.06			0.03	0.04	0.02					0.08
Dec-96						0.06	0.18	0.13	0.18	0.09	0.13	0.16	0.01	0.08	0.05	0.03					0.10
Jan-97																					
Feb-97						0.73	0.22	0.08	0.04	0.30	0.75	0.25	0.06	0.07	0.66	0.43					0.33
Mar-97						0.23	0.95	0.42	0.55	0.42	0.43	0.30	0.06	0.40	0.15	0.15					0.37
Apr-97						0.36	0.44	0.55	0.58	0.11	0.10	0.76	0.03	0.09	0.64	0.05					0.34
May-97						0.19	0.39	0.10	0.10	0.40	0.13	0.30	0.04	0.21	0.08	0.51					0.22
Jun-97						0.46	0.47	0.48	0.42	0.15	0.37	0.50	0.27	0.08	0.52	0.20					0.36
Jul-97						0.59	0.35	0.74	0.65	0.54	0.62	1.13	0.65	0.55	0.51	1.21					0.69
Aug-97						0.76	0.51	0.51	0.31	0.47	0.16	0.64	0.27	0.60	0.45	0.61					0.48
Sep-97						0.42	0.40	0.04	0.42	0.51	0.08	0.28	0.51	0.27	0.67	0.05					0.33
Oct-97						0.13	0.11	0.14	0.22	0.18	0.54	0.15	0.02	0.36	0.49	0.06					0.22
Nov-97						0.07	0.07	0.30	0.13	0.10	0.18	0.07	0.01	0.07	0.13	0.10					0.11
Dec-97						0.06	0.08	0.05	0.11	0.06	0.10	0.18	0.01	0.06	0.14	0.06					0.08
Jan-98																					
Feb-98						0.25	0.22	0.24	0.18	0.82	0.82	0.15	0.55	0.06	0.46	0.14					0.35
Mar-98						0.12	0.08	0.08	0.14	0.06	0.14	0.34	0.02	0.22	0.06	0.05					0.12
Apr-98						0.09	0.14	0.17	0.17	0.07	0.19	0.32	0.05	0.11	0.24	0.07					0.15
May-99	0.82	0.14																			0.48
Jun-99	0.56	0.12								0.62											0.43
Jul-99	0.52	0.54								0.89											0.65
Aug-99	0.04	0.46								0.76											0.42
Sep-99	0.20	0.29								0.67											0.39
Oct-99	0.44	0.44								0.49											0.46
Nov-99	0.07	0.07	0.09		0.31	0.38				0.45	0.38					0.03					0.22
Dec-99	0.21	0.15	0.11		0.39	0.37				0.08	0.30					0.39	0.34	0.66	0.35	0.55	0.33
Jan-00																					
Feb-00	0.09	0.33	0.15		0.20	0.10				0.86	0.87					0.34	0.12	0.58	0.48	0.62	0.39
Mar-00	0.91	0.38	0.48	0.70	0.58	0.07					0.45					0.67	0.55	0.29	0.30	0.54	0.49
Apr-00	0.64	0.11	0.85	0.83	0.63	0.57					0.57					0.94	0.58	0.53	0.90	0.87	0.67
May-00	1.04	0.54	0.51	0.51	0.82	0.61					0.93					0.55	1.09	0.55	0.66	0.46	0.69
Jun-00																					
Ave.	0.46	0.3	0.36	0.68	0.49	0.3	0.31	0.25	0.26	0.38	0.38	0.37	0.17	0.21	0.33	0.3	0.54	0.52	0.54	0.61	0.39

Table A-4: Monthly Coeffcients of Variation of Discharge, excluding all days without water deliveries.

	Kotri	Nara	Jamrao																		
	Gajrah	Nara	Dim	Dim	Shahu	Jamrao						West Branch									
	Dhoro Naro	Heran	Rawtiani	Md.Ali	Tail	Mirpur	Doso	Visro	Kahu	Bareji	Sanro	Lakhi	Bhitt	Sangro	Daulat	Bellaro	Digri	Potho	Khatian	Bagi	Ave.
Nov-96						0.11	0.20	0.04	0.03	0.06	0.06			0.03	0.04	0.02					0.07
Dec-96						0.06	0.18	0.13	0.18	0.09	0.13	0.16	0.01	0.08	0.05	0.03					0.10
Jan-97																					
Feb-97						0.06	0.22	0.08	0.04	0.30	0.75	0.25	0.06	0.07	0.13	0.09					0.19
Mar-97						0.23	0.30	0.13	0.36	0.14	0.16	0.30	0.06	0.09	0.15	0.15					0.19
Apr-97	0.19	0.18				0.11	0.17	0.28	0.14	0.11	0.10	0.20	0.03	0.09	0.16	0.05					0.14
May-97	0.11	0.09				0.05	0.19	0.10	0.10	0.21	0.13	0.13	0.04	0.21	0.08	0.09					0.12
Jun-97	0.20	0.11				0.06	0.11	0.14	0.11	0.15	0.15	0.18	0.02	0.08	0.10	0.06					0.11
Jul-97	0.13	0.10				0.19	0.09	0.29	0.23	0.19	0.14	0.12	0.04	0.22	0.11	0.11					0.15
Aug-97	0.20	0.12				0.04	0.08	0.12	0.31	0.13	0.16	0.19	0.03	0.03	0.06	0.10					0.12
Sep-97	0.14	0.08				0.11	0.20	0.04	0.13	0.05	0.08	0.07	0.02	0.03	0.08	0.05					0.08
Oct-97	0.13	0.10				0.13	0.11	0.14	0.22	0.18	0.28	0.15	0.02	0.14	0.18	0.06					0.14
Nov-97	0.06	0.09				0.07	0.07	0.11	0.13	0.10	0.18	0.07	0.01	0.07	0.13	0.10					0.09
Dec-97	0.02	0.05				0.06	0.08	0.05	0.11	0.06	0.10	0.18	0.01	0.06	0.14	0.06					0.08
Jan-98																					
Feb-98	0.07	0.10				0.15	0.22	0.24	0.18	0.11	0.20	0.15	0.03	0.06	0.15	0.14					0.14
Mar-98	0.08	0.08				0.12	0.08	0.08	0.14	0.06	0.14	0.34	0.02	0.22	0.06	0.05					0.11
Apr-98						0.09	0.14	0.17	0.17	0.07	0.19	0.32	0.05	0.11	0.24	0.07					0.15
May-99	0.02	0.14																			0.08
Jun-99	0.03	0.12								0.12											0.09
Jul-99	0.15	0.23								0.09											0.15
Aug-99	0.04	0.26								0.08											0.13
Sep-99	0.03	0.21								0.07											0.10
Oct-99	0.07	0.07								0.07											0.07
Nov-99	0.07	0.07	0.09		0.22	0.07				0.09	0.22					0.03					0.11
Dec-99	0.04	0.15	0.11		0.20	0.05				0.08	0.03					0.03	0.08	0.07	0.10	0.25	0.10
Jan-00																					
Feb-00	0.09	0.11	0.15		0.20	0.10				0.08	0.03					0.17	0.12	0.23	0.11	0.31	0.14
Mar-00	0.06	0.20	0.16	0.03	0.17	0.07					0.00					0.14	0.22	0.22	0.13	0.18	0.13
Apr-00	0.06	0.11	0.13	0.03	0.12	0.02					0.01					0.14	0.14	0.12	0.11	0.21	0.10
May-00	0.15	0.05	0.09	0.08	0.10	0.23					0.08					0.06	0.20	0.05	0.08	0.31	0.12
Jun-00																					
Ave.	0.09	0.12	0.12	0.05	0.17	0.1	0.15	0.13	0.16	0.11	0.15	0.19	0.03	0.1	0.12	0.08	0.15	0.14	0.11	0.25	0.13

Table A-5: Number of days when water was not delivered.

	Kotri Gajrah Dhoro Naro	Nara Nara Heran	Jamrao																		
			Dim Rawtiani	Dim Md.Ali	Shahu Tail	Jamrao						West Branch									
						Mirpur	Doso	Visro	Kahu	Bareji	Sanro	Lakhi	Bhitt	Sangro	Daulat	Bellaro	Digri	Potho	Khatian	Bagi	Ave.
Nov-96						0	1	0	0	0	0			0	0	0					0.1
Dec-96						0	0	0	0	0	0	0	0	0	0	0					0.0
Jan-97																					
Feb-97						6	0	0	0	0	0	0	0	0	8	4					1.6
Mar-97						0	13	4	4	4	4	0	0	4	0	0					3.0
Apr-97						3	4	5	7	0	0	10	0	0	8	0					3.4
May-97						1	3	0	0	3	0	2	0	0	0	6					1.4
Jun-97						5	5	5	4	0	3	5	2	0	6	1					3.3
Jul-97						7	3	9	8	6	8	17	9	6	6	18					8.8
Aug-97						11	6	6	0	5	0	8	2	8	5	8					5.4
Sep-97						4	3	0	4	6	0	2	6	2	9	0					3.3
Oct-97						0	0	0	0	0	5	0	0	3	5	0					1.2
Nov-97						0	0	2	0	0	0	0	0	0	0	0					0.2
Dec-97						0	0	0	0	0	0	0	0	0	0	0					0.0
Jan-98																					
Feb-98						1	0	0	0	10	10	0	6	0	4	0					2.8
Mar-98						0	0	0	0	0	0	0	0	0	0	0					0.0
Apr-98						0	0	0	0	0	0	0	0	0	0	0					0.0
May-99	7	0																			3.5
Jun-99	7	0								7											4.7
Jul-99	6	6								12											8.0
Aug-99	0	3								11											4.7
Sep-99	0	1								9											3.3
Oct-99	4	4								5											4.3
Nov-99	0	0	0		7	7				3	7					0					3.0
Dec-99	1	0	0		3	8				0	7					4	3	9	3	3	3.4
Jan-00																					
Feb-00	0	2	0		0	3				12	14					4	0	6	5	6	4.3
Mar-00	15	7	5	10	7	0					5					9	6	1	2	6	6.1
Apr-00	8	0	12	12	8	8					8					14	7	6	13	12	9.0
May-00	13	6	6	6	12	8					14					7	16	7	9	3	8.9
Jun-00																					
Sum	61	29	23	28	37	72	38	31	27	93	85	44	25	23	51	75	32	29	32	30	

Table A-6: Number of days when delivered discharge was less than 70% of design.

	Kotri	Nara	Jamrao																		
	Gajrah	Nara	Dim	Dim	Shahu	Jamrao						West Branch									
	Dhoro Naro	Heran	Rawtiani	Md.Ali	Tail	Mirpur	Doso	Visro	Kahu	Bareji	Sanro	Lakhi	Bhitt	Sangro	Daulat	Bellaro	Digri	Potho	Khatian	Bagi	Ave.
Nov-96						0	2	0	0	0	0	0	0	0	0	0					0.2
Dec-96						0	0	0	0	0	0	0	0	0	0	0					0.0
Jan-97						0	1	0	3	0	0	0	0	0	0	0					
Feb-97						6	3	0	0	1	11	4	0	0	11	4					3.6
Mar-97						4	17	4	4	4	4	22	0	4	5	0					6.2
Apr-97						3	4	5	7	0	0	11	0	0	19	0					4.5
May-97						1	4	0	0	3	0	3	0	3	0	6					1.8
Jun-97						5	5	5	4	0	4	6	2	0	10	1					3.8
Jul-97						8	3	12	8	6	8	17	9	7	6	18					9.3
Aug-97						11	6	6	0	5	0	8	2	8	5	8					5.4
Sep-97						4	3	0	4	6	0	2	6	2	9	0					3.3
Oct-97						0	0	0	0	0	5	0	0	3	7	0					1.4
Nov-97						0	0	2	0	0	0	0	0	0	7	1					0.9
Dec-97						0	0	0	0	0	0	0	0	0	4	0					0.4
Jan-98						0	0	1	1	0	1	1	0	0	0	0					
Feb-98						1	1	0	0	10	10	0	6	0	4	1					3.0
Mar-98						0	0	0	0	0	0	3	0	1	1	0					0.5
Apr-98						0	0	0	0	0	0	0	0	0	0	0					0.0
May-99	0	0																			0.0
Jun-99	0	0								0											0.0
Jul-99	0	0								0											0.0
Aug-99	0	0								0											0.0
Sep-99	0	0								0											0.0
Oct-99	0	0								0											0.0
Nov-99	0	0	0		0	0				0	0					0					0.0
Dec-99	0	0	0		0	0				0	0					0	0	0	0	3	0.3
Jan-00																					
Feb-00	0	0	0		0	0				0	0					0	0	0	0	0	0.0
Mar-00	0	0	0	0	0	0					0					0	0	0	0	0	0.0
Apr-00	0	0	0	0	0	0					0					0	0	0	0	0	0.0
May-00	0	0	0	0	0	0					0					0	0	0	0	0	0.0
Jun-00																					
Sum	0	0	0	0	0	43	49	35	31	35	43	77	25	28	88	39	0	0	0	3	

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